Beta-Gamma science for Sustainable Agriculture: taking the implications of complexity seriously.

Mario Giampietro

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Promotor:

Prof. Dr. Ir. Niels G. Röling - Hoogleraar Kennissystemen in Ontwikkelingslanden, Wageningen Universiteit

Promotiecommissie:

Dr. Silvio Funtowicz, Joint Research Centre of the European Commission, Ispra, Italy

Prof. Dr. Martin O'Connor, Université de Saint Quentin et Yvelines, Paris, France

Prof. Dr. Ir. Herman van Keulen, Wageningen Universiteit

Prof. Dr. Ir. Johan Bouma, Wageningen Universiteit

Prof. Dr. Ray Ison, The Open University Milton Keynes, England

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Confucius said:

“If a student is not eager, I won’t teach him;
If he is not struggling with the truth, I won’t reveal it to him.
If I lift up one corner and he can’t come back with the other three,
I won’t do it again.”

from ***The Analects by Confucius*** *7.8*

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Preface

Discussing of the implications of a paradigm change in science Allen et al (2001) say: "***A paradigm change modifies protocols, vocabulary or tacit agreements not to ask certain questions***" (pag. 480). If we agree with this brilliant definition and therefore if we accept that a scientific paradigm is "**a tacit agreement not to ask certain questions**" next step is to find out why certain questions are forbidden by it. In general, the questions that cannot be asked from within a scientific paradigm are those challenging the basic assumptions adopted in the foundations of the relative disciplinary scientific knowledge.

The enforcement of this tacit agreement is a must for two reasons. It is required to preserve the credibility of the established set of protocols proposed by the relative disciplinary field (what the students learn in University classes). It makes possible for the practitioners of a disciplinary field to focus all their attention and efforts **only on how to run properly the established set of protocols**, forgetting about theoretical issues and controversies. In fact, the acceptance of a scientific paradigm prevents any questioning **of the usefulness of the established set of protocols developed within a disciplinary field for dealing with the task** faced by the analyst.

When dealing with a situation of crisis of an existing scientific paradigm - and many seem to believe that in relation to the issue of sustainability of human progress we are facing one of these crises – we should expected that such a tacit agreement gets into troubles. Whenever the established set of protocols (e.g. analytical tool kits) available for making analysis within disciplinary fields is no longer useful, the number of people willing to ask forbidden questions reach a critical size that overcomes the defenses provided by academic filters. After reaching that point, criticizing the obsolete paradigm is no longer a taboo. As a matter of fact, nowadays, several "revolutionary statements" which carry huge theoretical implications about the invalidity of the foundations of leading scientific disciplines are freely used in the scientific debate. For example expressions like – "the myth of the perpetual growth is no longer acceptable (why?)", "it is not possible to find an optimal solution when dealing with contrasting goals defined on different dimensions and scales (why?)", "we cannot handle uncertainty and ignorance just by using bigger and better computers (why?)" – in the 70s, 80s were exchanged within sanguinary battle fields between opposite academic disciplines defending the purity of their theoretical foundations. These expressions are nowadays no longer contested. Actually we can even find softened versions of these statements included in the presentation of innovative academic programs and in documents generated by United Nation agencies.

This situation of transition, however, generates a paradox. In spite of this growing deluge of unpleasant forbidden questions about the validity of the foundations of established disciplinary scientific fields, nothing is really happening to the teaching of protocols within the academic fields under pressure for change. In fact, at this point, the lock-in which is protecting obsolete academic fields does no longer work against posing forbidden questions. Rather it works by preventing the generation of answers to these forbidden questions. The mechanism generating this lock-in is simple and conspiracy-free. Academic filters associated to obsolescent disciplinary knowledge do their ordinary work by attacking every deviance (= those that try to find new perspectives). This applies both to those that develop non-traditional empirical analyses – e.g. putting together data in a non-conventional way, especially when they obtain interesting results - or those that develop non-traditional theories – e.g. putting together ideas in a different way, especially when they obtain interesting results. The standard criticism in these cases is that "this is just empirical work without any sound theory supporting it" or that "this is just theoretical speculation without any empirical work supporting it". When innovative theories are developed to explain empirical results, the academic filter challenges every single assumption adopted in the new theory (even though they are totally neglecting to challenge even the most doubtful assumptions of their own discipline). Finally, whenever the academic filter is facing the unlikely event that: (i) a new coherent theory is put forward; (ii) this theory can be defended step by step starting from the foundations; (iii) experimental data are used to validate such a theory; (iv) this theory results useful for dealing with the tasks faced by the analysts; THEN the unavoidable reaction is always the same: "This is not what our disciplinary field is about. Practitioners of our field would never be interested in going through all of this".

Obviously, the analysis of this mechanism of lock-in – very effective in preventing the discussion of possible answers to forbidden questions - has a lot to do with the story that led to the writing of this thesis. This is why I decided to start with this preface that wants to be a warning to potential readers. This thesis represents a honest effort to do something innovative in the field of the integrated analysis of sustainability of agricultural systems. That is, a honest effort to answer a few of the forbidden questions emerging in the debate about sustainability. This thesis reflects a lot of work and a lot of traveling to visit the most interesting groups that are doing innovative things related to this subject in various disciplinary and interdisciplinary fields. This thesis has been written for those that are not happy with the analytical tools actually used to study and make models about the performance of farming systems, food systems and agro-ecosystems. Especially for those interested in considering simultaneously various dimensions of sustainability (e.g. economic, ecological, social) and willing to reflect in their models the non-equivalent perspectives of different agents operating at different scales.

The mechanism that generated the writing of this thesis is also simple. There is an old Chinese say (quoted by Röling, 1996 p. 36), which puts it in a very plain form: "**If you don't want to arrive where you are going, you need to change direction**".

What does mean for a scientist or a practitioner changing direction? In my interpretation of the Chinese say, this means going back to the foundations of the disciplinary knowledge that has been used to develop the analytical tools that are available and in use at the moment and try to see if it is possible to do things in an alternative way. Actually, when I started my journey, many years ago, as a scientist willing to deal with the sustainability of agriculture, I had to swim in a sea of complaints about inadequacy of reductionism, lack of holism, need of a paradigm shift in science. This sea of complaints was linked to the acknowledgment of a never-ending list of failures of the applications of the conventional approach in relation to the sustainability of agriculture both in developed and developing countries. However, in spite of all of these complaints, when looking at scientific papers dealing with the sustainability of agriculture, in the vast majority of the cases, I always found models which were based on the same old set of tools (e.g. statistical tests and differential equations). These models were applied to an incredible diversity of situations, always looking for the optimization of a function assumed to represent a valid (substantive) formal definition of performance for the system under investigation.

Since I was and I am still convinced not to be smarter of the average researchers of this field, I was forced to realize that if I wanted to arrive in a different place, I had to change the path I was on. Otherwise, I would have joined the party of "optimizers" already jammed at the end of it. When you took a wrong path and you want to get on another one, then you must go back to the bifurcation where you made the bad turn. This is why I decided to go back to the theoretical foundations of the analytical tools I was using, to try to see if it were possible to develop an alternative set of tools useful to analyze the complex nature of agro-ecosystems. Then I found out that the new field of complex systems theory implied the re-discovery of old epistemological issues and new ways of addressing the challenge implied by modeling.

This thesis is an attempt to share with the reader what I learned during this long journey. The text is organized in three parts:

* **Part 1 – Science for Governance: the clash of reductionism against the complexity of reality.** After acknowledging that there is a problem with reductionism when dealing with the sustainability of agro-ecosystems (in **Chapter 1**) the remaining 4 chapters provide new vocabulary, narratives and explanations for the epistemological predicament entailed by complexity. **Chapter 2** starts by looking at the roots of the epistemological predicament, focusing on the neglected distinction between perception and representation of the reality. Additional concepts required to develop alternative narratives are

introduced and illustrated with practical examples in **Chapter 3.** The resulting challenge for science when used for governance in face of uncertainty and legitimate contrasting values, is debated in general terms in **Chapter 4.** Finally, an overview of the problems associated to the development scientific procedures for participatory integrated assessment is discussed in **Chapter 5.**
* **Part 2 – Complex Systems Thinking: daring to violate basic taboos of reductionism.** This part introduces a set of innovative concepts derived from various applications of complex system thinking. These concepts can be used to develop a tool kit useful for handling Multi-Scale Integrated Analysis of agro-ecosystems. In particular three key concepts are introduced and elaborated in the 3 chapters making up this second part: (i) **Chapter 6** – the concept of Multi-Scale Mosaic Effect; (ii) **Chapter 7** – the concept of Impredicative Loop Analysis; (iii) **Chapter 8** – the concept of "Surfing Complex Time", which entails the unavoidable necessity of continuously developing and updating useful narratives.
* **Part 3 – Complex Systems Thinking in Action: Multi-Scale Integrated Analysis of Agro-ecosystems.** This part presents a tool kit based on a combined use of the previous three concepts that can be used to obtain a multi-scale integrated analysis of agro-ecosystems. This third part is organized into 3 chapters: (i) **Chapter 9** - Bridging disciplinary gaps across hierarchical levels –; (ii) **Chapter 10** – Linking changes in societal metabolism to the impact generated on the ecological context of agriculture; (iii) **Chapter 11** – Benchmarking and tailoring multi-objective integrated analysis across levels.

After having put the cards on the table with this outline, I can now move to the warning for potential readers: Who would be interested in reading such a thesis? Why someone should do that?

This is not a work for those concerned with being "politically correct" at least according to the definitions adopted by existing academic filters. Moreover, this thesis is weird according any of the conventional standards adopted by reputable practitioners. This is a scientific research in agriculture which is not aimed at producing "more" and "better". Rather this is a research about modeling which is aimed at learning how to define what "better" means for a given group of interacting social actors within a given socio-economic and ecological context. Within this frame the real issue for scientists is that of looking for the most useful scientific problem structuring.

It should be noted that hard scientists that use models to individuate the best solution [a solution that produces "more" and "better" than the actual one] are operating under the bold assumption that it is always possible to have available: (a) a "win-win" solution, that is, that "more" does not imply any negative side effects; and (b) a substantive formal definition of "better", which is agreed by all social actors, and which can be used without contestation as an input for optimizing models. According to this bold assumption, the only problem for hard scientists is that of finding an output generated by the model that determines a maximum in "improvement" for the system.

If we were not experiencing the tragic situation we are living in (= malnutrition, poverty and environmental collapse in many developing countries associated to bad nutrition, poverty and environmental collapse in many developed countries) this blind confidence in the validity of such a bold assumption could be a nice source of laugh. After having worked for more than 20 years in the field of ecological economics, sustainable development, and sustainable agriculture both in developed and developing countries, unfortunately, I no longer find the blind confidence in the validity of this bold assumption amusing.

Sustainability, when dealing with humans, means exactly the ability of dealing in terms of action with the unavoidable existence of legitimate contrasting views about what should be considered as an improvement. Winners are always coupled to losers. To make things more difficult nobody can guess all the implications of a change. If this is the case, then, how can this army of optimizers know that their definition of what is an improvement (the one they include in formal terms in their models as the function to be optimized) is the right one? How can be decided by an algorithm that the perspective and the values of the winners should be considered more relevant than the perspective and the values of the losers?

Sustainability means dealing with the process of becoming. If we want to avoid the accuse of working with an oxymoron (sustainable development), we should be able to explain what is that, in our models, remains the same when the system becomes something else (in a sustainable way). That is, we should be able to individuate in our models what remains the same when different variables, different boundaries and emerging relevant qualities will have to be considered to represent the issue of sustainability in the future. Optimizing models either maximize or minimize something within a formal (given and not changing in time) information space.

When dealing with a feasible trajectory of evolution, the challenge of sustainability is related to the ability to keep harmony among relevant paces of change for parts (which are becoming in time), which are making up a system (which is becoming in time), which is coevolving with its environment (which is becoming in time). This requires the simultaneous perception and representation of events over a variety of space-time scales. The various paces of becoming of parts, the system and the environment, are quite different from each others. Can this cascade of processes of becoming and cross-relations be studied using reducible sets of differential equations and traditional statistical tests? A lot of people working in hierarchy theory and complex system theory doubt it. This thesis discusses why this is not possible.

These are fundamental questions that should be taken seriously, especially by those that want to deal with sustainability in terms of hard scientific models (by searching for a local maximum of a mathematical function and for significance at the 0.01 level). It is well known that when dealing with life, hard science often tends to confuse "formal rigor" with "rigor mortis". To this regard the reductionist agenda is well known. In order to study living systems, first of all we have to kill them to prevent adjustment and/or changes during the process of measurement. The "rigorous way", for the moment, provides only protocols that require reducing wholes into parts and then measuring the parts to characterize the whole. It is possible to look at the relation of "wholes" and "parts" in a new way? Can we deal with chicken-egg paradoxes, when the identity of the parts determines the identity of the whole and the identity of the whole determines the identity of the parts? Obviously, this is possible. This is how life, languages and knowledge work. This thesis discusses why and how this can be done in Multi-Scale Integrated Analysis of agroecosystems.

Finally, there is another very interesting point to be made. Are these forbidden questions about science "new" questions? The obvious answer is not at all. These are among the oldest and more debated issues in human culture. Humans can only represent in their scientific analyses a shared perception about reality, not the reality. Models are simplified representations of a shared perception of reality. Therefore, by definition, they are all wrong, even though they can be very useful (Box, 1979). But in order to take advantage of their potential usefulness - in terms of a richer understanding of the reality - it is necessary to be aware of basic epistemological issues related to the building of models. The real tragedy is that activities aimed at developing this awareness are considered not interesting or even "not real science" by many practitioners in hard sciences. On the contrary, this is an issue that it is considered very seriously in this thesis. From this perspective Complex Systems Theory has the merit to have put back on the agenda of hard scientists a set of key epistemological issues debated in disciplines such as natural philosophy, logic, semiotic, which were viewed until recently as non-enough hard . . .

It is time to re-assure those potential readers that got scared from the outline and the following discussion. What all of this has to do with the sustainability of Agroecosystems? Well, the point I have been trying to make so far is that all of this has a lot to do with it.

In the last twenty years I have been generating a lot of numbers about the sustainability of agricultural systems, by studying this problem from different perspectives (technical coefficients, farming systems, global biophysical constraints, ecological compatibility) and using various sets of variables (energy, money, water, demographic, social). At the beginning the attempt to keep coherence in those heterogeneous set of data and models was done by following intuitions. Later on, after learning about hierarchy theory, Post-Normal Science, complex system theory (especially because of the gigantic contributions of Robert

Rosen) I realized that it was possible to back-up these intuitions with a robust theory. This made possible to organize the various pieces of the mosaic into an organic whole. This is what is presented in Part 2. Then Part 3 provides examples of applications of Multi-Scale Integrated Analysis of Agroecosystems to real cases. The results presented in the last Part, in my view, justify the length and the heterogeneity of issues presented in Part 1 and Part 2. In spite of this, I understand that cruising Part 1 and Part 2 remains not easy, especially for someone that is not familiar with the various issues discussed in the first 8 chapters. On the other hand, this can be an occasion for those that are not familiar with these topics to have a general overview of the state of the art and reference to the literature.

There is a standard predicament associated to scientific work that wants to be truly interdisciplinary. Experts of a particular scientific field will find the parts of the text dealing with their own field too simplistic and inaccurate (= an uncomfortable feeling when reading about familiar subjects). Whereas, they will find the parts of the text dealing with less familiar topics obscure and too loaded of useless and irrelevant details (= an uncomfortable feeling when reading about unfamiliar subjects). This explains why genuine trans-disciplinary work is difficult to sell. As readers we are all bothered when forced to handle unfamiliar types of narratives and disciplinary knowledge. Nobody can be a reputable scholar in many fields. In relation to this point, I can recycle the apology written by Schrodinger (1944) about the unavoidable need of facing this predicament. "*A scientist is supposed to have a complete and thorough knowledge, at first hand, of some subjects and, therefore, is usually expected not to write on any topic of which he is not a life master. This is regarded as a matter of noblesse oblige. For the present purpose I beg to renounce the noblesse, if any, and to be the freed of the ensuing obligation. My excuse is as follows: We have inherited from our forefathers the keen longing for unified, all-embracing knowledge. The very name given to the highest institutions of learning reminds us, that from antiquity to and throughout many centuries the universal aspect has been the only one to be given full credit. But the spread, both in and width and depth, of the multifarious branches of knowledge by during the last hundred odd years has confronted us with a queer dilemma. We feel clearly that we are only now beginning to acquire reliable material for welding together the sum total of all that is known into a whole; but, on the other hand, it has become next to impossible for a single mind fully to command more than a small specialized portion of it.* ***I can see no other escape from this dilemma (lest our true who aim be lost for ever) than that some of us should venture to embark on a synthesis of facts and theories, albeit with second-hand and incomplete knowledge of some of them -and at the risk of making fools of ourselves***".

To make the life of the reader easier, the text of the first 8 chapters (Part 1 and Part 2) has been organized in two categories of sections:
(1) **general sections** that introduce main concepts, new vocabulary and narratives, using practical examples and metaphors taken by normal life situations.
(2) **technical sections** that get into a more detailed explanation of concepts, using technical jargon and providing references to existing literature.

The sections which are marked as "technical" can be glanced through by those readers not interested in exploring details. In any case the reader will always have the option to get back to the text of these sections later on. In fact, when dealing with a proposal for moving to a new set of ***protocols, vocabulary and tacit agreements not to ask certain questions*** one cannot expect to get "everything" at once, just by a cursory reading of a text. Actually, the goal of the first 8 chapters is that of making the reader familiar with new terms, new concepts and new narratives, that will be used later on to propose innovative analytical tools. This means that the structure of this thesis implies a lot of redundancy. The same concepts are first introduced in a discursive way (Part 1), then re-explored using a technical language (Part 2), then they are adopted in the development of procedures useful to perform practical applications of multi-scale integrated analysis of agroecosystems (Part 3). Because of this, the reader should not feel frustrated by the high density of the information faced when reading for the first time some of the chapters in Part 1 and Part 2.

Acknowledgment

As discussed in a convincing way by Aristotle, it is not easy to individuate a single direct causation of a given event – i.e. the writing of a thesis - since in the real world several causes (material, efficient, formal and final) are always at work in parallel. Because of this, it is not easy for me to start a list of names from a given point on a page. There is a fractal universe of persons that with their actions were crucial for the writing of this thesis, which is impossible to handle in a linear way.

It is reasonable to start such a list from the category of efficient cause (those that generated the process). This implies starting with Wageningen University. First of all, the demiurgic intervention of Niels Röling that came up (over an Italian dinner) with the idea of the writing of such a thesis. In the restaurant the recipe came out pretty clear: one third epistemology, one third complex system theory and one third of examples of real applications to the sustainability of agriculture. The second crucial input was a question posed by Herman van Keulen during my first seminar given there. "You seem to believe that it is possible to establish a link between the various changes in indicators defined across different scales. But how can you establish a bridge across non-equivalent descriptive domains?". This question has been very important to me for two reasons: (1) this was the first time in my life that I found someone that was understanding perfectly what I was talking about when discussing of Multi-Scale Integrated Analysis (hey, I am not alone in the Universe!); and (2) this question made me aware that my firm belief about the possibility to establish a link across non-reducible indicators (something done by me in the past, but just following intuitions) was "not obvious at all" to other people. Actually, when confronted with such a direct question, in public, I was not able to offer a systemic explanation of my approach. Finally, the last key element in Wageningen has been the enthusiasm that Hans Schiere had, at that time, for complexity. My visiting period there (5 months) had the goal of exploring the possibility of using new concepts derived from this field for improving the analysis of sustainability. At that time, I had a few discussions with him about the problem of boundary definition in modeling. In one of that occasions I got a special assignment: "can you prove that it is impossible to find and use a unique 'substantive' boundary definition for a given system?". A few weeks ago, when I was finally able to answer in a very simple and direct way such a question (when editing the comments to Fig. 7.10) I realized that the thesis was over.

Another key efficient cause, that has to be associated to my choice of dedicating my life to research, has the name of David Pimentel. In the six years spent at Cornell University with him, I learned how to feel and smell the existence of hidden links in agriculture, when considering simultaneously biophysical, economic, social and ecological mechanisms of regulation. Then I learned from him how to follow the prey (looking for hard data proving the existence of these links), even when this requires putting together scattered clues and going for creative investigation. What I learned in scientific terms, then, is invaluable. However, for sure, the most important lesson which I learned by working with him has been on the human side. In order to do this job for good one has to work hard and forget about trying to be politically correct. Especially, when building up your own career you must resist the sirens' song of "cosí fan tutte . . .". You must keep going for your own way, no matter what.

Getting now into the list of people that were instrumental in shaping my understanding of complexity (the formal cause) there is a person that I never managed to meet: Robert Rosen. In my view, one of the greatest scientists of last century (passed away in 1998), that hopefully will get the due recognition in this century. In this thesis I just tried to build on his deep understanding of the link between basic epistemological issues and basic principles of a theory of complex systems.

Coming to the list of people that I was lucky enough to meet in person, I can organize the list according to topics:

* **Epistemology, Science for Governance, and Post-Normal Science** - Silvio Funtowicz (that I visited for 6 months at the Joint Research Center of the European Commission in Ispra), Jerome Ravetz, Martin

O'Connor, and Niels Röling (that opened for me the doors of Soft-Systems Methodology developed by Checkland). All people that I consider now as friends beside mentors;
* **Multi-Criteria Analysis, Societal Multi-Criteria Evaluation applied to Ecological Economics** – Joan Martinez-Alier and Giuseppe Munda (I visited both for 2 years at the Universitat Autonoma de Barcelona in Spain);
* **Complex Systems Theory and Hierarchy Theory** -Tim Allen (that I visited for 6 months in Madison), James Kay, David Waltner-Toews, Gilberto Gallopin. Again, it is a honor for me to consider them also as friends (none of us will ever forget the first meeting of the Dirk Gently group in 1995!).
* **Energy analysis and thermodynamics applied to sustainability analysis** – This list starts with Kozo Mayumi (the co-author of Chapter 6, Chapter 7, Chapter 8), that is a fraternal friend with whom I have been working since 1993. Together we developed the concept of Multi-Scale Integrated Analysis of Societal Metabolism. In this category I have to mention again Martin O'Connor, then James Kay and Roydon Frazer two exquisite theoreticians interpreting the concept of rigor in the correct way (avoiding sloppiness but at the same time daring to violate taboos when it is needed). Bob Ulanowicz is an important pioneer of this field, from whom I got the idea of the 4-angle model for the analysis across hierarchical levels of metabolic systems. Vaclav Smil, another guru of the analysis of energy and food security. A very nice and collaborative person. The list continues with Joseph Tainter, one of the few non-hard scientists, that is perfectly comfortable with handling these scientific concepts in his analysis of the sustainability of human societies. Last but not least, Sergio Ulgiati, Bob Herendeen and Sylvie Faucheux other friends/colleagues with whom I have been interacting now for more than a decade in this field.
* **Multi-Scale Integrated Analysis of Agroecosystems** – The list here starts with Tiziano Gomiero (the co-author of Chapter 11). Gianni Pastore and Li Ji, that were very active – in 1997 during the first development of the method - when processing a dataset gathered in a 4-year project in China. Bill Bland of the Agroecology program at the University of Madison with whom I had several discussions about theory and applications, when visiting there. Finally, various researchers involved in the SEAtrans project with whom I am collaborating now (and hopefully will keep collaborating in the future) H. Schandl, C. Grünbühel, N. Schulz, S. Thongmanivong, B. Pathoumthong, C. Rapera, Le Trong Cuc.

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According to the unwritten rules about the lay-out of acknowledgment sections, I cannot finish this section without the mandatory reference to my family and friends (moving to the final cause). In this case, I believe that a particular mention is really due for my wife, Sandra Bukkens. She has not only contributed in a substantial way to this thesis in an indirect way. In fact, she sustained almost entirely the share of the burden associated to the running of our household in the last 5 years. Five years during which our two daughters generated a remarkable demand of services and in which our household moved 6 times across 4 different countries. But also she has contributed in a direct way to this thesis, before this nomadic madness, by co-authoring with me several published papers dealing with related topics. A few of these papers are quoted and used in the text as sources of tables and figures.

Introduction

"**Science for governance**" - The new challenge for scientists dealing with the sustainability of agriculture in the new millennium.

"*A spectre is haunting European Agricultural Colleges. The spectre of multifunctional land use. All the agricultural academic powers of the old and new continents have entered in a holy alliance to exorcise this spectre* . . .". The development of agriculture in the 21st century is confronting academic agricultural programs with the need of handling "new" typologies of trade-offs and social conflicts, which are often difficult to compare and assess. This new challenge is associated nowadays to the concept of multifunctionality of land uses.

As a matter of fact, it should be noted that this is nothing new. Throughout the history of humankind the agricultural sector has always been multifunctional and at the basis of social conflicts. Because of this, until a recent past (let's say before 1900): (i) the perception of the usefulness of the agricultural sector (the criteria of performance); (ii) the representation of the agricultural sector (the attributes of performance); and (iii) the regulation of agricultural activities (selection and evaluation of policies and laws based on the selected set of criteria and attributes), have always been based on the simultaneous consideration of various perspectives and dimensions of analysis. In a modern jargon we can say that in the past (e.g. in pre-industrial times) the development of agriculture has always been driven by policies, which were selected and evaluated considering both long-term and short-term effects in relation to different dimensions of analysis (political, social, economic, ecological). Land was perceived as a source of food for survival, as well as a required asset to sustain soldiers. Depending on the location land was also seen as crucial to control trade. In addition to that, land had always also a sacred dimension to which anchor cultural values. People tend to associate their cultural identity with familiar landscapes (homeland). Finally, in relation to the ecological dimension land was often confused with nature and therefore considered as the given context within which, by default, humans have to play their part in the larger process of life.

If this is true, how does it come that academic agricultural programs find, nowadays, that the concept of multifunctional land use and the relative need of addressing multiple trade-offs and dimensions is a task which is perceived as new? To answer this question it is important to realize the deep transformations that the period of colonies first and the massive process of industrialization later induced in the metabolism of social systems in Europe first and in the rest of the developed world later. In these privileged spots of the planet economic growth could dramatically expand escaping, at least in the short term, local biophysical constraints. This special situation was able to change in a few decades the codified perception about the role of the agricultural sector. Fossil energy based inputs and imports were used to off-set bottlenecks on the natural supply of production inputs. In this situation, the choice of considering (= perceiving, representing, and regulating) "agriculture" just as a set of economic activities aimed at producing goods and profit – while neglecting other dimensions - resulted very rewarding.

This change in the perception of agriculture in western academic programs in the last decades was associated to a rapid economic growth in developed countries, and a rapid demographic growth in developing countries. During this rapid transition, those operating in the developed world learned that introducing major simplifications in the codified way of perceiving, representing and regulating agriculture could generate comparative advantages for their economies, at least in the short term. That is, by ignoring the constraints imposed by the old set of cultural values (e.g. the sacredness of land) and by ignoring ecological aspects (e.g. the necessity to maintain human exploitation within the limits required by eco-compatibility) farmers and those investing in farming could take out from the same unit of land much more food and at the same time could increase their operative profits. In this way, developed societies were able to support more "soldiers" per unit of land. It should be noted, however, that after the

industrial revolution the social role of "pre-industrial soldiers" was replaced by "non-agricultural workers". That is the fraction of the work force invested in operating machines in the industrial sectors was able to achieve an economic return per hour of labor much higher than that generated by farmers. To make things tougher for agriculture, the large variety of economic activities expressed by industrial societies implied that the very same land could be invested into alternative and more profitable uses. Modern economic sectors (both in production and in consumption) are competing with "old style agricultural practices" for the use of the available endowment of human activity and land. In this situation, workers invested in just "producing food" or land invested in just "keeping low the ecological stress" which is associated to food production (e.g. fallow) do imply a high opportunity cost in developed countries. In other words, "old style agricultural practices" were the losers in the definition of priorities when deciding the new development strategies for modern economies. As a consequence of this fact, for more than 5 decades now, technical progress in agriculture has been driven by two simple goals:
(i) maximizing biophysical productivity (= reducing the amount of human workers and the amount of space required to produce food, so that these valuable resources can became available to other economic activities giving higher return); and
(ii) maximizing economic performance (= the high opportunity cost of capital in developed countries requires reaching levels of return on investment comparable with those achieved in other sectors).

These two goals, when combined together, tend to generate a mission impossible syndrome. In fact, the goal of maximizing the biophysical productivity in terms of higher throughput per hectare and per worker translates into the need of massive investments of capital per worker. On the other hand, a large difference in the opportunity cost of production factors such as land and labor – required in large quantity in the agricultural sector compared with other economic sectors – translates into low competitiveness of developed farmers on the international market (in relation to farmers operating in developing countries). In developed countries with enough land – e.g. USA or Canada - the second goal was still an achievable one, at least before the third millennium. On the contrary, in other developed countries with high density of population – e.g. Europe or Japan – the second goal became soon a mission impossible, without economic subsidies. As soon as the down-hill slope of subsidies was taken, then the definition of the goal of "maximizing economic performance" dramatically changed.

At that point, the goal of "maximizing economic performance" in developed and crowded countries became that of reducing the fraction of total available economic capital which has to be invested in the agricultural sector. In fact, in developed countries the capital has a high economic opportunity cost. This implies that the agricultural sector with a high requirement of capital per worker and a low economic return on investments is forced to a continuous compression of the number of workers to handle this double task. The solution to this dilemma can be obtained by: (i) increasing the ratio capital per worker and capital per unit of land; while at the same time (ii) reducing both the number of workers and the land in production. Obviously the pace of reduction of the number of workers and the area of land in production has to be faster than the pace of growth of the required amount of capital per worker and per unit of land.

After having taken such a suicidal path for the sustainability of agriculture, many in developed countries were forced to recognize the original capital sin. The effects of the drastic simplifications adopted to perceive, represent and regulate agriculture, seen just as another economic sector which is just producing commodities, became crystal clear (at least to those willing to see it). The decision to adopt a mechanism of monitoring and control based mainly on money (e.g. the implementation of agricultural policies in the 60s and 70s mainly based on economic analysis) was reflecting such a hidden simplification. Basing the evaluation of policies mainly in economic terms implied missing for decades a lot of relevant information referring to additional dimensions of agriculture. These neglected dimensions (e.g. ecology - health of ecosystems; and cultural and social dimension – health of communities) are now slashing back on those in charge for determining agricultural policies. Even worse is the situation of developing countries were the societal context of agriculture is completely different from the developed world. In these countries, there is less capital available for agricultural activities in face of a growing demand for services and investments in the development of other economic activities. Moreover, the scarce capital left to agriculture has to be used to deal with a dramatic reduction of land per capita. Obviously, in this situation, the challenge of developing new technologies and new policies for agricultural development is becoming more and more hard to tackle. Due to the fact that the context of agriculture in developing countries is totally different from that in developed countries, we should expect that the idea of transferring either technologies (e.g. high tech GMOs) and/or policy tools (e.g. full market regulation), which were generated in developed countries, to developing countries is in general a recipe for failure.

The scale of the global transformation implied by the oil civilization has now reached a point in which a simplified perception of agriculture that implies ignoring important dimensions of sustainability can no longer be held without facing important negative consequences. The perception that human passed this critical threshold is indicated by the widespread use of the buzz-word "globalization" to indicate that something new is happening. As observed by Waltner-Toews and Lang (2001), the scale of human activity on this planet reached a point that no longer leaves room for "externalizations" (= short cuts providing temporary comparative advantage to those deciding to use them) to the global economy. In terms of pollution, the term globalization means that "what goes around comes around." In terms of international development the term globalization means that increasing someone profit because of favorable terms of trade implies impoverishing someone else. That someone else, sooner or later, will require assistance. Ignoring negative side effects on the environment in the long term (the key to the dramatic success of western science and technology in the last century) no longer pays. The environment will sooner or later present the bill, and it may be a very high one. Put in another way, the term globalization means acknowledging that sooner or later (the sooner the better) we will have to go back to the ancient practice of integrating the goal of economic growth with a set of additional goals such as equity, environmental compatibility, respect of diversity of cultures and values. This will require looking for wise solutions, rather than for optimal solutions.

This new situation which is challenging the conventional ideological paradigms of perpetual growth is generating an additional dose of stress for human societies. Social systems are facing a continuous need of fast adjustments of their established rules and "truths". Human societies all over the planet are forced to learn how to make tough calls in order to find the right compromise (the middle way) between "too much" and "too little" technical progress. This is the back-door through which the concept of "multifunctionality" of agriculture was re-discovered by the high-tech society. Within the army of scientists fully dedicated to "maximize" and "optimize", those that are meditating on the various dilemmas associated to issue of sustainability are discovering that there are a lot of additional goals that have to be considered when dealing with the sustainability of human development. That is, the two goals of "economic growth" and "technical progress" have to be considered as members of a larger family of goals that includes also: "respect for ecological processes", "more equity for present generation," "respect of the rights of future generations," "protection of cultural diversity," to arrive to deeper and more basic procedural issues such as: "learning how to define 'quality of life' when operating in a multicultural setting." In spite of the fact that these goals are becoming more and more important in the choice of sound policies for agricultural development, the scientific capability of supplying useful representations and structuring of these sustainability dilemmas is far behind the demand.

Niels Röling (2001) characterizes the need of a total rethinking of the performance of agriculture as the need of stipulating **a new social contract among the actors of the food system** (farmers, consumers, industry, scientists, administrators and their constituencies). This new social contract should be about how to use and distribute common resources in relation to an agreed upon: (a) set of activities judged as needed and admissible in the food systems; and (b) set of indicators of performance used for discussing and implementing what should be considered as a desirable food system. This new social contract requires considering, shared goals, legitimate contrasting views about positive results and negative side effects of human actions, discussing the validity of available analytical tools, which can be used to characterize the performance of the food system in relation to different attributes of performance, generating viable procedures able to guarantee quality in decision processes (quality has to do with competence, fairness, transparency, ability to learn and adapt).

This sudden change in the "terms of reference" of agriculture is challenging the conventional "codified knowledge" associated to the production of food and fibres. Such a knowledge, religiously preserved in the various departments of agricultural colleges, is nowadays just one of the many pieces of information required for solving the puzzle. The puzzle is the necessity of continuously updating both the definition and regulation of agricultural activities in a fast changing social context. This updating is getting more and more difficult because of: (1) the speed at which new social actors, social dynamics and technical processes emerge at different scales; (2) the growing awareness of the crucial and growing role that the ecological dimension plays in a discussion about sustainability. For these reasons the challenge of finding new analytical tools which can be used to deal with the sustainability of agricultural development is extremely important both within the developed and developing world.

The very concept of multifunctional land uses requires the adoption of the concept of multicriteria analysis of performance. This in turn requires a previous definition, at the social level, of an agreed-upon problem structuring. A "problem structuring" may refer to the decision of how to represent the system under analysis – e.g. when dealing with a simple monitoring of its characteristics - or to the decision of what scenarios should be considered – e.g. when discussing of potential policies. With a given problem structuring I mean the individuation of: (1) a set of alternatives to be considered as feasible and acceptable (what is the agreed upon option space). (2) a set of indicators reflecting legitimate but contrasting perspectives found among the stakeholders (= the relevant attributes of the system and what are the direction of change that should be considered as an improvement or a worsening – a Multi-Criteria space). (3) a set of non-reducible models useful to understand and simulate different types of causal relations (a multi-objective multi-scale integrated representation of changes in relevant attributes) in relation to the set of alternatives and the set of indicators; and (4) the gathering of enough data to be able to run the models and to discuss of pros and cons of different options in relation to the set of relevant criteria.

In this new framework, the scientists are just another class of non-equivalent observers part of a given society. As such they have to learn, together with the rest of the society, how to perceive and represent in a more effective way the performance of a multifunctional agriculture.

To face such a challenge, scientists have to learn how to put their old wine ("sound reductionist" analytical tools) into new bottles to address new types of problems. Their new goal is no longer that of finding "optimal solutions" (Optimal for whom? Optimal for how long? Optimal in relation to which criteria? Who is entitled to decide about these questions?). Rather scientists are asked to help different social actors to negotiate satisficing compromises about how to use their land, human time, technology and financial resources in relation to non comparable types of costs and benefits (e.g. social, economic, ecological, individual gain or stress) which are expected (but with large doses of uncertainty) to be associated to different policy choices.

In human affairs, in order to be able to solve a problem one has, first of all, to be willing to admit that such a problem does exist in the first place. The second step is to try to understand the nature of the problem in a way that can help the finding of solutions. An evident sign of crisis in the conventional scientific paradigm, when dealing with sustainability, is represented by the fact that the necessity of a paradigm shift is much clearer for the general public than for the community of politicians and scientists giving them advice. Often the sustainability predicament currently experienced by humankind is ignored (or even denied) in the analyses provided by many conventional academic disciplines and/or in the strategic planning of large national and international institutions. Common people, on the contrary, are forced to watch, in their daily life and every night in the news, the growing and widespread crumbling of ecological and social fabrics all over the planet. In front of this emotional stress they are not receiving any convincing explanations that current trends of environmental deterioration and uncontrolled growth of either population and/or aspirations are not just the result of a temporary crisis but "the challenge" for the stability of any political process in the next century. The implications of this new fact in terms of science for governance, are at least twofold:

* **on the scientific capability of providing useful representations and structuring of these new sustainability problems.**

* **on the political capability of providing adequate mechanisms of governance.**

This thesis deals only with the first of these two implications. However, the dual nature of this challenge implies that when dealing with the issue of sustainability the society is trapped in a chicken-egg paradox: (i) scientists cannot provide any useful input without interacting with the rest of the society; as well as (ii) the rest of the society cannot perform any sound decision making without interacting with the scientists. In general, these concerns have not been considered as relevant by "hard scientists" in the past. So that, the goal of "improving the quality of a decision process" was not considered to belong to the realm of scientific investigation. On the other hand, the new nature of the problems faced in this third millennium, implies that very often when deciding on facts that can have long term consequences we are confronting issues: "*where facts are uncertain, values in dispute, stakes high and decisions urgent*" (Funtowicz and Ravetz, 1991; 1999).

Funtowicz and Ravetz coined the expression ***Post-Normal Science*** to indicate this new predicament for scientific activity. Whenever scientists are forced by stakeholders to tackle specific problems at a given point in space and time, they can face a "mission impossible" according to the terms of reference of "normal science". There are problems and situations in which "risk" (defined as an assessment based on probabilities) cannot be assessed (e.g. potential environmental problems of large scale application of GMOs are associated with uncertainty and ignorance). There are other situations (e.g. whenever they are told "to fix Chicago in 30 days") in which scientists are facing: (a) events that do not make possible repetitions in experiments; and (b) a flow of questions from the stakeholders that would require a flow of scientific answers at a rate not compatible with the development of a "sound" scientific understanding. When operating in a "normal mode", scientists were used to have the privilege of picking up the best experimental setting for studying what they wanted to study, and in doing so, they could take all the time they needed to work out robust answers.

In a situation of Post-Normal Science not always "scientific rigor" coincides with "sound science". On the contrary, using risk assessment (e.g. using frequencies or estimated probabilities to assess risks) in cases in which one deals with irreducible uncertainty and genuine ignorance should be considered as "sloppy science". That is, the use of sophisticated statistical tests providing a significance of " 0.01" should not be confused with "sound science" when used in situations in which they do not make any sense (Giampietro, 2002). In this situation, those that refuse to sell "fake rigorous science" in exchange for power and/or academic recognition can find themselves marginalized in the debate over the future of our development. To make things worse, this situation makes possible to establish ideological filters based on pseudo-scientific rigor to avoid to confront unpleasant realities. The denial of the existence of a problem of global warming related to the accumulation in the atmosphere of greenhouse emissions is a well known example of this fact. When dealing with a complex reality and large scale problems (i.e. global warming) there is always some rigorous test that can be found to challenge the evidence supplied by the adverse side. But a broken clock indicating twice a day the "exact time" can result much less useful for decision making than a clock which slows down of a second every year, and which therefore is never indicating the "exact time" during a given day for the next months. When dealing with large scale issues, it is much better to have a sound understanding of the big picture even if details are missing, than a very accurate picture of just one piece of the puzzle which can only be studied rigorously when considered in pieces and held out of context.

This thesis wants to answer three questions crucial for scientists willing to be effective in the development of a science, which can result more useful for governance, in relation to the issue of sustainability of agriculture.
PART 1. What is the role that scientists working in the field of sustainability of agriculture should play in this process?
PART 2. Can we develop different scientific analysis using complex systems thinking?
PART 3. What alternative analytical tool kits can be developed for integrated analysis of agroecosystems?

PART 1

Science for Governance: the role of Beta-Gamma scientists

Chapter 1

The crash of reductionism against the complexity of reality

This chapter presents two practical examples of the general impasse that reductionism is experiencing when attempting to deal with the issue of sustainability. The goal of this section is that of providing a narrative and introducing basic issues, technical explanations and a more detailed analysis are provided in the next two chapters.

1. Example 1: In a complex reality it is unavoidable to find multiple legitimate views of the "same problem"

1.1 Contrasting but legitimate policy suggestions for sustainability.

In 1996 I was invited at an international conference in Zurich to debate in front of the media the problem of food security for humankind in the 21st century (SAGUF, 1996). The conference had the goal of commemorating the 50th anniversary of the Swiss Academy of Science. To celebrate this special event, beside the work of the conference, the organizers invited a panel of "very distinguished scholars" to close the conference with a reliable input of policy suggestions. A list of 6 of the policy suggestions given by different panellists is given in Fig. 1.1 The list includes three pairs of contrasting suggestions referring to the following fields: (1) food policies within countries, (2) international trade policies; (3) social policies dealing with the role of women in guaranteeing food security. The rationale of these suggestions is briefly discussed below:

* **food security within countries** - it is true that in the next century a growing fraction of population in developing countries will be urbanised. Therefore, keeping food prices low will be a key policy to guarantee food security for those people, which will be relying heavily on the market for their food supply. This is the explanation and the policy advice obtained when reading the problem at a given point in space and time (assuming the "ceteris paribus hypothesis" as valid). In fact, this was the view expressed by the international expert in food policy. On the other hand, when looking at evolutionary trends, it will only be possible to feed such a growing urban population if the productivity of farmers will be dramatically increased. Matching the additional food demand of the few billions of people arriving in the next decades mainly in the South will require a major increase in the flow of investments in agriculture. A dramatic increase in investments in farming will not happen without an adequate return of these investments. This can only be obtained by guaranteeing high prices paid to farmers. This was the view expressed by the professor of agricultural development. Framing the analysis of the future food security within an evolutionary context leads to a completely different policy.

* **the effects of world trade** - it is certainly true that developed countries are using both non-renewable and renewable resources taken from ecosystems of poor countries. In this way, people living in developed countries are reducing the amount of natural capital that can be used for development by people living in developing countries. This was the view expressed by an Institute of research focused on the sustainability of human development. On the other hand, many developing countries invested heavily in the intensification of their agricultural sector. In this way they are attempting to use comparative advantages (lower cost of labour, abundance of land) to boost their process of economic development attracting foreign currency. When considering this effort, they are today hampered by those policies of developed countries aimed at restricting food imports from South. This was the view expressed by a professor of international development. Also in this case, both rationales used to develop policy suggestions are correct. They are generated simply by different formulations of the

problem.

* **empowering women or preserving cultural heritage?** - it is obvious that the protection of the diversity of cultural identities and local historic heritage is a must for a sustainable global development. Such a long-term perspective was embraced by the representative of a Swiss NGO. On the other hand, a demand of empowerment coming from women abused by existing social habits cannot be dismissed just because of the need of preserving cultural diversity at any cost. In this case the other speaker (also a woman), was coming from a region in India where wives are burned alive with their death husbands. Her strong perception of the urgent need of change in cultural habits pushed her, in her role of analyst, to reduce the time horizon considered in evaluating the desirability and side effects of policies.

In this example, the experts asked to provide advices to "humankind" on how to improve the sustainability of food security were perfectly comfortable in making and defending their points. Moreover, they were all right. However, as soon as they were confronted with the fact that the information given by the panel was contrasting (a journalist actually made such an obvious remark) they could not figure out why this was happening. They immediately started to defend their theses AGAINST the others, and getting on the defensive showing their academic credentials ("I know what I am talking about . . . I am a well known professor . . . I have been working on this problem for decades . . ."). Under the pressure of the moment nobody even considered the possibility that legitimate but contrasting scientific truths can coexist!

Another interesting point can be driven home from this example. Looking at the different conclusions reached by the scientists it becomes immediately clear that scientists coming from different social contexts (e.g. developed countries versus developing countries) were adopting for their analysis different pre-analytical choices of their "problem structuring" (= choice of relevant goals, variables, explanatory dynamics for the select an explanatory model). Put in another way, the differences in policy recommendations were not generated by differences in the accuracy or validity of models or equations. Rather they were just reflecting basic differences in how the various scientists perceived and represented the problem to be tackled. Scientists operating in developed societies were suggesting policies aimed at preserving current steady-state (= keep prices low, reduce trading, keep cultural diversity at any cost). Whereas scientists coming from less developed countries were suggesting policies aimed at changing as fast as possible current situation of steady-state (= boost the evolutionary rate of the system). Probably, this clear-cut division at that conference has been generated by chance by the particular combination of invited speakers and topics assignment. However, it is sure that different perceptions of a given problem tend to reflect difference in the social context in which the scientist is operating. The possibility of multiple non-equivalent perceptions of the same situation is one of the typical characteristics of complexity and it is further elaborated in the following section.

1.2 Looking at non-equivalent useful pictures of a person, which one is the right one?

Before moving to the second example, this section discusses more in detail the impossibility to obtain "the right" picture of a given situation when dealing with complex systems organized in a nested hierarchy. In this section I want to make the point that it is literally impossible to get the "right picture" of a given complex system. Even when talking of "real pictures" (those printed on a paper or shown on a monitor), the complexity of the reality entails the unavoidable existence of multiple-identities that to be represented require the parallel use of non-equivalent pictures.

Let's imagine that we are request to pick a visiting scientist up at the airport. We are given the name - Dr. X - but we don't know her/his face. The most obvious additional input needed to perform our task is a picture of Dr. X. Let's imagine now that we ask for a picture and what we get from the mail is the picture given in Fig. 1.2a together with a note saying: "please find enclosed the picture of Dr. X that you requested". Such a picture is completely useless for our task, even though we cannot say that such a picture does not contain relevant information about Dr. X.. This picture makes possible to study how

Dr. X digests nutrients keeping her/him alive. Therefore, this picture (which has been taken from an experimental nutrition lab in my institute) reflects a very important option available to us for looking at human beings. It should be considered a crucial piece of information to study human sustainability.

Getting back to our story, we ask for another picture of Dr. X, this time a picture taken at a larger scale. In response to our request we get another picture, that shown in Fig. 1.2c together with a note saying: "following your request, please find enclosed a larger scale picture of Dr X, who is the one indicated by the arrow !" Also in this case, even if we cannot use this picture at the airport, this picture tells us useful information about Dr. X (= her/his relations with her/his social context). In fact, after a close examination we can say that Dr. X is resident in Italy and she/he is concerned with the problems of the environment (this is a picture of a rally of the Italian green party). Using this picture we got useful information bout Dr. X, but still this is not the information we were looking for our task.

When writing again yet for another picture, we specify, this time, that the picture of Dr. X has to include the "whole head" and "only the head" (we fix the scale at which the boundary is set for the representation, in order to get rid of possible non-equivalent representations generated by the arbitrariness of such a choice). Next picture (Fig. 1.2d) matches our constraints but still leaves us disappointed. In the picture given in Fig. 1.2d we see the "head" of Dr. X, but we cannot see her face. Now I used "her" since, at this point, with the help of a physician we can know that Dr. X is a woman. But the selection of mapping mechanism (pattern recognition based on x-rays rather than visible length-waves) still hides the information we need. The choice of using x-rays to take her picture, prevented us from seeing the face (= the pattern recognition that we need at the airport). However, the very same choice of using x-rays makes possible for us to learn useful information about Dr. X (= she has a sinusitis that should be taken care of).

The picture that enables us to recognize Dr. X among the people getting out from the gate at the airport is given in Fig. 1.2b.

Three points from this discussion:

(i) - systems that are organized over different hierarchical levels (such as humans made of organs, made of cells, made of molecules, made of atoms . . . which at the same time are part of a household, part of a community, part of a country, part of a large whole) show different identities when looked at (and represented) on these different levels. No matter how many photos we make of a person with a microscope (pictures of the type shown in Fig. 1.2a) we will never be able to see her face. The face is an "emergent property" that can be seen only adopting an appropriate selection of descriptive domain, that is: (1) an appropriate space-time scale; and (2) an appropriate system of encoding of relevant qualities (the head of Dr. X seen using X-rays does not show her face);

(ii) - non-equivalent descriptions referring to non-equivalent descriptive domains are not reducible to each-other. They catch and represent some aspects of the system (on a given scale) and hide other aspects of the systems (either on the same scale and/or on other scales). Therefore a description that makes us happy at a given point in space and time and in relation to a specific goal (picking up a given person at the airport) should not be considered as "better" than others. Someone with a different problem can find much more useful other descriptions. Going back to our story Dr. X experiencing a continuous headache and knowing very well her-own face would be happier with the encoding of the x-rays telling her about her sinusitis (Fig. 1.2d), than with the encoding used in Fig. 1.2b (seen every day when looking in the mirror). This is why one pays to get X-ray pictures.

(iii) - emerging properties generated when aggregating information at a different level can generate emergence in behaviours also in those that are using the information. For example, let's imagine that the person in charge for the "airport rescue mission" is a young single male scientist. After receiving the picture given in Fig. 1.2b, he could expand in his mind the set of potential interactions with Dr. X by including also that of getting out with her for dinner. Actually this enlargement of his "option space" can dramatically change his perception of the duty which has been assigned to him. What before was considered a chore (wasting valuable leisure time to get an unknown Dr. X at the airport) suddenly becomes a pleasant opportunity justifying his investment of leisure time. This dramatic change in perception would never have occurred if the information available was only that of Fig. 1.2a, 1.2c, 1.2d. When dealing with reflexive systems (humans), sudden changes in the characteristics of the observers can become crucial in determining the validity of a given problem structuring.

The relation of the non-equivalent views presented in Fig. 1.2 with the contrasting policy suggestions presented in Fig. 1.1 will be discussed in Chapter 2. For the moment what can be said is that reductionistic analysis based on the selection of a set of observable qualities encoded in measurable variables over a given descriptive domain represent just one of the possible pictures given in Fig. 1.1. That is, by using formal models, we can look at only one of the possible identities of the system at the time. This is what generates the existence of legitimate but contrasting policy recommendations based on non-equivalent problem structuring.

2. Example 2: for adaptive systems "ceteris" are never "paribus"- Jevons' paradox

2.1 Systemic errors in policy suggestions for sustainability

Jevons' paradox (F. Jevons, 1990) was first enunciated by William Stanley Jevons in his 1865 book *The Coal Question* (W.S. Jevons, 1865). Briefly it states that an increase in "efficiency" in using a resource (= defined as a better output/input ratio) leads, in the medium/long term, to an increased use of that resource (rather than to a reduction). At that time, Jevons was discussing possible trends of future consumption of coal and reacting to scenarios generated by advocates of technological improvements. Also at that time, some were urging to dramatically increase the "efficiency" of engines in order to reduce the consumption of fossil energy (the preoccupation for non-renewable fossil energy has a long history . . .). His point was that more efficient engines would have expanded the possible uses of coal for powering human activities and therefore they would have boosted rather than reduced the rate of consumption of existing coal reserves.

Jevons' paradox proved to be true not only with regard to demand for coal and other fossil energy resources but also with regard to demand for food resources. Doubling the efficiency of food production per hectare over the last 50 years (the Green Revolution) did not solve the problem of hunger, it actually made it worse, since it increased the number of people requiring food and the absolute number of malnourished (Giampietro, 1994a). In the same way, doubling the area of roads did not solve the problem of traffic, it made it worse since it encouraged the use of personal vehicles (Newman, 1991). As more energy efficient automobiles were developed as a consequence of rising oil prices, American car owners increased their leisure driving (Cherfas, 1991). Not only the number of miles increased but also the expected performance of cars grew; US residents are increasingly driving mini-vans, pick-up trucks, and four-wheel drives. More efficient refrigerators have become bigger (Khazzoom, 1987). A promotion of energy efficiency at the micro level of economic agents tends to increase energy consumption at the macro level of whole society (Herring, 1999). In economic terms, we can describe these processes as increases in supply boosting the demand in long-term, much stronger than the so called Say's Law.

Jevons' paradox has different names and different applications, for example it is called "rebound effect" in energy literature and "paradox of prevention" in relation to public health. In the latter case, the paradox consists of the fact that the amount of money "saved" by prevention of a few targeted diseases generates in the long term a dramatic increase in the overall bill of the health sector. Due to the fact that humans sooner or later must die (which is a fact that seems to be ignored by steady-state efficiency analysts) any increase in life span of a population directly results in an increase in health care expenses. Beside the higher fraction of retired in the population needing assistance, it is well known that the hospitalization of elderly is much more expensive than hospitalization of adults.

This last example leads us to the heart of the paradox. Technological improvements in "efficiency" of a process (e.g., increases in miles traveled per gallon of gasoline) represent improvements in *intensive variables.* That is, they can be defined as "improvement" per unit of something and under the ceteris paribus hypothesis that everything else remains the same. This means that an increase in efficiency could translate into savings **only when the system does not evolve in time** (when our steady-state representation of the system is satisfactory for the purposes of decision making). Unfortunately, complex systems, especially human systems, tend to adapt quite fast to changes. As soon as such "technological improvements" are introduced into a society, room is generated for either: (i) the addition of new activities (e.g. new models of car including new features, or a change in the distribution of individual over age classes with an increase of elderly); and/or (ii) a further expansion of current levels of activity (e.g., more people make more use of their old cars, or a larger population size). Former expansion refer to qualitative aspects of the systems (an addition of possible options in the set of accessible states), latter expansion represents a change in *extensive variables,* that is, in the dimension of the process (but using the same set of options). In conclusion, "increasing efficiency" (that is doing better according to the picture obtained at a particular point in space and time, in relation to a given associative context and a given set of goals) simply makes possible for systems to consider new alternatives or to expand the set of criteria considered for defining the performance of an activity. In no way this could be associated to an improvement of sustainability. For example, car air conditioning was at the beginning a fancy option, then it became a reasonable option also on medium/small cars and finally it became a relevant criteria considered by potential buyers at the moment of deciding what to buy. This change was made possible by the dramatic improvement in energy efficiency of engine and more in general cars. The energy saving obtained in relation to the activity of "just moving around" was used to make possible another activity, that of "moving around with a controlled and pleasant temperature". In terms of sustainability (e.g. human consumption of fossil energy) the dramatic increase in energy efficiency of engines and cars did not result in a reduction of consumption. This very same pattern will be discussed later on when discussing about the so called "agricultural treadmill".

The important point for our discussion is that "how the system will expand" and "what consequences will be generated by this expansion" are questions which cannot be answered (let alone predicted) by those studying the efficiency of a given process. For these reasons, sound decision making should be based on an assessment of the problem, which should be based on complementing views [e.g. both steady-state view and evolutionary view (trend analysis)]. Moreover, considering relevant system's qualities one at the time tends to generate contrasting indications on direction of changes (as in the problems of contrasting policy suggestions discussed in the previous example). Going back to the paradox of prevention, policies aimed at reducing health costs (e.g., smoking restrictions to prevent lung cancer) have the effect, in the long term, of increasing the cost of health care. However, paradox in the paradox, this is a good result for society. In fact, when assessing health care costs in an evolutionary perspective we can easily recognize that the ability to afford a larger bill for health care is an indicator of development for a human society. However, this double paradox points at the existence of a systemic error in many analyses of development. More on this in the following two sections.

2.2 Systemic errors in the development of strategies: the blinding paradigm

The issue of sustainability is determining a generalized critical appraisal of current strategy of technical progress. As a matter of fact, whenever we enlarge the scale used to evaluate the results of previous innovations, we are able to appreciate the general validity of Jevons' paradox. Technologies developed to solve a particular problem often had the effect to make things worse in relation to that particular problem. The mechanism seems to be repeated endlessly in three steps:

- STEP 1. Humans face a specific problem and define a simple terms of reference for the solution of it. They look for a fix of the problem according to a simplified description of it as seen at a particular point in space and time by a particular social group. This translates into: (1) the choice of a single space-time scale on which dynamics are represented. and (2) a representation of the problem over a finite performance space, based on a limited selection of relevant variables. This reflects a pre-analytical value call on the relevance of the set of qualities to be monitored. Often this simplification of the representation of the reality leads to the adoption of a mono-criteria mechanism of representation of the performance (e.g. Cost/Benefit Analysis maximizing welfare or a maximization of the efficiency of a given transformation). At this point, it is possible to generate, using hard science "optimizing functions" individuating "best possible courses of action". According to this simplified terms of reference scientists look for quick technological fixes aiming at eliminating the perceived problem according to the above set of assumptions.

- STEP 2. Technological fixes able to move the system closer to the so defined "optimal solution" are found, developed and applied on larger scale;
- STEP 3. The implementation of Step 2 induces in the long-term unexpected effects (a few factors and aspects not considered in the simplified problem structuring and therefore neglected in the formulation of the policy are amplified in their relevance and get into the picture. In many cases this mechanism leads even to an amplification of the very same problem that generated Step 1. As noted earlier, the successful implementation of a fix on large scale leads to change the societal perception of what should be considered as desirable, important or irrelevant.

What is disturbing in this pattern is its regular repetition in human affairs. A perfect example is represented by the fate of the green revolution. In the sixties, decision makers and scientists of developed countries entered into Step 1. They were facing the problem of two to three hundred million of malnourished people located mainly in developing countries. The representation of the problem was: current demand of food is larger than current supply (an analysis based on a quasi-steady-state representation). The obvious solution based on this problem structuring was to develop farming techniques able to produce more food (boost the supply). At this point, Step 2 was followed. The chosen technological fix was the green revolution. The name was chosen to stress the dramatic increase in yields obtained in food production thanks to technological fixes. The solution was applied to many areas of our planet fulfilling the goal fixed in Step 1 to increase the supply and the result was revolutionary indeed. The unavoidable arrival of Step 3 has been confirmed by the world conference organized by FAO in 1996. That is, 40 years after the first world conference, the aim of the second conference was the same. Focusing world attention on the urgent need of fighting hunger. The unexpected side effect of the technological fix developed in the sixties has been a huge increase in population induced by the increase in food supply. That is, the solution of doubling yields put forward in the 60s resulted into a more than proportional increase in the absolute number of malnourished (Srinivasan, 1985; Kates and Haarmann, 1992). It must be mentioned here, however, that in these 40 years many reputable scientists - including some of the fathers of the green revolution – have been warning against confusing the symptoms with the disease. Boosting food yields with the green revolution represented a short term technical patch capable of buying some time for the implementation of more structural changes in developing economies. For example, Norman Borlaug - that won the Nobel Prize for his contribution to the "green revolution" - in his 1970 Nobel Lecture literally says: "*The green revolution has won a temporary success in man's war against hunger and deprivation; it has given man a breathing space. If fully implemented, the revolution can provide sufficient food for sustenance during the next three decades. But the frightening power of human reproduction must also be curbed; otherwise the success of the green revolution will be ephemeral only*" (his lecture is available at: http://www.nobel.se/peace/laureates/1970/borlaug-lecture.html). However, such a message did not go through.

The last FAO summit of 1996 concluded with a pressing call for a new and convinced jump into a new Step 1. That is, decision makers and scientists gathered in this occasion adopted the same terms of references (problem structuring) as in the 1960s, which led to the same solution: developing another wave of silver bullets to increase food production, this times also resorting to genetically engineered crops (Giampietro, 1994a).

The blinding paradigm is quite clear. Improvements in "efficiency" of a certain activity can only be defined and assessed in terms of quantifiable increases in what is perceived to be at the moment to be a system quality to which is given "top priority". This translates into a strategy for increasing short-term returns in relation to such a priority based on "ceteris paribus" hypothesis. This is a snap-shot picture of the situation based on a given mix of: goals, perceived boundary conditions, available technical options, existing institutional settings, sets of relevant criteria selected and agreed upon (?!) to define the performance. ***The validity of this mix is assumed indefinitely into the future, even though this is never the case.*** Improvements in efficiency (which must refer necessarily to a specific and short-term view of "improvement" by those social groups in power) are in general paid for in terms of a lower sustainability of the "improved" societal activity in the long- term (as noted before) or when considering a different set of view points. That is, improvements in efficiency based on the consideration of a given set of criteria, tend to induce a worsening in relation to those criteria not considered in the original problem structuring. A winning solution at a certain hierarchical level tends to imply losers on different hierarchical levels. This fact can go undetected at the beginning, since these unpredicted phenomena tend to occur within different descriptive domains and on different space-time windows, often not considered by those in power (Giampietro, 1994b).

Side effects associated to the mismatch between the definition of "improvement" at a location specific scale and the open definition of "improvement" referring to an evolutionary scale is at the root of the so called "agricultural tread-mill" (Cochrane, 1958). A quick view of the various steps is given in Table 1.1 (from Röling, 2002). Again it is important to observe that the existence of "bifurcations" between: (a) a local definition of improvement; and (b) a larger scale definition of improvement; is a general feature to be expected when dealing with the mechanism of self-organization of adaptive systems. An innate tension among process of evolution and adaptation operating in parallel on different scales has the effect of keeping high the level of selective pressure on the evolving system (= thanks to the previous innovation the system is forced to innovate further more and at a faster pace . . .). The negative side effects is represented by the fact that a faster pace of innovation translates into a larger level of stress for the components of the system. The trajectory of technical development in agriculture is just one of the fields of possible application. Table 1.1 shows the remarkable similarity between the "agricultural treadmill" and the "golfer treadmill".

2.3 Systemic errors in the representation of evolution: the myth of dematerialization of developed economies (are elephants "dematerialized" versions of mice?)

As noted earlier, unless a comprehensive analysis of the changes induced by technological improvement is performed, including intensive and extensive changes and an adequate selection of descriptive domains considering changes on higher and lower hierarchical levels, it is easy to be misled by the counter-intuitive behavior of evolving complex systems. The myth of de-materialization of developed economies can be used as a good practical example.

When adopting an economic definition of energy efficiency (MJ of energy consumed per $ of GNP produced) one can get the false impression that technological progress is decreasing the dependence of modern economies on energy. In fact, many seem to be reassured by the fact that technological progress is associated with a decreasing ratio MJ/$-GNP in developed countries. However, this mapping of "improvement" relies on a variable that refers to an intensive variable, which is therefore not useful when dealing with the issue of sustainability. For example, in 1991 the United States operated at a much lower ratio of energy consumption per unit of GNP than, for instance, P. R. China (12.03 MJ/$ versus 69.82 MJ/$ respectively) – see **Fig. 1.3a.** On the other hand, because of this greater efficiency the United States managed to have a GNP per capita much higher than in P.R. China (22,356 $/year versus 364 $/year respectively) (WRI, 1994). That is, if we change the mechanisms of mapping changes moving to an extensive variable (by multiplying the energy consumption per unit of GNP by the GNP per capita) the picture is totally reversed. In spite of the significantly higher economic energy efficiency, the energy consumed per US citizen is 11-times higher than that consumed by a Chinese citizen. Obviously, this is just one of the possible mechanisms of mapping, if we compare these two countries considering also population size we would get another set of assessments referring to another relevant dimension of analysis.

If we look in parallel at the trends of "energy consumption per unit of GNP", "GNP per capita", "population size", "total energy consumption", and "energy consumption per capita" as reported in **Fig. 1.3a** and **Fig. 1.3b** for the USA in the period 1950–1990 we can clearly see the inverse relation between energy consumption ***per unit of GNP*** and ***the aggregate level*** of GNP per capita. In this way, the degree of '**de-materialization**' induced by technological progress in the U.S. economy can be checked by analyzing data of aggregate energy consumption published by USBC (1991) – **Fig. 1.3.** A reduction in the energy consumption per unit of GDP from 113.1 MJ/$ in 1950 to 25.1 MJ/$ in 1990 (a ratio of reduction of 4.5/1) had the effect to increase the aggregate consumption of commercial energy in the US economy from 34.5 terajoules in 1950 to 77.0 terajoules in 1990 (more than doubling the total energy consumption).

As indicated by **Fig. 1.3b** the aggregate energy consumption of USA increased not only because of an increase in consumption per capita but also because of an increase in population size. Latter phenomenon is explained not only by differences between fertility and mortality, but also by immigration, driven by the attractive economy. Actually, strong gradients in standard of living among countries - generated by gradients in efficiency – tend to drive labor from poorer to richer countries (Giampietro, 1998). For example, the dramatic improvement in energy efficiency that the state of California (USA) has achieved in the past decade (in terms of the intensive variable useful energy/energy input) will not necessarily curb total energy consumption in that state. Present and future technological improvement are likely to be nullified by the dramatic increase in immigration, both from outside and inside the USA, which make the Californian population among the fastest growing in the world. Again we find the systematic failure of accounting for the change in boundary conditions induced by the change in technology at the root of this counterintuitive trend.

In relation to the myth of dematerialization of developed economies it is time to mention the striking similarity in the pattern relating the two variables: (a) "intensity of metabolism"; and (b) "size" found when comparing socio-economic systems and biological organisms. In biology it is well known that animals with a smaller body size have a higher rate of energetic metabolism per kg of biomass. Actually there is an abundant literature on this phenomenon - a good overview of the literature can be obtained for empirical analyses in the book of Peters (1986); and for more recent theoretical applications in the book of Brown and West, (2000). Using available data (organized in tables or in parameters for equations that can be applied to different "typologies" of animals) we can calculate, for example, the relation between size and metabolic intensity for mammals of different size. For example, a male mouse weighting 20 grams - an extensive variable - has a metabolic rate of 0.06 W (= joule/second). That is male mice have a metabolic rate of 3 W/kg of body mass – an intensive variable. Whereas a male elephant weighting 6,000 kg - an extensive variable - has a total metabolic rate of 2,820 W which is equivalent to a metabolic rate of 0.5 W/kg of body mass - an intensive variable (Peters, 1986; pag. 31).

If we apply the same reasoning used by some neo-classical economists to describe the process of dematerialization of modern economies (= using an intensive variable assessing "energy intensity per unit of GNP"), we would find a quite bizarre result. When looking at animal biomass across the evolutionary ranking (= using an intensive variable assessing the energy expenditures per unit of biomass) we would find a quite peculiar way of defining the process of "dematerialization" in mammals. Since 10,000 kg of elephants consume much less (= 4,700 W) that 10,000 kg of mice (= 30,000 W), we have to conclude that elephants (with a low energy intensity per unit of biomass) should be considered ***a "dematerialized" version of mice*** (with a high energy intensity per unit of biomass). After all, this is exactly what we are told by neo-classical economists (and what is told in the vast majority of colleges dealing with the issue of sustainable development to students). According to this perception, the process through which very poor countries - based on location specific subsistence economies - are evolving into large developed countries - based on a global economy - is described as a process of "dematerialization" of world economy!

The fact that modern neo-classical economic analysis sees elephants as de-materialized versions of mice would be an amusing finding indeed, if this silly idea were not taught to students in almost every academic program dealing with the sustainability of human progress!

Table 1.1
Jevons' paradox in action: How many "treadmills" are out there waiting to be found?

"the agricultural treadmill" (after Röling, 2002)

1. Many small farms all produce the same product;
2. Because not one of them can affect the price, all will produce as much as possible against the going price;
3. A new technology enables innovators to capture a windfall profit;
4. After some time, others follow ('diffusion of innovations');
5. Increasing production and/or efficiency drives down prices;
6. Those who have not yet adopted the new technology must now do so lest they lose income (price squeeze);
7. Those who are too old, sick, poor or indebted to innovate eventually have to leave the scene. Their resources are absorbed by those who make the windfall profits ('scale enlargement').

"the golfer treadmill"

1. Many amateur players all play with the same result (e.g. very high handicap);
2. Because none of them has enough time to dramatically improve their personal skill, they all can happily play against their own high score;
3. A new technology enables innovators to reduce their score (e.g. clubs made of new expensive material capable of hitting the ball to a longer distance);
4. After some time, others follow ('diffusion of innovations');
5. Increasing the average distance achieved using 'high tech' clubs induces an increase in the average length of "par 4" and "par 5"holes in golf courses;
6. Those who have not yet adopted the new technology must now do so otherwise they will not even be able to maintain their original high handicap ("increase of the cost of the game");
7. Those who are too old or unable to innovate because of a low income eventually will see their status plummeting among the other golfers.

Fig. 1.1 International Conference on World Food Security
SAGUF -Zurich, October 9 - 10, 1996

National Policy	
Keep prices of food commodities LOW	**I.F.P.R.I. - U.S. scientist**
Keep prices of food commodities HIGH	**Ag. Econ. - Prof. from Pakistan**
International Policy	
REDUCING imports from the South	**Wuppertal Inst. - German scientist**
INCREASING imports from the South	**Ag. Dev. - Prof. from Ghana**
Social Policy	
PRESERVING local cultural heritage	**NGO - Swiss Feminist**
FIGHTING local cultural heritage	**Sociologist - Prof. from India**

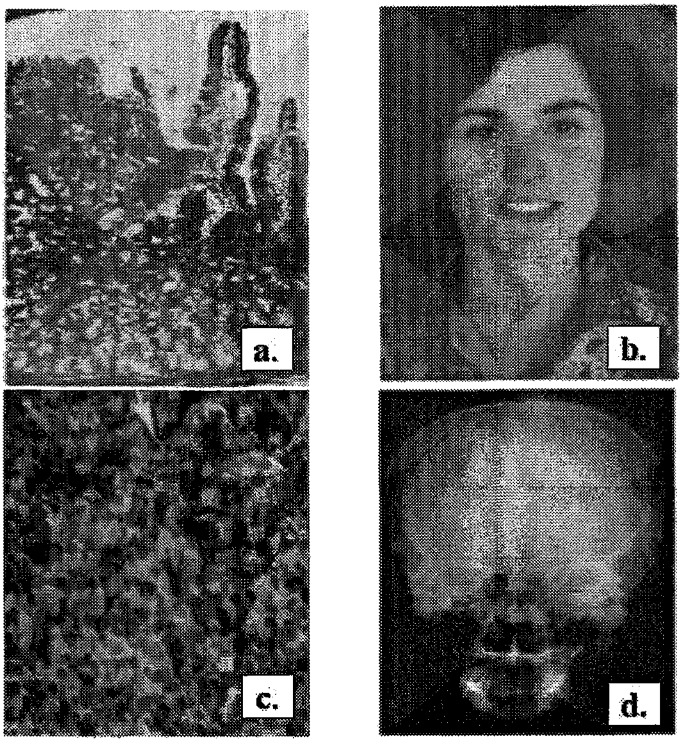
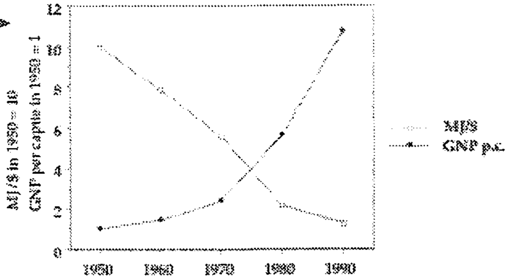


Fig. 1.2

Non-equivalent views of the same person

Fig. 1-3a

Ratio MJ/$ (ET/GNP) and
GNP per capita in the USA
in the period 1950 - 1990



The inverse relation between
intensive variables describing
the performance of USA in relation
to energy efficiency of the economy

Total Energy Consumption, Total Population,
and Energy Consumption per Capita
in the USA in the period 1950 - 1990

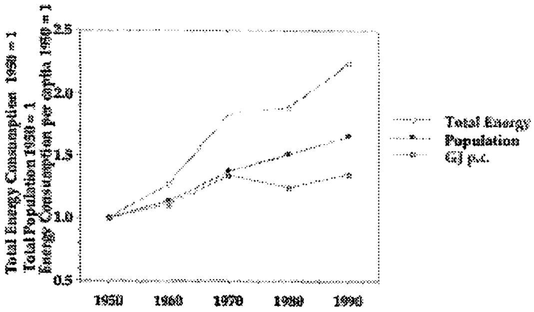


Fig. 1-3b

The picture of changes in energy
consumption of US economy
when describing the same trend
using an extensive variable (red line)

Chapter 2

The epistemological predicament entailed by complexity

This chapter has the goal of clarifying a misunderstanding often affecting the debate about how to handle in scientific terms the challenge implied by sustainable development. The misunderstanding is generated by a confusion between the two adjectives "complicated" and "complex". Complicatedness is associated to the nature and degree of ***formalization*** *obtained in the step of representation (the degree of "syntactic" entailments implied by the model). That is complicated is an adjective that refers to models and not to natural systems. Making a model more complicated does not help when dealing with complexity. Complexity means that the set of relations which can be found when dealing with the "representation of a shared perception" is virtually infinite, open and expanding. That is complex is an adjective that refers to the characteristics of a process of observation. Therefore, it requires addressing the characteristics of a complex "observer/observed" which is operating within a given context. Dealing with complexity implies acknowledging the distinction between perception and representation, that is the need of considering not only the characteristics of the observed, but also the characteristics of the observer. Scientists are always inside any picture of the "observer/observed" complex and never acting from the outside. In scientific terms this implies: (i) addressing the semantic dimension of our choices about how to perceive the reality in relation to goals and scales; (ii) acknowledging the existence of non-equivalent observers which are operating in different points in space and time (on different scales), using different detectors, different models and pursuing independent local goals; (iii) acknowledging that any representation of the reality on a given scale reflects just one of the possible shared perception found in the population of interacting non-equivalent observers. To make things more difficult both observed systems and the observers are becoming in time, but at different paces.*

2.1 Back to basic: "can science obtain an objective knowledge of reality?"

The main point of this chapter is that understanding complexity entails going beyond the conventional distinction between epistemology and ontology in the building of a new science for sustainability. To introduce such a basic epistemological issue I am pasting below a list of quotes taken from the paper *Einstein and Tagore: Man, Nature and Mysticism* (Home and Robinson, 1995). The paper is about a famous discussion that Einstein and Tagore had about science and realism.

List of quotes:
* "In classical physics, the macroscopic world that of our daily experience, is taken to exist independently of observers: the moon is there whether one looks at it or not, in the well known example of Einstein" . . . **"the physical world has objectivity that transcends direct experience and that propositions are true or false independent of our ability to discern which they are . . .**
(p. 172-173).
* "The laws of nature which we formulate mathematically in quantum theory deal no longer with the elementary particles themselves but with our knowledge of the particles" . . . "The nature of reality in the Copenhagen interpretation is therefore essentially epistemological, that is all meaningful statements about the physical world are based on **knowledge derived from observations. "No elementary phenomenon is a phenomenon until it is a recorded phenomenon"**. Einstein declared himself skeptical of quantum theory because it concerned 'what we know about nature', no longer 'what nature really does'. In science, said Einstein, 'we ought to be concerned solely with what nature does. Both Heisenberg and Bohr disagreed: in Bohr's view, it was 'wrong to think that the task of physics is to find out how nature *is*.

Physics concerns what we can say about nature". (p.173).

* ***Quote of Tagore:*** "This world is a human world – the scientific view of it is also that of the scientific man. Therefore the world apart from us does not exist. It is a relative world, depending for its reality upon our consciousness". (p. 174)

* ***Quote of Einstein:*** "The mind acknowledge realities outside of it, independent of it. For instance nobody may be in this house, yet that table remains where it is". (p. 174)

* ***Quote of Tagore:*** "Yes, it remains outside the individual mind, but not the universal mind. The table is that which is perceptible by some kind of consciousness we possess. . . . **if there be any truths absolutely unrelated to humanity, then for us it is absolutely non-existing"**. (p. 175).

At the end of this paper, three positions related to the question "does the reality exist and can science obtain an objective knowledge of it?" are summarized as follows:

(1) Einstein position – science must study (and it can) what nature does. Entities **do have well defined objective** properties even in the absences of any measurement and humans know what these objective properties are, **even when they cannot measure** them.

(2) Bohr's position – science can study starting from what we know about nature. **Objective existence of nature has no meaning independent of the measurement process.**

(3) Tagore position – science is about **learning how to organize our shared perceptions of our interaction with nature. Objective existence of nature has no meaning independent of the human pre-analytical knowledge of a typologies of objects to which a particular object must belong in order to be recognized as distinct from the background.**

The first two positions can be used to point at the existence of a big misunderstanding that some physicists have about the role of the observer in the process of scientific analysis. Quantum physics finally was forced to admit that the observer does play a role in the definition of what is observed. But still the interference generated by the observer, in quantum physics, is only associated to the act of measurement. Put in another way, it is the interaction between the measuring device and the natural system (an interaction required to obtain the measurement), which alters the natural state of the measured system. This is why smart microscopic demons could get rid of this problem. According to this view, if it were possible to look directly at individual molecules in some magic un-invasive way one could get knowledge (measures) avoiding at the same time the problem of the recognized interference observer/observed system.

Unfortunately things are not that easy. Epistemological problems implied by complexity (multiple scales, multiple identities, and non-equivalent observers) are so deep that even getting the help of friendly demons it would not be possible to escape the relative basic epistemological impasse.

In any scientific analysis of complex natural systems the step of measuring is not the only step in which the observer affect the perception and representation of the investigated system. Another and much more important "interference of the observer" is associated to the very definition of a **formal identity** for the system to be studied. This is a type of interference which has been systematically overlooked by hard scientists. The nature of this interference is introduced in the next section using again a practical example. A more detailed descriptions of relative concepts is given in Section 2.2.

2.1.1 The pre-analytical interference of the observer

In a famous article, Mandelbrot (1967) makes the point that it is not possible to define the length of the coastal line of Britain, if we do not first define the scale of the map we will use for our calculations. The smaller the scale (the more detailed the map) the longer will result the length **of the same segment of coast.** This means that the length of a given segment of the coast - its numerical assessment - is affected not only by the intrinsic characteristics of the observed system (i.e. the profile of a given segment of coast), but also by **a preliminary agreement about the meaning of what a segment of coast is.** That is, a preliminary agreement among interacting non-equivalent observers about the shared meaning that should assign to the string of words written in English "**a segment of coast**". Put in another way, this implies reaching an agreement on **how "a given segment of coast" should be perceived and how should be represented.** This means that such a number will unavoidably reflect also **an arbitrary choice** made by the analyst when deciding at which scale the system should be perceived and represented (before being measured). To better explore this point let's use a practical example, provided in Fig. 2.1, which is based on Mandelbrot's idea. The goal of this example is to explore the mechanism through which we can "see" different identities for the "same natural system" (in this case "a segment of coast") when observing (perceiving and representing) it in parallel on different scales. The arbitrary choice of deciding one of the possible scales at which the coast can be perceived, represented and observed, will determine the particular identity taken by the system and its consequent measure.

Imagine that a group of scientists is asked to determine **the orientation of the coastal line of Maine** (a state of the USA) providing scientific evidence backing up their assessment. Before getting into the problem of selecting an adequate experimental design for gathering the required data, scientists have first of all to agree about how to "share the meaning" given to the expression "orientation of the shore of Maine". Actually, it is at this very pre-analytical step that the issue of multiple identities of a complex system enters into play. In fact, let's imagine that we give to this group of scientists the representation of the coast shown in Fig. 2.1**a**. Looking at that map the group of scientists can safely state (it will be easy to reach an agreement on the related perception) that Maine is located on the East coast of the USA. A sound statistical experiment can be easily set to confirm such a hypothesis. For example, the experiment could be carried out by calling 500 Maine residents randomly selected on a phone book from London and Los Angeles at a given day-time asking them what time is it. Using such an input and the known differences in time zones between London and Los Angeles it is possible to scientifically prove that Maine is on the East coast of the USA.

However, if we had given to the same group of scientists a map of Maine based on a smaller scale for the representation of the coast - for example a map referring to the County level, as in Fig. 2.1**b** - then the group of scientists would have organized their perceptions in a different way. Someone who is preparing computerized maps of Maine by using satellite images could have easily provided empirical evidence about the orientation of the coastal line. By coupling remote sensing images with a general geo-referential system it can be "proved" that the orientation of the coast of Lincoln County is south.

What if we had asked another group of scientists to work on the same question, but having given to them a smaller map of the coast of Maine from the beginning? For example let's consider the map referring to the village of Colonial Pemaquid, in Lincoln County, in Maine – as in Fig. 2.1**c**. These scientists looking at that map would have shared yet another perception of the meaning to be assigned to the expression "orientation of a tract of shore of Maine". When operating from within this non-equivalent shared meaning assigned to this expression, they could have provided yet another contrasting statement about the orientation of this tract of coastal line. According to empirical analyses carried out at this scale, they could have easily concluded that the coastal line of Maine is actually facing west. Also in this case, such a statement can be "scientifically proved". A random sample of 1,000 trees can be used to provide solid statistical evidence, by looking at the differences of color on their trunks in relation to the side facing North. In this way, this group of scientists could have reached a remarkable levels of confidence in relation to such an assessment (e.g. P* = 0,01!). This new scientific inquiry performed by a different group of scientists operating within yet another distinct "shared perception" of the identity of the investigated system can only add confusion to the issue rather than clarifying things.

The situation experienced in our mental example by the various groups of different scientific observers given different maps of Maine is very similar to that experienced by scientists dealing with sustainability from within different academic disciplines. Our hypothetical groups of scientists were given "non-equivalent representations of the coastline of Maine" and this pushed them to agree on a particular perception of the meaning to be assigned to the label/entity "tract of coastal line". As it will be discussed more in detail in the rest of this chapter, the existence of **different legitimate formal**

identities for a natural system is generated by the possibility of having different associations between: (a) "a shared perception" about the meaning of a label (in this case the expression "tract of coastal line"); and (b) the corresponding "agreed representation" (in this case the non-equivalent maps shown in Fig. 2.1). Differences about basic assumptions and organized perceptions are in fact at the basis of the problem of communication among disciplinary sciences. For example, a cell physiologist assumes that the "biomass" of wolves (seen as cells) is operating at a given temperature and a given level of humidity. Whereas, an ecologists considers temperature and humidity of the environment as key parameters determining the survival of a population of wolves (parameters determining the amount of wolf biomass). Neo-classical economists often assume the existence of perfect markets, whereas historians study the processes determining the chain of events that make imperfect actual markets.

The mechanism assigning an identity to geographic objects implies that we should expect (rather than being surprised) to find new identities whenever we change the scale used to look at them. Getting back to our example, it would be possible to ask yet another group of scientists to clarify the messy "scientific empirical" information about the orientation of the coastal line of Maine. We can suggest to this group that in order to determine the "true" orientation of the coastal line of Main sophisticated experimental models should be abandoned getting back to basic empiricism. Following this rationale, we can ask this last group of scientists to go on a particular beach in Colonial Pemaquid to gather more reliable data in a more direct way (they should use the "down to the Earth" approach). The relative procedure is to put the feet into the water perpendicular to the water front while holding a compass in the hand. In this way they can literally "see" what the "real" orientation is. If they would do so on Polly Beach - Fig. 2.1**d** - they would find that all the other groups are wrong. The "truth" is that Maine has its shore oriented toward North. Such a shared perception of the reality, strongly backed up by solid evidence (all the compasses used in the group standing in the same beach do indicate the same direction . . .), will be difficult to be challenged!

The point to be driven home from this example is that different observers can make different pre-analytical choices about how to define [the meaning assigned to the particular string of words] "a segment of coast" which will make them to work with different identities for their "investigated system". This will result into the co-existence of legitimate but contrasting scientific assessments. This example introduces a major problem for reductionism. Whenever different assessments are generated by the operation of non-equivalent measurement schemes, linked to a logically independent choice of a non-equivalent perception/ representation of the same natural system, it becomes impossible to reduce the resulting set of numerical differences just by adopting a better or more accurate protocol of measurement or using a more powerful computer.

The four different views of Fig. 2.1 show that there are several possible couplets of "organized perceptions" (the meaning assigned to the label "coastal line") and "agreed representations" (types of map used to represent our perception of coastal lines) that can be used to plan scientific experiments aimed at answering the question "what is the orientation of a tract of coastal line of Maine"?

If we do not carefully acknowledge the implication of this fact, we may end up with "scientifically correct" (falsifiable through empirical experiments) but misleading assessments. For example, the assessment that Maine is on the East coast (based on an identity of the coastal line given in Fig. 2.1**a** and scientifically proved by a sound experiment of 500 phone calls) is misleading for a person interested in buying a house in Colonial Pemaquid with a porch facing the sun rising from the sea. For this goal the useful identity (and the relative useful experiment) to be chosen is that shown in Fig. 2.1**d**. At the same time, the information based on the identity of Fig. 2.1**a** is the right one for the same person, when she need to determine the time difference between Los Angeles and Colonial Pemaquid in order to make a phone call at a given time in Los Angeles. So far the story told through our mental example has shown the practical risk that honest and competent hard scientists may be fouled by some donors, that actually can provide research funds to make them prove whatever should be proved (that the coast is oriented toward North, South, East or West). Put in another way, the existence of multiple potential identities entails the serious risk that smart and powerful lobbies can obtain the scientific input they need just by showing in parallel to honest and competent scientists a given map of the system to be investigated together with a generous check of money for research.

The set of four different views (couplets of perceptions/representations) of the coastline given in Fig. 2.1 obviously can be easily related to the example of the four different identities of the same "natural system" (in that case a human being) given in Fig. 1.1. The same natural system is observable (= generating patterns on data-stream) on different scales, and therefore it entails the co-existence of multiple identities. The message given by these two figures is clear. Whenever we are in a situation in which we can expect the existence of multiple identities for the investigated system (complex systems organized on nested hierarchies) we must be very careful when using indications derived from scientific models. That is, we cannot attach to the conclusions derived from models some substantive value of absolute truth. Any formal model is based on a single couplet of "organized perception" and "agreed representation" at the time. Therefore, before using the resulting scientific input, it is important to understand the epistemological implications of having selected just one of the possible couplets (one of the possible identities) useful for defining the system. The quality check about "how useful is the model" has to be related to the "meaning" of the analysis in relation to the goal and not to the technical or formal aspects of the experimental settings (let alone the significance of statistical analysis at the 0.01 level). The "soundness" of the chain of choices referring to experimental setting (e.g. sampling procedure and measurement scheme) in relation to the statistics test used in the analysis, may result totally irrelevant for determining whether or not the problem structuring was relevant or useful for the problem to be tackled. Rigor in the process generating formal representations of the reality (those used in hard science) is certainly indispensable. But rigor is a condition necessary but not sufficient when dealing with complexity. Actually, a blind confidence in formalizations and algorithmic protocols can become dangerous if we are not able to define first of all in very clear terms where we stand with our perception of the reality and how such a choice fits the goals of the analysis.

It is time to get back to the original discussion about the "querelle" between Einstein and Tagore about science and realism. If we admit that the observer can interfere with the observed system even before getting into any action, during the pre-analytical step, simply by deciding **how to define the identity of the observed system,** then it becomes necessary to discuss more in details the steps and implications of this operation. The concept of identity will be discussed more in detail in section 2.2, for now it is enough to say that **the definition of an identity** coincides with **the selection of a set of relevant qualities that makes possible for the observer to perceive the investigated system as an entity (or individuality) distinct from its background and from other systems with which it is interacting.** However, we can distinguish between a **semantic definition of identity** which is a set of "expected qualities" associated to a direct observation of a natural system (e.g. a fish). This definition still belongs to the realm of semantic, since it is open (e.g. the list of relevant and expected qualities of a fish, is open and will change depending to who we ask). Moreover a semantic identity does not specify the procedure that will be used to make the observations (e.g. what signal detectors will be used to check the presence of fish and/or to establish a measurement scheme useful for represent it using a finite set of variables). For example, bees and humans see flower colors in different ways, even though they could result able to reach an agreement about the existence of different colors. A semantic definition of identity, therefore include an open and expanding set of shared perceptions about a natural system – see the examples given in Fig. 2.2. A semantic identity becomes a **formal identity** when it refers not only to a shared perception of a natural system, but also to an agreed-upon finite formal representation. That is, in order to represent a semantic identity in formal terms (e.g. to represent a fish in a model) we have to select **a finite set of encoding variables** (= a set of observable qualities that can be encoded into proxy variables), which will be used to describe changes in the resulting state space (for more see the theory about modeling relation developed by Rosen, 1986). This, however, requires selecting within the non-equivalent ways of perceiving a fish, illustrated in Fig. 2.3, a sub-set of relevant attributes that will be included in the model.

In conclusion, we can make a distinction that will be used a lot later on in this book:
* ***semantic identity*** = the open and expanding set of potentially useful shared perceptions about the characteristics of an equivalence class;
* ***formal identity*** = a closed and finite set of epistemic categories (observable qualities associated to proxies – e.g. variables) used to represent the expected characteristics of a member belonging to an equivalence class associated to a type.

By using this definition of semantic identity we can make an important point about the discussion between Einstein and Tagore. **The preliminary definition of an identity for the observed systems** (associated to an expected pattern to be recognized in the data stream, which makes possible the perception of the system in the first place) **must be available to the observer before the actual interaction observer/observed occurs. This applies either when detecting the existence of the system in a given place or when measuring some of its characteristics, let alone when we make models of that system.** This means that any observation not only requires the operation of a detectors gaining information about the investigated system through direct interaction (the problem implied by the operation of a measurement scheme, indicated by Bohr), but also the availability of a specified pattern recognition which must be know a-priori by the observer (the point made by Tagore). The measurement scheme has the only goal of making possible to detect an expected pattern in a set of data which are associated to a set of observable qualities of natural systems. These observable qualities are assumed to be (because of the previous knowledge of the identity of the system) a reflection of the set of relevant characteristics expected in the investigated system.

An observer that does not know about the identity of a given system would never be able to make a distinction between: (i) that system (when it is possible to recognize its presence in a given set of data in terms of an expected patterns associated to observable qualities of the system); and (ii) its back-ground (when the incoming data are considered just noise). The table in the room mentioned by Einstein in his discussion with Tagore can be there, but if the epistemic category associated to the equivalence class "table" is not in the mind of the observer - in the "universal mind" as suggested by Tagore or in the "World 3 of human culture" as suggested by Popper (1993) - it is not possible to talk of "tables" in the first place, let alone checking whether or not a table (or that table) is there.

The concepts of identity, multiple-identity, different perceptions/representation on different scales are discussed more in detail in the following section. The main point of the discussion so far is that scientists **can only measure specific representations** (using proxies based on observable qualities) **of their perceptions** (definition of sets of relevant qualities associated to the choice of a formal identity to be used in the model) **of a system.** That is, even when adopting sophisticated experimental settings **scientists are measuring a set of characteristics of a "type" associated to an identity assigned to an equivalence class of real entities (e.g. cars, dogs, spheres). This has nothing to do with the assessment of characteristics of any individual natural systems.**

In fact, it is well known that when doing a scientific inquiry any measurement referring to special qualities of a special individual is not relevant. For example, when asked to provide the assessment of the energy output of one hour of human labor we would be totally uninterested in assessing the special performance of Hercules during one of his mythical achievements or a world record established during the Olympic games. In science miracles and/or unique events do not count. Coming to the assessment of the energy equivalent of one hour of labor, we want to know "average values" (obtained through sound measurement schemes) referring to the energy output of 'one hour effort' performed by **a given typology of human worker** (e.g. man, woman, average adult). This is why we need an adequate sample of human beings to be used in the test. Scientific assessments must come with appropriate error bars. **Error bars and other quality checks based on statistical tests are required exactly to guarantee that what is measured are "observable qualities" characteristics of an equivalence class (belonging to a given type – i.e. average adult human worker) and not characteristics of any of the particular individuals**

included in the sample.

Put in another way, when doing experimental analyses **we don't want to measure the characteristics of any real individual entity belonging to the class** (of those included in the sample). **We want to measure only the characteristics of simplified models of objects sharing a given template (which are describable using an identity). That is, we want to measure the characteristics of the type used to identify an equivalence class** (the class to which the sampled entity belongs). This is why care is taken to eliminate the possibility that our measurement will be affected by special characteristics of individual objects (individual, special natural systems) interacting with the meter.

The previous paragraph points at a major paradox implied by science: (a) science has to be able to **make a distinction** between "types" and "individuals belonging to the same typology" (or between roles and incumbents using a sociological jargon, or essences and realization of essences using a philosophical jargon) when coming to the measurement step; but at the same time, (b) science has to **confuse** individuals belonging to the same type when coming to the making of models, in order to gain predictive power and compression. This paradox will be discussed in details in the rest of the book. This requires, however, the re-discovery of concepts and ideas which have been developed for centuries in philosophy (for an overview see Hospers, 1997), or in disciplines related to the process through which humans organize their perceptions so as to make sense of them - e.g. semiotic, for an overview see Barthes (1964); or the work of Polany (1958, 1977), and Popper (1993). This issue has been explored recently within the field of complex systems theory, especially in relation to the epistemological implications of hierarchy theory - Koestler (1968; 1978), Simon (1962), Allen and Starr (1982), Allen and Hoekstra (1992), O'Neill (1989), Ahl and Allen (1996). In the rest of this chapter I am just providing an introductory overview of these themes. The reader shouldn't feel uncomfortable with the high density of concepts and terms found in this Chapter. These concepts will be discussed again and more in detail later on. The main goal, now, is just to induce a first familiarization with new terms, especially for those that see them for the first time.

2.1.2 The take of complex systems thinking on science and reality

The idea that the pre-analytical selection of a set of encoding variables (deciding the formal identity which will be used as a model of the natural system) does affect what the observer will measure has huge theoretical implications. When using the equation of perfect gas (PV = nRT) we are adopting a model (a formal identity for the gas) that perceives/describes a gas only in terms of changes in Pressure, Volume, number of molecules and Temperature – with R as a gas constant. Characteristics such as smell or color are not considered by this equation as relevant qualities of a gas to be mapped in such a formal identity. Therefore, this particular selection of relevant qualities of a gas has nothing to do with the intrinsic "real" characteristics of the system under investigation (a given gas in a given container). This does not mean, however, that a modeling relation based on this equation is not reflecting intrinsic characteristics of that particular gas kept in the container, and therefore that our model is wrong or not useful. It means only that what we are describing and measuring with that model, after having selected one of the possible formal identities for the investigated system (a perfect gas), is a simplified version of the real system (a real amount of molecules in a gaseous state).

Any numerical assessment coming out from a process of scientific modeling and then measurement is coming out of a process of abstraction from the reality. "The model shares certain properties with the original system [e.g., *those belonging to the type*], but other properties have been abstracted away [e.g., *those that make the individual member special within that typology*]" (Rosen, 1977; pag. 230) – (the text in italic in parenthesis has been added by me to explain the reasoning proposed by Rosen in that paper). The very concept of selecting a finite set of encoding variables to define a formal identity for the system (defining a state space to describe changes), means "replacing the thing measured [e.g., *the natural system*] by a limited set of numbers" [e.g., *the values obtained through measurement for the selected variables used as encoding*] (Rosen, 1991; pag. 60).

According to Rosen (1991), experimentalists should be defined as those scientists that base their assessments on procedures aiming at generating abstractions from reality. The ultimate goal of a measurement scheme is, in fact, to avoid that the set of qualities of the natural system, which are not included in the formal definition of system identity, will affect the reading of the meters. Actually, when this happens, we describe the result of this event as a 'noise' which is affecting the numerical assessment of the selected variable.

When assuming the existence of simple systems (e.g. elementary particles) that can be usefully characterized using a very simple definition of identity (e.g. position and speed) one can be easily fouled by the neutral role of the observer. In this situation one can come up with the idea that the only possible interference that an observer can induce on the observed system is due to the interaction associated to the measurement process. But this limited interference of the observer is simply due to the fact that "simple systems" and "simple identities" which are applicable to all types of natural systems are not very relevant when dealing with the learning of interacting non-equivalent observers (e.g. when dealing with life and complex adaptive systems). Simple systems, in fact, can be defined as those systems in which there is a full overlapping of semantic identity (the open set of potential relevant system qualities associated with the perception of the system) with formal identity (representation of the system based on a finite set of encoding variables). This assumes also that with the formal identity we are able to deal with all system qualities that are considered as relevant by the population of non-equivalent observers: the potential users of the model.

This means that simple systems, such as "ideal particles", "frictionless or adiabatic processes" do not exist, they are rather artifacts generated by the simplifications associated to a particular association between perception and representation of the reality. This particular forced full overlapping of formal and semantic identity of the investigated system has been imposed on scientists operating in these field by the basic epistemological assumption of elementary mechanics. This explains why simple models of the behavior of simple systems are very useful, when applicable to real situations (e.g. the movements of planets). In these models the typologies of mechanical systems are viewed as not becoming in time. Unfortunately, when this is true, the relative behaviors are not relevant for the issue of sustainability.

Whenever the pre-analytical choices made by the observer when establishing a relation between the set of potential perceptions (the semantic identity) and the chosen representation (the formal identity used in the model) of a natural systems cannot be ignored, we are dealing with complexity. Let's imagine, for example, that the task of the scientists is that of perceiving and representing "her own mother" (which I hope reductionist scientists will accept to be a natural entity worth of attention). In any scientific representation of the behavior of "someone mother" the bias introduced by the process of measurement would result quite negligible when compared with the bias generated by the decision of what relevant characteristics and observable qualities of a mother should be included in the finite and limited set of variables adopted in the formal identity. Dealing with 1,000 persons it is much more difficult to reach an agreement about the right choice of the set of relevant qualities that have to be used in the definition of a mother, to describe with a model her changes in time, rather than to reach an agreement on the protocols to be used for measuring any set of agreed upon encoding variables. On the other hand, without an initial definition of what are the relevant characteristics associated to the study of a mother, it would be impossible to work out a set of observable qualities used for numerical characterizations (no hard science is possible).

This problem becomes even more important when the future behavior of the observer toward the observed system will be guided by the model that the observer used to observe the observed system. The problem of self-fulfilling prophecies is in fact a standard predicament when discussing of policy in reflexive systems (see Chapter 4 on Post-Normal Science).

These basic epistemological issues, which have been systematically ignored by reductionist scientists, are finally addressed by the emerging scientific paradigm associated to complex system thinking (and not even by all those working in Complexity). In fact, an intriguing definition of "complexity", given by Rosen [1977: p. 229], can be used to introduce the topic of the rest of this chapter: "a complex system is one which allows us to discern many subsystems ... [*a subsystem is the description of the system determined by a particular choice of mapping only a certain set of its qualities/properties*] ... **depending entirely on how we choose to interact with the system**". The relation of this statement to the example of Fig. 2.1 is evident.

Two important points in this quote are: (1) the concept of "complexity" is a property **of the appraisal process** rather than a property inherent to the system itself. That is, Rosen points at an epistemological dimension of the concept of complexity, which is related to the unavoidable existence of different relevant "perspectives" (= choices of relevant attributes in the language of integrated assessment) that can not be all mapped at the same time by a unique modeling relation. (2) models can see only a part of the reality, that part the modeler is interested in. Put it in another way, any scientific representation of a complex system is reflecting only a sub-set of our possible relations (potential interactions) with it. "A stone can be a simple system for a person kicking it when walking in the road, but at the same time be an extremely complex system for a geologist examining it during an investigation of a mineral site" (Rosen, 1977 p. 229).

Going back to the example of the equation of perfect gas (PV = nRT), as noted earlier it does not say anything about how they smell. Smell can be a non-relevant system quality (attribute) for an engineer calculating the range of stability of a container under pressure. On the other hand, it could be a very relevant system quality for a chemist doing an analysis or a household living close to the chemical plant. The unavoidable existence of non-equivalent views about what should be the set of "relevant qualities" to be considered when modeling a natural system, is a crucial point in the discussion of science for sustainability.

2.1.3 Conclusion

Before closing this introductory section I would like to explain why I had to embark in such a deep epistemological discussion about "the scientific process" in the first place. There are subjects that are taboo in the scientific arena, especially for modelers operating in the so called field of hard sciences. Examples of these taboos include avoiding to acknowledge:

(1) the existence of impredicative loops - chicken-eggs processes defining the identity of living systems requires considering self-entailing processes across levels and scales (what Maturana and Varela call ***processes of autopoiesis*** - Maturana and Varela, 1998, 1980). That is, there are situations in which identities of the parts are defining the identity of the whole and the identity of the whole is defining the identity of the parts in a mechanism which escapes conventional modeling.

(2) the co-existence of multiple identities - we should expect to find different boundaries for the same system when looking at different relevant aspects of its behaviour. Considering different relevant dynamics on different scales requires the adoption of a set of non-reducible assumptions about what should be considered as "the system" and "the environment" and therefore this requires the simultaneous use of non-reducible models.

(3) the existence of complex time – complex time implies acknowledging that: (a) the observed system changes its identity in time; (b) the observed system has multiple identities on different scales that are changing in time but at different pace; (c) the observed system is not the only element of the process of observation that is changing its identity in time. Also the observer does changes in time. This entails, that depending on the selection of a time horizon for the analysis we can observe: (i) multiple distinct causal relations among actors (e.g. the number of predators affecting the number of preys or viceversa). (ii) the obsolescence of our original problem structuring and relative selection of models (the set of formal identities adopted in the past in the models are no longer reflecting the new semantic identity – the new shared perceptions – experienced in the social context of observation). That is changes in: (a) the structural organization of the observed system; (b) in the context of the observed system; (c) in the observer; (d) in the context of the observer (e.g. goals of the analysis) may imply the need of adopting a different problem structuring (an updated selection of formal identities), that is a different meaningful relation between perception and representation of the problem.

Keeping these taboos within hard science implies condemning scientists operating within that paradigm to be irrelevant when dealing with topics such as life, ecology and sustainability. The challenges found when dealing with these three 'forbidden issues' while keeping a serious scientific approach are discussed in Chapter 5. Alternative scientific approaches can be developed by adopting complex system thinking are discussed in Chapter 6, Chapter 7, and Chapter 8 and applications to the issue of Multi-Scale Integrated Analysis of Agro-ecosystems are given in Chapter 9, Chapter 10, and Chapter 11. However, facing these challenges requires being serious about changing paradigm. This is why, before discussing of potential solutions (in Part 2 and Part 3) it is important to focus on the following points (the rest of Part 1):
(a) hard scientists must "stop the denial". These problems do exist and cannot ignored;
(b) there is nothing mystical about complexity: current epistemological impasse experienced by reductionism can be explained without getting into deep spirituality or meditations (even though their understanding facilitate both); and
(c) these three taboos can no longer be tolerated: the development of analytical tools based on the acceptance of these three taboos is a capital sin which is torpedoing the effort of a lot of bright students. A sin which is becoming too expensive to be afforded.

To make things worse, a lot of hard scientists are more and more getting into the business of "saving the world" and they want to do so by increasing the sustainability of human progress. They tend to do so, by applying hard scientific techniques aimed at the development of "optimal strategies". The problem is that they tend to individuate optimal solutions by adopting models which, in the best case scenario, are irrelevant. Unfortunately, in the majority of the cases, they use models based on the ceteris paribus hypothesis or single scale representation which are not only irrelevant for the understanding of the problems, they are also wrong and misleading.

To contain this growing flow of "optimizing strategies" supported by very complicated models it is important to get back to basic epistemological issues that seems to be vastly ignored by this army of good-intended world-savers. Moreover, in the field of sustainability, past validation has only a limited relevance. Scientific tools that proved to be very useful in the past - e.g. reductionist analyses, which were able to send a few humans on the moon - are not necessarily adequate to provide all the answers to new concerns expressed today by humankind - e.g. how to sustain a decent life of 10 billion humans on this planet. As noted in Chapter 1, humans are facing now new challenge that require new tools.

"Epistemological complexity" is in play every time the interests of the observer (the goal of the mapping) are affecting what the observer sees (the formalization of a scientific problem and the resulting model – the choice of the map). That is, when pre-analytical steps [= (1) the choice of the "space-time scale" at which the reality should be observed and (2) the previous definition of a formal identity of what should be considered as "the system of interest" (a given selection of encoding variables)] are affecting the resulting numerical representation of system's qualities. If we agree with this definition, we have to face the obvious fact that, basically, any scientific analysis of sustainability is affected by such a predicament.

In spite of this basic problem, there are a lot of applications of reductionist scientific analysis in which the problems implied by "epistemological complexity" can be ignored. This, however, requires the acceptance without reservations from the various stakeholders that will use the scientific output of the reductionist problem structuring. Put in another way, reductionist science works well in all cases in which **power is effective for ignoring or suppressing legitimate but contrasting views on the validity of the pre-analytical problem structuring within the population of "users" of scientific information** (Jerome Ravetz, personal communication). Whenever we are not in this situation we a re dealing with Post-Normal Science, which is discussed in Chapter 4.

2.2 Introducing key concepts: equivalence class, epistemic category and identity

TECHNICAL SECTION

In order to "make sense" of their perceptions of an external reality humans organize in their language shared perceptions into epistemic categories (e.g. words able to convey a shared meaning). Obviously, I do not want to get here into a detailed analysis of this mechanism. The study of how humans develop a common language is very old and the relative literature is huge. This section elaborates rather on the concept of ***identity***, which has already been introduced in the previous section.

Before getting into a discussion of the concept of identity, however, we have to introduce another concept, that of ***equivalence class***. An equivalence class can be defined as a group or set of elements sharing common qualities/attributes. The mathematical formal definition of equivalence relation [a relation (as equality) between elements of a set that is symmetric, reflexive and transitive and for any two elements either holds or does not hold] is difficult to apply to real complex entities. In fact, as discussed in the example of the coastal-line, non-equivalent observers adopting different couplet of "shared perception" and "agreed representation" can perceive and represent the same "entity" as having different identities and therefore, they would describe that entity using different *epistemic categories*. As result of this fact, the same segment of coastal line could belong simultaneously to different equivalence classes depending on which non-equivalent observer we ask [e.g. (i) coastal line segments oriented toward south; (ii) coastal line segments oriented toward north; (iii) coastal line segments oriented toward east . . .]

Let's imagine now to deal with the problem of how to load a truck. Non-equivalent observers will adopt different relevant "criteria" to define the "identity" (set of relevant characteristics) that defines a "load" in terms of an equivalence class of "items" to be put on the truck. For example, a hired truck driver worried of not exceeding the maximum admissible weight of her/his truck will perceive/represent as a relevant category for defining as "equivalent" the various items to be loaded, **the weight of these items.** With this choice whatever mix of items can be loaded, as long as the total weight does not surpass a certain limit – e.g. 5 tons. The accountant of the same company, on the other hand, will deal with the mix of items loaded on the truck in terms of their economic value. This criterion will lead to the definition of **a different equivalent class based on the economic value of items.** For example, in order to justify a trip [the economic cost of investing a truck and a driver in that trip], the load must generate at least 500 US$ of added value. So that 100 kg of rocks and 100 kg of computers can be seen as the same amount of load adopting the "truck driver definition" of equivalence class, whereas they will be considered as dramatically different by the definition of equivalence class given by the accountant.

Any definition of an equivalence class used for categorizing "physical entities" is therefore associated to a previous definition of a semantic identity (= a set of qualities which make possible to perceive those entities as distinct from their context in a goal oriented observation). An equivalence class of physical entities is therefore the set of all physical entities that will generate the same typology of perception (will be recognized as determining the same pattern in the data-stream used to perceive their existence) to the same observer. At the same time, the possibility to share the meaning given to a word (the name of the equivalence class) by a population of observers requires the existence of a common characterization of the expectations about a type (about the common pattern to be recognized) in the mind of the population of observers.

At this point the reader should have noticed that the series of definitions used so far for the concepts: "epistemic category", "equivalence class", "identity" start to look circular. Actually, when dealing with this set of definitions we are dealing with a clear impredicative loop (a chicken-egg paradox). That is: (A) "you must know a priori the pattern recognition associated to an epistemic category to recognize a given entity as a legitimate member of the class – you have to know what dogs are to recognize one"; and (B) "you can learn the characteristics to be associated to the label of the class, only by studying the characteristics of legitimate members of the relative class – you can learn about the class of dogs only by looking at individual dogs". A more detailed discussion of **impredicative loops**, and how to deal in a satisfactory way with the circularity of these self-entailing definitions is given in Chapter 7, so the reader must be patient to this regard for now. On the other hand, the reader should be aware that scientists are used to handle impredicative loops all the time without much discussion. For example, this is how statistical analysis works. You must know already that what is included in the sample - as a specimen - is a legitimate member of the equivalence class that you want to study. At that point you can study the characteristics of the class by applying statistical tests to the data extracted from the sample. So that you must already know the characteristics of a type (to judge what should be considered as a valid specimen in the sample) in order to be able to study the characteristics of that type with statistical tests.

In spite of this circularity, the impredicative loop leading to the definition of identities works quite well in the development of human languages. In fact, **it makes possible for a population of non-equivalent observers to develop a language based on meaningful words about an organized shared perception of the reality.** This translates into an important statement about the nature of reality. The ability to generate a convergence on the validity of the use epistemic categories in a population of interacting non-equivalent observers points at the existence of a set of ontological properties shared by all the members of the equivalence classes. A dog is called *perro* in Spanish, *chien* in French and *cane* in Italian. Different population of non-equivalent observers developed different labels for the same "entity" (the image of the equivalence class associated to the members belonging to the species *canis familiaris*). This identity is so strong that we can use a dictionary (establishing a mapping among equivalent labels) to convey the related meaning across populations of non-equivalent observers speaking different languages. That is, the "essence" of a dog (= the set of characteristics shared by the members of the equivalence class and expected to be found in individual members by those using the language) to which the different labels (*dog*, *perro*, *chien*, *cane*) refer must be the same. Also in this case, a discussion of the term "essence" and its possible interpretations and definitions within complex system thinking will be discussed at length in Chapter 7.

This remarkable process of convergence of different populations of non-equivalent observers on the definition of the same set of semantic identities (associated to the words of different language) can only be explained by the existence of ontological aspects of the reality which are able to guarantee the coherence in the perceived characteristics of the various members of equivalence classes associated to different identities (e.g. a dog) over a large space-time domain (over the planet across languages). IF various observers interacting with different individual realizations of members of the class (e.g. having distinct different experiences about individual dogs) are able to reach a convergence on a shared meaning assigned to the same set of epistemic categories (e.g. share a meaning when using the label dog). THEN the ontological properties of the equivalence class "dog" must be able to determine a recognized pattern on a space-time domain much large of that of individual observers, individual dogs and even individual populations of interacting non-equivalent observers which are using a common language. Put in another way, if all the observers perceiving the characteristics of a dog can agree on the usefulness and the validity of the identity associated to such a label, we can infer that something "real" out there is responsible for the coherence of the validity of such a label. **Such a "real" thing obviously is not an organism belonging to the species *canis familiaris*.** In fact any organism can only generate local patterns in data-stream (those recognized by a few observers) on a very limited space-time domain. In order to generate coherence across languages we must deal with an equivalence class of physical objects sharing the same pattern of organization and expressing a similar behaviors on a quite large space-time domain. This class must exist and interact with several populations of non-equivalent observers to make possible the convergence of on the use of a set of meaningful labels in a language. It is the shared meaning of different words in different language that makes possible to organize them in a dictionary.

The search for equivalence classes useful to organize our knowledge of physical entities through a label is a quite common experience for humans. We are all familiar with the use of assigning names to human "artifacts" (e.g. a refrigerator or a model of a car such as the Volkswagen golf). In different languages this implies establishing a correspondence between a given essence (= a semantic identity in our mind expressed as an expected set of common characteristics of the class of objects that are considered to be realization of that essence) and a label (the name used in the language for communicating – representing – such a perception). At this point it becomes possible to associate to these labels a mental representation of "perceived essences" – the most habitual images in our mind. The same mechanism applies in biology, where equivalence classes of organized structures are also very common (e.g. the individual organisms – that dog - belonging to a given species – *canis familiaris*).

I am arguing that this similarity between human made artifacts organized in equivalence classes and biological structures organized in species is not due to a coincidence, but that on the contrary it is a key feature of autopietic systems. The very essence of this class of self-organizing system is their ability of guaranteeing the coherence between:

(1) the ability of establishing useful relational functions, which define the essence of their constituent elements – this coherence has to be obtained at a large scale; and

(2) the ability to guarantee coherence in the process of fabrication of the various elements of the corresponding equivalence class – e.g. using a common blue print for the realization of the set of physical objects sharing the same essence – this coherence has to be obtained at a local scale.

According to the terms introduced so far we can say that elements belonging to the same equivalence class are **different realizations** of the same **essence** (they share the same semantic information about the common characteristics of the class) - Rosen, (2000).

The variability of the characteristics of different realizations belonging to the same equivalence class will depend on: (1) the quality of the process of fabrication (how well the process of realization of the essence is protected from perturbations coming from the environment); and (2) the accuracy of the information stored, carried and expressed by the reading of the blue-print against gradients between expected associative context of the type and the actual associative context of the realization.

At this point it should be noted again that, **any assessment of the characteristics of the template used to make an equivalence class or to the type used to represent members belonging to the class do not refer to the characteristics of any individual organized structure observed in the process of assessment. Rather, both measurements and assessments refer only to the relevant attributes used to define the equivalence class. Put in another way, scientific assessments refer to the image of the class - the type - and not to special characteristics of realizations. The variability of individual realizations will only affect the size of "error bars" describing various characteristics of individual elements in relation to the average values for the class.**

At this point, we have accumulated enough concepts for attempting a more synthetic definition of identity.

The etymology of the term ***identity*** comes from Latin "identidem" which is a contraction of "idem et idem" literally "same and same" (Merriam-Webster Dictionary). An identity implies using the same label for two tasks: (a) to identify mental entities (types representing the essence of the equivalence class as images in our mind) and (b) to identify physical entities perceived as members of the corresponding equivalence class (the set of all the specific realizations of that essence). As noted before such mechanism of identification (obtained using a sort of "stereo" complementing mapping) must result useful to: (1) see distinct things as the same (to gain compression) – e.g. all dogs are handled as if they were just dogs; but also, (2) handle each real natural system one at the time (to gain anticipation) – e.g. we can infer knowledge about this particular dog, from our general knowledge about dogs.

The concept of **identity** helps individual observers (at a given point in space and time) to handle their daily experience with natural systems. In fact, by using identities, an observer can either:

(1) identify an element of an equivalence class as an entity distinct from its context (e.g. to perceive the existence of a individual cow or the table in the room) – since it makes possible for the individual observer

the relative pattern recognition in the data stream coming from the reality. Depending on the type of detectors used to perceive the existence of that cow – sight, smell, touch – non-equivalent observers will adopt a different selection of relevant attributes (a different characterization of the type – selection of non-equivalent formal identities - for the same label). Obviously, a large carnivorous predator or an endo-parasite will map the formal identity of a cow in different ways; and

(2) infer information about the characteristics of a particular realization (any element of the class – again a particular cow met in a particular point in space and time) obtained from the knowledge of the class and not by previous experience with the same physical entity. Put in another way, an observer knowing about "cows" can know about characteristics of the essence, which are common to the members of the equivalence class and therefore can safely be assumed to be present also in that particular specimen. This implies that **even when meeting a particular cow for the first time**, an observer knowing about the characteristics of the type can infer that that particular cow has, inside her body, a pulsing heart even when is looking at her from 500 meters of distance.

The ability of associate the "right" set of epistemic categories to an individual realization (physical entity) recognized as belonging to a given equivalence class (associated to a label) can provide a huge power of compression and anticipation. But at the same time, this can be a source of confusion. In fact, one must be always aware that every cow, as well as every farm, every farmer or every individual ecosystem is special.

The validity of an identity requires two quality checks in parallel as illustrated in **Fig. 2.4**:

(1) a congruence check (in relation to an external referent) over a small scale. This check is about the validity of the correspondence between "***the mental object***" (semantic identity associated to an epistemic category in the mind of the observer) and "***the physical object***" (the experienced characteristics expressed by a member of the corresponding equivalence class) in relation to "***the given label***" used to link the expectations associated to the mental objects to the experience associated to the interaction with the individual realization of the corresponding type. This validity check is related to a local space-time domain. That is, it requires that individual observers using the set of epistemic categories associated to the label are able to verify the congruence between expectations - how a "cow" is expected to look and behave - and the pattern found in the data-stream obtained when interacting at a given point in space and time with a real-world entity which is assumed/recognized to be a member of the equivalence class - how that particular entity, identified as a "cow" is actually looking and behaving when interacting with the observer.

(2) a congruence check (in relation to an external referent) over a much larger scale about the congruence of the various identities assigned to different objects by a population of observers within a given language. It should be noted in fact, that the universe of words, semantic identities and epistemic categories is there before any individual human observer enters into play. That is, new human observers learn, when they are babies, how to name objects, use adjectives and to locate events in space and time according to an established set of epistemic tools found in the culture within which they grow up. This mismatch of between the space-time domain at which these tools are defined and the process of learning of individuals is at the basis of the perception that types and epistemic categories are out of time. The reader can recall here the world of ideas (e.g. Plato) out of time, or in more recent times, the WORLD 3 of established concepts (e.g. Popper, 1993). Obviously, the universe of epistemic tool of a cultural system is there before any individual observer enters into play, and therefore it looks like given (as the laws of a country) to individuals. As a matter of fact, the "***mental image of object A***" has to be shared by non-equivalent observers. This is what make possible to reach an agreed-upon representation of that object at the social level. This why new-comers into the culture and the language have to learn how to converge on "the set of categories usually associated to such a label" – the habitual descriptive domain adopted by society. This would be, for example, the definition of an entity found on the dictionary - see **Fig. 2.4.** Obviously, the "official" definition of an entity at the societal level does not match entirely with the personal perceptions

that different individuals have of dogs, cars, or other entities. However, when operating at a very large scale (as implied by the interaction of a population of non-equivalent observers over a large period of time) the problem of congruence among "official" definitions in languages operates above the level of individual observers and users of the language. The agreed upon definition (representation) of the semantic identity for individual objects (e.g. *the object A*) must be compatible also with the definition (representation) of other organized perceptions of other objects interacting with *object A*. Actually, this condition is a must. In fact, humans are able to define a mental image only in relation to other mental images (Maturana and Varela, 1998). That is, as soon as we define other identities – e.g. for *objects B, C,* and *D* which are interacting with *A* - we have to "socially organize" – at a level higher than that of individual observers - the sharing of the meaning assigned to labels (the representation of organized shared perceptions) about other mental objects interacting with *A*. Put in another way, the operation of a language requires reaching a socially validated habitual descriptive domain for each of "***the mental images of the objects*** (e.g. *B, C,* and *D*) interacting with *A* - this is shown in the upper part of **Fig. 2.4**. To do that humans have to introduce additional concepts such as Time and Space which are needed to make sense of their shared perceptions in relation to the various selections of identities. In fact, it is only within Time (relative representation of a rate of change compared to another rate of change used as reference) and Space (relative position of an object compared to another one used as a reference) that we can represent the relation and interaction between different set of mental objects. This is, what generates the existence of multiple identities for systems organized on different hierarchical levels. In fact, the various definitions of identities sharing compatible categories tend to cluster on different "scales" (= meaningful relations between a perception and representation of reality – Allen and Starr, 1982). This is what generate the phenomenon discussed in Fig. 1.1 and Fig. 2.1 of "emergence" of different identities on different scales. The need of reaching a mutual compatibility and coherence among the reciprocal definition of the various epistemic tools used in the process requires the use of different "clusters" of epistemic categories to perceive and represent the same system at different levels of organization. Only in this way it becomes possible to share the meaning of representations about perceptions in a common language. The coherence of a language, in fact, entails a set of reciprocal constraints derived from the mutual information carried out by epistemic categories.

When we talk of a check on the reciprocal compatibility of the universe of epistemic categories used to handle the perception and representation of the reality at different scales and in relation to different typologies of relevant qualities, we deal with a "validity check" which does not refer to any specific interaction between "observers" and "individual physical elements of equivalence classes". Rather this is a validity check that refers to the emergent properties of the whole language (Maturana and Varela, 1998).

2.3 Key concepts from Hierarchy theory: Holons and Holarchies

2.3.1 Self-organizing systems are organized in nested hierarchies and therefore entail non-equivalent descriptive domains

All natural systems of interest for sustainability (e.g. complex biogeochemical cycles on this planet, ecological systems and human systems when analyzed at different levels of organization and scales above the molecular one) are "dissipative systems" (Glansdorf and Prigogine, 1971, Nicolis and Prigogine, 1977, Prigogine and Stengers, 1981). That is they are self-organizing, open systems, away from thermodynamic equilibrium. Because of this they are necessarily "becoming systems" (Prigogine, 1978), that in turn implies that they: (i) are operating in parallel on several hierarchical levels (where patterns of self-organization can be detected only by adopting different space-time windows of observation); and (ii) will change their identity in time. Put it in another way, the very concept of self-organization in dissipative systems (the essence of living and evolving systems) is deeply linked to the idea of: (1) **parallel levels of organization** on different space-time scales, which entails the need of using multiple identities; and (2) **evolution,** which implies that the identity of the state space, required to describe their behaviour in a useful way, is changing in time. The two sets of examples discussed in Chapter 1.

Actually, the idea of systems having multiple-identities has been suggested as the very definition of hierarchical systems. A few definitions, in fact, say:

* "a dissipative system is hierarchical when it operates on multiple space-time scales - that is when different process rates are found in the system". (O' Neill, 1989)

* "systems are hierarchical when they are analyzable into successive sets of subsystems" (Simon, 1962: p. 468) - in this case we can consider them as near-decomposable.

* "a system is hierarchical when alternative methods of description exist for the same system" (Whyte et al. 1969).

As illustrated in the previous examples the existence of different levels and scales at which a hierarchical system is operating implies the unavoidable existence of non-equivalent ways of describing it. Examples of non-equivalent descriptions of a human being (Fig. 1.1) or geographic objects (Fig. 2.1) have been already discussed. Human societies and ecosystems are generated by processes operating on several hierarchical levels over a cascade of different scales. Therefore, they are perfect examples of nested dissipative hierarchical systems that require a plurality of non-equivalent descriptions to be used in parallel in order to analyze their relevant features in relation to sustainability (Giampietro, 1994a, 1994b; Giampietro et al. 1997; Giampietro and Pastore, 2001).

The definition of hierarchy theory suggested by Ahl and Allen is perfect for closing this section: "Hierarchy theory is a theory of the observer's role in any formal study of complex systems" (Ahl and Allen, 1996, p. 29).

2.3.2 Holons and Holarchies

Holons and holarchies are a new class of hierarchical systems relevant for the study of biological and human systems. In fact, in the case of biological and human holarchies this class is made up by self-organizing (dissipative) adaptive (learning) agents which are organized in nested elements. Gibson et al (1998) suggest for these systems the term of "Constitutive Hierarchies" following the suggestion of Mayr, (1982). Personally I prefer the use of the term – Holarchies - in order to acknowledge the theoretical work already developed in this field (started in the sixties) discussed below (and at the end of Chapter 3).

Each component of a dissipative adaptive system organized in nested elements may be called a 'holon', a term introduced by Koestler (1968; 1969; 1978) to stress its double nature of "whole" and "part" (for a discussion of the concept see also Allen and Starr, 1982, pp. 8-16). A holon is a whole made of smaller parts (e.g. a human being made of organs, tissues, cells, atoms) and at the same time it forms a part of a larger whole (an individual human being is a part of a household, a community, a country, the global economy). The choice of the term "holon" points explicitly at the obvious (in the perception of everyone, yet denied in the representation of reductionist science) fact that entities belonging to dissipative adaptive systems, which are organized in nested elements (say a dog, or a human being), have an inherent duality.

(A) Holons have to be considered in terms of their composite structure at the focal level (= they represent "emergent properties" generated by the organization of their lower level components) – a tiger as organism. We obtain this view when looking at the black box and inside to it at the pieces which are making it work. In this way we can perceive and represent HOW they work.

(B) Because of their interaction with the rest of the holarchy, holons perform functions that contribute to other "emergent properties" expressed at a higher level of analysis – functions which are useful for the higher level holon to which they belong – e.g. the role of tigers in ecological systems. We obtain this view when looking at what the black box does within its larger context. In this way, we can perceive and represent WHY the black box makes sense in its context.

A nested adaptive hierarchy of dissipative systems (a system made of holons) **can be called a holarchy** (Koestler, 1969 p. 102).

A crucial element to be clarified is that the very concept of holarchy – what represents the individuality of a holarchy – implies the ability of preserving a valid mapping between a class of "organized structures"

(e.g. a population of individual organisms belonging to a species) and the associate functions (e.g. the set of functions related to the ecological role of the species). That is, the two non-equivalent views of a holon must be and remain consistent with each other in time. This means that a holarchy, to remain alive, must have the ability to coordinate across levels:
(i) mechanisms generating the realization of a class of organized structures expressing the same set of characteristics (e.g. making similar organisms by using a common blue print when making a population of tigers) at one level. and (ii) mechanisms guaranteeing the stability of the associative context within which the agency of these organized structures translates into the expression of useful functions – e.g. the preservation of a favourable habitat for the individuals belonging to the species *Panthera Tigris*. The informed action of agents has to guarantee an admissible environment for the process of fabrication of organisms. Recalling the discussion about the concept of identity, **the individuality of a holarchy can be associated to the ability to generate and preserve in time the validity of an integrated sets of viable identities (on different scales).**

When dealing with holons and holarchies we face a standard epistemological problem. The space-time domain which has to be adopted for characterizing their "relational functions" - when considering higher-level perception/description of events - does not coincide with the space-time domain which has to be adopted for characterizing their "organized structure" (when considering lower-level perception/ description of events).

When using the word "dog" we refer to any individual organism belonging to the species *"canis familiaris"*. At the same time, the characterization of the holon "dog", refers both: (a) to a type characterized in terms of relational functions associated to the niche of that species. These functions are expressed by the members of the relative equivalence class (the organisms belonging to that species) in a given ecosystem; and (b) to a type characterized in terms of structural organization, the same organization pattern is share by any organism belonging to the equivalence class. This means that when using the word "dog" we loosely refer both to the characteristics relevant in relation to the niche occupied by the species in the ecosystem (to "dogginess" so to speak) and to the characteristics of any individual organism belonging to it (to the organization pattern expressed by realized dogs, that is by individual organisms including the dog of our neighbor). Every "dog", in fact, belongs, by definition, to an equivalence class (e.g. the species *"canis familiaris"*) even though, each particular individual, has some "special" characteristics (e.g. generated by stochastic events of its personal history) which make it unique.

That is, any particular organized structure (the dog of the neighbor) can be identified ***as different from other members of the same class***, but at the same time, it ***must be a legitimate member of the class*** in order to be considered as a dog.

Another example of holon, this time taken from social systems, could be the President of the USA. In this case Mr. Bush is the lower level "organized structure" that is the "incumbent" in the "role" of President of the USA for now. Any individual human being (required to get a realization of the type) has a time closure within this social function - under existing US constitution - of a maximum of 8 years (two 4-year terms). Whereas the US Presidency, as a social function, has a time horizon which can be estimated in the order of centuries. In spite of this fact, when we refer to the 'President of the USA' we loosely address such a holon, without making a distinction between the role (social function) and the incumbent (organized structure) performing it. The confusion is increased by the fact, that you cannot have an operational U.S. President without the joint existence of: (1) a valid role (institutional settings) and (2) a valid incumbent (person with appropriate socio-political characteristics, verified in the election process). On the other hand, the existence and the identity of Mr. Bush as an organized structure (e.g. a human being) able to perform the specified function of 'US president' is totally logically independent (when coming to representation of its physiological characteristics as human being) from the existence and the identity of the role of the Presidency of the USA (when coming to representation of its characteristics as social institution) and viceversa. Human beings were present in America well before the writing of US constitution.

The concept of "holon" as a constitutive complex element of self-organizing systems operating on nested hierarchical systems is crucial to understand the standard epistemological predicaments faced by hard science. In fact, the dual nature of holons entails/requires the existence of an 'image' of it in the epistemological tool kit used by humans to describe complex systems. This image refers not to the specific characteristics of an "incumbent" or of "individual realizations", but rather to the characteristics of the type itself. However, these characteristics must be found in a particular natural system recognized as belonging to that class. In the literature of complex systems there is a significant convergence on the point that in order to deal with complexity scientists should look for a new mechanism of mapping based on the overlapping of two non-equivalent representations. This means using a sort of representation of the natural system "in stereo" based on the simultaneous use of two complementing views. Herbert Simon (Simon, 1962) proposes the need of using in combination two concepts: "organized structure" and "relational function" as a general way to describe elements of complex systems. Kenneth Bailey (Bailey, 1990) proposes the same approach - but using different terms "role" and "incumbent" - when dealing with human societies. Salthe (Salthe, 1985) suggests a similar combination of mappings based on yet another selection of terms: "individuals" (as equivalent of "organized structures" or "incumbents") and "types" (as equivalent of "relational functions" or "roles"). Finally, Rosen (2000) proposes, within a more general theory of modeling relation, a more drastic distinction which gets back to the old Greek philosophical tradition. He suggests to make a distinction between: "individual realizations" (which are always "special" and which cannot be fully described by any scientific representation due to their intrinsic complexity) and "essences" (associated to the typical characteristics of an equivalence classes). The logical similarity between the various couplets of terms is quite evident.

As noted earlier, when developing his theory of modeling relation, Rosen (1986) suggests that scientists must always keep a clear distinction between: "**natural systems**" (which are always "special" and which cannot be fully described by any scientific representation due to their intrinsic complexity) and "**representation of natural systems**", which are based on the use of "**epistemic categories**" (based on the definition of a set of attributes required to define equivalence classes used to organize the perception and representation of elements of the reality over types). The use of epistemic categories makes possible a compression in the demand of computational capability when representing the reality (e.g. say "dog" and you include them all). But this implies generating a loss of 1 to 1 mapping between representation and direct perception (this implies confusing the identities of the individual members of equivalence classes).

2.3.3 Near-decomposability of hierarchical system: triadic reading

In order to better understand the nature of the epistemological predicament faced when making models of Holarchic systems, it is opportune to reflect on how it is possible to describe a part of them (or a given view of them) as a 'well defined entity' separated from the rest of the reality (= has having an identity separated from the rest of the holarchy) in the first place. Put in another way, if the holarchy represents a continuous of nested elements across levels and scales, how does it come that we can define a given identity (the perception of a face, a cell, or a crowd as illustrated in Fig. 1.1) for a part of it, as it were separated from the rest? Any definition of a system, in fact, requires a previous definition of identity that makes possible to individuate it as distinct from the background (that makes possible to define a clear boundary between the system and its environment). However, when we apply this rationale to the representation of a holon, we have to include in our representation of the "environment" of a given holon, the remaining part of its own holarchy! For example, human beings have to be considered as the environment (given boundary conditions) of their own cells. At the same time, we have to admit that cells behaviors (e.g. the insurgence of some disease) can affects directly those large scale mechanisms guaranteeing the boundary conditions of the cell (the health of the individual to which the cells belong). In the same way, when considering humans as entities operating within a given ecosystem (their environment) it is well known that with their behavior humans can affect the stability of their own boundary conditions (e.g. pollution or greenhouse emissions). When dealing with the representation of a part of a holarchy as distinct from the environment, we must be aware of the fact that this is an artifact, since holarchic dissipative systems cannot be isolated from their context. Their very identity depends on the interaction across boundaries in cascade across levels. When dealing with dissipative holarchies, the clear distinction between "system" and "environment" becomes fuzzy and ambiguous, especially when we want to consider several dynamics on different levels (and scales) at the same time.

In spite of this general problem, the possibility to perceive and represent a part of a holarchy as a separated entity from the whole to which that part belongs is related to the concept of **near-decomposability** - introduced by Simon in his seminal paper – "The architecture of complexity" (Simon, 1962). This principle refers more in general to the epistemological implications of hierarchy theory.

Hierarchy theory sees holarchies as entities organized through a system of filters operating in a cascade - a consequence of the existence of different process rates in the activity of self-organization (Allen and Starr, 1982). For example, a human individual makes decisions and change her/his daily behavior based on a time scale that relates to her/his individual life span. In the same way, the society to which she/he belongs also makes decisions and continuously changes its rules and behavior. Differences in the pace of becoming generate constraints within the holarchy: "slaves were accepted in the United States in 1850, but would be unthinkable of today. However, society, being a higher level in the hierarchy than individual human beings, operates on a larger spatio-temporal scale" (Giampietro, 1994b). The lower frequency of changes in the behavior of the society are perceived as laws (filters or constraints) when read from the time scale of which individual are operating. That is, individual behavior is affected by societal behavior in the form of a set of constraints ("this is the law") defining what individuals can or cannot do on their own time scale.

Getting into Hierarchy Theory jargon: the higher level, because of its lower frequency, acts as a filter constraining the 'higher frequency' activities of the components of the lower level into some emergent property. For more see Allen and Starr (1982). Additional useful references on Hierarchy Theory are: Salthe (1985, 1993), Ahl and Allen, (1996), Allen and Hoekstra (1992), Grene, (1969), Pattee (1973), O'Neill et al. (1986). Obviously, also processes occurring at the lower hierarchical levels matter. In fact, there is where structural stability is guaranteed. This means that there are different dynamics and mechanisms operating in parallel on different levels which are actually affecting each other. The deep epistemological punch of hierarchy theory is that it is not possible to recognize (perceive) and describe (represent) a system organized in nested hiearchies by adopting a single validated model (a model able to make valid predictions on the basis on the congruence of simulated inferences on the values taken by variables with a stream of data coming from the reality). In fact, such a validation must necessarily refer to a single scale – or a single descriptive domain.

We all know the popular line within the community of dynamical modelers that "stocks" are just flows that go extremely slowly and that "flows" are just fast going stocks. In this example, the decision to call something either a stock or a flow will depend on the choice, made by the modeler, when selecting a given time differential for the model. Put in another way, the possibility of associating a label (either "stock" or "flow") to a recognized pattern in the reality (to assign an identity to a process in our representation of our perception of it) is determined by the speed at which such an identity is perceived to change in time compared with the rate of perceived changes in its context.

If we adopt this view it is clear that we must expect the existence of different perceptions (and therefore representations) of the same reality made by non-equivalent observers (e.g. a human being with a life span of several decades and a drosophila with a life span of a few days) even when dealing with the same natural systems – again see Fig. 2.1. For example, even though human beings do change their aspect during their life time, the pace of such a process is slow enough to make possible the neglecting of the perception of this change on a daily base. As a matter of fact, the process of perception and representation of our own image is updated every day. That is, each one of us **sees** always **the same person** in the mirror, when brushing the teeth every morning. However, this does not guarantee that two school-mates meeting after 30 years would be able to recognize each-other. In this case, a symmetrical bifurcation entails a lack of validity in the information stored in these two persons, about the pattern recognition and representation of the other. If the two would have been required to give an input for a facial sketch (identikit) of both, them-selves and the other, they would have provided a very updated information for their own face, but a completely wrong input about the other.

In this example the two non-equivalent observers are not using different detectors to look at each other (actually they are using exactly the same "hardware" and "software" for making their observations), but simply they are adopting a different time differential to update their perceptions and representations of changes. The difference in the time differential implies a completely different selection of relevant qualities to be included in the perception and representation of changes. For the daily observation, coarse features (remaining stable over a time duration of months) are ignored in favor of finer grain resolution of changes over details. This implies that coarse feature changes are ignored in daily observation. The updating of the image of a friend after a 30-year period (which has lost a lot of details in the storage) on the contrary has to do with updating first of all, the correspondence of coarse characteristics. From this example we can guess the existence of "mosaic effects" within the information gathered within the holarchy. The interaction of non-equivalent holons within a stable holarchy requires the integration and the ability of making an effective use of different flows of information coming from non-equivalent observers operating on different hierarchical levels and space-time scales.

Holarchies are characterized by 'jumps' or 'discontinuities' in the rates of activity of self-organization (patterns of energy dissipation) across the levels. Hierarchical levels are, in fact, the result of differences in process rates related to energy conversions stabilized on controlled autocatalytic-loops (Holling, 1995; Odum, 1971; 1983). The mechanism of lock-in associated to the generation of an autocatalytic loop is what generates the discontinuities in scales, which are at the real root of near-decomposability.

The principle of near-decomposability explains why scientists are able to study simplified models of natural systems over a wide range of order of magnitudes, from the dynamics of sub-atomic particles to the dynamics of galaxies in astrophysics. When dealing with hierarchical systems we can study the dynamics of a particular process on a particular level by adopting a description that seals-off higher and lower levels of behavior. In this way, we can obtain a description that is able to provide an operational identity (a finite set of relevant qualities) for the system under investigation. This has been proposed as an operation of "triadic reading" or "triading filtering" by Salthe (1985). This means that we can describe, for example, in economics consumer behavior while ignoring the fact that consumers are organisms composed of cells, atoms and electrons. The concept of triading reading refers to the choice done by the scientist of three contiguous levels of interest within the cascade of hierarchical levels through which holarchies are organized.

That is, when describing a particular phenomena occurring within a holarchy we have to define a group of three contiguous levels starting with:

1. Focal level - this implies the choice of a space-time window of observation at which the qualities of interest of the particular holon (expressed in the formal identity) can be defined and studied with using a set of observables (encoding variables assumed to be proxy of changes in the qualities considered as relevant). For example, if we are dealing with consumer behavior we will not select a space-time scale able to detect qualities referring to electrons. Therefore, the choice of variables able to catch changes in the relevant qualities of our system reflects: (1) the goal of our analysis (why we want to represent its behavior) and (2) the characteristics of the measurement scheme (the type of detectors available to generate data stream and the experimental setting used to extract data from the reality);

2. Higher level - the choice of a formal identity for the investigated system at the focal level is based on the assumption that changes of the characteristics of the higher level are so slow when described on the space-time window of the Focal level that they can be assumed to be negligible. In this case, the higher level can be accounted for - in the scientific description - as a set of external constraints imposed on the dynamics of the focal level (= the given set of boundary conditions).

3. Lower level - the difference of time differentials across levels implies also that the mechanisms determining the dynamics of lower level components are not always relevant in relation to the mechanisms determining the behavior on the focal level description. In fact, when considering the aggregate behavior of lower level elements, lower level activity can be accounted for in terms of a statistical description of events occurring there. In this way, the "individuality" of lower level elements is "averaged out" by considering such a variability as 'noise'. That is, when adopting a triading reading, the identity of lower level elements is accounted for in the Focal description just in terms of a set of initiating conditions determining the outcome of the studied dynamics.

To give an example of triadic reading, economic analyses describe the economic process by adopting a focal level with a time window: (i) small enough to assume changes in ecological processes such as climatic changes or changes in institutional settings (the higher level) negligible; and (ii) large enough to average out 'noise' from processes occurring at the lower level - e.g., non-rational consumer behavior of artists, terrorists, or Amish is averaged out by a statistical description of the preferences of population (Giampietro, 1994b).

It should be noted, however, that the trick of the triadic reading works well only when applied to those parts of holarchies which have a quite "robust" set of identities. That is, in those cases in which the simultaneous interaction of processes occurring on lower, higher and focal level manage to generate a lock-in (a mechanism of self-entailment across dynamics operating in parallel over different hierarchical levels) which guarantee stability and/or resilience toward external (from the higher level) and internal (from the lower level) perturbations. This requires holarchies able to generate robust integrated patterns on multiple-scales (the can guarantee the validity of a coordinated set of identities over different levels – as in the examples of Fig. 1.1). The various patterns expected/recognized on different levels should be stable enough to justify the expression "quasi-steady-state" to the perception/representation of the system over the focal level.

Clearly the process of triadic reading can be repeated across contiguous levels through the holarchy (see **Fig. 2.5**). That is a household can be at the same time (i) the higher level (= the fixed boundary context) for an individual belonging to it (for those scientists interested in studying the behavior of individuals – e.g. a psychologist); or (ii) the focal level (for those scientists interested in describing possible changes in household identity in relation to changes in the social context, or the characteristics of individuals – e.g. anthroplogist); or (iii) the lower level (= organized structures determining emergent properties on the focal level) for social systems (for those scientists studying the behavior of social systems made up of households). Due to this chain of relations across levels of holons the issue of sustainability requires the consideration of at least 5 contiguous hierarchical levels at the same time (Flood and Carson, 1988) as shown in **Fig.2.5**. In fact, when considering 5 contiguous levels we can describe those processes that determine the various relevant aspects of the stability of the holon under investigation:

(i) the set of identities of lower level organized structures (parts), which determines with its 'variability of typologies of components' and 'distribution over possible typologies' of the population of components - initiating conditions;

(ii) the pattern referring to the focal level (the whole), for which we can simulate behavior with an appropriate model after receiving the required information about the actual state of boundary conditions (referring to the higher level) and initiating conditions (referring to the lower level); and

(iii) the identity of the environment (the context) which is influencing the admissible behaviors of the system on its focal level.

That is the sustainability of the process represented in the original triadic reading requires to verify the compatibility of changes occurring at different speeds on these 5 contiguous levels. This means also that if we want later on scaling up and down the effects of changes induce at any of these 5 levels in the holarchy, or if we want to establish links among non-equivalent descriptions referring to the non-reducible identities defined on different levels, it is crucial to have an adequate information about the various identities interacting among these 5 levels. This is at the basis of the concepts developed in Part 2 and applied in Part 3.

It is important to recall here the warning about the epistemological implications of the trick of triadic reading across levels as shown in **Fig. 2.5**. This is where the epistemological predicament of holons enters into play. As observed by O'Neill et al. (1989) biological systems have the peculiar ability of being both in 'quasi-steady-state' and 'becoming' at the same time. Their hierarchical nature makes possible this remarkable achievement. In fact, biological systems are well describable as in quasi-steady-state on small space-time windows (when dealing with the identity of cells, individual organisms, species). That is, on the bottom of the holarchy. However, the more we move up in the holarchic ladder, the more we find "entities" which are becoming. That is, when using a much large space-time window (moving to the perception/representation of higher holarchic level) we are forced to deal with the process of evolution (e.g. ecosystems types co-evolving within Gaia). At this levels new "essences" (roles or types) are continuously added to the open information space of the holarchy. This implies that the near-decomposability of hierarchical systems works well only when the observer is focusing on: (a) a well defined part of the holarchy at the time; and (b) when the set of qualities of interest to be isolated (= the identity we decide to adopt to describe the holon) can be assumed to be stable on the time window considered relevant for the analysis (the lower we are in the ladder of the Holarchy, the better). When dealing with the sustainability of human societies this rarely occurs. The reader can recall here the example of the difference in difficulty faced when trying to reach an agreement on a formal identity to be used for particles and/or for mothers. The higher one goes in the holarchies and the richer becomes the set of categories included in the semantic identity. This implies that the tougher it becomes to reach an agreement on how to compress this semantic identity into a finite, limited, closed formal identity.

2.3.4 Types are out of scale and out of time, Realizations are scaled and getting old

A **type** is referring to a given set of relations of qualities of a system associated to the ability to express some emergent property in a given "associative context". Koestler (1967) in his "The ghost in the machine" uses the term "associative context" in a description of the relative cognitive process. The term "associative context" indicates that the characteristics of a given type are always associated to the actual possibility to perform a given, expected function. The type is assumed to operate in its expected environment (e.g. niche for a population of a given species). Living fishes have water as associative context, birds have air. Humans cannot operate in melted iron.

In the same way, also epistemic categories used to organize our perceptions and to communicate meaning require/imply/entail the existence of a right associative context for the type to which they refer. Change the expected associative context to a word and you get a joke (Koestler, 1967). For example, the old joke ["I met a guy with a wooden leg called Joe Smith" - "and what was the name of the other leg?"] is based on the violation of the basic association of the name "Joe Smith" to "person". In the joke the label "Joe Smith" is rather associated to the word "leg".

The concept of a ***required associative context*** for a given realization of an essence applies to both the epistemological (e.g. words) and ontological (e.g. members of an equivalence class) side. In fact, in the real operation of dissipative system the existence and survival of an organism also invokes the unavoidable association with an appropriate environment. An "***admissible environment***" is the concept proposed by Rosen, 1958a and 1958b for biological systems. The environment must be a source of admissible inputs and a sink for admissible outputs. Actually, Prigogine (Prigogine, 1978) when introducing the rationale of dissipative systems uses the same concept. There is no realized "organized structure" of dissipative systems that can perform a given function (or keep its own individuality) without ***favorable boundary conditions*** (without operating within its required associative context).

As noted by Allen and Hoekstra (1992) the definition of a type "per se" does not carry a scale-tag. A given ratio between the relative size of the head, the body and the legs of a given shape of organism can be realized at different scales (actually this is the basis of modeling). **It is only when a particular**

typology is realized, that the issue of scale enters into play. At that point scale matters in relation to: (1) the definition of the identity of lower level elements (level $n-1$) responsible for the structural stability of the system (at the focal level n) – **what the realization is made of**; (2) the definition of the identity of the context (level $n+1$) in which the system has to be able to express its function – **what the realization is interacting with.**

The special status of "types" which are out of scale means also that they are out of time. Models are made with types, and therefore the validity of models requires the validity and usefulness of the relation between: (a) type; (b) associative context; and (c) goal of the analysts. As discussed later on, this is why a quality control on the validity of a given model has always to be based first of all on a semantic check about its usefulness at a given point in space and time. Models have to "makes sense", they must convey meaning and make possible the organization of perceptions of a group of observers about what is known about a given problem.

The discussion of the dual nature of holons is reminiscent of the principles of quantum mechanics articulated in the 1920's, those of indeterminacy and complementarity. Complementarity refers to the fact that holons, due to their peculiar functioning on parallel scales always require a dual description. The relational functional nature of the holon (focal-higher level interface) provides the context for the structural part of the holon (focal-lower level interface), which generates the behavior of interest on the focal level. Therefore, an holarchy can be seen as a chain of contexts and relevant behaviors in cascade. The niche occupied by the dog is the context for the actions of individual organisms, but at the same time any particular organism is the context for the activity of its lower level components (organs and cells dealing within organisms with viruses and enzymes).

Established scientific disciplines rarely acknowledge that the unavoidable and prior choice of 'perspective' determining what should be considered the relevant action and what its context - which is implied by the adoption of a single model (no matter how complicated) - implies a bias in the consequent description of complex systems' behavior (Giampietro, 1994b). For example, analyzing complex systems in terms of organized structures - or incumbents (e.g. a given doctor in a hospital) - implicitly requires assuming for the validity of the model: (1) a given set of initiating conditions (a history of the system that affects its present behavior). and (2) a stable higher level on which functions - or roles - are defined for these structures in order to make them "meaningful", useful and, thus, stable in time (Simon, 1962). That is, the very use of the category "doctors" implies, at the societal level, the existence of a job position for a doctor in that hospital together with enough funding for running the hospital.

Similarly, to have "functions" at a certain level, one needs to assume the stability at the lower levels where the structural support is provided for the function. That is, the use of the category "hospital" implies that something (or rather someone) must be there to perform the required function (Simon, 1962). In our example the existence of a modern hospital - at the societal level - implies also the existence of a supply of trained doctors - potential incumbents - able to fill the required roles (an educational system working properly). All these considerations become quite practical when systems run imperfectly, as when (e.g.) doctors are in short supply, have bogus qualifications, are inadequately supported, etc.

Hence, no description of the dynamics of a focus level, such as society as a whole, can escape the issue of **structural constraints** (*what/how*, explanations of structure and operational going on at lower levels) and at the same time the issue of **functional constraints** (*why/how*, explanations of finalized functions and purposes, going on at or in relation to the higher level). The key for dealing with holarchic systems is to deal with the difference in space-time domain which has to be adopted for getting the right pattern recognition. Questions related to the why/how questions (to study the niche occupied by the *"canis familiaris"* species or the characteristics of US Presidency) are different from those required for the what/how questions (to study the particular conditions of our neighbor's dog related to her age and past, or the personal conditions of Mr. Bush this week). They cannot be discussed and analyzed by adopting the same descriptive domain. Again, even if the two natures of the holon act as a whole, when attempting to represent and explain both the "why/how questions" and the "how/what questions" we must rely on complementary non-equivalent descriptions, using a set of non-reducible and non-comparable representations.

Conclusion: the ambiguous identity of Holarchies

Holons and holarchies require the use of several non-equivalent identities to be described even though they can be seen and perceived as a single individuality. The couplets of "types" (or "roles") and "individual realizations" (or "incumbents") overlap in natural systems when coming to specific actions (e.g. Mr. Bush and the President of the USA decide as a whole). However, the two parts of the holon have different histories, different mechanisms of control and diverging local goals. For example, the case of Monica Lewinsky which led to a procedure of impeachment for Mr Clinton has been about legitimate contrasting interests expressed by the dual nature of that specific holon (= the wants of Mr. Clinton as a human being in a particular moment of his life diverged from the goals of the institutional role associated to US presidency). Unfortunately, scientific analyses trying to model holons operating within holarchies, have no other option but that of considering a single formal identity for each acting holon at the time. At this point models referring to just one of the two relevant identities associated to the label, can only be developed within the particular descriptive domain associated to the selected identity (either referring to the role or the incumbent).

The existence of a multiplicity of roles for the same natural system operating within holarchies shows the inadequacy of the traditional reductionist scientific paradigm for modeling them. For the assumption of a single goal and identity for the acting holon (which is necessary for mapping its behavior with a given inferential system) restricts it to a particular model (descriptive domain), to the exclusion of all others.

Models of adaptive holons and holarchies, no matter how validated in the past, will become obsolete and wrong.

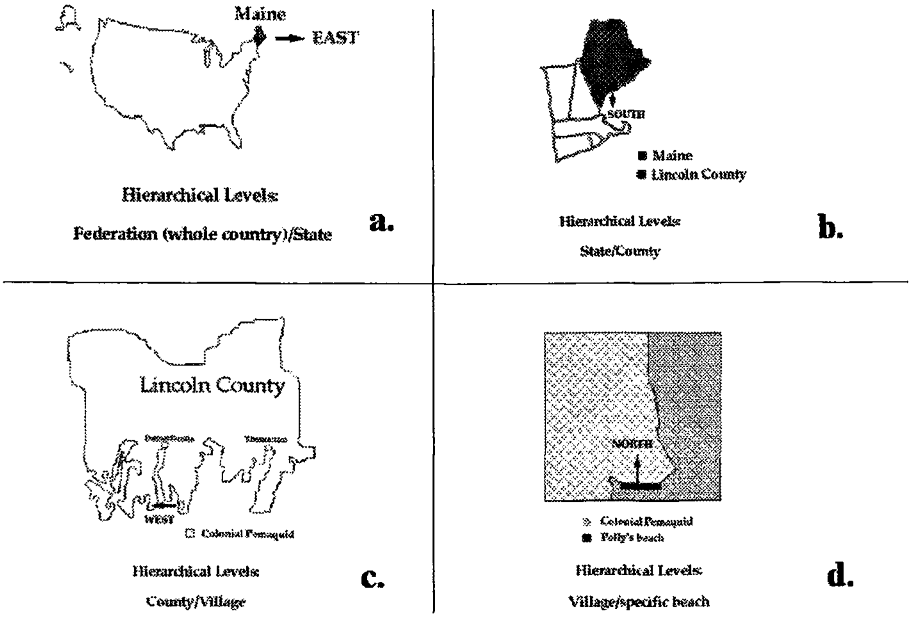
To get a quantitative characterization of a particular identity of a holon one has to assume the holarchy is in steady-state (or at least in quasi-steady-state). That is, one has to choose a space-time window at which it is possible to define a clear identity for the system of interest (*the triadic reading* is often expressed using the more familiar term of "ceteris paribus assumption"). However, as soon as one obtains the possibility to quantify characteristics of the system after "freezing it" on a given space-time window, one loses, as a consequence of this choice, any ability to see and detect existing evolutionary trends (recall here the Jevons paradox discussed in Chapter 1). Evolutionary trajectories are detectable only using a much larger space-time scale than that of the dynamic of interest (Salthe, 1993). This implies admitting that sooner or later the usefulness of current descriptive domain and the validity of the selected modeling relation will expire. By choosing an appropriate window of observation we can isolate and describe, in simplified terms, a domain of the reality – the behavior of a system within a descriptive domain - the one we are interested in. In this way it is possible to define boundaries for a specified system, which can be considered, then, as independent entity from the rest of the holarchy to which they belong. The side effect of this obliged procedure, however, is the neglect, either aware or unaware, of: (1) dynamics and other relevant features which are occurring outside the space-time differential selected in the focal descriptive domain; (2) changes in other system's qualities which were not included in the original set of observable qualities and encoding variables used in the model.

When dealing with becoming systems, we should expect that it will be necessary to continuously update the identities used in evolving descriptive domains (we should expect that useful definitions of the state space will change in time). Georgescu-Roegen, (1971) used to say that modeling means a "heroic simplification of reality". Each model reflects a given application of a triadic filtering to the reality based on a previous definition of a "time duration" for the system and the dynamic of interest included in the analytical representation. When we do that, we are choosing just one of the possible non-equivalent descriptive domains for perceiving and representing our system. This explains why there can be no complete, neutral, objective study of a holarchic system, and why these systems are "complex" in the sense of having multiple legitimate meaningful relations between perception and representation.

This is particularly important when dealing with the issue of sustainability. The existence of wide differences in time scales in problems of sustainability is well known. For example: (1) the process of biological evolution (e.g. the becoming of ecological holons) requires the use of "relevant time differentials" of thousands of years. (2) the process of evolution of institutional settings of human societies requires the use of "relevant time differentials" of centuries. (3) the process of evolution of human technology requires the use of "relevant time differentials" of decades. (4) when dealing with price formation we are dealing with a time differential of one year or less. (5) preferences and feelings of individuals can change in a second. Obviously the epistemic categories, formal identities and relative models required for representing changes over these different time windows cannot be mixed.

To make things more complicated, complex adaptive systems tend to pulse and operate in cyclic attractors. This implies an additional problem. Scientific analyses should be able to avoid confusing movements of the system over predictable trajectories in a given state space (e.g. the trajectory of a perfect pendulum), with changes due to the genuine emergence of new evolutionary patterns. As discussed Chapter 8, we can detect "genuine emergence" by the fact that we have to update identity of the state space used in the analysis. Emergence implies the use of new epistemic categories and new modeling relations in the observer/observed complex.

Fig. 2.1 Orientation of the coastal-line: non-equivalent perceptions



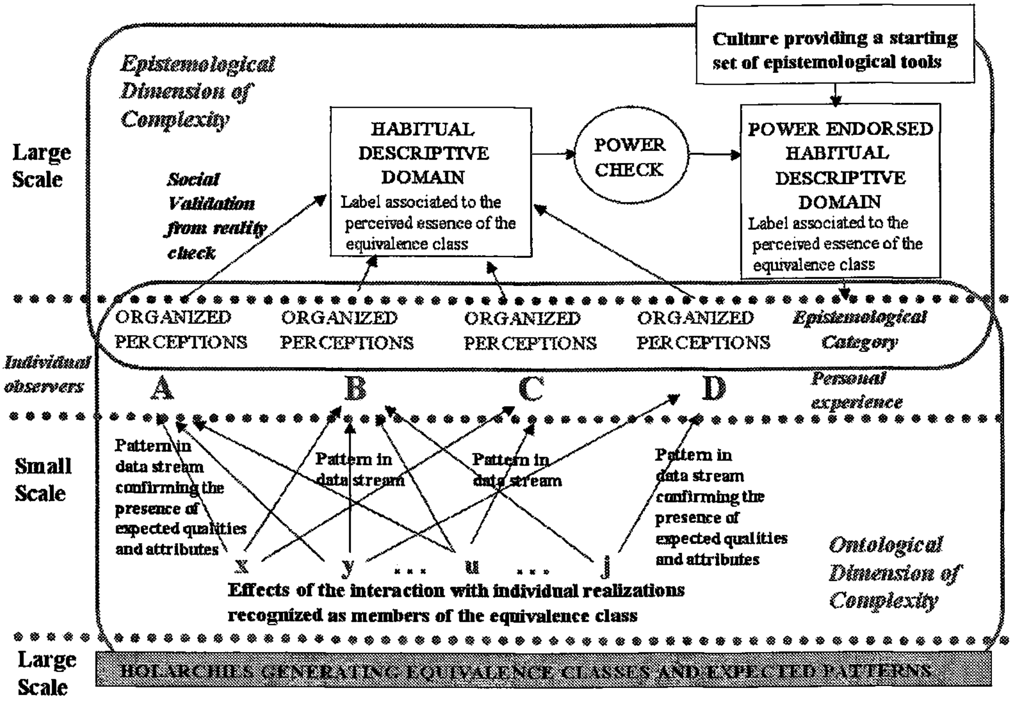
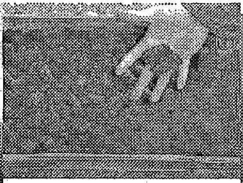
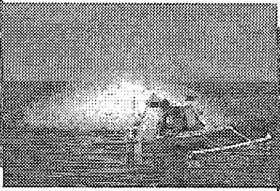
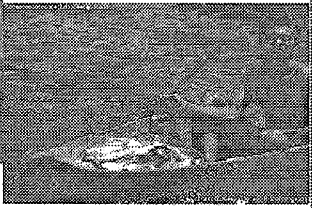


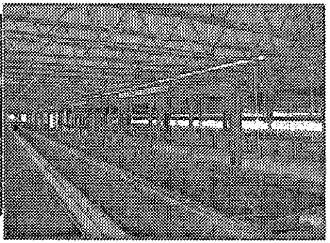
Fig. 2.4 A synthetic view of the processes leading to the definition of identities for holons

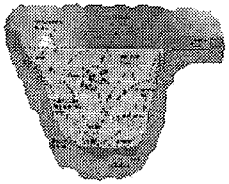

A trophy

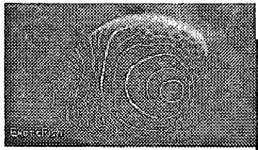

A feed


A target for bomb

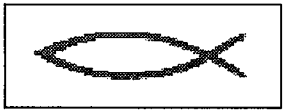

Subsistence food


An animal to rear

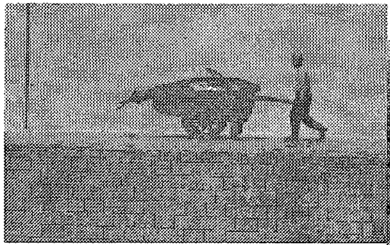

An ecosystem component

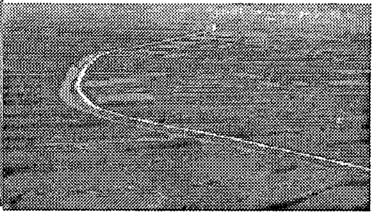

A beautiful thing


A deadly thing

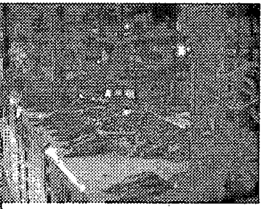

A Christian symbol

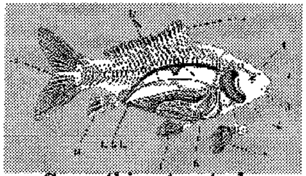

A chinese character


Somehting heavy to carry


A cause of environmental impact


A source of income


Dry food


Something to study

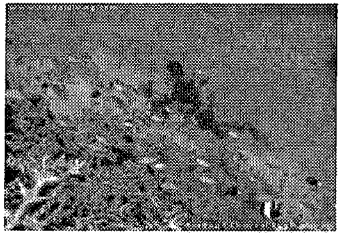

A touristic attraction

Fig. 2.2 The open universe of the semantic identity for a **fish** . . .

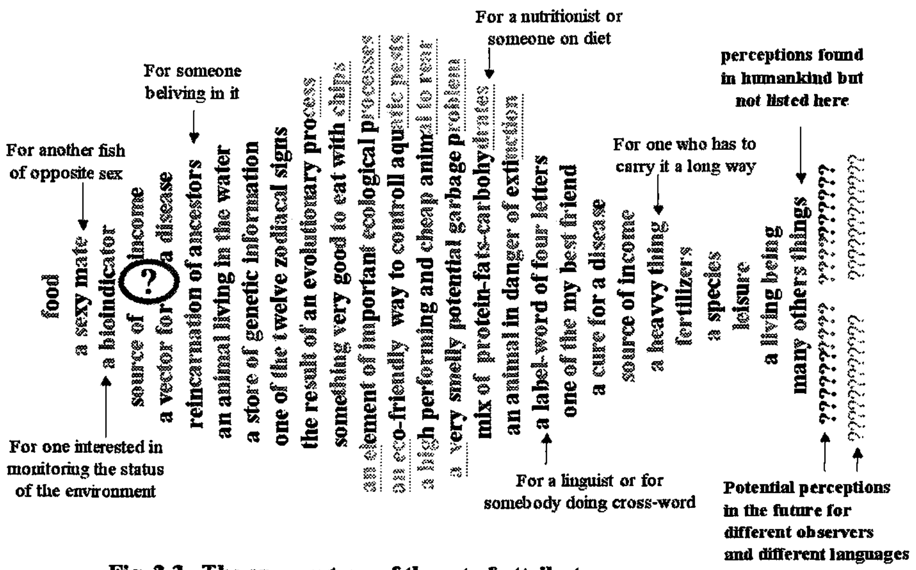
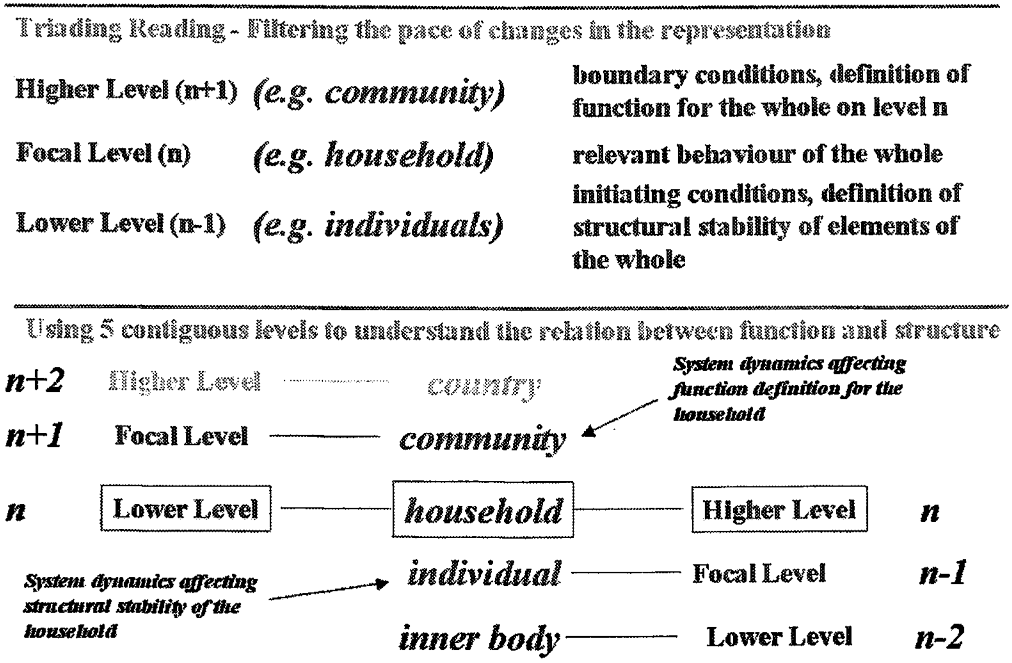


Fig. 2.3 The open nature of the set of attributes making up the semantic identity of a fish (After Gomiero, 2003)

Fig. 2.5 Triading reading and the need of 5 contiguous levels



Chapter 3

Complex system thinking: new concepts and narratives

This chapter provides practical examples which illustrate the relevance of the concepts introduced in Chapter 2 with the challenge faced by scientists working in the field of sustainable agriculture. In fact, it is important to have a "feeling" of practical implications of complexity in terms of operation of scientific protocols of analysis, before getting into an analysis of the challenges faced by those willing to do things in a different way (Chapter 4 and Chapter 5), and before exploring innovative concepts that can be used to develop new analytical approaches (the three chapters of Part 2).

3.1 Non-equivalent descriptive domains and non reducible models are entailed by the unavoidable existence of multiple-identities

3.1.1 Defining a descriptive domain

Using the rationale proposed by Kampis (Kampis, 1991: p. 70) we can define a particular representation of system as "the domain of reality delimited by interactions of interest". In this way one can introduce the concept of "descriptive domain" in relation to the particular choices associated to a formal identity used to perceive/represent a system organized on nested hierarchical levels. A descriptive domain is the representation of a domain of reality which has been individuated on the basis of a pre-analytical decision on how to describe the identity of the investigated system in relation to the goals of the analysis. Such a preliminary and "arbitrary" choice is needed in order to be able to detect patterns (when looking at the reality) and to model the behavior of interest (when representing it).

To discuss of the need of using in parallel non-equivalent descriptive domains we can use again the 4 views given in Figure 1.1 applying to them, this time the metaphor of sustainability. Let's imagine that the 4 non-equivalent descriptions presented in Figure 1.1 were referring to a country (e.g. the Netherlands) rather than to a person. In this case, we can easily see how any analysis of its sustainability requires an integrated use of these different descriptive domains. For example, by looking at socioeconomic indicators of development (Fig. 1.1B) we "see" this country as a beautiful woman (i.e. good levels of GNP, good indicators of equity and social progress). These are good system's qualities, required to keep low the stress on social processes. However, if we look at the same system (same boundary), but using different encoding variables (e.g. a different formal identity based on a selection of biophysical variables) - Figure 1.1D in the metaphor - we can see the existence of a few problems not detected by the previous selection of variables (i.e. a sinusitis and a few dental troubles in the real picture). In the metaphor this picture can be interpreted, for the Netherlands, as an assessment of accumulation of excess of nitrogen in the water table, growing pollution in the environment, excessive dependency on fossil energy and dependence on imported resources for the agricultural sector. Put in another way, when considering the biophysical dimension of sustainability we can "see" some bad system's qualities, which were ignored by the previous selection of economic encoding variables (a different definition of formal identity for the perception/representation). Analyses based on the descriptive domain of Figure 1.1A are related to lower levels components of the system. In the Dutch metaphor, this could be an analysis of technical coefficients (e.g. input/output) of individual economic activities (e.g. the CO_2 emissions for producing electricity in a power plant). Clearly, the knowledge obtained when adopting this descriptive domain is crucial to determine the viability and sustainability of the whole system (= the possibility to improve or to adjust the overall performance of Dutch economic process if and when changes are required). In the same way, an analysis of the relations of the system with its larger context can imply the need of considering a descriptive domain based on pattern recognition referring to a larger space-time domain (Fig. 1.1C). In the Dutch metaphor this could be an analysis of institutional settings, historical entailments, or cultural constraints over possible evolutionary trajectories.

3.1.2 'Non-equivalent descriptive domains' imply 'Non-reducible assessments'

The following example refers to 4 legitimate non reducible assessments and can be related again on the 4 views presented in Figure 1.1. This is to show how general and useful is the pattern of multiple identities across levels. The metaphor this time is applied to the process required to obtain a specific assessment such as: "kg of cereal consumed per capita by US citizen in 1997". The application of such a metaphor to the assessment of cereal consumption per capita is shown in **Fig. 3.1**. Let us imagine that to get such a number a very expensive and sophisticate survey is performed, at the household level. By recording events in this way we can learn that each US citizen consumed, in 1997, 116 kg of cereals per person per year.

On the other hand, by looking at the FAO Food Balance Sheet [FAO agricultural statistics URL] - which provides for each FAO-member country a picture of the flow of food consumed in the food system - we can derive other possible assessments for the "kg of cereals consumed per capita by US citizen in 1997".

A list of non-equivalent assessments could include:

(i) cereals consumed as food, at the household level. This is the figure of 116 kg per year per capita for US citizen, in 1997, discussed before. This assessment can also be obtained by dividing the total amount of cereals directly consumed as food by the population of USA in that year.

(ii) consumption of cereals per capita in 1997 as food, at the food system level. This value is obtained by dividing the total consumption of cereals in the US food system by the size of US population. This assessment is more than 1,015 kg (116 kg directly consumed, 615 kg fed to animals, plus almost 100 kg of barely for making beer, plus other items related to industrial processing and post-harvest losses).

(iii) amount of cereals produced in US per capita, in 1997, at the national level, to obtain an economic viability of the agricultural sector. This amount is obtained by dividing total internal production of cereals by population size. Such a calculation provides yet another assessment: 1,330 kg/year per capita. This is the amount of cereal used per capita by US economy.

(iv) total amount of cereals produced in the world per capita, in 1997, applied to the humans living within the geographic border of the USA in that year. This amount is obtained by dividing total internal consumption of cereal at the world level in 1997 (which was 2×10^{12} kg), by world population size in that year (5,800 millions). Clearly, such a calculation provides yet another assessment: 345 kg/year per capita (160 kg/year direct, 185 kg/year indirect). This is the amount of cereal used per capita by each human being in 1997 on this planet. Therefore this would represent the share assigned to US people when ignoring heterogeneity of pattern of consumption among countries.

The 4 views of Figure 1.1 can be used again as done in **Fig. 3.1** to discuss the mechanism generating these numerical differences. In the first two cases, we are considering only the direct consumption of cereals as food. On a small scale - assessment #(1) reflecting Figure 1.1A in the metaphor - and on a larger scale - assessment #(2) referring to Figure 1.1B in the metaphor. The logic of these two mappings is the same. We are mapping flows of matter, **with a clear identification in relation to their role**: food as a carrier of energy and nutrients, which is used to guarantee the physiological metabolism of US citizens. This very definition of consumption of "kg of cereals" implies a clear definition of compatibility with physiological processes of conversion of food into metabolic energy (both within fed animals and human bodies). This implies that since the mechanism of mapping is the same (in the metaphor of Figures 1.1A and 1.1B, we are looking for pattern recognition using the same visible wave-length of the light) we can bridge the two assessments by an appropriate process of scaling (e.g. Life Cycle Assessment). This will require, in any case, different sources of information related to process occurring at different scales (e.g. household survey + statistical data on consumption and technical coefficients in the food systems). When considering assessment #(3) we are including in such an assessment "kg of cereals" which are not "consumed" either directly or indirectly by US households in relation to their diet. The additional 315 kg of cereals produced by US agriculture per US citizen for export (assessment #(3) minus assessment #(2)), are brought into existence only for economic reasons. But exactly because of that, they should be considered as "used" by the agricultural sector and the farmers of that country to stabilize its own economic viability. The US food system would not have worked the way it did, in 1997, without the extra income provided to farmers by export. Put it in another way, US households "indirectly used" this export (= took advantage of the production of these kg of cereals) for getting the food supply they got, in the way they did. This could be in the metaphor the pattern presented in Figure 1.1D. We are looking at the same head (the US food system in the analogy) but using a different mechanism of pattern recognition (using X-rays rather than visible light). The difference in numerical value between assessment #(1) and #(2) is generated by a difference in the hierarchical level of analysis. Whereas the difference between assessment #(2) and #(3) is generated by a "bifurcation" in the definition of indirect consumption of cereals per capita (a biophysical definition versus an economic definition). Finally, Figure 1.1C would represent the numerical assessment obtained in #(4), when both the scale and the logic adopted for defining the system is different from the previous one (US citizen as members of humankind).

The fact that these differences are not reducible to each other does not imply that any of these assessments is useless. Also in this case, depending on the goal of the analysis, each one of these numerical assessments can carry useful information.

3.2 The unavoidable insurgence of errors in a modeling relation

3.2.1 "Bifurcation" in a modeling relation and emergence

To introduce this issue let's consider one of the most successful stories of hard science in this century: the claimed "full understanding" achieved in molecular biology of the mechanism through which genetic information is stored, replicated, and used to guarantee a predictable behavior in living systems. This example is not only relevant for supporting the statement made in the title of this section, but also for pointing at the potential risks that a "modeling success" can induce on our ability to understand complex behaviors of real systems.

To cut a long and successful story very short we can say that, in terms of modeling, the major discoveries made in this field were: (A) the identification of carriers of information as "DNA bases" organized into a double helix; (B) the individuation and understanding of the mechanisms of encoding based on the use of these DNA bases to: (i) store and replicate information in the double helix, and (ii) transfer this information to the rest of cell. This transfer of information is obtained through an encoding and decoding process which leads to the making of proteins. Due to the modulation of this making of proteins in time, the whole system is able to guide the cascade of biochemical reactions and physiological processes. In particular, 4 basic DNA bases were identified (their exotic names here are not relevant here, so that we use only the first capital letter of their names: C, G, T and A) which were found to be the only components used to encode information within DNA double helix.

Two pairs of these bases are mapping onto each-other across helixes. That is, whenever there is a C on one of the two helix there is a G on the other (and viceversa); the same occurs with A and T. This means that if we find a sequence CCAATGCG on one of the two helix of the DNA we can expect to find the complementing sequence GGTTACGC on the other. This self-entailment (loop of resonating mappings in time) across linked sequences of bases is the mechanism which explains the preservation of a given identity of the DNA in spite the large number of replications and reading processes. By applying a system of syntactic rules to this mechanism of reciprocal mapping it is also possible to explain, in general terms, the process of regulation of biochemical behavior of cells (= some parts of DNA strings made up of these 4 bases have regulative functions, whereas other parts are codifying the actual making of proteins).

At this point this process of handling information from "what is written in the DNA" to "what is done by the cells", can be represented in a simplified form (modeled) by using "types". That is, there is a closed set of "types" (= triplets of bases) which are mapping onto a closed set of "types" (the aminoacids used to make proteins). Obviously, there are a lot of additional specifications required, but details are not relevant here. What is relevant is the magnificent success of this modeling relation. The model was so good in explaining the behavior of interest that nowadays not only humans can manipulate genetic information within living systems to interfere with their original system of storage of information and regulation, but also humans arrived at making machines which can generate sequences of DNA following an input given by the computer.

The big success of this model is also reason for concern. In fact, according to this modeling relation we are told at school - when learning about DNA behavior - that a "mutation" represents an "error" in the mechanism handling genetic information. This expression "error" in fact refers to the fact that a given type on one side of the mapping (e.g. a given basis A) is not generating the expected type on the other side of the mapping (e.g. the complementing basis T). This can imply that a given triplet can be changed and therefore generating an incorrect insertion of an aminoacid in the sequence making up a protein.

According to Rosen (1977, pag.231) what the expression error means "is something like the following: DNA is capable of many interactions beside those involved in its coding functions. Some of these interactions can affect the coding functions. When such an interaction occurs, there will be a deviation between what our simple model tells us ought to be coded, and what actually is coded. This deviation we call a mutation, and we say that the DNA has behaved erroneously". Even over a cursory reflection we can immediately see that any system handling genetic information within a becoming system must have, in order to keep the ability to evolve, an open information space which has to be used to expand the set of possible behaviors in time (to be able to become something else). Such a system therefore must admit the possibility of inducing some changes in the closed set of syntactic entailments among types which represents its - closed - information space. The closed information space is represented by what has been expressed up to now by the class of individual organized structures which have been produced in the past history of the biological system to which the studied DNA is associated. In order to evolve biological systems "need" mutations to expand this closed set, therefore, they must be "able" to have mutations. The existence and the characteristics of this function (the ability to have mutations), however, can only be detected over a space-time window much larger than the one used to describe mechanical events as done by molecular biology. Being a crucial function, the activity of "inducing changes on the DNA in order to expand the information space" requires a careful regulation. That is, the rate of mutations must not be too high (to avoid the collapse of the regulative mechanisms on the smaller space-time window of operations within cells). On the other hand, it has to be large enough to be useful on an evolutionary space-time window to generate new alternatives, when the existing structures and functions become obsolete. The admissible range of this rate of mutation obviously depends on the type of biological system considered, for example within biological systems high in the evolutionary rank, it is sexual reproduction of organisms, which takes care of doing a substantial part of this job with less risks . . .

In any case, the point relevant in this discussion is that mutations are not just "errors" but rather the expression of a useful function needed by the system. The only problem is that such a function has not be included in the original model used to represent the behavior of elements within a cell-type adopted by molecular biology in the 60s and early 70s. These models were based on a preliminary definition of a closed set of functions linked to the class of organized structures (DNA bases, triplets, aminoacids) considered over a given descriptive domain. Within the descriptive domain of molecular biology (useful to describe the mechanics of the encoding of aminoacids onto triplets in the DNA) the functions related to evolution or co-evolution of biological systems cannot be seen. This is what justifies the use of the term 'error' within that terms of reference.

The existence of machines able to generate sequences of DNA is very useful, in this case, to focus on the crucial difference between biological systems and human artifacts (Rosen, 2000). When a machine making sequences of DNA bases is including in the sequence a basis which is different from that written on the string used as input to the computer, then we can say that the machine is making an error. In fact, being a human artifact, the machine is not supposed to self-organize nor becoming. A mechanical system is not supposed to expand its own information space. Machines have to behave according to the instructions written before (and used to) making them by someone else. On the space-time scale of its life-expectancy the organized structure of a machine has no other role, but that of fulfilling the set of functions assigned by the humans that made it. Living systems are different.

Going back to the example of DNA the more humans study the mechanism storing and processing genetic information, the more it is becoming clear both in molecular biology and in theoretical biology that the handling of information in DNA-based system is much more complex than the simple cascade of a couple of mappings: [C <->G, T<->A] and [closed set of triplets types --> closed set of aminoacid types].

The lesson from this story is clear: whenever a model results very useful, those that use it tend, sooner or later, to confuse the "type" of success (the representation of a relevant mechanism made using types, that is by adopting a set of formal identities) with the "real natural system" (whose potential semantic perceptions are associated to an open and expanding information space) which was replaced in the model by the types.

Due to this unavoidable generation of errors every time we make models of complex systems, Rosen suggests (1985 - in the chapter on theory of errors) to use the term "bifurcations" whenever we face the existence of two different representations of the same Natural System which are logically independent of each other.

The concept of bifurcation in a modeling relation entails the possibility of having two (or more than two) distinct formal systems of inferences, which are used on the basis of different selection of encoding variables (selection of formal identities) or focal level of analysis (selection of scale) to establish different modeling relations for the same "natural system". As noted earlier bifurcations are therefore entailed also by the existence of different goals for the mapping (by diverging interests of the observer) and not only by intrinsic characteristics of the observed system.

The concept of bifurcation implies the possibility of a total loss of 'usefulness' of a given mapping. For example, imagine that we have to select an encoding variable to compare the "size" of London (U.K.) and Reykjavik (Iceland). London would result larger than Reykjavik, if the selected encoding for the quality "size" is the variable population. However, by changing the choice of encoding variable, London would result smaller than Reykjavik if the perception of its "size" is encoded by the variable: 'number of letters making up the name' (= a new definition of the relevant quality to be considered when defining the size of London and Reykjavik). Such a choice of encoding could be performed by a company which makes road signs.

In this trivial example we can use the definition of identity discussed in Chapter 2 to study the mechanism generating the bifurcation. In this case, two non-equivalent observers:
(1) Someone willing to characterize "London" perceiving this label as a proxy for a city will adopt a formal identity which associated to such a label an epistemic category related to its size that can have as a proxy - population size. (2) Someone working in a company making road-signs, perceiving this label just as a string of letters to be written in its product, will adopt a formal identity for such a name in which the size is associated to a category based on the "demand of space on road-sign". The proxy for this system quality will be the number of letters making up the name. Clearly, the existence of a different "logic" in selecting the "category" and the "proxy" used to encode what is relevant in the quality "size" is related to a different meaning given to the perception of the label "London". This is the mechanism generating the parallel use of two non-equivalent identities for the same label. Recall here the example of the multiple bifurcations about the meaning of the label "segment of coastal line" in Fig. 2.1.

This bifurcation in the meaning assigned to the label is then reflected into numerical assessments which are no longer necessarily supposed to be neither reducible into each-other or directly comparable by the application of an algorithm. A bifurcation in the system of mapping can be seen as - as stated by Rosen (1985: p. 302) - "*the appearance of a logical independence between two descriptions*". As discussed in Chapter 2 **such a bifurcation depends on the intrinsic initial ambiguity in the definition of a natural**

system by using symbols or codes: the meaning given to the label "London" (a name of a city made up of people or a 6-letter-word). As observed by Schumpeter (1954: p. 42) - "*Analytical work begins with material provided by our vision of things, and this vision is ideological almost by definition*".

3.3 The necessary semantic check always required by mathematics

Obviously, bifurcations in systems of mappings (reflecting differences in logic) will entail bifurcations also in the use of mathematical systems of inference. For example a statistical office of a city recording the effect of the marriage of two "singles" already living in that city and expecting a child would map the consequent changes implied by these events in different ways according to the encoding used for assess changes in the quality "population".

The event can be described either as: 1 + 1 → 1 (both before and after the birth of the child) if the mapping of population is done using the variable "number households". In alternative as: 1 + 1 → 3 (after the birth of the child) if the mapping is done in terms of "number of people" living in the city. In this simple example, it is the definition of the mechanism of encoding (implied by the choice of the identity of the system to be described - i.e. "households" versus "people" - which entails different mathematical descriptions of the same phenomenon). The famous quote of *A.N. Whitehead and B.Russell in Principia Mathematica* can be recalled here: "*The above proposition [1+1=2] is occasionally useful*".

The debate about the possibility of replacing external referents (semantic) with internal rules (syntax) is a very old one in mathematics. The Czech-born mathematician Kurt Gödel demonstrated that in mathematics it is impossible to define a complete set of propositions that can be proven either true or false on the basis of a pre-existing internal set of rules and axioms. Depending on the meaning attributed to the statements about numbers within a given mathematical system one has to go *outside* that system looking for external referents. This is the only way to individuate the appropriate set of rules and axioms. However, after such an enlargement of the system, we will face a new set of unprovable statements (that would require an other enlargement in terms of additional external referents). This is a process that leads to an infinite regress.

Any formalization requires always a semantic check even when dealing with familiar objects such as number: "*the formalist program was wrecked by the Gödel Incompleteness Theorem which showed that Number Theory is already non formalizable in this sense. In fact, Gödel (1931) showed that any attempt to formalize Number Theory, to replace its semantic by syntax, must lose almost every truth of Number Theory*"(Rosen 2000, pag 267).

The true age of dinosaurs and the "weak sustainability" indicator

To elaborate on the need of a continuous semantic check when using mathematics, it can be useful to recall the joke proposed by Funtowicz and Ravetz (1990) exactly for this purpose. The subject of the joke is illustrated in **Fig. 3.2.** The skeleton of a dinosaur (an exemplar of *Funtravesaurus . . .*) is in a museum with a sign saying "age 250,000,000 years" in the original label. However, the janitor of the museum has corrected the age into 250,000,008. When asked about the correction, he gave the following explanation : 'When I got this job, 8 years ago, the age of this dinosaur, written on the sign, was 250,000,000 years. I am just keeping it accurate.'

The majority of the people listening to this story do interpret it as a joke. To explain the mechanism generating such a perception we can use the same explanation about jokes discussed before about the leg named Joe. When dealing with the age of a dinosaur nobody is used to associate to such a concept a numerical measure which includes individual years. However, as noted by Funtowicz and Ravetz commenting this joke, when considering the formal arithmetic relation **A + B = C**, there are not written rules in mathematics which prevent the summing of **A** expressed in hundreds of millions to **B** expressed in units. Still the common sense (semantic check) tells us that such an unwritten rule should be applied. The explanation given by the janitor simply does not make sense to anybody familiar with measurements.

In this case, it is the incompatibility in the two processes of measurement (that generating **A** and that generating **B**), which makes impossible there summing. A more detailed discussion of this point is provided in a technical session [section 3.7] at the end of this chapter. What is bizarre, however, is that very few scientists operating in the field of Ecological Economics seem to object at a similar summation proposed by economists when dealing with issue of sustainability. For example, the weak sustainability indicator proposed by Pearce and Atkinson (1993) is supposed to indicate whether or not an economy is sustainable. According to this formal representation of changes in an economy, weak sustainability implies that an economy "saves" more than the combined depreciation on human-made and natural capital. The formal representation of this rule is given in relation 1 (where: S is savings, HMC human-made capital and NC natural capital):

$$S \geq dHMC/dt + dNC/dt \qquad (1)$$

There are very good reasons to criticize this indicator (for a nice overview of such a criticism see Cabeza, 1996), mainly related to the doubtful validity of the assumptions that it implies. That is, a full substitutability of the two different forms of capital mapped by the two terms on the right (e.g. technology cannot replace biodiversity). But this is not the argument relevant here. The epistemological capital sin of this equation is related to its attempt to collapse into a single encoding variable (a monetary variable) two non-equivalent assessments of changes referring to "system qualities" that can only be recognized using different scales and therefore can only be defined using non-equivalent descriptive domains. An assessment referring to **dNC/dt**, uses a formal identity expressing changes using as relevant variable **1996-US$**. Such an assessment can only be obtained by using a measurement scheme operating with a time differential of less than one year (assuming a validity of the "ceteris paribus" assumption for no more than 10 years). On the contrary, changes in natural capital refer to qualities of ecosystems or biogeochemical cycles that have a time differential of centuries. The semantic identity of Natural Capital implies qualities and epistemic categories that, no matter how creative is the analyst, cannot be expressed in 1996-US$ (a measurement scheme operating on a dt of years). In the same way, changes measured in 1996-US$ cannot be represented when using variables able to catch changes in qualities with a time differential of centuries. Each of the two terms "dHMC/dt" and "dNC/dt" cannot be detected when using the descriptive domain useful to define the other.

In conclusion, the sum indicated in relation (1) first of all does not carry any metaphorical meaning since the two forms of capital are not substitutable, and second, in any case could not be used to generate a normative tool, since it would be impossible to put meaningful numbers into that equation.

3.4 Bifurcations and Emergence

The concept of bifurcation has also a positive connotation. It indicates the possibility of increasing the repertoire of models and metaphors available to our knowledge. In fact, a direct link can be established between the concept of "bifurcation" and the concept of "emergence". Using again the wording of Koestler (1968) we have a "discovery" - Rosen (1985) suggests to use for this concept the term "emergence" - when two previously unrelated frames of reference are linked together. Using the concept of equivalence classes both for organized structures and relational functions, we can say that "emergence" or "discovery" is obtained: (1) when assigning a new class of relational functions (which implies a better performance of the holon on the focal/higher level interface) to an old class of organized structures or (2) when using a new class of organized structures (which implies a better performance of the holon on the focal/lower level interface) to an existing class of relational functions. We can recall again the example of the joke, in which a new possibility of associating words is introduced "opening" new horizons to the possibility of assign meaning to a given situation.

An emergence can be easily detected by the fact that **it requires changing the identity of the state space used to describe the new holon.**

A simple and well known example of "emergence" in dissipative systems is the formation of "Bénard cells" [= a special pattern appearing in a heated fluid when switching from a linear molecular movement to a turbulent regime]. For a detailed analysis of this phenomenon from this perspective see Schneider and Kay, (1994). The emergence (the formation of a vortex) requires the need of using in parallel 2 non-equivalent descriptive domains to properly represent such a phenomenon. In fact, the process of self-organization of a vortex is generating in parallel both "an individual organized structure" and "the establishment of a type". We can use models of dynamic of fluids to study, simulate and even predict this transition. But no matter how sophisticated these models are they can only guess the insurgence of a type (= under which conditions you will get the vortex). From a description based on the molecular level it is not possible to guess the direction of rotation that will be taken by a particular vortex (if clockwise or anti-clockwise). Whereas, when observed at a larger scale, any particular Bénard cell, because of its personal history, will have a specific identity, that will be kept until it remains alive (so to speak). This symmetry breaking associated to the special story of this individual vortex will require an additional source of information (external referent) to determine whether the vortex is rotating clockwise or anti-clockwise. However, in order to do so, we have to adopt a new scale for perceiving and representing the operation of a vortex (above the molecular one) to detect the direction of rotation. This implies also the use of a new epistemological category (i.e. clockwise or anti-clockwise) not originally included in the equations. To properly represent such a phenomenon we have to use a descriptive domain which is not equivalent to that used to study lower level mechanism. Put in another way, the information required to describe the transition on two levels (characterizing both the individual and the type) can not be all retrieved describing events at the lower level. More about this point in the discussion about the root of incommensurability between squares and circles given in the technical section 2.7.

Another simple example can be used to illustrate the potential pitfalls associated to generation of policy indications based on the extrapolation to a large scale of findings related to mechanisms investigated and validate at the local level. Let's imagine that a owner of a sex shop is looking for advice about how to expand the business by opening a second shop. Obviously, when analyzing the problem at a local level (e.g. when operating in a given urban area) the opening of two similar shops close to each other has to be considered as a "bad policy". The two shops will compete for the same flow of potential customers and therefore the simultaneous presence of two similar shops in the same street is expected to reduce the profit margin of each of the two shops. However, let's imagine now the existence of hundreds of sex shops in a given area. This implies the emergence of a new system property, which is in general called "red light district". Such an emergent property express functions that can only be detected at a scale larger than the one used to study the identity of an individual sex shop. In fact, "red light districts" can attract potential buyers also from outside the local urban area or from outside the city. In some cases they can even drive customers from abroad. In technical jargon we can say that the domain of attraction for potential customers of a red-light district is much larger that the one typical of an individual sex shop. This can imply that - getting back to the advice required by the owner of an individual sex shop – there is a trade-off to be considered when deciding whether to open a new shop in a "red light district". The reduction of profit due to the intense competition has to be weighted versus the increase of customers flow due to the larger basin of attraction. Such a trade-off analysis is totally different if the shop will be opened in a normal area of the city.

In conclusion, whereas it is debatable whether or not the concept of emergence implies something "special" in ontological terms, it is clear that it implies something "special" in functional and epistemological terms. **Every time we deal with something which is "more than" and "different from" the sum of its parts, we have to use in parallel non-equivalent descriptive domains to represent and model different relevant aspects of its behavior. The parts have to be studied in their role of parts and the whole has to be studied in its role as a whole.** Put in another way, emergence implies for sure a change (a richer information space) in the observer/observed complex. The implications of this fact are huge. When dealing with the evolution of complex adaptive systems (real emergence) the **information space that has to be used for describing how these systems change in time is not closed and knowable "a priori"**. This implies that models, even if validated in previous occasions, not necessarily will result good in predicting future scenarios. This is especially true when dealing with human systems (adaptive reflexive systems).

3.5 The crucial difference between risk, uncertainty and ignorance

The distinction proposed below is based on the work of Knight (1964) and Rosen (1985). Knight distinguishes between cases in which it is possible to use previous experience (e.g. record of frequencies) to infer future events (e.g. guess probability distributions) and cases in which such an inference is not possible. Rosen (1985), in more general terms, alerts on the need of being always aware of the clear distinction between a "natural system", which is operating in the complex reality and "the representation of a natural system" which is scientist-made. Any scientific representation requires a previous "mapping", within a structured information space, of some of the relevant qualities of the natural system with encoding variables (the adoption of a formal identity for the system in a given descriptive domain). Since scientists can handle only a finite information space, such a mapping implies the unavoidable missing of some of the other qualities of the natural system (those not included in the selected set of relevant qualities).

Using these concepts it is possible to make the following distinction between Risk and Uncertainty. **Risk** (= situation in which it is possible to assign a distribution of probabilities to a given set of possible outcomes – e.g. the risk of losing when playing the "roulette"). The assessment of risk can come either from the knowledge of probability distribution over a known set o f possible outcomes obtained using validated inferential systems or in terms of agreed-upon subjective probabilities. In any case, RISK implies an information space used to represent the behavior of the investigated system which is: (i) closed; (ii) known; and (iii) useful (= the formal identity adopted includes all the relevant qualities to be considered for a sound problem structuring). In this situation, there are cases in which we can even calculate with accuracy the probabilities of states included in the accessible state space (e.g. classic mechanics). That is, we can make reliable predictions of the movement in time of the system in a determined state space – **Fig. 3.3a.**

The concept of risk is useful when dealing with problems: (i) easily classifiable (about which we have a valid and exhaustive set of epistemological categories for the problem structuring). (ii) easily measurable (the encoding variables used to describe the system are "observable" and measurable, adopting a measurement scheme compatible in terms of Space-Time domain with the dynamics simulated in the modeling relation). Under these assumptions, when we have available a set of valid models, we can forecast and usefully represent what will happen (at a particular point in space and time). When all these hypotheses are applicable, the expected errors in predicting the future outcomes are negligible. In alternative, we can decide to predict outcomes by using probabilities derived from our previous knowledge of frequencies – **Fig. 3.3b.**

Uncertainty (= situation in which it is not possible to generate reliable prediction of what will happen). That is, UNCERTAINTY implies that we are using to make our prediction an information space, which is: (i) closed; (ii) finite; and (iii) partially useful, according to previous experience, but, at the same time, there is awareness that this is just an assumption that can fail.

Therefore, within the concept of UNCERTAINTY we can distinguish between:

* **Uncertainty due to indeterminacy** (= there is a reliable knowledge about possible outcomes and their relevance, but it is not possible to predict, with the required accuracy, the movement of the system in its accessible state space. – e.g. the impossibility of predict the weather in 60 days from now

in London) – **Fig. 3.4a.** Indeterminacy is also unavoidable when dealing with "reflexivity" of humans. The simultaneous relevance of characteristics of elements operating on different scales (= the need of considering more than one relevant dynamic in parallel on different space-time scales) and non-linearity in the mechanisms of controls (the existence of cross-scale feed-backs) entail that expected errors in predicting future outcomes can become high (butterfly effect, sudden changes in the structure of entailments in human societies - laws, rules, opinions). Uncertainty due to indeterminacy implies that we are dealing with problems which are **classifiable** (we have valid categories for the problem structuring), but that they are not fully measurable and predictable.

Whenever we are in presence of events in which "emergence" should be expected, we are dealing with a new "dimension" of the concept of uncertainty. In this case, we can expect that the structure of causal entailments in the natural system simulated by the given model can change and/or that our selection of the set of relevant qualities (formal identity) to be used to describe the problem can become no longer valid. This is a different type of uncertainty.

* **Uncertainty due to ignorance** (= situation in which it is not even possible to predict what will be the set of attributes that will result relevant for a sound problem structuring) – an example of this type of uncertainty is given in **Fig. 3.4b.** IGNORANCE implies the awareness that the information space used for representing the problem is: (i) finite and bounded, whereas the information space, that would be required to catch the relevant behavior of the observed system, is open and expanding. and (ii) our models based on previous experience are missing relevant system qualities. The worst aspect of scientific ignorance is that it is possible to know about it, only through experience. That is, when the importance of events (attributes) neglected in a first analysis becomes painfully evident. For example, Madame Curie, who won two Nobel Prizes (in Physics in 1903, and in Chemistry in 1911) for her outstanding knowledge of radioactive materials, died of leukemia in 1934. She died "*exhausted and almost blinded, her fingers burnt and stigmatised by 'her' dear radium*" Raynal, (1995). The same happened to her husband and her daughter. Some of the characteristics of the object of her investigations, known nowadays by everybody, were not fully understood, at the beginning of this new scientific field, not even by the best experts available.

There are typologies of situations in which we can expect to be confronted in the future with problems that we cannot either guess or classify at the moment. For example, when facing fast changes in existing boundary conditions. In a situation of rapid transition we can expect that we will have to learn soon new relevant qualities to consider, new criteria of performance to be included in our analyses, and new useful epistemological categories to be used in our models. That is, in order to be able to understand the nature of our future problems and how to deal with them we will have to use an information space different from the one used right now. Obviously, in this situation, we cannot even think of valid measurement schemes (how to check the quality of the data), since there is no chance of knowing what encoding variables (new formal identities expressed in terms of a set of observable relevant qualities) will have to be measured.

Even admitting that ignorance means exactly that it is not possible to guess the nature of future problems and possible consequences of our ignorance, this does not mean that it is not possible to predict, at least, when such an ignorance can become more dangerous. For example, when studying complex adaptive systems it is possible to gain enough knowledge to identify basic features in their evolutionary trajectories (e.g. we can usefully rely on valid metaphors). In this case, in a rapid transitional period, we can easily guess that our knowledge will be affected by larger doses of scientific ignorance.

The main point to be driven home from this discussion over risk, uncertainty and ignorance is the following. In all cases in which there is a clear "awareness" of living in a fast transitional period in which the consequences of "scientific ignorance" can become very important, it is wise not to rely only on reductionist scientific knowledge (Stirling, 1998). The information coming from scientific models should be mixed with that coming from metaphors and additional inputs coming from various systems of knowledge found among stakeholders. A new paradigm for science - Post-Normal Science - should aim at establishing a dialogue between science and society moving out from the idea of a one-way flow of information. The use of mathematical models, as the ultimate source of truth, should be regarded just as a sign of ignorance of the unavoidable existence of scientific ignorance.

3.6 Multiple causality and the impossible formalization of sustainability trade-offs across hierarchical levels

3.6.1 Multiple causality for the same event

The next example deals with multiple causality: that is a set of 4 non-equivalent scientific explanations for the same event are listed in **Fig. 3.5** (the event to be explained is the possible death of a particular individual). This example is particularly relevant since each of the possible explanations can be used as an input for the process of decision making.

(1) Explanation #1 refers to a very small space-time scale at which the event is described. This is the type of explanation generally looked for when dealing with a very specific problem (= when we have to do something according to a given set of possibilities, perceived here and now = a given and fixed associative context for the event). Such an explanation tends to generate a search for maximum efficiency. According to this explanation we can do as good as we can, **assuming that we are adopting a valid, closed and reliable information space.** In political terms, these type of "scientific explanations" tend to reinforce current selection of goals and strategies of the system. For example, policies aimed at maximizing efficiency implies not questioning (in the first place) basic assumptions and the established information space used for problem structuring;

(2) Explanation #2 refers again to a small space-time scale at which the event is described. This is the type of explanation generally looked for when dealing with a class of problems that have been framed in terms of the WHAT/HOW question. We have an idea of the HOW (of the mechanisms generating the problem) and we want to both fix the problem and understand better (fine tuning) the mechanism according to our scientific understanding. Again we assume that the basic structuring of the available information space is a valid one, even though we would like to add a few improvements to it;

(3) Explanation #3 refers to a medium/large scale. The individual event here is seen through the screen of statistical descriptions. This type of explanation is no longer dealing only with the WHAT/HOW question but also, in an indirect way with the WHY/WHAT question. We want to solve the problem, but in order to do that we have to mediate between contrasting views found in the population of individuals to which we want to apply policies. In this particular example, dealing with the trade-offs between individual freedom of smoking and the burden of health-costs for the society generated by heavy smoking. We no longer have a closed information space and a simple mechanism to determine optimal solutions. Such a structuring of the problem requires an input from the stakeholders in terms of "value judgment" (= for politicians this could be the fear of losing the next elections);

(4) Explanation #4 refers to a very large scale. This explanation is often perceived as "a joke" within a scientific context. My personal experience is that whenever this slide is presented at conferences or lessons, usually the audience starts laughing when seeing the explanation "humans must die" listed among the possible scientific explanations for the death of an individual. Probably this reflects a deep conditioning to which scientists and students have been exposed for many decades. Obviously, such an explanation is perfectly legitimate in scientific terms when framing such an event within an evolutionary context. The question then becomes why it is that such an explanation tends to be systematically neglected when discussing of sustainability? The answer is already present in the comments given in **Fig. 3.5.** Such an explanation would force the scientists and other users of it to deal explicitly and mainly with "value judgments" (dealing with the "why" or "what for" question rather than with the "how" question). Probably this is why, this type of question seems to be perceived as not "scientifically correct" according to western academic rules.

Also in this example we find the standard predicament implied by complexity: the validity of using a given scientific input depends on the compatibility of the simplification introduced by the "problem structuring" with the context within which such an information will be used. A discussion about pros and cons of various policies restricting smoking would be considered unacceptable by the relatives of a patient in critical conditions in an emergency room. In the same way, a physiological explanation on how to boost the supply of oxygen to the brain would be completely useless in a meeting discussing the opportunity of introducing a new tax on cigarettes.

3.6.2 The impossible trade-off analysis over perceptions: weighing short term versus long term goals

The example given in **Fig. 3.6** addresses explicitly the importance of considering the hierarchical nature of the system under investigation. This example has been suggested to me by David Waltner-Toews (personal communication – details on the study are available at the URL of International Development Research Centre – IDRC – listed in reference). The goal of this example is to illustrate that when reading the same event on different levels (on different space-time horizons) we will see different solutions for the very same problem. A compared evaluation of these potential alternative solutions is impossible to formalize.

Very quickly, the case study deals with the occurrence of a plague in a rural village of Tanzania. The plague was generated by the presence of rats in the houses of villagers. The rats moved into the houses following the stored corn, which previously was stored outside. The move of the corn inside the houses resulted necessary due to the local collapse of the social fabric (it was no longer safe to store corn outside). Such a collapse was due to the very fast process of change of this rural society (triggered by the construction of a big road). Other details of the story are not relevant here, since this example does not deal with the implications of this case study, but just points at a methodological impasse.

A simple procedure that can be used to explore the implication of the fact that human societies are organized in holarchic way is indicated in **Fig. 3.6.** After stating the original problem as perceived and defined at a given level, it is possible to explore the causal relations in the holarchy by climbing the various levels through a series of "why and because" (upper part of **Fig. 3.6**). When arriving to an explanation which has no implications for action we can stop. Then we can descend the various levels by answering new types of questions related to the "how and when" dimension (lower part of **Fig. 3.6**).

Looking at possible ways of structuring the problem experienced by the villagers following this approach, we are left with a set of questions and decisions typical of the "Science for Governance" domain:

- *What is the "best" level that should be considered when making a decision about eliminating the plague? Who is entitled to decide that?* The higher we move in the holarchy the better is the overview of parallel causal relations and the richer (more complex) is the explanation. On the other hand, this implies a stronger uncertainty about predicting the outcome of possible policies as well as a longer lag-time to get a fix (= prolongation of sufferance of lower level holons = those affected by the plague in the village - in this specific case, mainly women). The smaller is the scale, the easier the identification of direct causal relations (= the easier the handling of specific projects looking for quick-fixes). However, faster and more reliable causal relations (leading to rapid solutions) carry the risk of curing symptoms rather than causes. That is, the adoption of a very small scale of analysis can imply the risk of "locking in" the system in the same dynamic that generated the problem in the first place. Since this main dynamics operating on a larger scale has not been addressed in the "location specific" analysis.
- *How to assess the trade-offs linked to the choice of a level rather than another?*

When using a very short time horizon to fix the problem (e.g. kill the rats while keeping the society and the ecosystem totally unbalanced) it is likely to get, sooner or later, into another problem. If rats were just a symptom of some bigger problem, the cause is still there. On the other hand, when using a too large time horizon (e.g. trying to fix the injustice in the world) implies a different risk. That of attempting to solve the perceived problem very far in the future or distant in space, basing our policies on present knowledge and boundary conditions (perceptions referring to a very small space-time scale). The very same problems we want to save today with major structural changes in social institutions could have a different and easy solution in 20/50 years (e.g. climatic changes that make impossible life in that area). If this is the case, policies aiming only at a quick relief to the suffering of the poor (e.g. killing the rats) could have been implemented without negative side-effects (e.g. generation of a lock-in of a larger scale problem). Unfortunately we can never know this type of information ahead.

- *It is our integrated assessment of changes reflecting existing multiple goals found in the system?* Any integrated assessment of the performance of a system depends on:
(1) expectations and related priorities (relevant criteria to be considered and weighting factors among them); and (2) perception of effects of changes (the level of satisfaction given by a certain profile of values taken by indicators of performance). In turn, these expectation and perceptions both heavily depend on: (i) the level of the holarchy at which the system is described (e.g. if we ask the opinion of the president of Tanzania or of a farmer living in that village); and (ii) the identity of the various social groups operating within the socio-economic system at any given level in the holarchy. For example, farmers of a different village in Tanzania can have different perspectives on the effects of the same new road. In the same way, women or men of the same village can judge in different way the very same change.
- *What is the risk that cultural lock-in - which is clearly "space and time specific" - is preventing the feasibility of alternative solutions?* It is well known that the past – in the form of cultural identity in social systems - is always constraining the possibility of finding new models of development. This is why, changes imply always tragedy (Funtowicz and Ravetz, 1994). As noted earlier, when solving a sustainability problem socio-economic systems have to be prepared to lose something to get something else. This introduces one of the most clear dimension of incommensurability in the analysis of sustainability trade-offs. Decisions about sustainability have to be based on a continuous negotiation. The various stakeholders should be able to reach, in an adequate period of time, a consensus on the nature of the problem and, an agreement on how to deal with it. In particular this implies deciding on:

(i) what do they want to keep of present situation [e.g. how important is to keep what they are getting now?].
(ii) what do they want to change in present situation [e.g. how important is to get away as fast as possible from current state?].
(iii) how reliable is the information which is used to translate into practical action the agreement reached about points: (i) and (ii)?

These questions can be reformulated as: when forced to re-define their identity as a social system, what do they want to become and at which cost?

Clearly, a total agreement over a common "satisficing trade-offs profile" is certainly not easy to reach (if not impossible) in any social system. The unavoidable existence of different perceptions about how to answer these questions can only be worked out through negotiations and conflicts. Negotiations and conflicts are crucial to keep diversity in the social entity. A standard solution of imposing a particular view-point (= a given best "satisficing trade-offs profile") with the force (hegemonization) - beside the very high cost in terms of human suffering - carries the risk of an excessive reduction in the cultural diversity, and therefore a dramatic reduction of adaptability, in the resulting social systems. The expression "Ancien Regime Syndrome" proposed by Funtowicz and Ravetz (personal communcation) exactly indicates that boosting short-term efficiency through hegemonization in a society is often paid for in terms of lack of adaptability in the long term. Such a typical pattern leading to the collapse of complex social organization has been discussed in detail by Tainter, (1988). More on the nature of this dilemma in the next section.

3.6.3 The impossible trade-off analysis over representations: the dilemma "efficiency" versus "adaptability"

Adaptability and flexibility are crucial qualities for the sustainability of adaptive systems (Conrad, 1983; Ulanowicz, 1986; Holling, 1995). They both depend on the ability of preserving diversity (actually this is also the theoretical foundation of democracy). However, the goal of preserving diversity *per se* collides with that of augmenting efficiency at a particular point in space and time (this is the problem with total anarchy). Efficiency, in fact requires elimination of those activities that are less performing according to a given set of goals, functions and boundary conditions and an amplification of those activities which are perceived as the most performing at a given point in space and time. Clearly this general rule applies also to technological progress . For example, in agricultural production, "improving" world agriculture according to a given set of goals expressed now by a given social group in power and according to present perception of boundary conditions (e.g. plenty of oil) is implying a dramatic reduction of the diversity of systems of production (e.g. the disappearance of traditional farming systems). More and more (driven by technological innovations such as the green revolution) agricultural production all over our planet is converging on a very small set of standard solutions (e.g. monocultures of high yielding varieties supported by "energy intensive" technical inputs, such as synthetic fertilizers, pesticides and irrigation - Pimentel and Pimentel, 1996). On the other hand, the "obsolete" agricultural systems of production, being abandoned all over the planet can show a very high performance when assessing them under a different set of goals and criteria (Altieri, 1987) .

When reading the process of evolution in terms of complex systems theory (Giampietro, 1997; Giampietro et al, 1997), we can observe that, in last analysis, the drive toward instability is generated by the reciprocal influence between efficiency and adaptability. The continuous transformation of "efficiency" into "adaptability" and that of "adaptability" into "efficiency" is the responsible for the continuous push of the system toward non-sustainable evolutionary trajectories. This is a different view of the Jevons' paradox or the agricultural treadmill discussed in Chapter 1. The steps of this cycle (with an arbitrary choice of a starting step) are:
(i) accumulation of experience in the system leads to more efficiency (by amplification of the most performing activities and elimination of the less performing); (ii) more efficiency makes available more surplus to fuel societal activities; (iii) the consequent increase in the intensity and the scale of interaction of the socio-economic system with its environment, implies an increased stress on the stability of boundary conditions (more stress on the environment and a higher pressure on resources). This calls for increased investments in adaptability; (iv) in order to be able to invest more in adaptability (= expand the diversity of activities, which implies developing new activities that, at the moment, can result not particularly performing) the system needs to be more efficient - i.e. has to better use it experience on how to produce more. This can only be obtained by an amplification of the most performing activities and an elimination of the less performing. At this point the system gets back into the step (i)

An overview of the co-existence of different causal paths between efficiency and adaptability, described on different time scales, is illustrated in **Fig. 3.7**. When considered on a short time scale, efficiency would imply a negative effect on adaptability and vice-versa. When a long-term perspective is adopted, they both thrive on each other. However, the only way to obtain this result (based on a sound Yin-Yang tension) is by continuously expanding the size of the domain of activity of human societies. That is, increases in efficiency are obtained by amplifying the most performing activities, without eliminating completely the obsolete ones. These activities will be preserved in the repertoire of possible activities of the societal system (as a memory of "different meanings" of efficiency when adopting a different set of boundary conditions and a different set of goals). When the insurgence of new boundary conditions or new goals will require a different definition of efficiency, the activities amplified until that moment, will become obsolete, and the system will scan for new (or old) ones in the available repertoire. In this way, at each cycle, societal systems will enlarge their repertoire of knowledge of possible activities and accessible states (boost their adaptability). This expansion in the computational capability of the society, however, requires an expansion of its domain of activity, that is an increase in its size (no matter how we decide to measure its size – total amount of energy controlled, of information processed, of kg of human mass, of GNP) – Giampietro et al. 1997.

Sustainability of societal systems can therefore only be imagined as a dynamic balance between the rate of development of their "efficiency" and "adaptability". This can be obtained by a continuous change of structures to maintain existing functions and a continuous change of functions to maintain existing structures. Put it in another way, neither a particular societal structure or a particular societal function can be expected to be "sustainable" indefinitely in the future.

As noted before, practical solutions to this challenge means deciding on how to deal with the tragedy of change. That is, any social system in its process of evolutions has to decide how to become a different system, but maintaining in this process its own individuality (more on this in Chapter 8). The "feasibility" of this process (which is like changing the structure of an airplane while flying on it) depends on the nature of internal and external constraints faced by society. The "advisability" of the final changes (what the plane will look like at the end of the process, if still flying) will depend on the legitimate contrasting perceptions of those flying on it, their social relation and the ability expressed by such a society to make wise changes to the plane at the required speed.

In this way we found an additional complication to the practical operationalization of the process of decision making for sustainability. In fact, not only, it is difficult to find an agreement on what are the most important feature to preserve or to enhance when attempting to build a different flying airplane. But this decision has to be taken without having a solid information about the feasibility of the various possible projects to be followed. As noted earlier, the definition and forecasting of viability constraints is unavoidably affected by a large dose of uncertainty and ignorance about possible unexpected future situations. Put in another way, when facing the sustainability predicament, humans must continuously gamble trying to find a balance between their efficiency and adaptability. In cultural terms, this means finding an equilibrium in focus between the consideration that has to be given to the importance of the past and the future in shaping the identity of their civilization (Giampietro, 1994a).

3.7 Perception and representation of holarchic systems

TECHNICAL SECTION

3.7.1 The fuzzy relation between ontology and epistemology in holarchic systems

The goal of this section is to wrap up the discussion on the epistemological/ontological melt-down implied by the mechanism of autopoiesis of languages and holarchies. This will be done by using the concepts introduced in this chapter and those introduced in Chapter 2.

First of all, let's get back to the peculiar implications of the concept of holon in relation to ontology and epistemology. Such a concept has been introduced by Koestler exactly to focus and deal with the melt-down found when dealing with holons. Recalling one of his famous examples Koeslter says (1968 pag.87) that it is impossible to individuate what a given opera of Puccini – e.g. La Boheme – is in reality. In fact, we can assist to various representations of it (individual realizations), which would be all different from each other. At the same time, the very same representation is always perceived as "La Boheme" even if in different ways by different spectators (non-equivalent observers). Such an opera was conceived as an individual "essence" by Puccini, but then it was formalized (encoded) into a set of formal identities (e.g. manuscripts with lyrics, musical scores, description of costumes and set decorations). After that, various directors, musicians, singers, costume designers willing to represent "La Boheme" have adopted different semantic interpretations of such a family of formalizations. To make things more intriguing it is exactly this process of semantic interpretation of formal identities and consequent action which implied the generation of a new generation of formalizations, which managed to maintain alive such an individuality. The individuality of "La Boheme" will remain alive only in presence of a continuous agreement among: (1) those providing representations (producing realizations of it), that is musicians, singers, administrators of opera theaters, etc. ; and (2) those making the production possible (those supporting the process of realization), that is the spectators paying for assisting to these representations and/or decision-makers sponsoring the opera. That is, the surviving of the identity of "La Boheme" depends on the ability to preserve the meaning assigned to the label "La Boheme" by interacting non-equivalent observers. This keeps alive the process of resonance between semantic interpretation to previous formalizations of the relative set of identities to generate a new generation of formalizations to be semantically intepreted.

In this example, we recognize the full set of concepts discussed in Chapter 2. A given "opera by Puccini" refers to an equivalence class of realizations all mapping onto the same: (a) label "Boheme", and (b) essence - the universe of "images of that opera" in the mind of those sharing the meaning assigned to that label. This process of resonance between labels, realizations and shared perception about meaning was started by an individual event of "emergence" when Puccini wrote the opera the first time (adding a new essence to the set of musical operas). The validity of this essence requires a continuous semantic check based on the valid use of formal identities required to generate equivalence classes of realization.

In this process, the individuality of "la Boheme" is preserved through a process of convergence of meaning in a population of non-equivalent observers, and agents which must be able to recognize and perceive the various realizations they experience in their life as legitimate members of that equivalence class. It should be noted that such an identification can be obtained using non-equivalent mappings (an integrated set of identities that makes possible the successful interaction of agents in preserving the meaning of such a process). *"Some can recognize the words of a famous aria -'your tiny hand is frozen' after having lost the melody, whereas other can recognize the melody after having lost the world"* (Koeslter, 1968 pag.87). Other can use as key code for recognizing operas special costumes or special situations (e.g. a person totally deaf sitting in a Opera hall can associate the presence of elephants on the stage to the representation of the Aida of Verdi!).

Obviously, the same mechanism generating/preserving a semantic identity of pieces of art can be applied to other types of artistic objects such as a play of Shakespeare or a famous painting of Picasso (a photographic reproduction would be then a formal identity of it, which is missing relevant aspects found in the original).

The rest of this section makes the point that this fuzzy relation between ontology and epistemology (= the existence of valid epistemic categories requires the existence of an equivalence class made up of realizations, and an equivalence class of realizations requires the existence of epistemic categories) is not only found when dealing with the perception/representation of artistic objects. Rather this is a very generic mechanism in the formation of human knowledge. To make this point, I propose to have another look at a simple, "innocent", geometric object defined within the classic Euclidean geometry - e.g. a triangle - using the various concepts introduced so far.

A "triangle" is clearly an essence associated to a class of geometric entities. The definition of such an essence is based on a specified, given, relation among lower level elements (the three segments representing the sides of the triangle). Put in another way a "triangle" is by definition a whole made up of parts. That is, it expresses an emergent properties at the focal level (that of being a triangle) due to the organization of lower level elements (the segments making up its sides). The triangle is an emergent property in the sense that the epistemic category "triangle" refers to a descriptive domain (a two dimensional plane) non-equivalent to the descriptive domain used to perceive and represent segments (which is one-dimensional). It would be impossible to make a distinction between a triangle and a square for an observer living in a one-dimensional world unless they would walk around the observer rotating at a given pace (recall the famous book *Flatland* of Edwin Abbott, 1952). Still this implies using a two-dimensional plane in order to be able to get around the triangle . . .

When considering a triangle we deal with its identity in terms of: (1) a label (the word "triangle" in English and "triangulo" in Spanish); (2) a mental image common to people sharing the meaning assigned to this label, (3) a class of objects that are perceived as being realizations of this essence. Obviously, a class of triangular objects (realizations of such an essence) must exist, in fact this is what made possible for humans to share the meaning given to the label in the form of the mental image of it.

In terms of hierarchy theory we can say that a triangle is a hierarchically organized entity. That is, in order to have a realization of such an identity you must have first of all the realization of three segments (lower level components defined in one dimension), which must be organized into a two-dimensional figure on a plane. In turn a segment is perceived and represented as made up of points. Because of this hierarchical nature there is a double set of constraints associated to the existence of such an object: (1) on the relative length of each of the three segments making up the sides; (2) on the shape of the three angles determined on and/or determining the corners. The existence of these constraints on the relative size of lower level elements and their relative position is related to the required closure of the geometric object. Put in another way, the very identity of this complex object implies a self-entailment among the various identities of its component elements: (1) lower level identities of segments (relative length); (2) focal level identity of the triangle (relative position of the sides within the whole). The existence of these constraints makes possible to compress the requirement of information to represent such an object. That is, knowing about the identity of two of the angles entails knowing about the identity of the third one. Knowing the length of the various segments makes possible to know about angles. Actually, the existence of this self-entailment among the characteristics of the focal level (level n) and the characteristics of lower level elements (level $n-1$) is the subject of elementary trigonometry. When expressed in this terms a triangle is an essence referring to various possible types (= relational definition of the whole based on the definition of a relation among lower level elements) and therefore is without scale. However, in order to make possible for humans to share the meaning given to the label "triangle" - to abstract from their interaction with the reality a mental image of triangles - humans must have seen in their daily life several practical **realizations** of this type. Moreover, when discussing and studying triangles humans must make realizations (representations) of the types related to this essence (e.g. different types of triangles such as "right triangle isosceles") in order to be able to check with measurements the validity of their theorems.

Therefore, even when dealing with a very abstract discipline such as geometry humans cannot get rid of the duality between essences and realizations. As soon as an observer either represents a geometric object or perceives it as a natural system belonging to the class of triangles (by associating the shape of a real entity to the mental image of triangles) we are dealing with a case in which a particular type (belonging to the essence) has been realized at a certain scale. The very possibility of doing geometry, therefore requires the ability of making and observing realizations of essences at different scales. That is, the operation of pattern recognition based on mental images (related to a pre-analytical definition of types or essences) "per se" would not imply a given scale. However, both processes, that of: (a) observation and measurement (using a detectors of signals, which imply a scale because of the interaction associated to the exchange of signals); and (b) fabrication (making and assemblage of lower level structural elements) are necessarily scaled.

The perception and representation of a triangle refers in parallel to two definitions of scales: (a) the scale required to perceive, represent, measure and fabricate lower level structural elements (e.g. segments); and (b) the scale required to perceive, represent, measure and fabricate focal level elements (e.g. triangles) when putting together these lower elements into a whole. A series of triangles of the same shape (type) and different sizes is shown on the top of **Fig. 3.8**. The given typology can be defined by using the relation between the relative "measure" of angles and sides. When dealing with a type we are talking of "relative" measures. A concept that assumes (requires or entails) the compatibility in the accuracy of the process of:
(1) actual measurement of both angles and side length:
(2) fabrication of the geometric object.

Coming to possible realizations of this set of triangles with different sizes (but all belonging to the same type) we can imagine (Fig. 3.8):
(a) a triangle having a size in the order of cm (made by drawing with a pencil three segments on a paper on our desk and observed while sitting at the desk);
(b) a triangle with the size in the order of meters (made by putting together wooden sticks in the back yard and observed from the window of the attic of our house);
(c) triangle with the size in the order of km (made by the connection of three highways and observed from an airplane).

Let's imagine now that we want to assess the different size of these three realizations which are all mapping onto the same type of triangle. This assessment must be associated to a process of measurement. Measuring implies the definition of a "differential" which is related to the accuracy of the measurement scheme. That is, the smallest difference in length which can be detected by the measuring device for segments (e.g. dx), and the small difference which can be detected by the measuring device for angles (e.g. dα). In the same way we can define another relevant space differential, related to the process of representation of such an object (fabrication of individual realization of this essence). This would be the smallest gradient in length and in angle definition that can be handled in the process of representation. An idea of the potential problems faced when constructing a triangle in relation to the relative scale of segments and the whole is given in the bottom of **Fig. 3.8**. Those familiar with working in Power-Point or other graphic software will immediately recognize the nature of this problem faced when zooming too much into the drawing.

We can talk or discuss about measures of a triangle (what makes useful the identity of a triangle throughout trigonometry) **only after assuming that the two non-equivalent differentials are compatible.** The two differentials in fact are not necessarily always compatible: (a) one refers to the operation of measurement of structural elements at the level ***n-1***; and (b) one refers to the representation of the structural elements into a whole at the level ***n***. Using the vocabulary introduced in the previous sections the compatibility of the two differentials means that lower level elements and whole must belong to the same descriptive domain.

Robert Rosen (2000, chapter 4) discusses of the root of incommensurability introducing exactly this topic. His example is that it is possible to express without problems the identity of a particular type of triangle (e.g. "isosceles right triangle") in terms of a given relation between its parts. A consequence of this definition is that according to the Pythagorean theorem, the size of the square built on the hypotenuse is equal to the sum of the two squares built on the other two sides. That, is when dealing with a two dimensional objects (a triangle) it is possible to express in general terms the relation among its elements using a mapping referring to a two dimensional representation (squares with squares).

The problem starts when we try to use a one-dimensional descriptive domain for mapping the relation between elements of a two-dimensional object. This led to the introduction of irrational numbers (the length of the hypotenuse is equal to the length of one of the other two sides time the square root of 2) and real numbers which are - as proved by Zeno paradox - uncountable (Rosen, 2000; p. 74). In this case, the three non-equivalent concepts: (1) measuring, (2) constructing and (3) counting can no longer be considered as compatible or reducible to each-other (Rosen, 2000 pag. 71). This example raises the following question. Why when we adopt as descriptive domain a two-dimensional plane we can express the relation among the sides of this triangle in terms of squares without problems, whereas when we use a one-dimensional descriptive domain - using relation among segments - things do get more difficult? An explanation can be given by using the concepts discussed before. A two dimensional descriptive domain assumes the parallel validity of two non-equivalent external referents. (1) the possibility of constructing and measuring lower level elements (with a dx related to length of segments); and at the same time: (2) the possibility of constructing and measuring another characteristic quality of such a system, namely the angles formed by the sides. The forced closure of the triangle on the corners implies assuming the compatibility between the differential ***dx*** related to the measuring and representation of the length of lower level elements (segments) and the differential ***dα*** related to the measuring and representation of their relative position (angles) within the whole object. When we talk of the sum of the squares constructed on the various sides, we are assuming the compatibility of ***dx*** and ***dα*** in the various operations required for making such a sum. In the Pythagorean theorem, in fact, squares **are assumed to be valid measuring tool.** That means supposing that all the squares have in common a smaller square U that can be used as unit to "count off" an integral number of times their area. This is "a kind of quantization hypothesis, with the U as a quantum" (Rosen, ibid.). That is, the hypothesis of an associative descriptive domain for two-dimensional geometric objects is based on the assumption of an agreed upon representation of triangles and squares in which the two segments in a corner are seen as perfectly touching. This means, that there is a total agreement among various observers about the exact relative position of lower level elements within the geometric figure in relation to both the operation of measurement and representation (in terms of length of sides and measure of angles). This requires a compatibility between the accuracy in the measurement of angles and the accuracy in the determination of the length (again see the example provided in the bottom of **Fig. 3.8**) in relation to the process of fabrication. As soon as we want to compress the perception and representation of a hierarchically organized object (referring to a two-dimensional epistemic category) into a numerical relation among segments (referring to a one-dimensional epistemic category) we loose the assumed parallel validation of two external referents, and therefore the possibility of generalizing this mapping.

The same mechanism (non-equivalence of the associative descriptive domain) can be used to explain the incommensurability between squares and circles. The very definition of a circle entails an essence based on a given relation among lower level elements - points - which by definition do not have scale and that therefore should be considered as other essences (they cannot have scaled realizations which are measurable). This is where the systemic incompatibility between the two descriptive domains enters into play. The descriptive domain of a square (as well as triangles and polygons) must provide compatibility between the differentials referring to the construction and measure (perception and representation) of both segments - at the level *n -1* - and angles - at the level *n*. Whereas, the descriptive domain of the circle refers only to a measure of the distance of the various points making up the circumference from the center (at the level *n)*. Put in another way, the definition of the identity of a square entails more information than a circle (e.g. in relation to the making and measurement of segments and in relation to the making and measurement of the square). Elementary geometry uses this entailment to infer a lot of relations between parts and wholes in geometric objects. Whereas, the essence of a circle is based on a definition of lower level elements (points) which must be dimensionless. Because of this, it leaves open the issue of how to judge the compatibility between the space differential referring to the perception and representation of circles. A square is a real holarchic system, a circle is an image, which can be always be realized, but with a weaker identity.

As it will be discussed in Part 2, the definition of an identity for a triangle or a square is the result of an impredicative loop. The processes of realization (representation) and measurement (perception) of the various holons in parallel on different scales must converge on a compatible definition of it on a relative descriptive domain. Segments are whole made up of points, and at the same time are parts making up the square. This very mechanism of definition of identities in cascade entails that the characteristics of elements expressed and/or detectable at one level do affect (and are affected) by the characteristics of other elements expressed and/or detectable at a different level.

A more detailed discussion on how to perform the analysis of impredicative loops, the basis of integrated assessment on multiple levels for complex adaptive holarchic systems, is given in Chapter 6 and Chapter 7.

It is time to end this wrap-up. This discussion about abstract geometric objects is very important for two reasons. First, because it proves that the approach based on complex system theory discussed so far is very general and makes possible to gain new insight even when getting into very old and familiar subjects. Second, because mathematics and geometry are the most important repertoire of metaphors used by humans to build their epistemic tools. So we can learn from the existence of various types of geometry a crucial distinction about different classes of epistemic tools:

* There are epistemic tools - like those provided by classic Eucledian geometry – that consist of a set of definitions of essences out of scale and not becoming in time (e.g. the ideas of Plato). An example would be classic geometric objects (like triangles, squares and circles) which are scale independent. This set of essences and relative types are out of time not only in relation to their relative self-entailment, but also in

relation to their usefulness as epistemic tools. The fact that these "essences" can become irrelevant for the observer is not even considered as possible.

* There are epistemic tools that - like the objects defined in fractal geometry - consist of a set of definitions of essences not becoming in time. However, the identity of these fractal objects (e.g. the Julia set) implies the existence of multiple identities depending on how the observer looks at them. When, perceiving and representing a fractal object on different scales we have to expect the co-existence of different views of it. A set of different views of the Mandelbrot set referring to different levels of resolution (by zooming in and out of the same geometric object) are given in **Fig. 3.9**.
Also in this case, the definition of this set of multiple identities is not related to the relevance (the usefulness) that the knowledge of this set of identities can have for the observer.

* There are epistemic tools - referring to the perception and representation of dissipative learning holarchic systems - that consist of a set of integrated identities which are scaled, since they requires an implicit step of realization to be preserved as types. This explains the existence of the natural set of multiple identities integrated across scale found in biological and human systems (e.g. the different views of a person shown in Fig. 1.1). In these systems, **the stability of higher level holons is based on the validity of the identity of the class of realizations of lower level holons (consistency of the characteristics of the members of equivalence classes of dissipative systems). In turn lower level holons depend, for their structural stability on the stability of the identity of higher level holons.** As soon as, one put in relation this dependency across levels, one is forced to admit that depending on where one select the focal level, the identity of a given level is affected by the set of identities determining boundary conditions (on the top) and structural stability (on the bottom). To make things more challenging:
(1) this integrated set of identities across scale (the different views shown in Fig. 1.1 and Fig. 3.1) **evolves in time.**
(2) the ability to have an updated knowledge of this integrated set of identities across scale which is becoming in time, is crucial for the survival and the success of the observer.

This second observation leads to the concept of complex time - discussed in Chapter 8 - which entails: (1) the need of using various differentials for an integrated representation of the system on different levels (the simultaneous use of non equivalent models) - *at a given point in time.* (2) the continuous updating of these models - *over a certain time horizon.* (3) the continuous updating of the selection of relevant characteristics used to characterize the identity of the individuality of the holarchy, in relation to the changing goals of the observer - *on a larger time horizon.*

3.7.2 Dealing with the special "status" of Holons in science

"Wholes and parts in this absolute sense just do not exist anywhere either in the domain of living organisms or of social organization" Koestler, 1968 - Pag.48

After this long discussion we are left with a huge question: **why, in the first place, do we get "equivalence classes of organized structures" in the ontological realm?** That is, why a lot of natural systems are organized in class of organized structures that share a common set of characteristics?

Two quick answers to this question are:
(1) systems organized in hierarchies and equivalence classes are easier to perceive, represent and to model (to be represented with compression and anticipation). Therefore, systems that base their own stability on the validity of anticipatory models for guiding their action (this is how Rosen calls self-organizing systems generating life - Rosen, 1985, 1991) will be advantaged if operating in a universe made up of facts (events, behaviors) organized over typologies. Actually, there is more. Even if the reality is/were made

up of facts, events and behaviors generated by entities which are both organized in typologies and non organized in typologies (just special individual events), the ability to perceive and represent "essences" by interacting observers developing anticipatory models can only be developed in relation to facts, events and behaviors organized in typologies. In fact, all the rest (special individual entities and behaviors) can only be perceived as noise, since the data-stream could not be interpreted or compressed through mapping (for more see the work of Herbert Simon; 1967).
(2) systems organized in hierarchies are more robust against perturbations. This is true both in relation to the process of their fabrication [the reader can recall here the metaphor of the two clock makers given by Simon (1968): the one assembling clocks using a hierarchical approach – using sub-units in the process of assemblage - was much more resilient to perturbations than the other] and in relation to their operation. Indeed, hierarchical structures operating in parallel on different scales, can modulate their level of redundancy of organized structures and/or functions (buffer against perturbations) which can be diversified in relation to critical functions on different scales, different tasks in different situations (e.g. critically organized across levels and scales). This dramatically helps the building of an effective filter against perturbations across scales.

Therefore, the concepts of holons and holarchies even if still quite esoteric to the general reader, seem to be very useful for dealing with the handling of the epistemological challenge implied by complexity. These concepts entail the existence of *natural multiple-identities* in complex adaptive systems. These multiple identities are generated not only by epistemological plurality (by the unavoidable existence of non-equivalent observers deciding how to perceive and describe the reality using different criteria of categorization and different detectors), but also by *ontological/functional characteristics* of the observed systems, which is organized on different levels of structural organization.

From this perspective here is a lot free information that is carried out by a set of natural identities carried out by of a holon belonging to a biological or human holarchy. This is at the basis of the concept of multi-scale mosaic effect.

A holarchy can be seen as a set of natural identities assigned to its own elements by the peculiar process of self-organization over nested hierarchical elements.

According to the metaphor proposed by Prigogine (1978) dissipative autopoietic holarchies remains alive, using *recipes* (information stored in DNA) *to stabilize physical processes* (the metabolism of organisms carrying that DNA) and *physical processes* (the metabolism of organisms carrying that DNA) to stabilize *recipes* (information stored in DNA) – this chicken-egg loop has to be verified and validated at the global and local scale. The same concept has been called as a process of self-entailment of natural identities by Rosen (1991), which implies a continuous process of "validation" of the set of natural identities assigned to the various holons by this process of autopoiesis. This translates in a continuous validity check on: (a) the information referring to the essence of various elements - at the large scale. This is the mutual information that the various elements carry about each-other, resulting in the ability of keeping coherence and harmony in the interaction of the various elements; (b) the ability of a given process of fabrication informed by a blue-print of being effective in expressing specimens of the same class of organized structure with a good degree of accuracy - at the local level. Therefore a set of multiple identities indicates the past ability to keep a correspondence between: (a) the definition of essence for the class – that is, the large scale validity of the information referring to the characteristics of the equivalence class – the function of the holon in the larger context; and (b) the viability of structural characteristics of the class - that is, the ability of keeping coherence in the characteristics of members of an equivalence class (a set of organized structures sharing the same blue print and process of fabrication) within their admissible associative context.

3.8 Conclusions

In this chapter I tried to convince the reader that there is nothing transcendent about complexity, something, which implies the impossibility of using sound scientific analyses (including reductionist ones). For sure, when dealing with the processes of decision making about sustainability we need more and more rigorous scientific input to deal with the predicament of sustainability faced by humankind in this new millennium.

On the other hand, complexity theory can be used to show clearly the impossibility to deal with decision making related to sustainability in terms of "optimal solutions" determined by applying algorithmic protocols to a closed information space. When dealing with complex behaviors we are forced to look for different causal relationships among events and keep the information space open and expanding. The various causal relations found by scientific analyses will depend not only on intrinsic characteristics of the investigated system, but also on decisions made in the pre-analytical steps of problem structuring. We can only deal with the scientific representation of a nested hierarchical system by using a strategy of stratification (= by using a triadic reading based on the arbitrary selection of a focal space-time differential able to catch one dynamic of interest at the time).

In order to be able to use fruitfully science, when discussing of sustainability, humans should just stop pretending that their processes of decision making are based on the ability to detect the "best" of the possible courses of action, after applying standard protocols based on reductionist analyses. This has never been done in the past, it is not done at the present, and it will never be done in the future. Any "decision" always implies a political dimension, since it is based on imperfect information in relation to a given set of goals. Otherwise it should be called "computation" (R. Fesce; personal communication).

The confusion on this point is often generated by the fact that, in the last decades, in Western countries the "elite" in power, for various reasons, decided to pretend that they were taking decisions based on "substantive rationality". Clearly, this was simply not true, and the clash of reductionist analyses against the issue of sustainability in these decades is clearly exposing such a faulty claim. Complex systems theory can help in explaining the reasons of such a clash. Any definition of priorities among contrasting indicators of performance (reflecting legitimate non-equivalent criteria) is affected by a bias determined by the previous choice of how to describe events (the ideological choices in the pre-analytical step...). That is, such a choice reflects the priorities and the system of values of some agent in the holarchy.

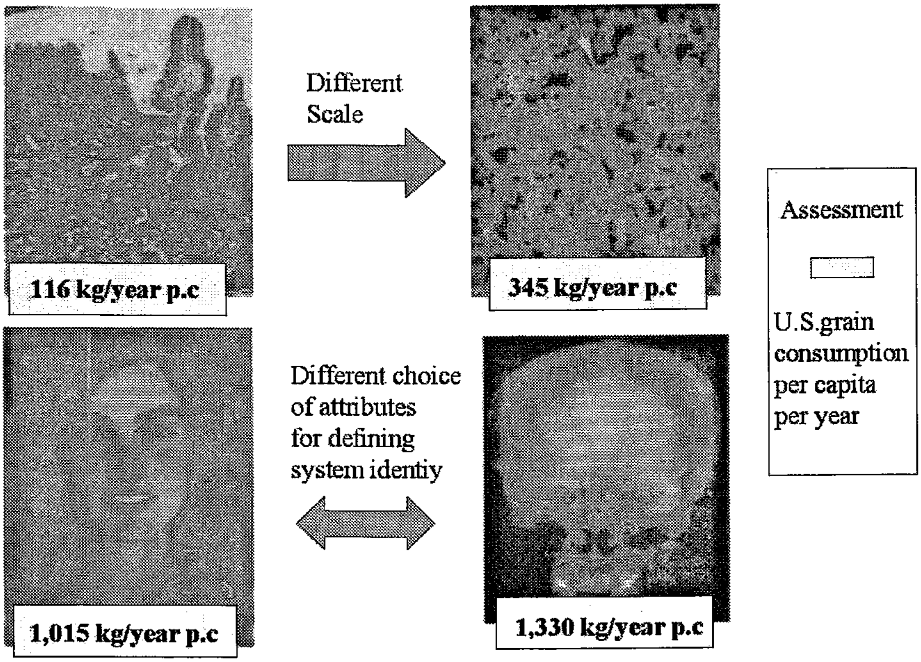
When dealing with the problem of how to do a sound problem structuring, we are in a classic example of a chicken-egg situation. The results of scientific analyses will affect the selection of what is considered relevant (how to do the next pre-analytical step) and what is considered relevant (what has been done in the past pre-analytical step) did affect the results of scientific analyses. This chicken-egg pattern simply explains the co-existence of alternative, non-equivalent and legitimate "structuring" of sustainability problems found in different human groups separated by geographic and social distances. Different groups went through different paths related to how to organize their perception and representation of their interaction with the world. After acknowledging this fact, we cannot expect that scientists operating within a given set of assumptions (e.g. that given by an established disciplinary field) can be able to boost the "quality" of any process of societal problem structuring by forcing their own view on the others. The only viable way out of this epistemological predicament is the establishments of procedures of integrated assessment based on trans-disciplinary analyses and participatory techniques. That is, by establishing an iterative interaction between scientists and stakeholders as implied by the concept of "procedural rationality".

The unavoidable existence of reciprocally irreducible models and the goal of increasing the richness of scientific representation, however, should not be misunderstood as an invitation to avoid decisions on how to compress in a useful way the set of analytical tools used to represent and structure our problems. On the contrary, the innate complexity of sustainability issues requires a rigorous filter on sloppy scientific analyses, poor data, inadequate discussion of basic assumptions.

Reciprocally irreducible models may have significant overlap in their descriptive domains. In this case, the parallel use of non-equivalent models dealing with the same system can be used not only to increase the richness of scientific representation, but also help to uncover inconsistencies in the basic hypotheses of the different models, numerical assessments, and predicted scenarios. An application of this rationale in terms of biophysical analyses of sustainability is discussed in Part 2 and Part 3. In my view, this is a crucial application of complexity in relation to integrated assessment on multiple scales.

Unfortunately, the problem of "how to improve the quality of a decision process" has not been considered as relevant by "hard scientists" in the past. They have been focused only on finding the best solutions. However, the new nature of the problems faced by humankind in this third millennium implies a new challenge for science. This new term of reference is especially important for those working in the field of integrated assessment of human development.

Fig. 3-1 Non-Equivalent descriptive domains = Non-reducible Models



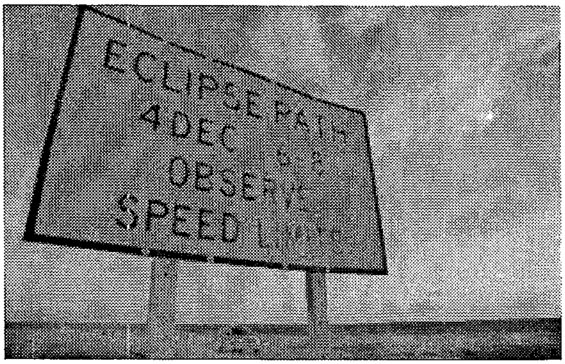


Fig. 3.3a
Guessing eclypses predictive power very high

The quality to be guessed (position in time) can be described by a valid model

Fig. 3.3b
Conventional risk assessment prediction using frequencies to estimate probabilities

Information space known, associative context given, nothing changes in time

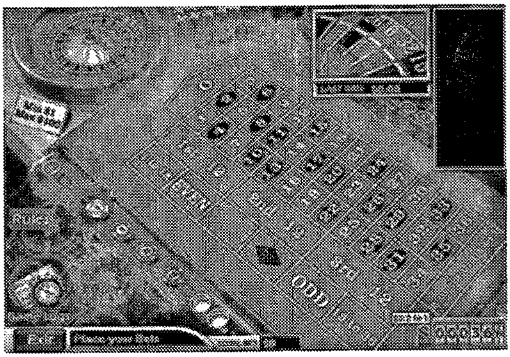
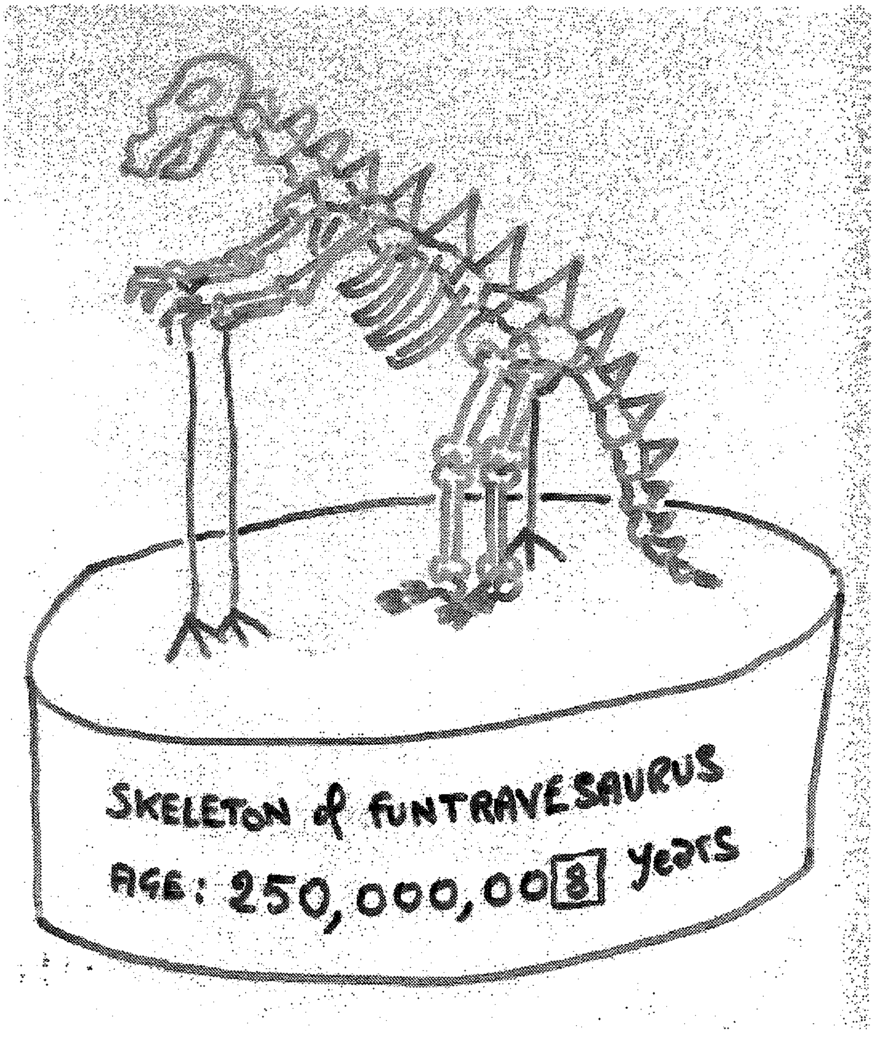


Fig. 3.2 The "true" age of the dinosaur



After Funtowicz and Ravetz, 1990
Drawing by Mario Giampietro

Fig. 3.4a
Prediction facing uncertainty
Image by EUMETSAT

information space known but depending on the time horizon considered changes cannot be predicted with the required accuracy

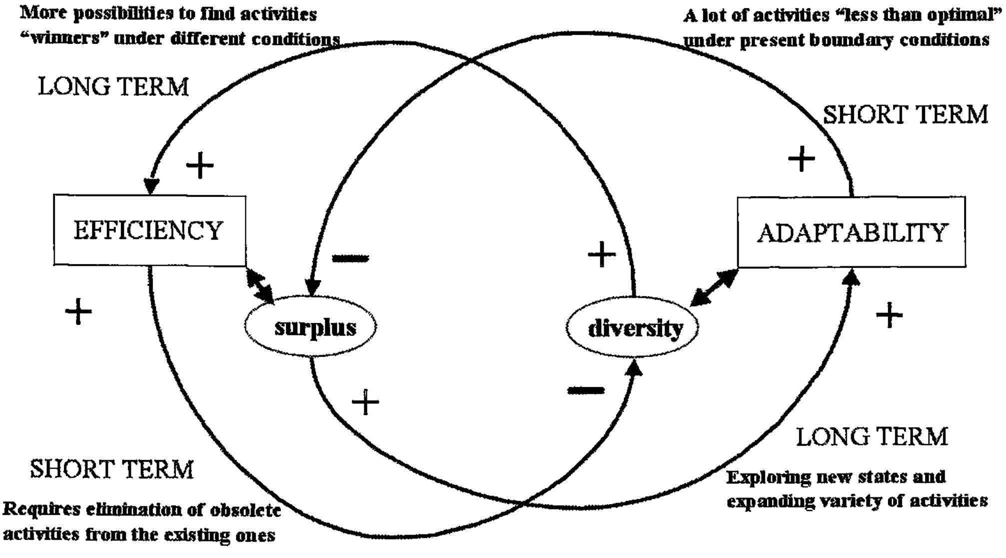
“Butterfly effect” - Nobody can predict the weather in London in 60 days . . .

Fig. 3.4a
Prediction facing IGNORANCE

It is not about being unable of guesstimating probabilities Rather, it is about ignoring the relevant attributes that will matter for us in the future

Alice wondering about the “DRINK-ME” bottle

Fig. 3.7 “Self-entailment” of **Efficiency** and **Adaptability** across scales



Explanation	Associative context	Time Horizon
#4 "Humans must die"	Theoretical discussion on sustainability addressing the "tragedy of change"	LARGE
#3 "Heavy smoker"	Meeting at the Ministry of Health to discuss new taxes on cigarettes	
#2 "Lung cancer"	Meeting in a hospital for treatment	
#1 "No oxygen to the brain"	Emergency Room	SMALL

Fig. 3.5 : multiple scientific explanations for a given event

Event: THE DEATH OF A PARICULAR INDIVIDUAL

EXPLANATION 1 --> "no oxygen supply in the brain"
Space-time scale VERY SMALL *Example*: EMERGENCY ROOM
Implications for action: APPLY KNOWN PROCEDURES
Based on known HOW - past affecting strongly present actions

EXPLANATION 2 --> "affected by lung cancer"
Space-time scale: SMALL *Example*: MEDICAL TREATMENT
Implications for action: KNOWN PROCEDURES & EXPERIMENTATION
Looking for a better HOW - past affecting present, but room for change

EXPLANATION 3 --> "individual was a heavy smoker"
Space-time scale: MEDIUM *Example*: MEETING AT HEALTH MINISTRY
Implications for action: MIX EXPERIENCE AND WANTS INTO POLICY
Considering HOW and WHY - past and "virtual future" affecting present

EXPLANATION 4 --> "humans must die"

Space-time scale: VERY LARGE *Example*: SUSTAINABILITY ISSUES
Implications for action: DEALING WITH THE TRAGEDY OF CHANGE
Considering WHY - "virtual future" (values) affecting present

Fig. 3.6 Multiple causality for a given problem: plague in the village

****

Phase 1: climbing the Holarchy through resonating WHY and BECAUSE

WHY there is the plague in the village?

BECAUSE rats and humans interact too much - **WHY?**

BECAUSE the structure of local Society and Ecosystem were disturbed - **WHY?**

BECAUSE an exogenous model of development was imposed on them - **WHY?**

BECAUSE of lack of empowerment of local communities (changes too much influenced by western models) - **WHY?**

BECAUSE two socio-economic systems with a big difference in their level of development are interacting too much (North/South). This is generating a strong friction on lower level holons (= changes are so fast, that marginal social groups operating on a very small scale have no power of negotiation) -**WHY?**

BECAUSE of historical accidents and different boundary conditions

—> *answer indicating that there is nothing we can do about it*

****

Phase 2: re-descending the Holarchy through resonating HOW and WHEN

HOW/WHEN can we eliminate the problem?

HOW/WHEN - existing difference between North and South can be eliminated? Which one of the two models of development we like most ? Which model is feasible for the entire world? (= compatible with biophysical constraints, compatible with different cultures)? What is the lag time needed for expected changes ?

HOW/WHEN - can we re-establish a fair negotiation among the elements of the holarchy in spite of the large differences between North and South ? (it is possible to empower local communities ? how ? what is the expected lag time to get relevant changes ?)

HOW/WHEN - can we generate room for expressing local aspirations within the constraints given by the evolutionary trajectory of the larger system to which the community belongs ?

HOW/WHEN - the disturbance to the local ecosystem and the local social system can be reduced to acceptable levels? what are the possible options? what are the expected lag time to get results? what is the level of uncertainty on the options?

HOW/WHEN - can we eliminate the rats ? what is the expected lag time? What are the costs? What are possible negative side effects ? If rats are symptoms rather than the real cause, then, there is any negative feed-back in curing symptoms?

Fig. 3.7 “Self-entailment” of **Efficiency** and **Adaptability** across scales

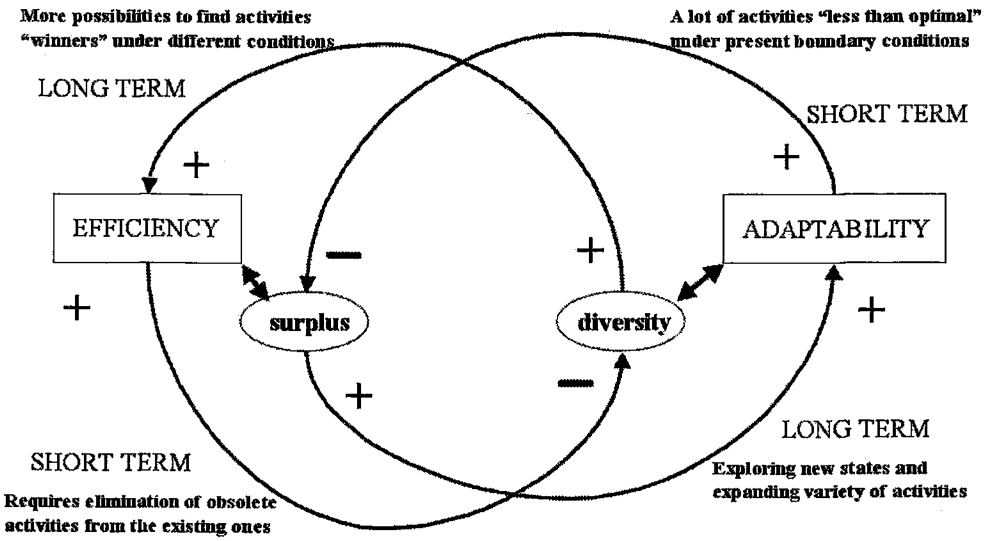
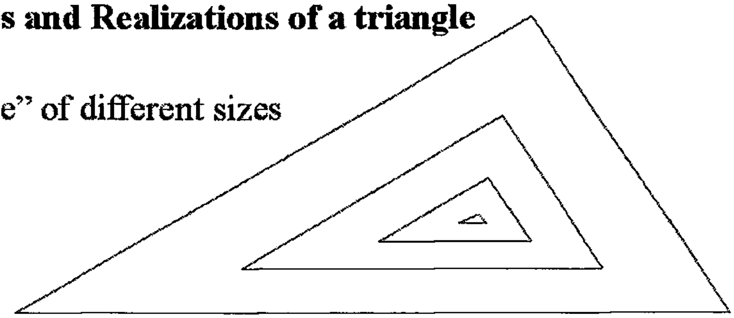


Fig. 3.8 Types and Realizations of a triangle

Same “triangle” of different sizes



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Different realizations of the same triangle at different scales

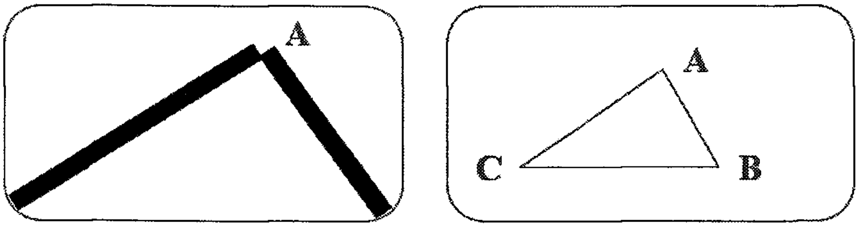
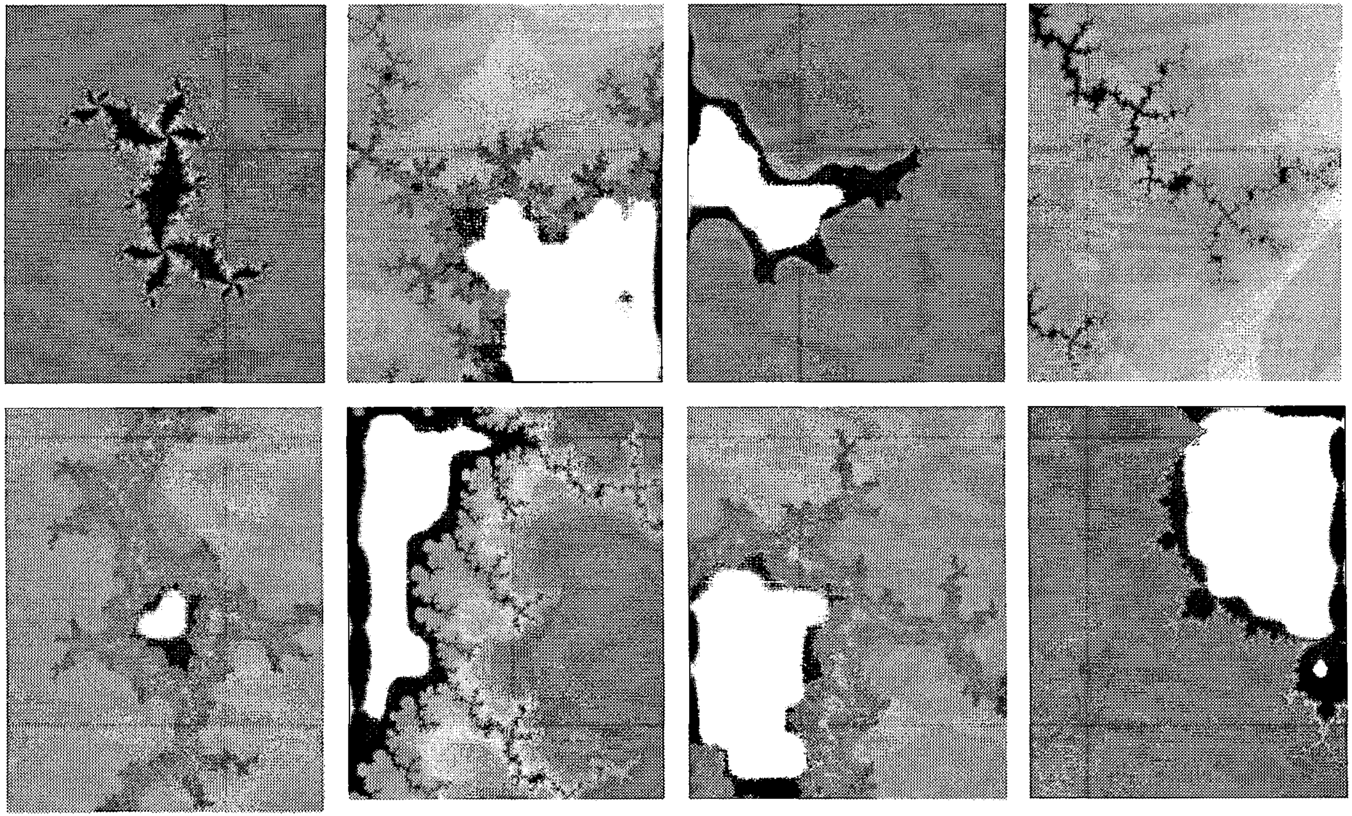


Fig. 3.9 Different identities of the Mandelbrot set

Images from Julia and Mandelbrot Explorer by D. Joyce

http://aleph0.clarku.edu/~djoyce/julia/explorer.html



Chapter 4

The New Terms of Reference for Science for Governance: Post-Normal Science

This chapter addresses the epistemological implications of complexity. In fact, according to what discussed so far hard science when operating within the reductionist paradigm is not able to handle in a useful way the set of relevant perceptions and representations of the reality used by interacting agents, which are operating on different scales. No matter how complicated, individual mathematical models cannot be used to represent changes on a Multi-Scale Multi-Objective performance space. However, to make things worse, it must be acknowledged that there are two relevant dimensions in the discussion about Science for Governance. One related to the DESCRIPTIVE side (e.g. the ability of representing the effect of changes in different descriptive domains by using an appropriate set of indicators), and one related to the NORMATIVE side (e.g. the ability to reach an agreement on the individuation of an advisable policy to be implemented in face of contrasting values and perspectives). As noted in Chapter 2 and Chapter 3, this two dimensions are only apparently separated since due to the epistemological implications discussed so far, even when operating within the descriptive domain, there are a lot of decisions that are heavily affected by power asymmetry. Who decide on how to simplify the complexity of the reality? Who decides whose perceptions are the ones to be included in the analysis? Who chose what is the appropriate language, relevant issues, significant proofs? Put in another way, the very definition of a problem structuring (how to describe the problem) entails a clear bias for the normative step. The reverse is also obviously true (policies are determined by the agreed perceptions of costs, benefits, risks of potential options). In conclusion, the issue of Science for Governance requires also addressing the issue of how to generate procedures which can be used to perform multi-agent negotiations aimed at getting compromise solutions on a multicriteria performance space. The general implications of this fact are discussed in this chapter, whereas technical aspects related to the role of scientists in this process are discussed Chapter 5.

4.1 Introduction

There is a very popular family of questions that very often is used when discussing about sustainability. For example, **Richard Bawden** makes often the point that both: (A) the scientists in charge for developing scenarios, models, indicators and assessments and (B) the stakeholders in charge for the process of decision making should first of all address the following three questions: (1) What constitute an improvement? (2) Who decides? (3) How do we decide about it? **Joe Tainter**'s list of questions includes: (1) sustainability for whom?; (2) for how long?; (3) at which cost? The **group of Ecological Economics in Barcelona** has another variant: (1) what do we want to sustain? (2) who decided that? (3) how fair was the process of decision? Remaining in the field of Ecological Economics, **Dick Noorgard** has been using for more than a decade his own list including a quite similar combination of questions.

These are just a few samples taken from a large and expanding family. In fact, the same semantic message can be found over and over when looking at the work of different groups of sustainability analysts. The meaning of this family of questions is that in order to produce a relevant and useful scientific input (before getting into the step of formalization with models, based on a selection of variables and thresholds/benchmarks on indicators) scientists have to answer first of all a set of **semantic questions** that are difficult to be formalized.

With "semantic" I mean the ability to share the meaning assigned to the same set of terms by the population of users of those terms. Very often the task of checking on the semantic of the problem structuring (validity of assumptions and relevance of the selection of encoding variables) is not included among the activities of competence of reductionist scientists. However, when dealing with legitimate contrasting views, uncertainty and ignorance, multiple identities of systems operating in parallel on different scales, such a "quality check" becomes an additional requirement for the scientists willing to deal with sustainability.

This statement is so obvious to appear trivial. However, looking at the huge amount of literature dealing with optimization of the performance of farming systems or the optimization of techniques of production one can only wander.

IF scientists are operating in a situation in which they cannot specify with absolute certainty what is the output of agriculture (Commodities? Quality food? Clean water? Preservation of desirable landscapes? Preservation of Biodiversity? other outputs for other people?);

THEN it is not possible to calculate any indicator of absolute efficiency (leading to the individuation of the best strategy of maximization) using 'classical' reductionistic approaches.

The message given in the previous chapters is that the concept of multifunctionality in agriculture translates into the impossibility of: (a) representing in a coherent way different typologies of performance (on the descriptive side); and (b) optimizing simultaneously different types of performance (on the normative side). The analyst has to deal with different assessments which requires the use of non-reducible models (= the modeling of different causal mechanisms operating at different scales). The simultaneous use of non-reducible models (referring to logically independent choices of meaningful representations of shared perceptions) imply incommensurability and incomparability of the information used in the integrated assessment.

Talking of quality check, there is another practical impasse found when considering the reliability of scientific inputs to the process of decision making, which is related to the timing imposed on the scientific process by external circumstances.

IF scientists are forced by stakeholders to tackle specific problems at a given point in space and time (according to a given problem structuring), the pace and the identity of the scientific output is imposed on them by the context;

THEN scientists can face a "mission impossible" in delivering high quality output in this situation. Depending on the speed at which the mechanisms generating the problem to be studied are changing in time or the speed at which the relevance of issues change in time, it can become impossible even for smart and dedicated scientists to develop a "sound" scientific understanding.

The question of "how to improve the quality of a decision process which requires a scientific input which is affected by uncertainty" has to be quickly addressed by both scientists and decision makers. In 2002 the Royal Swedish Academy of Sciences gave the Nobel prize in economics to Prof. Kahneman for his pioneering work on integrating insights from psychology into economics "especially concerning human judgment and decision-making under uncertainty, where he has demonstrated how human decisions may systematically depart from those predicted by standard economic theory" as said in the official citation. As noted earlier traditional reductionist theory posits human beings as rational decision-makers. But in reality, according to Kahneman people cannot make rational decisions, because "we see only part of every picture."

When science is used in policy, lay-persons (e.g. judges, journalists, scientists from another field, or just citizens) can often master enough of the methodology to become effective participants in the dialogue. This necessary step will be easier to take if scientists make an effort to package in a more "user friendly" way their scientific input. This effort from the scientists is unavoidable since this extension of the "peer community" is essential for maintaining the quality of the process of decision making when dealing with reflexive complex systems.

It is relation to this goal that Funtowicz and Ravetz developed the new epistemological framework called "Post-Normal Science". The message is clear science in the policy domain has to deal with two crucial aspects *uncertainty* and *value conflict.* The name "post-normal" indicates a difference from the puzzle-solving exercises of normal science, in the Kuhnian sense (Kuhn, 1962). Normal science, which was so successfully extended from the laboratory of core science to the conquest of nature through applied science, is no longer appropriate for the solution of sustainability problems. Sending a few humans for a few hours on the moon is a completely different problem than keeping in harmony and decent conditions in the long run 8 billion humans on this planet. In sustainability problems social, technical and ecological dimensions are so deeply mixed that it is simply impossible to consider them as separated, one at the time, as done within conventional disciplinary fields.

4.2 The Post-Normal Science rationale

4.2.1 The basic idea

To introduce the basic concepts related to Post-Normal Science we use here a presentation given by Funtowics and Ravetz themselves in the introductory book "Chaos for Beginner" (Sardar and Abrams, 1998 - pag. 157 to 159):

> *In pre-chaos days, it was assumed that values were irrelevant to scientific inference, and that all uncertainties could be tamed. That was the "normal science" in which almost all research, engineering and monitoring was done. Of course, there was always a special class of "professional consultants" who used science, but who confronted special uncertainties and value-choices in their work. Such would be senior surgeons and engineers, for whom every case was unique, and whose skill was crucial for the welfare (or even lives) of their clients.*
>
> *But in a world dominated by chaos, we are far removed from the securities of traditional practice. In many important cases, we do not know, and we cannot know, what will happen, or whether our system is safe.* ***We confront issues where facts are uncertain, values in dispute, stakes high and decisions urgent.*** *The only way forward is to recognize that this is where we are at. In the relevant sciences, the style of discourse can no longer be demonstration, as for empirical data to true conclusions. Rather, it must be dialogue, recognizing uncertainty, value-commitments, and a plurality of legitimate perspectives. These are the basis for post-normal science.*
>
> *Post-normal science can be illustrated with a simple diagram* ***(Fig. 4.1):***
> *Close to the zero-point is the old-fashioned "applied science". In the intermediate band is the "professional consultancy" of the surgeon and engineer. But further out, where the issues of safety and science are chaotic and complex, we are in the realm of "post-normal science". That is where the leading scientific challenges of the future will be met.*
>
> *Post-Normal Science (PNS) has the following main characteristics:* ***Quality*** *replaces* ***Truth*** *as the organizing principle.*
>
> *In the heuristic phase space of PNS, no particular partial view can encompass the whole. The task now is no longer one of accredited experts discovering "true facts" for the determination of "good policies". PNS accepts the legitimacy of different perspectives and value-commitment from all the stake-holders around the table on a policy issue. Among those in the dialogue, there will be people with formal accreditation as scientists or experts. They are essential to the process, for their special experience is used in the quality control process of the input. The housewife, the patient, and the investigative journalist, can assess the quality of the scientific results in the context of real-life situation. We call these people an "extended peer community". And they bring "extended facts", including their own personal experience, surveys, and scientific information that otherwise might not have been in the public domain.*
>
> *PNS does not replace good quality traditional science and technology. It reiterates, or feedbacks, their products in an integrating social process. In this way, the scientific system will become a useful input to novel forms of policy-making and governance.*

4.2.2 PNS requires moving from a "substantial" to a "procedural" definition of sustainability

It is often stated that Sustainable Development is something that can only be grasped as a "fuzzy concept" rather than expressed in an exact definition. This is due to the fact that Sustainabe Development is often imagined as a static concept that could be formalized in a definition out of time applicable to any specific situation which does not need external semantic referents to get an operational meaning. In order to avoid this trap, we should move to a definition of sustainability which requires/implies the ability of a society to perform external semantic "quality checks" on the correct use of all adjectives and terms used in the definition. When this ability exists, Sustainable Development can be defined as "**the ability of a given society to move, in an adequate time, between satisficing, adaptable, and viable states**". Such a definition explicitly refers to the fact that sustainable development has to do with a process of social learning (procedural sustainability) rather than to a set of once-and-for-all definable qualities (substantial sustainability). This distinction recalls that made by another Nobel prize winner in Economics Herbert Simon (1976, 1983) about the different types of "rationality" used by humans when deciding in the economic process.

Put in another way, it is not possible to provide a syntactic representation and formulation of sustainability - both in descriptive and normative terms - which can be applied to any practical case. On the contrary, the idea of Post-Normal Science entails the need of using always a semantic check to arrive to a shared meaning among stakeholders about how to apply general principles to a specific situation (when deciding in a given point in space and time).

A procedural sustainability implies the following points:

(1) governance and adequate understanding of present predicaments - as indicated by the expression: "the ability to move, in an adequate time,";

(2) recognition of legitimate contrasting perspective related to the existence of different identities for stakeholders. This implies: (i) the need of an adequate integrated representation reflecting different views (quality check on the descriptive side) and (ii) an istitutional room for negotiation (quality check on the normative side) - as indicated by the expression: "satisficing";

(3) recognition of the need of adopting an evolutionary view of the events we are describing (strategic assessment over possible scenarios). This implies the unavoidable existence of uncertainty and indeterminacy in the resulting representation and forecasting of future events. When discussing of adaptability (the usefulness of a larger option space in the future) reductionistic analyses based on "ceteris paribus" hypothesis have little to say - as indicated by the expression: "adaptable";

(4) recognition of the need of relying on sound reductionistic analyses to verify within different scientific disciplines the "viability" of possible solutions in terms of technical, economic, ecological and social constraints - as indicated by the expression: "viable states".

This definition of sustainable development implies a paradigm shift in the process which is used to generate and organize the scientific information for decision making and which can be related to the very concept of Post-Normal Science.

Introducing the Peircean semiotic triad

The validity of models, indicators, criteria and data used in a process of decision making can only be checked against their usefulness for a particular social group – at a given point in space and time - in guiding action. This implies viewing the process of generation of knowledge as an iterative process occurring across several space-time windows:

(i) one at which it is possible to define a validity for the modeling relation;

(ii) one at which it is possible to generate experimental datasets, through measurement schemes;

(iii) one at which the knowledge system - within which the scientist is operating – is able to define it-self in relation to: (1) goals; (2) perceived results of current interaction with the context; and (3) experience accumulated in the past.

An overview of such an iterative process across scales is given in **Fig. 4.2** using the Peircean semiotic triad as a reference framework (Peirce, 1935). The cyclic process of resonance between the three steps: Pragmatics - Semantic - Syntax is seen as a process of iteration which goes in parallel in two opposite directions (double asymmetry). The two loops operating in opposite directions on different space-time windows are shown in **Fig. 4.2.** The reader can recall here the need of using two non-equivalent external referents in the iterative process of convergence of shared meaning about identities in holarchies (or words in the formation of languages) in Chapter 2 (Fig. 2.4).

Starting with the smaller one (the clock-wise one in the inside of the scheme), out of the existing reservoir of known models, which have been validated in the past, the box called 'Syntax' provides the tools needed to generate numerical assessments (reflecting the identities assigned to relevant systems to be modeled) - REPRESENT. This makes possible to recognize patterns and organized structures as types and members of an equivalence class. This is what provides a set of descriptive tools that makes possible to run models in order to generate useful predictions. In order to get into the APPLY step, however, we have first to go through a 'Semantic' check which implies defining the validity of the selected models (from Syntax) in relation to the given goal and context. Gathering data is an operation belonging to the 'Pragmatics' domain and implies a direct interaction with the natural world. In this step the system of knowledge is gathering information about the world organizing the perceptions through the existing set of known epistemic tools. The result of this interaction is the experimental data set. TRANSDUCE here means that the system of knowledge is internalizing the information obtained when interacting with the Natural World according to the two steps REPRESENT and APPLY.

The larger, counter-clock wise loop is related to events occurring on a larger scale. Starting from the same box 'Syntax', we have this time that the operation TRANSDUCE implies generating predictions about expected behaviors on the basis of the scientific knowledge available to guide action. The interaction with the natural world (belonging to 'Pragmatics') is based on the APPLY of these scientific predictions for guiding actions in relation to the existing set of goals. At this point a 'Semantic' check is needed to assess whether or not the scientific input was useful for guiding such interaction.

If the perceived results of the interaction with the natural world are consistent with the existing set of goals, the scientific input is judged adequate. In this case, the system of knowledge (which is the result of a converging process over the diagram) confirms such a system of models as one of the tools in the repertoire of validated models (to be applied in the same situation) and will rely again on it for future decisions - REPRESENT. If, on the contrary, important gaps are found between the qualities that are perceived to be relevant for achieving the existing set of goals and the set of qualities mapped by the chosen set of models (the scientific input failed in helping the achievement of goals) then the Semantic check declares a particular system of models obsolete implying an updating in the step REPRESENT.

It is obvious that the diagram described in Fig. 4.2 is no longer describing only the process of making models. Rather it addresses also the effects that the use of models induce on those using the validated knowledge in the interaction with their context. This is why scientists have to be told whether or not the scientific input they are generating is relevant. In the diagram, in fact, there are several scales and several actors supposed to generate the emergent property of the whole. There are individual scientists developing competing models within individual scientific fields. There are groups of scientists expanding and adjusting the identity of competing scientific fields. Then, the various stakeholders and social actors of the society interact in different ways to legitimize the use of science within the processes of decision making. According to this frame, we should view any system of modeling just as a component of a larger system of knowledge which is in charge for operating an endless process of convergence and harmonization of heterogeneous flows of information referring to: (a) a common experience (given past); (b) a set of different and legitimate goals (possible virtual futures); which must always be linked to an evaluation of (c) present performance in relation to the existing goals and the context. Such a continuous filtering of information across scales and in relation to the need of continuously updating of the identity of the various components of the society implies again a fuzzy chicken-egg type of process (impredicative loop) rather than a clear-cut, "once and for all" describable process. Scientists are operating within an existing system of knowledge and because of that they are affected in their activity by its identity and are affecting with their activity its identity.

4.2.3 A semiotic reading of the PNS diagram

The problem of governance of human systems can be related to the necessity of selecting components of the holarchy which have to (or should be) sacrificed for the common good. Thanks to the duality of the nature of holons, components to be sacrificed not necessarily have to be real individual organized structures. Holons to be sacrificed can be jobs, firms, traditions, values, cities. In other cases, however, the sacrifice is tougher and it can entail destroying resources and in some cases even individual humans (e.g. in the case of war). On the other hand, this process of elimination and turn-over is related to life. Within adaptive holarchies components have to be continuously eliminated (turn-over on the lower level holons within larger holon) to guarantee the stability of the whole. The term governance refers to human system, which can be characterized as reflexive systems. This means that "human will" does affect the pattern of selective elimination of holons within a human holarchy, which therefore is no longer determined only by external selection and pure chance. Evolution, progress and more in general the unavoidable process of "becoming" imply for human systems the necessity of continuously facing the "tragedy of change" (a term coined for Post-Normal Science by Funtowicz and Ravetz). Even the most innocent and laudable intention framed within a given problem structuring – e.g. the "elimination of poverty" - will end up by eliminating from our universe of discourse identities relevant within a non-equivalent problem structuring – e.g. eliminating poverty entails the elimination of the various identities taken by the poor. Holons and holarchies can survive only because of their innate tension (a real Ying and Yang tension) between the need of preserving identities and the need of eliminating identities. This means that conflicting interests and conflicting goals are unavoidable within holarchic systems. The search for win-win solution valid on different time scales and in relation to the universe of the agents is just a myth. The problem is therefore, how to handle these tensions within systems that express awareness and reflexivity in parallel at different hierarchical levels (e.g. individual human beings, households, communities, regions, countries, international bodies).

The holarchic nature of human societies implies two major problems related to their capability of representing themselves and of individuating rational choices. Robert Rosen, an important pioneer in the applications of complex system thinking to the issue of sustainability and governance – can be quoted here:

(1) Life is associated to the interaction of non-equivalent observers. Legitimate and contrasting perceptions and representations of the sustainability predicament are not only unavoidable but also essential to the survival of living systems.

"*The most unassailable principle of theoretical physics asserts that the laws of nature must be the same for all the observers. But the principle requires that the observers in question should be otherwise identical. If the observers themselves are not identical; i.e. if they are inequivalent or equipped with different sets of meters, there is no reason to expect that their descriptions of the universe will be the same, and hence that we can transform from any such description to any other. In such a case, the observers' descriptions of the universe will* ***bifurcate*** *from each other (which is only another way of saying that their descriptions will be logically independent; i.e. not related by any transformation rule of linkage). In an important sense, biology* ***depends*** *in an essential way on the proliferation of inequivalent observers; it can indeed be regarded as* ***nothing other than*** *the study of the populations of inequivalent observers and their interactions*". (Rosen, 1985 p. 319).

This passage makes a point related to biology, which, obviously would result much stronger when related to the status of sciences dealing with the behaviour of social systems.

(2) The sustainability of a holarchy is an emergent property of the whole that cannot be perceived or represented from within. *The sustainability predicament cannot be fully perceived by any of the components of social systems.*

"*The external world acts both to impose stresses upon a culture and to judge the appropriateness of the response of the culture as a whole. The external world thus sits in the position of an outside observer. Since selection acts on the culture as a whole, there is only an indirect effect of selection on the members of the culture and hence* *on their internal models of the culture. This is indeed, a characteristic property of aggregates like multi-cellular organisms or societies; namely, that selection acts not directly on the individual members of the aggregate, but on the aggregate as a whole. We have seen that the behaviors of the aggregate as a whole are not clearly recognizable by any of the members of the aggregate and therefore none of the internal models of the aggregate can comprehend the manner in which selection is operating. Stated another way, the members of a culture respond primarily to each other, and to each other's models, rather than to the stresses imposed on the culture by the external world. They cannot judge the behaviour of the culture in terms of appropriateness at all, but only in terms of deviation from their internal models* (Rosen, 1975; p. 145)".

These two passages beautifully resume what said before about the impossibility to define in absolute terms the optimal way to sustainability. It is impossible to define in an objective way what is the right mix between efficiency and adaptability or - expressed in a non-equivalent way - between the respecting or the breaking of the rules (recall here the example of the mutations on DNA, which are "errors" when considered at one scale and "useful functions" when considered at another scale). Within the same holarchy, the very fuzzy nature of holons, which are vertically coupled to form emergent whole, implies that there is a hierarchical level at which humans express awareness (= individual humans being), which does not coincide with the hierarchical level at which they express systems of knowledge (= culture which is a property of societal groups). In turn, none of these levels coincides with the hierarchical level at which the mechanisms generating biophysical constraints – the mechanisms relevant in relation to sustainable development – are operating (= e.g. global stability for ecological, economic and social processes).

Put in another way, the growing integration of various human activities over the planet requires a growing ability to represent, link, assess, and govern, which in turn requires an increased harmonization of behaviors expressed by different actors/holons (national governments, international bodies, individual human beings, communities, households). This translates into the need of developing non-equivalent meaningful perceptions/representations of processes occurring in parallel on different space-time scales.

To make things more difficult, these integrated representations must result useful in relation to the existing diversity of systems of knowledge. This is where, in these decades, the drive given by reductionist science to technical progress got into trouble. As remarked by Sarewitz, (1996, pag. 10), "*The laws of nature do not ordain public good (or its opposite), which can only be created when knowledge from the laboratory interact with the cultural, economic, and political institutions of society. Modern science and technology is therefore founded upon a leap of faith: that the transition from the controlled, idealized, context-independent world of the laboratory to the intricate, context-saturated world of society will create social benefit.*"

The global crisis of governance can be associated to the fact that science and technology are no longer able to provide all the useful inputs required to handle in a coordinated way: (i) the process of economic expansion (which is represented and regulated with a defined set of tools - economic analyses - that worked well only for a part of humankind in the past); (ii) the discussion on how to deal with the tragedy of change occurring within fast becoming cultural identities both in developed and developing countries; and (iii) the challenge of handling the growing impact of human activity on ecological processes (which, at the moment, is not understood and represented well enough, especially for large scale processes such as those determining the stability of entire ecosystems and/or the stability of the entire biosphere).

At this point it can be useful to go again over the diagram of Post-Normal Science given in **Fig. 4.1** trying, this time, to frame the basic message using the semiotic triad of Peirce. The original diagram proposed by Funtowicz and Ravetz is a very elegant and powerful descriptive tool able to catch and communicate to a general audience, in an extremely compressed way, the most relevant features of the challenges implied by PNS. Any attempt to present a different version of it implies certainly the risk of loosing much of its original power of compression. However, exploring more in detail the insights given by this diagram can represent a useful complementing input. The complementing diagram (certainly more crowded of information and much less self-explanatory) is presented in **Fig. 4.3**.

- **The horizontal axis**, which is called "uncertainty" in figure **Fig. 4.1**, is the axis which refers to the dimension REPRESENT of the triad. This has to do with the **descriptive role of scientific input (e.g. Multi-Scale Integrated Analysis)**. Moving from the origin toward right means changing the size and the nature of the descriptive domain used to represent the event. The label SIMPLE on the left side of the axis indicate that in this area we are dealing with only one relevant space-time differential to be considered when representing the main dynamics of interest. This also implies that we can describe the behavior of interest without being forced to use simultaneously non-reducible non-equivalent descriptions (the model adopted is not affected by significant bifurcations). In this situation, we can ignore the problems generated by: (i) the unavoidable indeterminacy in the representation of initiating conditions of the natural system represented (the triadic filtering is working properly); and (ii) the unavoidable uncertainty in any predicted behavior of the natural system modeled (the assumptions of a quasi-steady state description under the ceteris paribus hypothesis are holding). Simple models works well for handling simple situations (e.g. the building of an elevators). Moving to the right means a progressive increase of epistemological problems: the relevant qualities to be considered in the problem structuring require the consideration of non-equivalent perceptions of the reality and therefore the relative models can be represented only by adopting different space-time windows and/or using non-equivalent descriptive domains (e.g. maximization of economic profit and minimization of impact on ecological integrity, or in a medical situation deciding between contrasting indications about costs, risks, and expected benefits, both in the short and long term). The more we move to the right the more we need to use a COMPLEX representation of the reality. This implies considering a richer mosaic of observers/observed complexes. System's behavior must be based on the integrated use of various relevant identities of the system of interest that in turn translate into the use of several space-time differentials, non-equivalent descriptions e non-reducible models. An unavoidable consequence of this fact, is that the levels of indeterminacy and uncertainty in the prediction of causality (e.g. between the implementation f a policy and the expected effect) become so high that it requires the parallel use of different typologies of external semantic checks. Recalling the discussion in Chapter 3 uncertainty can be due to two different mechanism: (i) lack of inferential systems which are able to simulate causal relations among observable qualities on the given descriptive domain (= uncertainty due to indeterminacy); (ii) lack of knowledge about relevant qualities of the system (already present but ignored or which will appear as emergent property in the future) that should be included in one of the multiple identities used to represent the system in the integrated analysis (= uncertainty due to ignorance).

- **The vertical axis**, which is called "decision stakes" in figure **Fig. 4.1**, is the axis which refers to the dimension "APPLY" of the triad. This has to do with the **normative aspect (e.g. Multi-Criteria Evaluation)** of the process of decision making. Moving from the origin toward upper values means changing the scale of the domain of action. The label DEMAND OF QUALITY CHECK which is changing between LOW (close to the origin) and HIGH (up in the axis) indicates the obvious fact that a change in the scale of the domain of action requires a different quality in the input coming from the step REPRESENT. The scientific input has to be adequate both in: (1) **extent** (covering the larger space-time window of relevant patterns to be considered). That is, large scale scenarios must forget about the ceteris paribus hypothesis and look at key characteristics of evolutionary trajectories; and (2) **resolution** (being able to consider all lower-level details which are relevant for the stability of lower level holons). When operating at a low "demand for quality check" – close to the origin of the axis - we are dealing with very well established relational functions performed by very robust types within very robust associative context.

When dealing with the description of the behavior of reflexive systems (humans) we face additional problems, due to the unavoidable presence of: (1) various systems of knowledge found among social actors, which entail the existence of different and logically independent definition of the set of relevant qualities to be represented - reflecting past experiences and different goals. and (2) high speed of becoming of the social system under analysis which is generating the relevant behavior of interest (human systems tend to co-evolve fast with their context). This implies the need of establishing an institutional activity of "quality control" and "patching and restructuring" of the models and indicators used in the process of decision making to perform the step REPRESENT.

As noted earlier the fast process of becoming is an unavoidable feature of human societies. Every time we consider to represent their behavior on a large space-time domain and a domain of action quite large we have to expect that, on the upper part of the holarchy, larger holons cannot be assumed to be in steady-state. That is, the ceteris paribus assumption, becomes no longer a reliable assumption to make. Rather they should be expected to be in a transitional situation in a continuous movements over their evolutionary trajectory (and therefore impossible to predict with simple inferential systems).

- **Area within the two axis**, in the graph of the PNS presented in **Fig. 4.2** there is a third diagonal axis required to complete the semiotic triad of Peirce – an axis related to TRANSDUCE - which wants to indicate the peculiar and circular (egg-chicken) relation between the activities related to Represent (descriptive side) and Apply (normative side). Various arrows starting from the two axis and clashing on the diagonal axis indicate the different direction of influence that the various activities of the semiotic triad have on each other over different areas of the diagram:

--> *Applied Science* - when simple descriptive domains are an acceptable input for guiding action (e.g. specific technical problems, studying elementary properties of human artifacts – the design and the safety of a bridge), we are in the area of applied science. In this case: (i) the qualities to be considered as relevant for the step REPRESENT are given (that is reflected in a selection "by default" of criteria and variables to be used to represent the problem – a standard type – bridge – operating in its expected associative context);

(ii) the weight to be given to the various indicators of performance is also assumed to be given to the scientist by society (e.g. design and action must optimize efficiency or minimize costs).

All other significant dimensions of the problem have been taken care by the scientific framing of the problem (problem structuring) given to the engineer (in the case of the bridge). Reductionist models are the basis for the step representation in this area. They imply the generation of a clear input for guiding action within well specified and know associative contexts (e.g. the application of protocols for building and maintaining bridges). Under these conditions, the specific identity of the scientist providing such an input to the process is really not relevant. Her/his personal values cannot affect the identity of the representation input in a relevant manner. Therefore any information about the cultural or political identity of the scientist in charge for delivering the descriptive input to the process of decision making is not considered relevant.

--> *Professional Consultancy* - when simple descriptive domains are no longer fully satisficing for guiding actions (e.g. when dealing with problems requiring the consideration of several non-commensurable criteria), we are in the area of professional consultancy. In this cases the step represent is based on the use of metaphors (applications of models verified and applied before, but that in the case in analysis can not be backed up by an experimental scheme). This is always the case when dealing with the specific performance of a specific natural system at a particular point in space and time and that implies important stakes for the decision maker (e.g. an advice asked to a surgeon about a delicate medical situation). This situation implies the mixing of: (i) a generic input for guiding actions (expressed in terms of metaphors or principles to be used in a defined class of situations) derived from existing and codified knowledge; and (ii) a "tailoring" of such a useful information, which is asked to the expert for dealing with the specific case. When asked to put her/his head in the mouth of a tiger (when facing very high stakes) the tamer needs: (i) a basic knowledge about tigers behavior (retrievable from books); PLUS (ii) experience and direct knowledge about past interaction with that particular specimen of tiger; PLUS (iii) a guesstimate based on gut-intuitions (reading/feeling) about what this particular specimen of tiger will do at this particular point in space and time. Obviously, in these cases, the particular identity of the scientist providing the input about a meaningful perception/representation is no longer irrelevant for the stakeholder getting advice from the scientist. If you put a crucial decision about your life in the hands of a surgeon, you want to know about its characters and special aspects as a person.

In the field of "professional consultancy" both the individual natural system to be modeled (belonging

to an equivalence class associated to the type) and the individual modeler (belonging to an equivalence class of scientists – medical doctors) are considered "special" since the particular combination of the two can make an important difference. In this case, value judgments are essential on both sides: when "perceiving/representing" – on the descriptive side - (since the scientist will apply the available metaphors according to her/his particular perception of the specific situation) and when "applying" – on the normative side - (since the decision maker will select the scientist to hire, according to various criteria which are not only related to the nature of the specific problem to be solved). Moreover, the decision maker can decide not to follow the advice received by the consultant if such an advice is not convincing enough. In this case, the selection of the particular scientist to be used in the step "represent" will be based on her/his perceived ability to: (i) use a set of incommensurable criteria (the set of qualities to be considered as relevant for the step REPRESENT) which reflects those relevant also for the decision maker; and (ii) tailor her/his profile of weighting factors over incommensurable criteria (the final advice about what to do) according to the ideas expressed by the decision maker that hired her/him as a consultant.
–> *Post-Normal Science* - when several descriptive domains are required to consider various non-equivalent causal relations and the domain of action includes the unavoidable interaction of agents adopting heterogeneous systems of knowledge, we no longer can expect to have a "unique objective input" about how to perceive and represent the problem that can be used as basis for structuring the process of decision making. As noted earlier, the unformalizable tension between compression and relevance (on the descriptive side) as well as between adaptability and efficiency (on the normative side) make virtually impossible to handle in a rational (syntactic) way the search for the best course of action in human systems. Actually, if we move too much to the upper-right corner of the graph we can arrive to an area in which the whole system is evolving by continuously generating emergent properties. This frontier area escapes any possible definition of "improvement" or "worsening". An useful problem structuring is simply not possible, because: (1) on the descriptive side (horizontal axis) we cannot have a prediction and therefore an useful understanding of possible future scenarios. This prevents the development of adequate (relevant and therefore useful) descriptive domains. Ignorance means that we do not know and cannot know about future emergent properties. We cannot know what new indicators referring to new relevant qualities have to be used now to decide what to do (Fig. 3.4b). In last analysis we lack of the ability of assigning useful identities to the future organized structures and relational functions (holons) of becoming systems. Obviously, this makes "unthinkable" any attempt to represent our future perceptions of them. (2) on the normative side we do not have any possibility of reaching an agreement about what should be a shared meaning of perceptions of future events in relation to the future cultural identities which will be associated to distinct systems of knowledge. Not only we lack of any input on the descriptive side, but also we lack of crucial inputs (goals, wants, fears of future generations) on the normative side. In conclusion, within this area – when considering a very large scale and evolutionary processes – things just happen out of human control. It is important to note - as remarked by Rosen in the previous quote - that any qualification of scenarios in the very long term, is unavoidably affected by our limited ability to represent now the future perceptions that humans will have of their reality then. Present generation must necessarily base its reasoning on an image biased by perspectives belonging to lower hierarchical level perceptions (the various social groups expressing now their systems of knowledge within the existing holarchy).

The area called Post-Normal Science is living dangerously on the border with the area of professional consultancy on one side and on the area of impossible handling of an agreed upon representation of future perceptions. In this edge new "meanings" are being generated within human systems of knowledge but still these new meanings have not been fully internalized by existing cultures. In this part of the plan the complexity of description to be used in the process of decision making is so high, that it implies a continuous process of learning (= patching and updating of the systems of knowledge used) in REPRESENT through the iterative process shown in **Fig. 4.2.** The scale at which humans try to keep coherence between perceptions and representations is so large that social holarchies at that level are becoming something else at a speed that prevent the consolidation of agreed upon validated and established common knowledge of the whole. The continuous creation of meaning can be interpreted as the ability to find new combination of identities for the definition of a shared problem structuring that "make sense" (= results useful) in relation to the successful interaction of non-equivalent agents.

Clearly, when dealing with the semiotic triad at this level the only way to verify the efficacy of any knowledge system is by checking its usefulness in guiding actions. The semiotic triad can be seen as a process of social learning aimed at tuning the patching and the updating of the various systems of knowledge to the process of co-evolution of different social-systems with their contexts. What is important here is to be aware that the context for a knowledge system is never "a biophysical environment" (i.e. ecological process), but rather the activities controlled by other systems of knowledge within a given biophysical environment. This is why nobody can see the whole. The demand for adaptability implies that, in this process of becoming, social systems should be able to increase their cultural diversity (to avoid hegemonization of one system of knowledge on the others). This can only be obtained by sharing the stress generated by the tragedy of change. That is, the preservation of cultural identity requires an institutionalized process of negotiation among different social holons, in order to guarantee the diversity of systems of knowledge from massive extinctions (Matutinovic, 2000). Put in another way, this view implies that conflicts are important, since they are the sign of existence of diversity. This is a must for guaranteeing the sustainability of human development in the long run.

In this view, a full reliance on "rational choices" (e.g. a maximizing of the performance according to a representation of benefits supposed to be "substantive"- since it reflects existing perceptions of a given social group in power) cannot be a wise choice. Humans can and should decide to go for "sub-optimal solutions" (even when facing an easy definition of local optimum) just to preserve diversity and to avoid the collapse of cultural diversity. This is what is done, for example, when allocating resources on marginalized social groups.

On the other hand, this rule does not require always an express enforcement, since human systems already go for "sub-optimal solutions". They do so, because they do not have the time or the means to look for rational choices (= maximization of her/his own utility under a given set of assumptions and institutions), or rather simply because they like "sub-optimal solutions" - when standing for our own values, going for romantic escapades, drinking with friends, fighting for justice, smoking, doing "the right thing right now", gambling. From this perspective it is possible to see that "passional choices" (as opposed to rational choices) are perfectly defendable in scientific terms. Ethics and rebellion, vices and deep values affecting human choices, in fact, play a crucial role in keeping alive the process of evolution of social systems and this tension between mechanisms keeping order and generating disorder can be easily related to the unavoidable uncertainty related to the process of evolution of becoming systems. Errors and mutations so dangerous at one level are needed and useful at a higher one. Long term sustainability of reflexive systems requires that agents decide using a mix of rational and passional choices. In fact, in the long term and in relation to the whole complex of interacting non-equivalent observers, at any given point in space and time (within a given descriptive domain) not only it is impossible to select optimal solutions on a pure rational basis, but also it is impossible to select "suboptimal solutions".

In conclusion, when dealing with Post-Normal Science: (i) the right set of relevant criteria to be used to represent a problem is not known or knowable "a priori". A satisficing set of relevant criteria can only be obtained as the result of the negotiation among various stakeholders which are collectively dealing with the stress implied by the tragedy of change; (ii) the weight to be given to incommensurable and contrasting criteria of performance cannot be defined once-and-for-all after considering existing knowledge system(s) and applicable over the planet to different location specific situations. (iii) it is impossible to have an objective definition of "the best thing to do" not even at a particular point in space and time. After all, the very choice of assigning different weights to non-reducible indicators of performance in a specific situation for a specific social element is equivalent to a choice of "the best" sub-optimal solution, which by definition is a non-sense.

4.3 "Quality" replacing "Truth" - science, sustainability and decision making

In the last two centuries, "hard sciences" have been focusing only on those situations that were easy to represent and to model with success. Problems requiring too many relevant variables and non-equivalent descriptions were considered non interesting (or even non scientifically relevant) since they were not easy to compress through "heroic simplifications". On the other hand, in these decades the fast process of industrialization and globalization is posing new types of challenge to the process of governance of human development. Under these circumstances a "curiosity driven" science (= picking up only those topics that happen to be tractable) is no longer useful for the stabilization of current systems of control. The sustainability predicament is asking scientists to fill, as fast as possible, an increasing 'knowledge deficit' generated by a lack of useful representation tools and useful predictive models to be used in the process of decision making. However, when framing the problem in this way, we have to notice that these epistemic tools required to perceive and represent problems and predictive models to assess potential solutions should include in their descriptive domain the very same human holons which are making the representation and those which are making the decisions. This implies a short-cut in the semiotic triad (something which can be called "epistemological hyper-complexity").

As observed in the introduction, at this regard, it is interesting to note that up to know the official academic world has tried to ignore as much as possible this problem trying to stick to the "business as usual" paradigm. Paradoxically, it is on the side of the decision makers (and even more on the side where the other stakeholders are operating) that the uneasiness for this situation is getting more and more evident. Governments and non-governmental organizations are the actors more active in putting on the agenda the discussion on new paradigms to be used in the perception and representation of the sustainability predicament. This growing concern of decision makers about the loss of confidence in the public opinion in the conventional academic establishment has been generated by repeated situations in which the general public refused to accept as "reliable" and "verified" the various "scientific truths" proposed by the academic world. For example, in many European countries the public opinion openly disbelieved the proclaimed safety of nuclear energy after the Chernobyl accident, or the proclaimed safety of eating meat after the "mad cow" disease. This led to a disbelief in the safety of eating food produced with genetically engineered organisms, even in absence of major crisis so far.

This is a crucial point for our discussion, since a loss of confidence in the "truth" individuated and certified by scientists can have very dangerous consequences in terms of loss of legitimization of the system of control operating within a social contract. This is another basic idea put forward by Funtowicz and Ravetz in relation to the concept of Post-Normal Science. In these days of big changes and transitions, traditional science is no longer able to play the same role it used to play in the last two centuries in the legitimization (linked to social stability) of systems of control in western societies. This basic idea is illustrated in **Fig. 4.4**.

The organization of the state in Europe before the scientific revolution of 17th century was based on a system of control (a hierarchy of power) which was getting its legitimization directly from **God** (**Fig. 4.4a**). This "absolute" source of legitimization was then reflected into the figure of the King that was the entity in charge for performing semantic checks ("quality control") over the validity of the specific standardized societal system of knowledge adopted in the given society. Clearly, in his job the King was using a certain number of advisors, which were selecting, storing and refining better representative tools whenever this activity was convenient for the interests of the King. At the beginning of modern states the process of democratization and the reduction of the influence of religions in determining the legitimization of systems of control (hierarchy of power) implied that in many western states a different mechanism of legitimization was needed (**Fig. 4.4b**).

Truth (linked to the assumed possibility of relying on a "unique", "verified", and "reliable" standardized system of knowledge – substantive rationality) was assumed to lead directly to the possibility of acting for the common good of the community. Governance therefore was assumed to be linked to the activity of "doing the right choices according to such a truth". In this way, it was still possible to obtain the legitimization of the system of control (linked to the organization of the state) according to the set of relations indicated in **Fig. 4.4b**. It should be noted that the birth of these western modern states coincided with an evolutionary phase of fast expansion (colonization, industrial revolution) and therefore with the need of massive investments in efficiency which were continuously paying-back. The fact that western countries were in an evolutionary phase of rapid expansion implied a demand for a large degree of hegemonization of the winning patterns. Therefore, the underlying idea that sound governance could be obtained relying only on just one unique standardized system of knowledge was not particularly disturbing.

Clearly, in this way it was assumed that a "quality control" (= semantic check on the efficacy - in relation to the existing set of goals - of the existing repertoire of representation and normative tools) on the validity of such unique and generalized system of knowledge was actually possible. Obviously this quite bold assumption can only be held for a short period of time, that is only: (i) during an evolutionary phase of rapid expansion; (ii) for societies characterized by a quite homogeneous distribution of cultural identities and (iii) for societies operating on a relatively small space scale (western countries during the industrial revolution). When dealing with issues like sustainability on a global scale this assumption is simply no longer working.

This is where the need of a paradigm shift enters in play. The call of Post-Normal Science for replacing "Truth" with "Quality" means moving from substantial rationality [forgetting about the validity of the two assumptions: (i) the existence of solutions and accessible states for human holarchies which are optimal in "absolute" terms; and (ii) the possibility to find and moving to them in a finite amount of time] to a procedural rationality [assuming that it is not possible to represent or define "optimal" solutions; due to the epistemological predicament of real life, we can only look for "satisficing" solutions – perceived sub-optimal ones].

The consequences of this paradigm shift are very important for determining alternative ways for organizing scientific information in the process of decision making (**Fig. 4.4c**). Trust - which entails concepts such as: reciprocity, loyalty, shared ethical values among the various stakeholders involved in the process of negotiation – becomes the crucial input in the new challenge of governance.

4.4 Example - what has all this to do with the sustainability of agriculture? The challenge of "operationalizing" the precautionary principle

The example discussed in this section refers to the application of the precautionary principle to the regulation of GMOs. The unavoidable arbitrariness in the application of the precautionary principle can be related to the deeper epistemological problems affecting scientific analyses of sustainability discussed in the previous chapters. Hence traditional risk analysis (probability distributions and exact numerical models) becomes powerless. The precautionary principle entails that scientists move away from the concept of "substantive rationality" (trying to indicate to society optimal solutions) to that of "procedural rationality" (trying to help society in finding "satisficing" solutions).

4.4.1 The precautionary principle

The precautionary principle was explicitly recognized during the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992, and included in the Protocol on Biosafety signed in the Convention on Biological Diversity, 28 January 2000 (CEC, 2000). It justifies early action in the case of uncertainty and ignorance in order to prevent potential harm to the environment and human health: "the principle states that potential environmental risks should be dealt with even in the absence of scientific certainty"(Macilwain, 2000). Obviously, its very definition introduces a certain ambiguity in its possible enforcement. *How* to decide if the potential environmental risk is sufficient to warrantee action? In spite of the difficulty in its application, the precautionary principle has recently been re-stated as a key guiding concept for policy in a communication from the European Commission (CEC, 2000). This move has increased tension between stake-holders because there is "considerable confusion, and differing perspectives, particularly on different sides of the Atlantic, amongst scientists, policymakers, business people and politicians, as to what the precautionary principle does, or should, mean" (EEA, 2001). Given the difficulty in obtaining reliable cost-benefit quantifications for uncertain future scenarios of environmental hazards, the precautionary principle is often regarded as a disguised form of protectionism (ACCB, 2000; Foster et al. 2000) or even as a 'Trojan horse' used by activists moved by ideological biases against technological progress (Miller, 1999).

Indeed, the message of the precautionary principle is clear in its substance, but extremely vague when it comes to practical applications. Its implicit demand for a more effective way of managing hazard than traditional scientific risk assessment (Macilwain, 2000) is generating heated discussions in the scientific community of traditional risk analysis. There are those that still stand for numbers and hard proofs as requisite for action, while others call for the adoption of a new paradigm in science for governance (Funtowicz and Ravetz, 1992).

Against this background, In the rest of this section I elaborate on the following points:

a) In order to understand the practical problems faced when trying to operationalize the precautionary principle, one should be aware of the clear distinction between the scientific concepts of risk, uncertainty and ignorance. I discuss these concepts and question the current practice of only using traditional risk analysis when discussing of large-scale release of genetically modified organisms (GMOs) into the environment and sustainability in general.

b) Alternative analyses can be used to deal with the ecological hazards of large-scale release of GMOs. I illustrate the possible use of metaphors derived from system analysis and network analysis, and of general ecological principles.

c) A paradigm shift is needed when dealing with integrated assessment of sustainability. I will argue that the scientific community should move from the paradigm of 'substantive rationality' (trying to indicate to society optimal solutions) to that of 'procedural rationality' (trying to help society in finding 'satisficing' solutions).

4.4.2 Ecological principles and hazards of large-scale adoption of genetically modified organisms

Is there someone that can calculate the risks (e.g., probability distributions) for a world largely populated by genetically modified organisms? Given the definitions of risk, uncertainty and ignorance introduce in Chapter 3 (in particular **Fig. 3.4**), the answer must be no. Nobody can know or predict the consequences of a large-scale alteration of genetic information in plants and animals. The consequences of this perturbation should be considered on various different hierarchical levels and non-equivalent dimensions of interest (human health, health of local ecosystems, health of economies, health of communities, health of the planet as a whole) (Giampietro, 2003).

The mad-cow disease nicely illustrates this issue. In the discussion of the use of animal protein to feed herbivores in the 1980s, with the aim to augment the efficiency of beef production, nobody could have calculated the 'risk' of the insurgence of Bovine Spongiform Encephalopathy (BSE). To do that, one should have known that a hitherto unknown brain protein, known nowadays as *prion*, could lead to an animal disease that also affects human beings (for an overview of this issue see www.mad-cow.org/). When dealing with a complex problem, such as the forecasting of possible side effects of a change imposed on an adaptive self-organizing system, *metaphors* (even if developed within other scientific disciplines) can be more useful than validated models developed in the field of interest. In the specific case of animal feed regulation, for example, one could have found useful indications from the field of network analysis. Network analysis shows that a 'hypercycle' in a network is a source of trouble - e.g., microphone feedback to the amplifier to which it is connected - (Ulanowicz, 1986). Indeed, also in dynamic system analysis it is known that a required level of accuracy in predictions cannot be maintained in the presence of autocatalytic loops. That is, when an output feeds back as input, even small levels of indeterminacy can generate unpredictable large effects – the so-called 'butterfly effect'.

For example, the idea of cows eating cows implies a clear violation of basic principles describing the stability of ecological food webs (probable troubles). Therefore, the need of extreme precaution when implementing such a technique of production could have been guessed before knowing of the technicalities regarding the specific mad cow disease (the specific set of troubles). The lesson to be learned is clear. When dealing with a new situation it is not wise to rely only on the 'assessment of probabilities' provided by experts that claim to prove that there is negligible risk. Numerical assessments of risks must necessarily assume that the old problem structuring will remain valid in the future. This is usually an incorrect assumption for complex adaptive systems (Rosen, 1985, Kampis, 1991, Ulanowicz, 1986, Gell-Mann, 1994). Thus, in these cases system thinking may be more useful because it shows that large-scale infringing of systemic principles will lead, sooner or later, to some yet-unknowable, and possibly unpleasant, events. Below, I further elaborate an example of system thinking to characterize potential problems related to large-scale adoption of genetically modified organisms in agricultural production.

Reduction of Evolutionary Adaptability and Increased Fragility

As discussed in Section 3.6.3 efficiency requires: 1) elimination of those activities that are less-performing according to a given set of goals, functions and boundary conditions, and 2) amplification of those activities perceived as best-performing at a given point in space and time. Clearly this general rule applies also to technological progress in agricultural production. 'Improving' world agriculture, according to a given set of goals expressed by the social group in power and according to the present perception of boundary conditions, has led to a reduction of the diversity of systems of production (e.g., abandoning traditional systems of agricultural production). On the other hand, these 'obsolete' systems of production often show high performance when adopting different goals or criteria of performance (Altieri, 1987). Several ecologists, following the pioneering work of E.P. Odum (1989), H.T. Odum (1983) and Margalef (1968), have pointed at the existence of 'systemic properties' of ecosystems that are useful to study and formalize the effect of changes induced in these systems. Recent developments of these ideas within the emerging field of complex system theory led to the generation of concepts such as ecosystem integrity (Ulanowicz, 1995) and ecosystem health (Kay et al. 1999). Methodological tools to evaluate the effect of human-induced changes on the stability of ecological processes focus on structural and functional changes of ecosystems (Ulanowicz, 1986; Fath and Patten, 1999) using: relative size of functional compartments, the value taken by parameters describing expected patterns of energy and matter flows, the relative values of turn-over times of components, and the structure of linkages in the network. In particular, network analysis can be usefully applied in the analysis of ecological systems (Fath and Patten, 1999, Ulanowicz, 1997) to:

(a) explore the difference between development (harmony between complementing functions, including efficiency and adaptability, reflected into the relative size of the various elements) and growth (increase in the throughput obtained by a temporary take over of efficiency over diversity),

(b) estimate the relative magnitudes of investments in "efficiency" and "adaptability" among the system processes.

When looking from this perspective at possible large-scale effects from massive use of GMOs in agricultural production, it shows that current research in genetic engineering goes against sound evolutionary strategies for the long-term stability of terrestrial ecosystems (Giampietro, 1994). That is, the current direction of technological development in agriculture implies a major takeover of efficiency over adaptability (based on the representation of benefits on a short-term horizon and using a limited set of attributes of performance). For example, the number of species operating on our planet is in the order of millions, within which the edible species used by humans are in the order of thousands (Wilson, 1988). However, due to the continuous demand for more efficient methods of production, 90% of world food is produced today using only 15 vegetal and 8 animal species (FAO statistics). Within these already few species used in agriculture, the continuous search for better yields (higher efficiency) is liquidating the wealth of diversity of varieties accumulated in millennia of evolution (Simmonds, 1979). FAO estimates that the massive invasion of commercial seeds resulted in a dramatic threat to the diversity of domesticated species. In fact, available data on genetic erosion within cultivated crops and domesticated animals are simply scaring (FAO, 1996; Scherf, 1995). This is a good example of an important and unexpected negative side effect generated by a large-scale application of the green revolution (Giampietro, 1997b).

C.S. Holling –another of the fathers of modern ecology– uses a famous line to indicate the negative consequences of lack of diversity of ecological processes in terms of increased fragility: "a homogeneous ecological system is a disaster waiting to happen" (Holling 1986, 1996). Technological progress in agriculture can easily generate the effect of covering our planet with a few best-performing high-tech biologically organized structures (e.g. a specific agent of pest resistance coded in a piece of DNA). In this case it will almost be sure that, due to the large scale of operation, something that can go wrong (even if having a negligible probability in a laboratory setting) will go wrong. The resulting perturbation (e.g. some unexpected and unpleasant feedback) could easily spread through the sea of homogeneity (i.e., genetically modified monocultures) giving little or no time to scientists to develop mechanisms of control.

The threat of reduction of biodiversity applies also to the diversity of habitats. Moving agricultural production into marginal areas (in agronomic terms), hitherto inaccessible to traditional crops, is often listed among the main positive features of GMOs. In this way, humans will destroy the few terrestrial ecosystems left 'untouched' (escaping until now from excessive exploitation) that provide diversity of habitats essential for biodiversity preservation. In this regard, note that humans already appropriate a significant fraction of the total biomass produced on earth each year (Vitousek et al. 1986).

But even when looking at potential positive effects, one is forced to question the credibility of the claim of GMOs developers that they will be able to increase the eco-compatibility of food production for 10 billions. Given the basic principles of agroecology (Gliessman, 2000; Pimentel and Pimentel, 1996), one is forced to question the idea that simply putting a few high-tech seeds of genetically modified crop plants in the soil could stabilize nutrient cycles within terrestrial ecosystems at a pace dramatically different from the actual ones. This is like trying to convince a physician that by manipulating a few human genes it will be possible to feed humans 30 000 kcal of food per day (ten times the physiological rate) without incurring any negative side effect. An ecological metaphor can also be used to check this idea (Giampietro, 1994b). Even if we "engineer" a super spider, potentially able to catch 10 times more flies than the ordinary species, the super spider will be limited in its population growth by the availability of flies to eat. Flies in turn will be limited, in a circular way, by other elements of the terrestrial ecosystem in which they live. Unless we provide an extra supply of food for these super spiders, their enhanced characteristics will not help them to expand in a given ecological context. This concept can be translated to agriculture: If one takes away from an ecosystem many tons of biomass per hectare with "super harvests", then one has to put enough nutrients and water back into the soil in order to sustain the process in time (to support the relative photosynthesis).

This is why high-tech agriculture is based on the systematic breaking of natural cycles (independently from the presence of GMOs). That is high tech agriculture necessarily has to be a high-input agriculture (Altieri, 1998). Talking of the green revolution, E.P. Odum notes: "cultivation of the 'miracle' varieties requires expensive energy subsidies many underdeveloped countries cannot afford" (Odum E.P. 1989, p. 83). Because of the high demand of technical capital and know-how of high-input agriculture many agro-ecologists share the view of the difficulty of implementing high-tech, GMO-dependent production in developing countries (Altieri, 2000).

As soon as one looks at ecological effects of innovations in agriculture, one finds that important side effects often tend to be ignored. For example, 128 species of the crops that have been intentionally introduced in the United States have become serious weed pests, which are causing more than 30 thousand million US dollars in damage (plus control costs) each year (Pimentel et al. 2000). When dealing with ecological systems, and in particular with the growing awareness of the possible impact of GMOs on non-target species and additional ecological side effects (Cummins, 2000), one should always keep the following (old) aphorism in mind: "You can never do just one thing".

4.4.3 Precautionary principle and the regulation of genetically modified organisms

The economic implications of national regulations for the protection of the environment, and of human, animal and plant health can be huge. In relation to international trade of genetically modified food, the following quotation illustrates this quite clearly. "US soybean exports to EU have fallen from 2.6 billion annually to 1 billion . . . Meanwhile, Brazilian exporters are doing a brisk business selling "GE-free" soybeans to European buyers. . . James Echle, who directs the Tokyo office of the American Soybean Association, commented, "I don't think anybody will label containers genetically modified, it's like putting a skull and crossbones on your product" (UNEP/IISD 2000).

This is why the trade dispute between the EU and the USA over genetically modified food is bringing the precautionary principle on the top of the political agenda. In this particular example, in spite of the increasing attention given to the relationship between environment and trade (UNEP/IISD 2000), the interpretation of the various key agreements on international trade is still a source of bitter controversy (Greenpeace, 2000).

Also within the European Union, the precautionary principle is generating arguments between the Commission and individual member states in relation to the moratorium on field trials on GM crops (Meldolesi, 2000), as well as among different ministers within national governments in relation to the funding of research on GMOs (Meldolesi, 2000). Again, it is easy to explain such a controversy. The simple fact that there is 'hazard' associated with large-scale adoption of GMOs in agriculture does not imply *per se* that research and experimentation in this field should be stopped all together. Current demographic trends clearly show that we are facing a serious hazard (social, economic, ecological) related to future food production, although the successful and safe translation of high-tech methods to an appropriate agricultural practice is widely recognised as being problematic.

Such a hazard applies to all forms of agricultural development also when excluding GMOs. However, deciding whether or not there is sufficient scientific evidence to justify action requires a broader perspective on the hazards, a perspective that goes beyond reductionist science. In particular, the weighting of evidence must be explicit, as well as the inclusion of issues of actual practice, technology, environment and culture.

Life is intrinsically linked to the concept of evolution, which implies that "hazard" is a structural and crucial feature of life. Current debates on the application of the precautionary principle to the regulation of GMOs are simply pointing at a deep and much more general dilemma faced by all evolving systems. Any society must evolve in time and as a consequence it must take chances, when deciding how and when to innovate. This predicament cannot be escaped, whether society decides to take action - because of what is done - or not to take action - because of what is not done - (Ravetz, 2001). Technical innovations have an unavoidable component of gambling. Possible gains have to be weighted against possible losses in a situation in which it is not possible to predict exactly what may happen (Giampietro, 1994). This implies that when dealing with processes expressing genuine novelties and emergence we are moving in a field in which traditional risk analysis is basically helpless.

The challenge for science, within this new framework, becomes that of remaining useful and relevant even when facing an unavoidable degree of uncertainty and ignorance. The new nature of the problems faced in this third millennium (due to dramatic speed of technical changes and globalization) implies that more and more decision makers face "PNS situations" (= facts uncertain, values in dispute, stakes high and decisions urgent) (Funtowicz and Ravetz, 1992). That is, when the presence of 'uncertainty/ ignorance' and 'value conflict' is crystal clear from the beginning, it is not possible to individuate an objective and scientifically determined 'best course of action'. Put in another way, when dealing with this growing class of problems the era of closed expert committees seems to be over. Crucial to this change of paradigm is the re-discovery of the old concept of scientific ignorance, which goes back to the very definition of scientists given by Socrates: "scientists are those that know about their ignorance."

These are relevant points since on the basis of the Agreement on the Application of Sanitary and Phytosanitary Measures (valid since January 1995) the World Trade Organization authorizes [or prevents] (article 2.2) all member countries to enforce the precautionary principle if there is [not] "enough" scientific evidence (see http://www.wto.org/english/tratop_e/sps_e/spsagr_e.htm). In particular, article 2.2 has been used to oppose compulsory labeling of genetically modified food. The reasoning behind this opposition appears to be based on the concept of "substantive rationality" and it is well illustrated by a paper of Miller (1999) published on the Policy Forum of Science. Labeling requirements should be prevented since they "may not be in the best interest of consumers" (Miller, 1999). The same paper identifies the best interest of consumers with lower production costs, possibility of achieving economies of scale, and keeping at maximum speed research and development of GMOs [i.e. maximization of efficiency]. Referring to a decision of the U.S. Court of Appeals (against labeling requirements) he comments: "labeling cannot be compelled just because some consumers wish to have the information" (Miller, 1999).

Two questions can be used to put in perspective the difference between the paradigm of substantive rationality and that of procedural rationality when dealing, as in this case, with scientific ignorance and legitimate contrasting perspectives:

* What if the perception of 'the best interest of consumers' adopted by the committee of experts does not coincide with the set of criteria considered relevant by the consumers themselves? For example, assume that there is a general agreement among scientists that the production of pork is more efficient and safer than production of other meats. Should then the government deny Muslims or Jews the right to know through a label- whether or not the meat products they buy do include pork? If we agree that Muslims and Jews have a right to know, then why should consumers that are concerned with the protection of the environment have less right to know -through a label- if the food products they buy contain components that are derived from GMOs?

* What if the assessment of 'better efficiency and negligible risk' provided by the committee of experts will turnout to be wrong? Actually this is exactly what happened in the European Union with the decisions regulating the use of animal protein feeds for beef production (the move that led to the insurgence of mad cow disease).

4.4.4 Conclusions

Globalization implies a period of rapid transition in which the global society as a whole has to learn how to make tough calls finding the right compromise (the middle way) between 'too much' and 'too little' innovation. Since nobody can know *a priori* the best possible way of doing that, satisficing solutions (Simon, 1976), rather than optimal solutions, to this challenge can only be found through a process of social learning on how to better perceive, describe and evaluate the various trade-offs of sustainability. Scientists have a crucial role to play in this process. But to do that, they have to learn how to help rather than hamper this process. In this respect, the concept of "scientific ignorance" is very useful to put back scientists within society ("procedural rationality" requires a two-way dialogue) rather than above the society ("substantive rationality" implies a one-way flow of information).

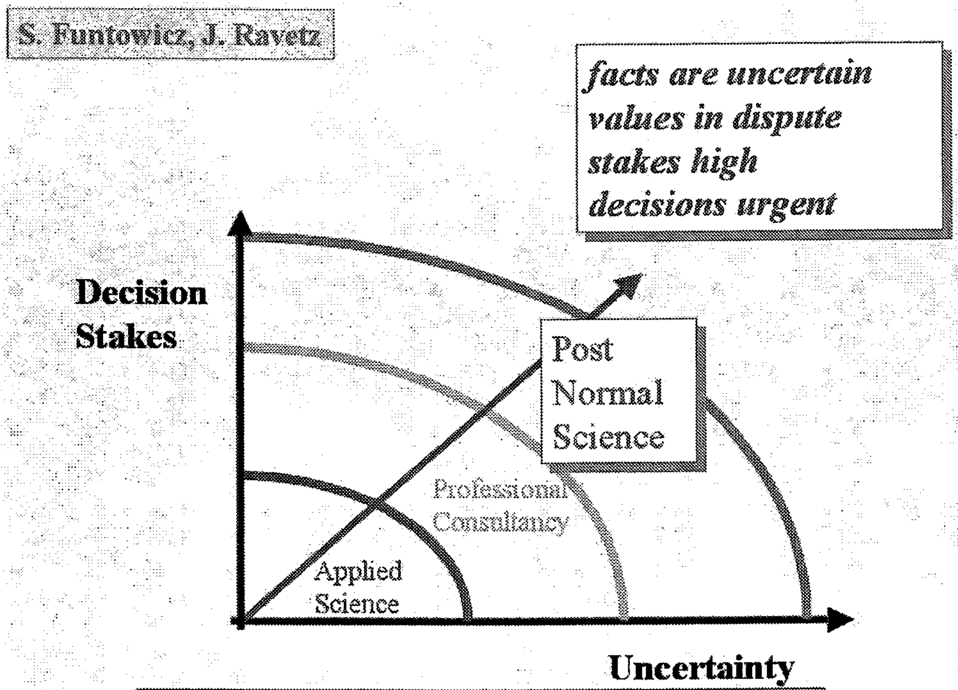
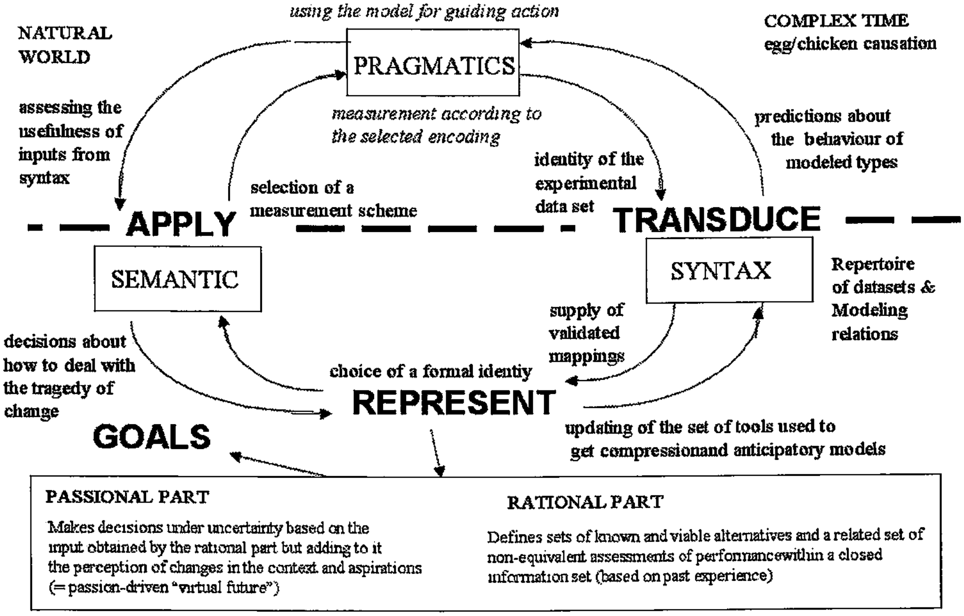


Figure 4.1 The Post-Normal Science diagram

Fig. 4.2 Self-entailing process generating knowledge



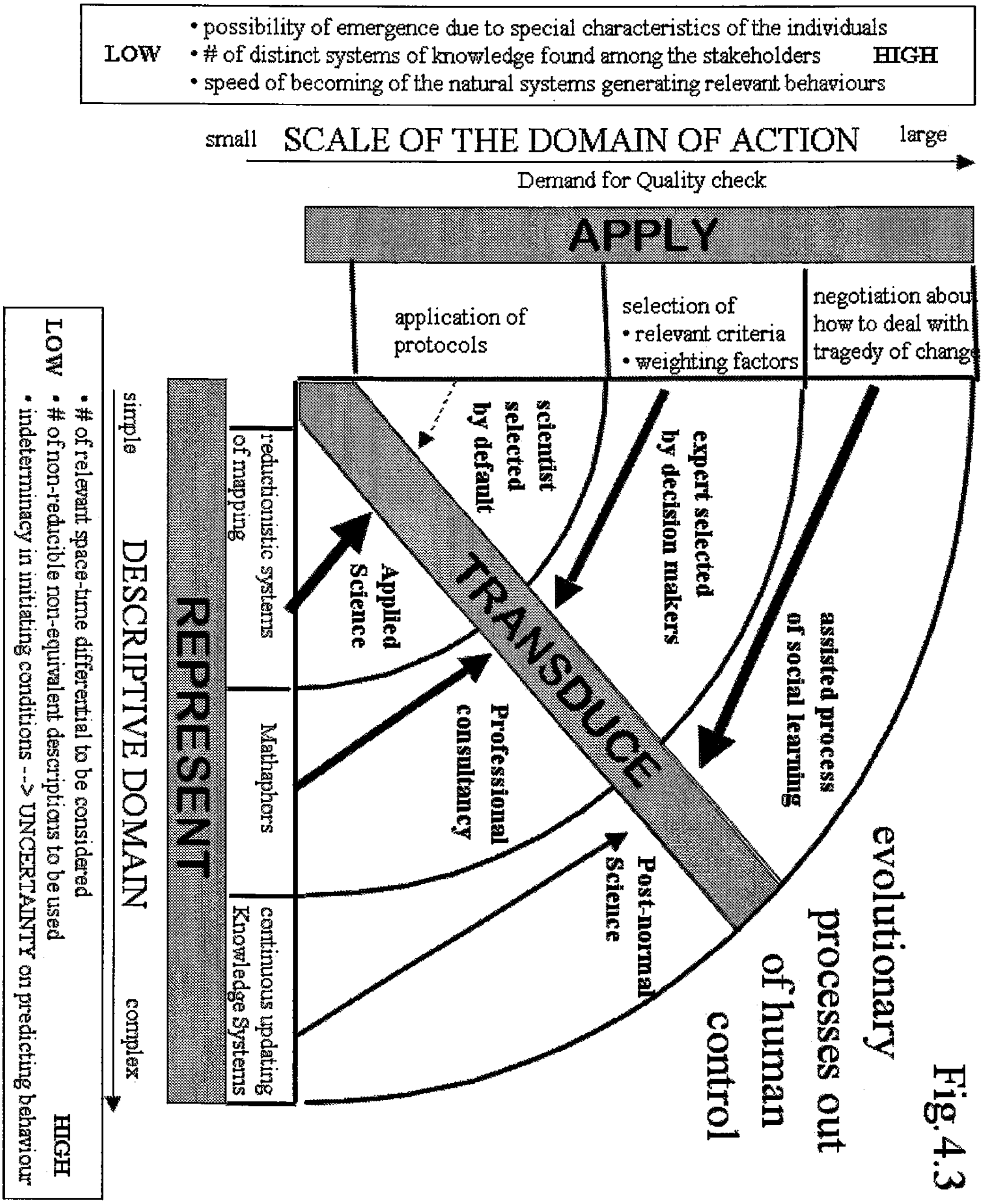
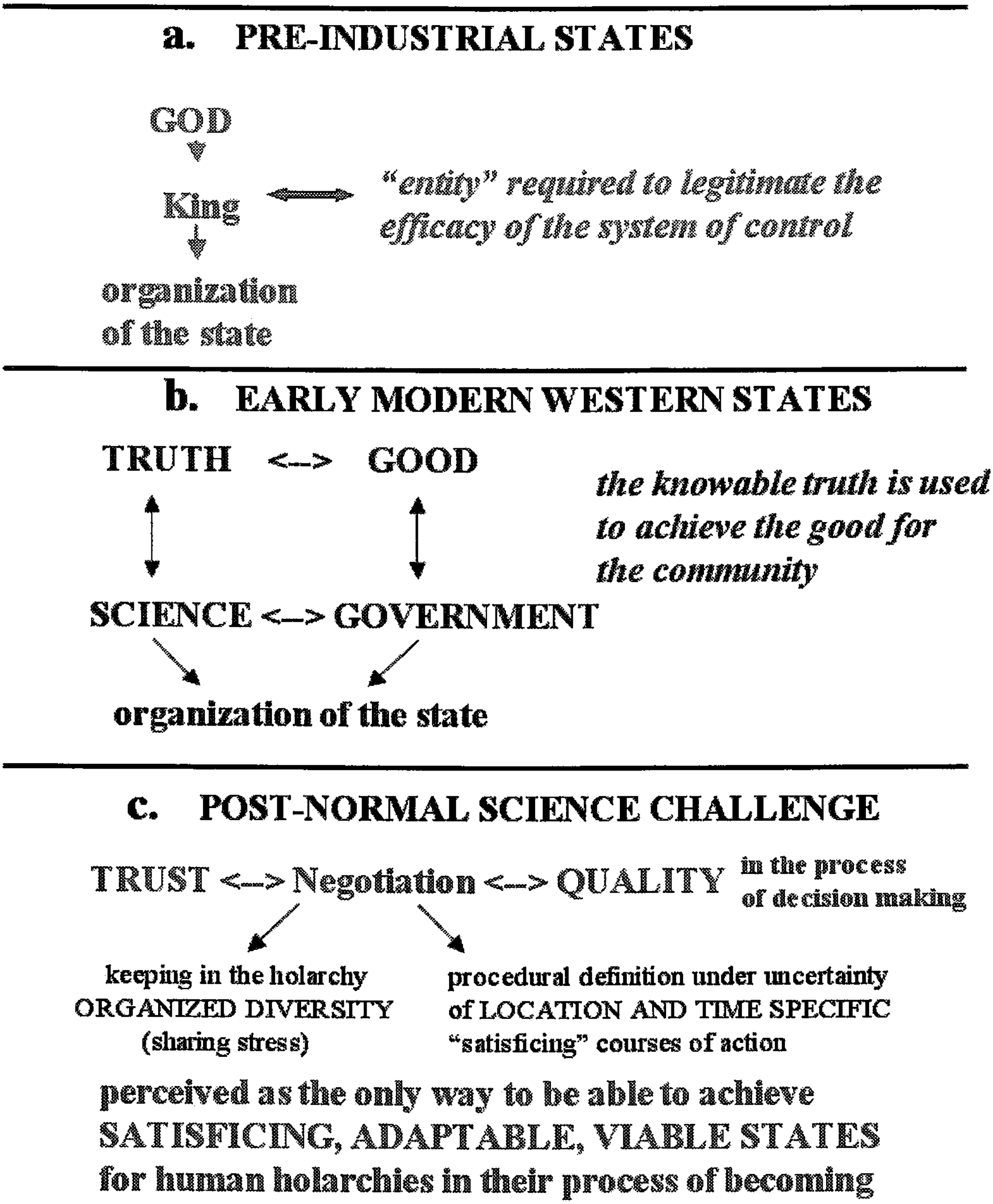


Fig.4.3
LOW
• possibility of emergence due to special characteristics of the individuals
• # of distinct systems of knowledge found among the stakeholders
• speed of becoming of the natural systems generating relevant behaviours
HIGH
small
SCALE OF THE DOMAIN OF ACTION
large
Demand for Quality check
APPLY
application of protocols
selection of
• relevant criteria
• weighting factors
negotiation abou
how to deal with
tragedy of chang
scientist selected by default
expert selected by decision makers
assisted process of social learning
TRANSDUCE
Applied Science
Professional consultancy
Post-normal Science
evolutionary processes out of human control
REPRESENT
reductionistic systems of mapping
Mathaphors
continuous updating Knowledge Systems
simple
DESCRIPTIVE DOMAIN
complex
LOW
• # of relevant space-time differential to be considered
• # of non-reducible non-equivalent descriptions to be used
• indeterminacy in initiating conditions --> UNCERTAINTY on predicting behaviour
HIGH

Fig.4.4 - Different ways of legitimizing systems of control (hierarchy of power) within human societies



a. PRE-INDUSTRIAL STATES

GOD

King ⟷ *"entity" required to legitimate the efficacy of the system of control*

organization of the state

b. EARLY MODERN WESTERN STATES

TRUTH <--> GOOD

SCIENCE <--> GOVERNMENT

the knowable truth is used to achieve the good for the community

organization of the state

c. POST-NORMAL SCIENCE CHALLENGE

TRUST <--> Negotiation <--> QUALITY in the process of decision making

keeping in the holarchy
ORGANIZED DIVERSITY
(sharing stress)

procedural definition under uncertainty
of LOCATION AND TIME SPECIFIC
"satisficing" courses of action

perceived as the only way to be able to achieve SATISFICING, ADAPTABLE, VIABLE STATES for human holarchies in their process of becoming

Chapter 5

Integrated Assessment of Agro-ecosystems and Multi-Criteria Analysis: basic definitions and challenges

This chapter addresses the specific challenges faced by scientists willing to contribute to a process of integrated assessment. Integrated assessment when applied to the issue of sustainability has to be associated to a Multi-Criteria analysis of performance, which by definition is controversial. This in turn requires: (1) a preliminary institutional and conflict analysis (to define what are the relevant social actors and agents whose perceptions and values should be considered in the analysis, and what are the power relations among them); (2) the development of appropriate procedures able to involve in the discussion about indicators, options and scenarios the largest number of relevant social actors; (3) the development of fair and effective mechanisms of decision making. The continuous switching of causes and effects among the activities related to both the DESCRIPTIVE dimension and the NORMATIVE dimension makes this discussion extremely delicate. Scientists describe what is considered relevant by social actors and social actors consider relevant what is described by scientists. The two decisions: (i) who are the social actors included in this process; and (ii) what should be considered as relevant when facing legitimate but contrasting views among the social actors; are two key issues that have to be seriously considered by the scientists in charge for generating the descriptions used for the integrated assessment. This is why I decided to provide an overview of terms and problems related to this relatively new field. This chapter provides an overview of concepts, problems and bibliographic references for those not familiar with this new field.

5.1 Sustainability of agriculture and the inherent ambiguity of the term Agro-ecology

The two terms included in the title of this chapters (1) Integrated Assessment, and (2) "Agro-Ecosystems" are two terms about which it is almost impossible to find definitions which will generate an unanimous consensus. In fact, "Integrated Assessment" is a neologism which is getting more and more popular in the scientific literature dealing with sustainability. There is an international journal (http://www.szp.swets.nl/szp/frameset.htm?url=%2Fszp%2Fjournals%2Fia.htm) and a scientific society with this name, to which one should add a fast growing pile of papers and books dedicated to this subject. This term, however, is mainly getting popular outside the field of scientific analysis of agricultural production. Very little use of this term can be found in journals dealing with the sustainability in agriculture. The other term "agro-ecosystems" is a term derived from the concept of "agroecology", which is another neologism introduced in the 80s. This is a term which, on the contrary, is very popular in the literature of sustainability of agriculture. At this point of the book, it is possible to make an attempt to justify the abundant use of neologisms done so far. Nobody likes using a lot of neologisms or, even worse, "buzz-words" in scientific work. A simple look at the two definitions of neologism found in the Merriam-Webster Dictionary explains why:

Neologism = *(a) a new word, usage, or expression (2) a meaningless word coined by a psychotic.*

Introducing a lot of neologisms without being able to share the meaning of them with the reader tends to classify the user/proponent of these neologisms in the category of psychotic. On the other hand, when an old scientific paradigm is no longer able to handle the challenge (and we hope that at this point in the text we manage to convince the reader that this is the case with integrated analyses of sustainability) it is necessary to introduce new concepts and words in order to explore and build new epistemological tools. Moreover, a lot of new words and concepts are already used in the field of Integrated Assessment and Multi-Criteria Analysis (and this author has nothing to do with this impressive flow of neologisms), so that I found important to share with the reader the meaning of these new terms. In particular, what is relevant here is the application of the concept of "integrated assessment" to the concept of "agroecosystems". Before getting into this discussion, let's start with the definition of the term: "agroecosystem" that implies dealing with the concept of "agroecology".

The term Agroecology was proposed, in a seminal book, by Altieri in 1987 (Altieri, 1987). This was an attempt to put forward a new catch-word pointing at the need of introducing a paradigm shift in the world of agricultural research when taking seriously the issue of sustainability. In that book Altieri focuses on the **unavoidable existence of conflicts** linked to the concept of sustainability in the field of agriculture. His main point is: IF we define the performance of agricultural production only in economic terms, THEN other dimensions such as the ecological dimension, the health dimension and the social dimension will be the big losers of any technical development in this field. When mentioning "conflicts" here we do not refer only to conflicts between social actors, but also to conflicts between optimizing principles derived by the adoption of different scientific analyses of agriculture (when getting into the normative side by using different definition of "costs" and "benefits"). That is, an anthropologist, a neo-classical economist and an ecologist tend to provide very different views of the performance of the very same system of shifting cultivation in Papua New Guinea.

Two main lines of action were suggested by Altieri:

(1) the concept of agroecology has to be associated to a total rethinking of the terms of reference of agriculture (what should be considered as an "improvement" in the techniques of production? "improvement" for whom? in relation to which criterion? which time horizon should be adopted to assess improvements?), and

(2) the concept of agroecology requires expanding the universe of possible options (technical solutions, technical coefficients, socio-economic regulations) for agricultural development. This can be obtained in two ways: (a) by exploring new alternative techniques of production (changing the existing set of available technical coefficients); as well as (b) studying and preserving the cultural diversity of agricultural knowledge already existent in the world (preserving techniques guaranteeing technical coefficients, which could result useful when adopting different optimizing functions).

It should be noted, that the majority of groups using the term Agroecology, especially in the developed world, endorsed basically the second line, without fully addressing the implications of the first. The basic idea of this position can be characterized as follows. *The sustainability predicament and the existing difficulties experienced by agriculture both in developed and developing countries is just due to the fact that humans are not using* ***the most appropriate technologies and not relying on a given set of "sound principles."*** Put in another way, this second historical interpretation of the term "agroecology" assumes a substantive definition of it. The vast majority of the people using this interpretation tend to associate the term agroecology with concepts like: "organic farming," "Low External Input Agriculture," "small is beautiful," "empowerment of family farms." They are assuming that the solution out of the current lack of sustainability in agriculture can be found relying on "sound principles" and by studying "how to produce more profit with: (a) less environmental impact; and (b) happier farmers."

The problem with this position is that it does not address: (1) the unavoidable existence of conflicts implicit in the concept of sustainable development; (2) the unavoidable existence of uncertainty and ignorance about our knowledge of future scenarios. Put in another way, the very concept of sustainability entails an unavoidable dialectics between both actors and strategies. When discussing of the development of agricultural systems **there is not one set of most appropriate technologies.** At each point in space and time the objectives (goals, targets), the constraints (resources, laws, taboos), available set of options, available set of acceptable compromises among which to chose, **must be first explicitly defined for the scientists.** Only at this point it becomes possible for them to identify a set of appropriate technologies either based on (a) politically-defined priorities among the different objectives; or (b) a negotiated consensus on a compromise solution that realizes all the various goals (as expressed by relevant social actors) to some extent.

This is why, in the last two decades, the first direction of research suggested by Altieri, "totally rethinking the terms of reference of agriculture" has also been ~~is~~ gaining attention. This radical position seem to be supported by those working on scenarios about the future of agriculture (e.g. within the US to avoid the Blank hypothesis – Blank, 1998). It is also shared by those working on ex-post evaluation of agricultural policies (e.g. the massive failure of development programs of UN agencies in developing countries and that of agricultural policies in EU). In fact, a complete recasting is at the moment the official position of the European Commission for the future of European agriculture (e.g. http://www.newscientist.com/news/news.jsp?id=ns99991854).

In face of this mounting pressure, the forces for "business as usual" (economic and political lobbies, academic institutions) are trying to develop a strategy of damage control. Many within the agricultural establishment say that a "total rethinking" is not really needed. They suggest that a few technical adjustments and a little more talking with the farmers will suffice. They also recommend a few new regulations to internalize some of the externalities that have until now escaped market mechanisms. This position has important ideological implications. It accepts the notion that technical development of agriculture should be driven "by default" by the maximization of productivity and profit (bounded by a set of constraints to take care of the environment and the social dimension).

Personally, I do not have any intention of getting into an ideological discussion of this type. This chapter and this book are written assuming as valid the "emerging paradigm" that perceives the development of rural areas in terms of "integrated resource management carried out by multifunctional land use systems." In this paradigm "flexibility in the management strategy" and "participatory techniques for defining what should be the desirable characteristics of the system" are assumed to be necessary steps to achieve such a goal. Therefore, in the rest of this chapter I will not deal with the question: "why should we do things in a different way when perceiving and representing the performance of agriculture" but rather with the question "how can we do things in a different way?"

In fact, acknowledging the need for a total rethinking of agriculture is just the first step. In order to act we must reach first an agreement as to how things should be done in a different way. This can be achieved only by answering some tough questions such as: Who is supposed to rethink the terms of reference of agriculture? How might we change the shape of the plane on which we are flying? What to do if different social actors have different views on how to make changes? An acute problem to this regard is that both colleges of agriculture and reputable scholars, in general, are less than fully willing to engage in this debate, perhaps because they view "totally rethinking the terms of reference of agriculture" as a threat to their present agenda._ This is, however, not reasonable:

IF we acknowledge that changes on the societal side resulted in a shift in the priorities among objectives and in some cases led to the formulation of completely new objectives in agriculture,

THEN we are forced to accept the following conclusions: (a) we have to do things differently in agriculture, and in order to do that (b) we have to perceive and represent things differently in the scientific disciplines dealing with description of agricultural performance.

As soon as one tries to draw this logical consequence however, one crashes against one of the mechanisms generating the lock-in on "business as usual." Much funding of colleges of agriculture is channelled through private companies with a clear agenda (maximizing profit through maximization of productivity). Even public funding is heavily affected by lobbies, which are operating within the conventional paradigm. These lobbies perceive agriculture just as an economic sector producing commodities and added value.

To the best of my knowledge, the only big agricultural University that is working hard on a radical and dramatic restructuring of its courses (to reflect a total rethinking of the terms of reference for agriculture) is Wageningen University in the Netherlands. Actually the restructuring started with its very name. It used to be the glorious WAU – Wageningen Agricultural University – until two years ago, then they dropped the A!

A very quick resume of relevant events leading to this restructuring is that the big departments resisted in the early 90s any friendly attempts at change from the inside. Actually, they reacted to signals of crisis by doing "more of the same thing". The concept of "Ancient Regime Syndrome" proposed by Funtowicz and Ravetz (= when facing a crisis, do more of the same, even though it is not working), discussed in Chapter 4 should be recalled here. The fatal response of agricultural departments was "better" and more complicated optimizing models to get additional economies of scale and increases in efficiency. At the very moment when the basic assumptions of agriculture as "an economic sector **just producing commodities"** were under revision, the credibility of these assumptions was stretched even further. The catastrophe came when the rest of society (e.g. consumers, farmers, politicians) imposed a new research agenda in a quite radical way. They were told, "No more money for models that optimize the ratio of milk produced per unit of nitrogen and phosphorus in the water table." And the edict was given almost overnight.

Central to any discussion about a different way to perceive and represent the performance of agricultural systems is the idea that "agricultural production" is not the full universe of discourse for any of the relevant agents operating at different levels (households, local communities, counties, states, countries, international bodies). Then it becomes obvious that analytical approaches aimed at "optimizing production techniques" do not represent the right way to go. When we analyze the "livelihood" of households, local communities, counties, states, countries, international bodies a sound representation of the performance of agricultural activities (how to invest a mix of production factors to alter ecosystems in order to produce food and fibers) is just a part of the story. That is: (1) The mix of relevant activities considered in the analysis has to include more than just the production of crops and/or animal products. (2) The list of consequences considered in the analysis has to include more than economic and biophysical productivity of agricultural techniques (e.g. additional relevant indicators should address social impact, health impact, ecological impact, quality of life). Performing this integrated analysis does not require the introduction of new revolutionary analytical tools, but rather the ability to provide new packages for existing tools.

In engineering, for example, it is possible to have a rigorous treatment of decision support analysis for design. The terms used there are: Multi-Objective Decision Making, Multi-Attribute Decision Making (e.g. http://design.me.uic.edu/~mjscott/papers/95f.pdf). The big advantage of industrial design is that all the relevant information for defining the performance of the designed system is supposed to be available to the designer. The same approach is explored in other fields dealing with the issue of sustainability (e.g. Ecological Economics, Science for Governance (participatory Integrated Assessment), Evaluation of Sustainability, Natural Resources Management). The application of these concepts is generally indicated under a family of names like: Integrated Assessment, Sustainability Impact Assessment, Strategic Environmental Assessment, Extended Cost Benefit Analysis.

However, when applying these tools to self-organizing systems, especially when dealing with reflexive systems (humans), a multi-criteria evaluation has to deal with 3 huge systemic problems:

- it is not possible to formalize a procedure to define in a substantive way (outside of a specific and local context of reference) what is the right set of relevant criteria of performance that should be considered for a "sound analysis."
- it is unavoidable to find legitimate contrasting views on what should be considered as an improvement or which should be considered the best alternative to select. Social agents will always have divergent opinions. For example, it is unavoidable to find different opinions on whether it is good or bad having nuclear weapons or using genetically modified organisms.
- it is not possible to get rid of uncertainty and ignorance in the various scientific analyses that are required. This implies that not all the data, indicators and models required to consider different dimensions of analysis (the views of different agents at different

levels) have the same degree of reliability and accuracy.

Because of these three major problems there is a general convergence in the field of Integrated Assessment and Multiple Criteria analysis that it is not possible to achieve the "right problem structuring" of a sustainability problem without the integrated and iterative use of two types of tool kit:

(A) **'Discussion Support Systems'** (this is a terms introduced by H. van Keulen)

In this activity scientists are the main actors and social actors the consultants: the goal is the development of integrated packages of analytical tools required to do a good job on the descriptive side. The resulting information space used in the decision making process has to represent the system of interest, in scientific terms, on different scales and dimensions of analysis. This information space has to be constructed according to the EXTERNAL input received from the social actors of what is relevant and what is good and bad. The social actors, as consultants, have to provide a package of questions to be answered. But the scientists are those in charge to process such an input according to the best available knowledge of the issue.

This is a new academic activity, which implies a strong scientific challenge: keeping coherence in an information space made up of non-equivalent descriptive domains (different scales and different models). This requires an ability to make a team of scientists coming from different disciplines interact on a given problem structuring provided by the society. This is what we will introduce later on under the label of ***Multiple Scale Integrated Analysis.***

(B) **'Decision Support Systems'**

In this activity social actors are the main actors and scientists the consultants: the goal is the development of an integrated package of procedures required to do a good job on the normative side. The resulting process should make possible to decide, through negotiations: (1) what is relevant and what should be considered as good and bad in the decision process, (2) what is an acceptable quality in the process generating the information produced by the scientists (e.g. definition of quality criteria: relevance, fairness in respecting legitimate contrasting views, no cheating with the collection of data or choice of models), and (3) deciding an alternative (or a policy to be implemented).

This process requires an EXTERNAL input (given by scientists) consisting in a qualitative and quantitative evaluation of the situation on different scales and dimensions. In their input scientists have to include also information about expected effects of changes induced by the decision under analysis (discussion of scenarios and reliability of them). But the social actors are those in charge to process such an input. This is what we will introduce later on as ***Social Multi-Criteria Evaluation*** following the name proposed by Munda (2003).

Since the scientific process associated to the operation of the tool kit A affects the social process associated to the operation of the tool kit B and vice versa, the only reasonable option to handle this situation is to establish some form of iteration between the two. In doing this, however, it must be clear that Process A is a scientific activity (that requires an input from social actors) and Process B is a social activity (that requires an input from scientists). **Both of them, however, depend on each other. This is where the need of a new type of "expertise" enters into play. In order to have such an iterative process it is necessary to implement an adequate procedure.**

The rest of this chapter is divided in 3 sections. Section 5.2 discusses the systemic problems faced when considering agriculture in terms of multifunctional land use. Any analysis based on indicators reflecting legitimate but contrasting views and referring to events described at different scales implies facing serious procedural problems. This section makes the point that when dealing with the sustainability of agriculture we do face a Post-Normal Science situation. Section 5.3 provides an overview of concepts and tools available for dealing with such a challenge (e.g. Integrated Assessment, Multi-Criteria Evaluation, and a first view at Multi-Objective Multi-Scale Integrated Analysis) as well as practical examples of problems associated to their use. Section 5.4 briefly describes exiting attempts of establishing procedures able to generate the parallel development of discussion support systems and decision support systems and then an iteration between the two (e.g. the Soft-Systems Methodology proposed by Checkland – Checkland, 1981; Checkland and Scholes, 1990). Section 5.5 provides a practical example (the current making of farm bills) in which we can appreciate the need of developing as soon as possible these procedures.

5.2 Dealing with multiple perspectives and non-equivalent observers.

In this section we elaborate on the two points discussed in the introduction:

(1) it is unavoidable to find legitimate contrasting views on what should be considered as an improvement or which should be considered the best alternative to select (section 5.2.1).

(2) it is not possible to formalize a procedure to define in a substantive way what is the right set of relevant criteria that should be considered to perform a "sound analysis" (section 5.2.2).

5.2.1 The unavoidable occurrence of non-equivalent observers

The lady shown in **Fig. 5.1** is performing a very old traditional technique of Chinese farming. She is applying "night soil" (human excrements) to her garden making sure that as little as possible of this valuable resource gets lost in the recycling. This is why she carefully pours only small amounts of the organic fluid on each plant. There are plenty of pictures like this of this lady, since the colleagues (i.e. ecologists and experts of organic agriculture) that were working with me in a project there, were delighted by this image. They took about fifty pictures of her in different moments of her daily routine. For westerners this picture is a vivid metaphor of the ultimate ecological wisdom of ancient agriculture: the closure of the cycle of nutrients between humans and nature. The unexplained mystery associated to such a vivid metaphor, though, is that this image is disappearing from this planet pretty quickly.

Later on, when talking to that lady I asked explanations about the abandonment of this and other ecological friendly activities (such as digging silt out of channels) so valuable for the preservation of Chinese agro-ecological landscapes. She replied asking me abruptly: "Have you been in Paris?" "Of course I have been in Paris" was my immediate (and careless) answer. At that point she could go for it. "I have never been in Paris. None of those living in this village has ever been in Paris. None of my daughters will ever go to Paris. You want to know why? Because we have been digging channels and carefully pouring 'night soil' to preserve this agro-ecosystem instead. Personally, I don't want to do that anymore. If things will not change during my lifetime, I want that at least my grand-grand children will have the option to go to Paris. If this agro-ecosystem is going to hell, I am happy about that, the sooner the better."

The three points relevant about this story are: (1) a clear disagreement about basic goals and strategies among different actors. Our team of scientists was in China with the goal of preserving that agro-ecosystem, whereas the lady had the goal of getting rid of it (she was forced to keep recycling "night soil" but for her this was only a temporary solution needed for feeding her family); (2) the parallel use of different and logically independent indicators of performance for a given agro-ecosystem. The team of agroecologists in our project was happy about her recycling according to the indications given by bio-indicators (earthworms) assessing changes in the health of the soil. The lady was unhappy about night-soil in relation to her "impossibility to go to Paris" used as indicator of the performance of agronomic activities; (3) the tremendous speed at which human systems can redefine what is desirable and acceptable. Our local students told us, to explain her reaction, that a TV set just arrived in the village and this generated a communal daily watching. The soap opera in fashion at the moment - when the picture was taken - featured two Chinese *yuppies* living in Paris and drinking champagnes in cold flutes. This was enough for the villagers watching the show to update their representation of what should be considered as a desirable and acceptable socio-economic performance of agricultural activities. The picture which the lady pouring night-soil had in mind for the future of her great grand-daughter was more related to what shown in **Fig. 5.2.**

5.2.2 Non-reducible indicators and non-equivalent perspectives in agriculture

When dealing with sustainable agriculture we have to expect a representation of performance which has to be based on different criteria (reflecting the different values and goals) and different hierarchical levels (requiring a mix of non-equivalent descriptive domains). Without using a multilevel analysis, it is very easy to get models that simply suggest to shift a particular problem between different descriptive domains. Put in another way, "optimising models" based on a simplification of real systems within a single descriptive domain just tend to externalise the analysed problem out of their own boundaries. For example, economic profit can be boosted by increasing ecological or social stress. In the same way, ecological impact can be reduced by reducing economic profit, and so on. That is, conventional scientific analyses in general provide policy suggestions which are based on the detection of some "benefits" by a given model referring to a certain descriptive domain and by the neglecting of other "costs" ignored by the model since they are detectable only on different descriptive domains (when adopting a different selection of variables). This "epistemological cheating" can be avoided only by adopting a set of different descriptive domains able to "see" those costs 'externalized' (put under the carpet) by a given mechanism of accounting. By using an integrated set of indicators we can observe that problems "externalised" by the conclusions suggested by one model (based on an optimizing variable defined on a given scale - e.g. when describing things in economic terms over a 10-year time horizon) reappear amplified into one of the parallel models (based on a different optimizing variable defined on a different scale - e.g. when describing the same change in biophysical terms on a larger 1000-year time horizon). As discussed in chapter 2 and 3, the ability of any model to "see" and encode some qualities of the natural world implies that the same model cannot "see" other qualities detectable only on different descriptive domains.

To provide an example of non-equivalent indicators that can be used to characterize historical changes in a farming system **Fig. 5.3** provides examples of 4 numerical assessments characterizing the dramatic developments of farming systems in rural China.

Land requirement for inputs: the first indicator used in **Fig. 5.3a** is related to the profile of land use. In particular, the numerical assessment indicates the percentage of crop land invested by farmers with the aim of guaranteeing nutrient supply to crop production. In the 1940s, about 30% of crop land was allocated to green manure cultivation and hence this land was unavailable for subsistence or cash crop production. The intensification of crop production, driven by population growth and socioeconomic pressure, led to a progressive abandonment of the use of green manure (too expensive in terms of land and labor demand), that is to a general switch to synthetic fertilizer use. This resulted in a sensible increase in multiple cropping practices and, consequently, in a dramatic improvement of agronomic indices of crop production (e.g., yields per hectare), that is a dramatic increase in crop production for self-sufficiency and freeing land for cultivation of cash crops (Li Ji et al. 1999). However, according to current trends, a further increase in demographic and economic pressure may lead to further intensification of agricultural throughputs (Giampietro, 1997a; 1997b). In this case, depending on the ratio "sales price of crops/cost of fertilizer" as well as technical coefficients we could easily return - in the first decade of the 2000 - to the 30% mark as it was in the 1940s.That is, about 30% of the land invested in cash crops will be used just to pay for technical inputs. Put in another way, when considering the criteria: "land requirement for stabilizing agricultural production" (= resource eaten by an internal loop within the system of production) the two solutions requiring a 30% investment of the total budget of available land to make available the required production inputs are equal for the farmer. According to farmers' perception the same fraction of land is lost whether it is to green manure production or to crop production to purchase chemical fertilizer. The characterization (mapping of system qualities) given in **Fig.5.3a** is not able to catch the difference implied by these two solutions. Other criteria (and therefore indicators) are needed if we want to obtain a richer characterization (a better explanation) of such a trend.

Household's perspective: when considering as indicator of performance the parameter "productivity of labor" (**Fig. 5.3b**) we see that the solution "chemical fertilizer" implies a much higher labor productivity than the "green manure" solution. Higher labor productivity in this case translates into a higher economic return of labor. Depending on the budget of working time available to the household, it is possible to reduce, in this way, the fraction of working time allocated to self-sufficiency and - as consequence - to increase the fraction of working time allocated to cash flow generation (either on farm and/or off-farm) and leisure. Thus, even if 30% of the available budget of land is lost to fertilization, according to the new criteria "labor productivity" farmers will prefer the solution of chemical fertilizer for it enables a better allocation of their time budget.

Country's perspective: when considering as indicator of performance the parameter " productivity of food of cropped land" -**Fig. 5.3c** –we see that the solution "chemical fertilizer" implies a much higher land productivity than the "green manure" solution. In fact, the land used to produce crops for the market to pay for chemical fertilizer (perceived as lost by farmers), when considered at the national level is seen as land that produces food for the urban population. On the contrary, green manure production is seen by the national Government as an use of cropping area which does not generate food. Indeed, the goal of the central government of China to boost food surplus in rural areas, making possible to feed the growing urban population, may actually lead to a promotion of policies of intensification of agricultural production by boosting the use of technical inputs. Given this goal, an excessive "fraction of farmers' land budget" eaten by the cost of purchasing chemical fertilizer would discourage farmers from intensive use of technical inputs. Therefore, the central government can decide to subsidize the use of these inputs. As seen from the farmer's perspective, a lower cost of fertilizer reduces the fraction of their land that has to be invested to procuring fertilizer and therefore induces an intensification of agricultural production. Note however that the reduction of "land lost to buy chemical fertilizer" - as detected by the farmer perception - and an increase in "crop land productivity" - as detected by the central government - obtained by subsidization of fertilizer in turn increases another relevant indicator: the "economic cost of internal food production" (yet another relevant criteria for the Chinese government when deciding about policies of agricultural development). That is, the advantage given by the use of subsidies to fertilizer - characterized by the indicator "crop land productivity" induces a side effect which can be detected only by using an additional criteria (and relative indicator) referring to the country level: "the economic burden of subsidizing technical inputs" (note that this is a relevant indicator which is not given in **Fig. 5.3**).

An ecological perspective: When considering the ecological perspective, we find a totally different picture of the consequences of the two "30% of land budget allocation to fertilizer" solutions. The use of green manure in the 1940s was certainly benign to the environment because the flow of nutrients in the cropping system was kept within a range of values of intensity close to those typical of natural flows. Put it in another way, the acceleration of nutrient throughputs induced by the use of synthetic fertilizers dramatically increased the environmental stress on the agroecosystems. When biophysical indicators of environmental stress are considered to characterize the considered trend, we obtain an assessment of performance which is totally unrelated (logically independent) from assessments based on the use of economic variables. For example (**Fig. 5.3d**) 800 kg of synthetic fertilizer applied per hectare per year (due to the high multiple-cropping index) are "too much fertilizer" for a healthy soil, no matter how the economic cost of fertilizer compares with its economic return.

A couple of points can be driven home from this example: (i) the same criteria (land demand per output) can require different indicators, when reflecting the perspective of performance related to different hierarchical levels. Indicator **5.3a** and **5.3c** are giving contrasting indications about the solution "green manure" versus "synthetic fertilizer" in relation to use of land. Farmers "see" no-difference for the two solutions, the government of the country "sees" the two solutions as dramatically different; (ii) criteria and indicators referring to different descriptive domains (**Fig. 5.3d** and **5.3b**) ("environmental loading assessed in kg of fertilizer/ha" versus "labor productivity expressed either in added value/hour or kg of crop/hour") reflect not only incommensurable qualities, but also the existence of unrelated (logically independent) perceptions and systems of control. As a consequence, when dealing with trade-offs defined on different descriptive domains we cannot expect to work out simple protocols of optimization able to compare and maximize relative costs and benefits. Recalling the examples provided in Chapter 3 we can say that the existence of multiple relevant hierarchical levels, non-equivalent descriptive domains, can imply a non-reducibility of models on the descriptive side. This leads to a problem that Munda (2003) calls "**technical incommensurability**" (the impossibility of establishing a clear link among non-equivalent definitions of costs and benefits obtainable only on non-reducible descriptive domains). Whereas a difference in the perception about priorities (the two different views about the future of agriculture shown in **Fig. 5.1** and **Fig. 5.2**) found in social actors carrying conflicting goals and values should be associated to "**social incommensurability**" (Munda, 2003). More on this in the following section.

5.3 Basic concepts referring to Integrated Analysis and Multicriteria Evaluation

In this section I provide an overview of concepts and definitions which is an attempt to frame the big picture within which the various pieces of the puzzle belong. A more detailed discussion about how to build analytical tool kit for integrated analysis of agroecosystems is provided in Part 3.

5.3.1 Definition of terms and basic concepts

** Problem structuring required for Multi-Criteria Evaluation*

This refers to the identification of relevant qualities of the system under investigation which have to be characterized, modeled and assessed in relation to the specified set of goals expressed by relevant social actors. This integrated appraisal leads to the individuation of a set of relevant issues to be considered in the formal problem structuring in terms of a list of: (a) options; (b) criteria; (c) indicators and measurement scheme; that will be used to decide about action.

** Multi-Scale Integrated Analysis (multiple set of meaningful perceptions/representations)*

The simultaneous consideration of a set of system qualities (judged relevant for the goals of the study in the first step of problem structuring) which must be observable and can be encoded into variables used in the set of selected models. Depending on the set of relevant criteria, MSIA may require the parallel use of indicators referring to different scales and dimensions of analysis. - e.g. GNP in US$, Life expectancy, MJ of fossil energy, level of food intake, fractal dimension of cropfields, Gini Index for equity, efficiency indices, nitrogen concentration in the water table.

** Challenge associated with the descriptive side (how to do a MSIA)*

Studying non-equivalent typologies of: (a) performance indicators; and (b) mechanisms generating relevant constraints; in relation to a given problem structuring.

Standard objective of MSIA is the simultaneous consideration of economic viability, ecological compatibility, social acceptability, and technical feasibility.

This requires the ability to simultaneously:

(1) describe different effects in relation to the selected set of relevant constraints using different indicators;

(2) understand the various mechanisms generating relevant features and patterns using in parallel non-reducible models;

(3) gather the adequate information required to operate the selected sets of indicators and models;

(4) assess the quality of the results obtained in the steps (1), (2) and (3).

* ***Challenge associated with the normative side (how to compare different indicators, how to weight different values, how to aggregate different perspectives – Social Multicriteria Evaluation).***
From a philosophical perspective, it is possible to distinguish between two key concepts (Martinez-Alier et al., 1998; O'Neill, 1993):

Strong comparability that is, it is possible to find a single comparative term by which all different policy options can be ranked. Strong comparability can be divided into: (a) **strong commensurability** - i.e. it is possible to obtain a common measure of the different consequences of a policy option based on a quantitative scale of measurement, and (b) **weak commensurability** - i.e. it is possible to obtain a common measure of the different consequences of a policy option but only based on a qualitative scale of measurement. The concept of strong comparability implies the assumption that the "value" of "everything" (including your mother) can be compared to the value of "everything else" (including someone else's mother) by using a single numerical variable (e.g. monetary or energy assessments).

Weak comparability implying **incommensurability** - i.e. there is an irreducible value conflict when deciding what common comparative term should be used to rank alternative actions.

As noted in previous chapters complex systems exhibit multiple-identities because of: (a) epistemological plurality (non-equivalent observers see different aspects of the same reality) and (b) ontological characteristics (nested hierarchical systems can only be observed on different levels using different types of detectors and different typologies of pattern recognition). This is what leads to the distinction proposed by Munda about:
(a) Social incommensurability referring to the existence of a multiplicity of legitimate values and points of views in society. It is not possible to decide in a substantive way that a set of "values" of a social group is more valuable than a set of "values" of another social group.
(b) Scientific/technical incommensurability referring to the non-reducibility of non-equivalent models. This is justified by hierarchy theory and it can be related to the impossible task of representing multiple identities (as resulting from analysis on different scales) in a single descriptive model. It is not possible to decide in a substantive way that a given system description related to a particular level of analysis and/or using a certain disciplinary view is more relevant that another.

* ***The rationale for Societal Multi-Criteria Evaluation***
It is important to note that weak comparability does not imply at all that it is not possible to use "rationality" when deciding. Rather, it implies that we have to move from a concept of "substantive rationality" (based on strong comparability) to that of "procedural rationality" (based on weak comparability and SMCE). Procedural rationality is based on the acknowledgement of ignorance, uncertainty and the existence of legitimate non-equivalent views of different social actors (Simon, 1976; 1983). "A body of theory for procedural rationality is consistent with a world in which human beings continue to think and continue to invent: a theory of substantive rationality is not" (Simon, 1976).

Concepts like welfare and sustainability are multidimensional in nature. Therefore, the evaluation of technological progress, policies, public plans or projects has to be based on procedures that explicitly require the integration of a broad set of various and conflicting points of view and the parallel use of non-equivalent representations. Consequently, multicriteria methods are in principle an appropriate modeling tool for policy issues including conflicting socio-economic and nature conservation objectives.

5.3.2 Tools available to face the challenge

In the last years the use of multicriteria methods has been gaining popularity at increasing pace. The major strength of multicriteria methods is their ability to address problems marked by various conflicting evaluations (Bana and Costa, 1990; Beinat and Nijkamp, 1998; Janssen and Munda, 1999; Munda, 1995; Nijkamp et al., 1990; Vincke, 1992; Voogd, 1983; Zeleny, 1982).

To make clearer the idea of Multi-Criteria analysis in relation to the concepts presented before, let's discuss a very simple illustrative example. Let's imagine that one wishes to buy a new car and wants to decide among the existing alternatives on the market. Let's also imagine that her/his choice would depend on four main criteria: economic, safety, aesthetic and driving. In order to describe the mechanism of decision it is necessary to specify first the criteria (dimensions of performance) taken into account **by a given buyer, since it is not possible to know all the potential criteria which are used by the universe of non-equivalent buyers operating in this world.** Whatever is the selection of criteria considered, however, it is sure that some of the criteria (measured by their relative indicators) will result: (1) *technically incommensurable* (price in dollars, speed in Km/h, fuel consumption in liters of gasoline used for 100 Km and so on), and (2) *conflicting in nature* (e.g. the higher the safety characteristics required the higher the economic cost). The performance of any given alternative, according to the set of relevant criteria can be characterized through a multicriteria impact profile, which can be represented either in a matrix form, as shown in **Fig. 5.4** or in a graphic form, as shown in **Fig. 5.5**. These multicriteria impact profiles can be based on quantitative, qualitative or both types of criterion scores.

Another crucial feature related to the available information for decision-making concerns the uncertainty contained in this information (i.e. how reliable are the criterion scores contained in the impact matrix). Whenever it is impossible to establish exactly the future state of the problem faced, one can decide to deal with such a problem either in terms of *stochastic uncertainty* (thoroughly studied in probability theory and statistics) or in terms of *fuzzy uncertainty* (focusing on the ambiguity of the description of the event itself) (Munda, 1995). However, one should always be aware that genuine ignorance is always there too. This predicament is particularly relevant when facing sustainability issues, because of large differences in scales of relevant descriptive domains (e.g. between ecological and economic processes) and the peculiar characteristics of adaptive systems (adaptive systems are self-modifying and becoming systems – see the relative discussions in Chapter 2 and Chapter 3). In these case it is unavoidable that the information used to characterize the problem is affected by subjectivity, incompleteness and imprecision (e.g., ecological processes are quite uncertain and little is known about their sensitivity to stress factors such as various types of pollution). A great advantage of multicriteria evaluation is the possibility to take these different factors into account.

* *Formalization of a problem structuring through a multicriteria impact matrix*

A very familiar example of an impact matrix related to the structuring of a decision process is provided in **Fig. 5.4**. This is a typical multicriteria problem (with a discrete number of alternatives) which can be described in the following way: A is a finite set of n feasible policy options (or alternatives); m is the number of different evaluation criteria g_i $i=1, 2, \dots, m$ considered relevant in a decision problem, where the action **a** is evaluated to be better than action **b** (both belonging to the set A) according to the i-th criterion if $g_i(a)>g_i(b)$. In this way a decision problem may be represented in a tabular or matrix form. Given the two sets of: A (of alternatives – in this case models of car to buy) and G (of evaluation criteria in this case 4 criteria). Assuming the existence of n alternatives and m criteria, it is possible to build an $n \times m$ matrix P called an evaluation or impact matrix (see **Fig. 5.4**) whose typical element p_{ij} $(i=1, 2, \dots, m; j=1, 2, \dots, n)$ represents the evaluation of the j-th alternative by means of the i-th criterion. Obviously, to have a process of decision in a finite time, n and m in such an impact matrix have to be finite and data should be available to characterize the various options.

* *A graphical view of the impact matrix: Multi-Objective Integrated Representation (MOIR)*

The graph shown in **Fig. 5.5** (a different representation of the information presented in the impact matrix given in **Fig. 5.4**) is an example of Multi-Objective Integrated Representation (= a set of different indicators reflecting different criteria of performance selected in relation to different objectives associated to the analysis). In this way, we can visualize in a graphical form the information given **Fig. 5.4**. This form of graphic representation is getting quite popular in the literature of integrated analysis.

The popularity of this graphic form is due to some additional features possible on the resulting problem structuring. In the graph shown in **Fig. 5.5** (starting with the same problem structuring given in **Fig. 5.4**), there are 12 *indicators*, indicated by the 12 axes on the radar diagram (e.g. price, maintenance costs, fuel consumption). These indicators can be grouped into 4 main *dimensions* of performance or *criteria* (economic, safety, aesthetic and driving). *Goals* (for each indicator) can be represented as target values over the set of selected indicators. In **Fig. 5.5** they are indicated by the bullets on the various indicators in the radar diagram.

In this way, it is possible to bridge three different hierarchical levels of analysis: (1) the definition of performance in general terms, obtained by selecting the set of different relevant dimensions. This is associated to the answers given to a set of semantic questions about sustainability (sustainability of what? for whom? on which time horizon?), (2) the formulation of general objectives in relation to the selection of indicators (what should be considered as an improvement or a worsening in relation to the different criteria and indicators, where are the goals, what should be considered as acceptable). This makes possible to reflect the perspectives found among the stakeholders, and (3) translation of these general principles into a numerical mapping of performance over a set of indicators and measurement schemes required for data collection which are necessarily context specific (location specific description). At this point a Multi-Scale Integrated Analysis based on the simultaneous scientific analysis of different attributes (using non-equivalent descriptive domains) requires a tailoring of the semantic of the problems structuring into a "context specific" formalization (required to perform scientific analyses).

When dealing with a graphic representation of this type, it becomes possible, to discuss about the definition of:

(a)

special threshold values (e.g. a limited budget of money for buying the car) implied by the existence of *constraints* on the value that can be taken by the criteria or attributes. In this case a set of constraints defines a *feasibility region* (i.e. a set of constraints defines what can be done or carried out). In the example given in **Figure 5.5**, the feasibility region would be the area on the radar diagram.

(b)

areas in the admissible range of values associated to qualitative differences in performance. This requires a previous process of normalization on benchmark values within the viability domains. For example, the "flag model" developed in the school of Nijkamp (e.g. at: http://www.tinbergen.nl/discussionpapers/97074.pdf) proposes three sections within the viability domain: (1) good (in green) – data in this area indicate a good state of the investigated system in relation to a given indicator; (2) acceptable (in yellow); and (3) unsatisfactory (in red).

Also in this case things look good on paper, but as soon as one tries to get into the process of definition of the various viability domains one is forced to admit the limitations implied by the epistemological predicaments already discussed in Chapter 2 and 3: (a) any procedure of "normalization" and definition of "performance score over areas" in the admissible range is unavoidably affected by value judgment, and (b) any assessment of viability, compatibility and acceptability into the future is affected by an unavoidable dose of uncertainty and ignorance.

5.4 The deep epistemological problems faced when using these tools

5.4.1 The impossible compression of infinite into finite required to generate "the right" problem structuring

As noted earlier scientists working on MSIA in order to be able to provide the right set of data and models require to receive from the social actors an agreed upon and closed problem structuring. That is a formal definition of what is the problem in the form of a specification of what type of scientific information is required for characterizing it. A closed problem structuring, in turn, requires a previous clear definition of the goals of the analysis. This implies that every social process used to select a policy or to rank options requires, in the first place, an operational definition of an agreed upon set of common "values" for the community of social actors. In the example of Fig. 5.5, this would be a preliminary definition of what would be "a valuable car" for the household buying it. On the other hand, the very concept of the unavoidable existence of non-equivalent observers/agents entails the existence of different interests, differences in cultural identities, different fears and goals. Even different individuals within the same household can have different definitions of what is "a valuable car" for them. As consequence of this, when considered one at the time, social actors would provide different definitions of what is the right set of criteria and indicators which should be used to reflect their own definition of "value" in the decision. This set of values is then difficult to aggregate to reflect the set of values adopted by the household as a whole when deciding what car to buy.

When assessing policies or ranking technical options we are first of all making a decision about **what is important** for the community of the social actors (as a whole) as well as **what are the relevant characteristics** of the problem described in the models. This requires addressing three different problems: (1) exploring the variety of legitimate non-equivalent perspectives found among the social actors (this is especially relevant for normative purposes), (2) generating the best possible representation of the state of the art knowledge relevant for the decision to be made (this is especially relevant for descriptive purposes), and (3) trying to find a fair process of aggregation of contrasting preferences and values (this is crucial to have a fair process of governance).

An overview of the challenge faced when attempting to generate a "fair" and "effective" problem structuring, within a process of decision making is given in **Fig. 5.6**. Very little explanation is needed to illustrate this overview. Three relevant points are:

(1) Any problem structuring implies a "mission impossible" of compressing a virtually infinite and unstructured universe of discourse and values (goals, organized perceptions, meanings, epistemological categories, alternative models) which could be used in the problem structuring, into a finite and structured information space. It is therefore sure that each problem structuring is missing relevant aspects of the problem and is reflecting a power struggle among social actors;

(2) the pre-analytical step of compression of the virtually infinite and unstructured universe of discourse into a finite and structured information space is the most crucial step of the whole process of decision making. In this step, basically whatever relevant for determining the decision is already decided. That is: (a) whose perspectives do count; (b) whose alternatives should be considered among the possible choices; (c) what are the criteria and indicators to use in the characterization of the possible alternatives; (d) what are the models to use to represent causality and to construct scenarios; (e) what data should be considered as reliable. It is remarkable that **this step is not object of any discussion by reductionist scientists.** Reductionist science in order to operate must have a closed problem structuring as a starting input. **The discussion of how to generate this finite and structured information space, however, is not included in the realm of scientific activities.** It is important to keep in mind that when one is working on formal models everything that is relevant for a discussion about "how to help social actors with different perspectives to negotiate a compromising solution" is already gone.

(3) It is impossible to do this compression in a "satisficing" way (as suggested by H. Simon, 1976 & 1983 instead of "optimal") way in a single step. Therefore, we should expect that any sound process of decision making related to sustainability cannot be the result of a single process of individuation of the optimal alternative. Rather we should expect an iterative process of problem structuring and discussion (exploring different possible ways of compressing and structuring the universe of discourse into a finite information space). This can imply going over and over the compression performed in the step 2. This would be the process of negotiation among different stakeholders with legitimate non-equivalent perspectives to arrive to an agreed upon problem structuring. The usefulness of scientific analyses based on the "finite information space ***i***" – obtained in the step ***i*** - is mainly related to the possibility to generate a better compression of the universe of discourse into a different "finite information space ***i+1***" – obtained in the step ***i+1***. This goal should be considered more important than that of individuating the "best" course of action in the final step ***n*** – within the final "finite information space ***n***". In becoming systems it is impossible to reach the final step determining the "most suitable" information space to be used in decision making. Therefore, we should rely on the metaphor of the Peircean triad (**Fig. 4.2**) visualizing a continuous process of learning how to make better decisions.

5.4.2 The Bad Turn Taken by Algorithmic Approaches to Multi-Criteria Analysis

The implications of the first compression shown in **Fig. 5.6** have always been clear to smart economists. For example, Georgescu-Roegen (1971) talks of "heroic compression" implied by the choices made by scientists when representing the complexity of reality into a given model. Schumpeter (1954, p.42) observes that: "Analytical work begins with material provided by our vision of things, and this vision is ideological almost by definition." Myrdal (Nobel Prize in economics) states: "that ignorance, as the knowledge is intentionally oriented" in his 1966 books "Objectivity in Social Science."

But even when ignoring the implications of this "heroic compression," as done by many neo-classical economists nowadays, a lot of problems remain. In fact, things are still quite messy also when dealing with the second compression indicated in **Fig. 5.6.** How to decide the best alternative in face of uncertainty, legitimate contrasting views and incommensurable indicators, which still are affecting the information space considered in the given problem structuring? Put in another way, even if one can start from a multicriteria information space finite, discretized and assumed to be valid - as shown in **Fig. 5.4** or **Fig. 5.5** - things are still not easy when coming to selecting a final decision. Such a second compression still requires the ability of dealing with information coming from a heterogeneous information space made up of a set of indicators referring to non-equivalent descriptive domains (dealing with technical incommensurability). This requires handling and comparing several dimensions of performance that can only be analyzed using non-reducible models (models assessing profits are not reducible to models assessing ecological integrity).

The troubles associated to the formalization of the universe of potential perceptions and existing values into a closed and finite problem structuring point at an additional problem. Not only the double compression indicated in Fig. 5.6 and obtained at a given point in time is a mission impossible, but also one should be aware that the universe of potential perceptions and existing values is **open and expanding**! As already observed in Chapter 4 and as discussed again in the section of complex time in Chapter 8, when dealing with sustainability we must acknowledge that **both the observed and the observer are becoming in time.**

The reaction of reductionism when facing this challenge followed (and it is still following in different contexts) the standard strategy. First of all a total denial: "there is nothing that cannot be reduced to Cost/Benefit Analysis." That is, try to ignore the problem until it will disappear. The majority of neo-classical economists working on Cost/Benefit Analyses to deal with problems that would require MSIA and SMCE, in fact, operate under such an assumption. They seem to believe that it is possible: (a) to reduce all types of costs and benefits into a single mapping expressed in monetary value (e.g. US$ of 1987); and (b) to aggregate in a neutral ("objective") way all the different perspectives found among the stakeholders about what should be considered as "a cost" and what should be considered as "a benefit". In spite of their clear "untenability" these assumptions are needed to escape such an impasse. This has led to a situation in which even experts of Cost-Benefit Analysis such as E.J. Mishan complain about the misuse of such a tool. CBA is a useful tool, but it should not be applied well outside its original domain of competence (e.g. see Mishan, 1993). These two assumptions, however, are held because of their huge ideological implications. They are required to defend the claim that it is possible to handle in a "scientific way" ('neutral, value-free' assessment) the weighting of different typologies of performance (equity versus profit, social stress versus ecological integrity, values of a social group versus values of another social group). A huge amount of literature is available providing technical arguments attacking these assumptions (e.g. an overview in O'Connor and Spash,1998; Mayumi, 2001). Personally, I do not believe that a lot of disciplinary discussions are required to assess their credibility. A simple practical reflection can do it. This means assuming that when facing a tough decision related to an important conflict in social systems (e.g. dispute about world trade of GMOs) the happiness and the health of your children, the 'value' of your mother, and the memory of your cultural heritage can be: (a) first measured and expressed in US$ of 1987; and then (b) compared with the value of someone else's children, mother and cultural heritage. Very few people can really believe that this is possible in their heart.

This is why smarter reductionists realized that the reduction/collapse of different typologies of performance using a single variable like "US$ of 1987" (or MJ of fossil energy) is a mission impossible. Smarter reductionists realized that those assumptions in spite of their ideological relevance cannot be held any longer. This is why the second attempt to keep the claim of a "neutral-value-free" input of science in the process of decision making was aimed at operationalizing in a technocratic way Multi-Criteria Analysis (MCA). The gospel remained always the same: "if human mind cannot handle the simultaneous analysis of non-equivalent indicators characterizing multiple options, computers will." The Impact Matrix represented in Fig. 5.4 is an example of a formalization of the problem structuring associated to a multi-criteria evaluation of cars at the moment of purchasing one. I have not enough competence or space to get into a detailed analysis of the formalist/algorithmic approach to MCA. Such a field is quite established with a huge amount of literature available. Even manuals sponsored by government are nowadays available (e.g. Dogson et al. 2000). I am dealing in this section only with an analysis of the impossibility of using the information provided by this impact matrix to calculate in an algorithmic way "the best possible car" to buy. The main point I want to drive home is that in spite of its "reassuring" formal look, this impact matrix hides a lot of problems.

To short cut long discussions let's use a couple of trivial examples:

* *Incommensurability among the different indicators of performance and coexistence of legitimate constrasting perspectives*: In my life, I have adopted the two profiles of "satisficing performance" (the two illustrated in **Fig. 5.5**) when buying a car. A profile of satisficing performance reflects the particular selection of weighting factors chosen to weight the priorities among different attributes of performance. Actually, the two profiles shown in **Fig. 5.5** can be used to study the differences in my mechanisms of evaluation associated to different historic moments of my life. When I was a student with a low income (line 1), none of the criteria represented in **Fig. 5.5** were relevant for the purchasing of a car but that of being cheap. However, as soon as I became a father of two with a tenured position, the profile of my multicriteria satisfaction for the buying of a car changed (the second profile – line 2 - is self-explanatory). In this example, we can see that even for the same person it is not possible to define a "default" weighting profile among different indicators of performance referring to different criteria. As a consequence, a committee made up of the best experts in the world cannot decide what should be considered an optimal car (used where? for whom? for doing what? when?)!

* *Unavoidable handling of non-reducible assessments referring to non-equivalent descriptive domain:* Any numerical assessment refers to our representation of our perception of the reality and therefore is affected by choices made by the observer. As discussed in the example of **Fig. 3.1** (Chapter 3) even a simple "hard" measurable number such as the "kg of cereal consumed in 1997 per capita in the USA" can exhibit multiple identities depending on the reason why we want such an assessment.

As already noted at the end of section 3.1 the differences in the 4 non reducible assessment of "US cereal consumption per capita in 1997" given in **Fig. 3.1** do not imply that any of these assessments is wrong or useless. Each one of those numerical assessments could be the right one (useful information) depending on the interests of the social actors. This is why it is important to develop procedures that enable the integrated handling of a heterogeneous information space. Otherwise we could find two different scientists fighting over a Multi-Criteria Impact matrix about the numerical value to be assigned to a cell, without understanding that the number to be used in the process of benchmarking on a given indicator depends on a lot of assumptions that have to be explicitly discussed in the process of generation of the integrated assessment.

* *Unavoidable existence of uncertainty and ignorance.* Going back to the example of the problem structuring related to the choice of a car to buy. When going for a short sabbatical in Madison with my family, in January 2002, I had to actually get into a process involving an MCIA and SMCE for buying a car for real. In the process that led to the closure of our information space (the formal problem structuring adopted by our household) we – as a family - did not include a lot of indicators that other people may have included. For example, we did not considered the environmental impact of our choice (we selected a big old car for safety and economic reasons). Probably this was due to the fact that we were buying a car only for 5 months and while operating abroad. Another explanation could be that we did not had available a valid model to associate our personal choice of a car to possible consequences in the short, medium and long period on the health of the environment. That is, for the environment it is better to buy an old big car, which is recycled, or a new car which is more energy efficient?

There is another important criteria/indicator that was missing in our selected problem structuring: the relation between the size of the garage of our rented house and the size of the car to be purchased! Our big car did not fit into our garage, and we had to leave it out through the freezing winter months of Madison. Every morning from January to late March, when de-icing the windows and taking away the snow before using the car I regretted our ignorance about the relevance of that indicator . . .

* *Unavoidable existence of conflict among social actors.* What is illustrated in **Fig. 5.7** (also called social impact matrix) is a complementing analysis of the matrix shown in **Fig. 5.4**. This has to do with the study of conflict analysis. This time, the matrix is constructed by judging the different options in relation to the interests/opinions of the various social actors. Obviously to do that it is necessary to ask them. Also in this case (I am again applying this matrix to our family decision to buy a car in Madison) the figure is self-explanatory. The different stakeholders in my family had different power in the process of decision making. My wife, as designated taxi-driver, had veto power. Then the other members of the family had a decreasing influence on the basis of their accumulated experience about cars. Obviously, our process of decision making was strongly influenced by such a ranking. But what if the concern of my younger daughter Sofia ("it must be red") would have suddenly became relevant? Let's imagine that Sofia were given suddenly (by a political decision) a "veto power" on the selection process. Obviously, the whole problems structuring, starting with the selection of the set of alternatives considered in the matrix and the data collection in the field, would have to be completely different! Actually, none of the used cars we evaluated in the process of selection was red! Deciding about the validity of the scientific information included in the problem structuring (often considered to be as a 'scientifically substantive' input) has a lot to do with power relation among the social actors. In fact, this is what determines the identity of the option space about which the scientific input is required

Also in this case, I am providing trivial examples of very sophisticated procedures and tools.

Several methods have been developed for introducing conflict analysis in a frame of Multicriteria Decision Support. One example is NAIADE - Novel Approach to Imprecise Assessment and Decision Environments – which is structured in a software – for applications see http://alba.jrc.it/ulysses/voyage-home/naiade/naiade.htm . For an overview of similar methods see also http://www.dodccrp.org/Proceedings/DOCS/wcd00000/wcd00091.htm .

5.4.3 Conclusion

Several protocols for decision-making can be based on the application of predetermined algorithms to an impact matrix as the one shown in **Fig. 5.4.** These protocols often require an input from the social actors (e.g. how to weight the differences in priorities in relation to different attributes and non-equivalent criteria). However, the adoption of algorithmic protocols must assume: (a) the validity of a given problem structuring (as it this were a substantive definition of the "right" problem structuring); and (b) the possibility to select an optimal solution in a single process. On the contrary, from the examples discussed so far, I claim that the two processes of Multi-Scale Integrated Analysis and Societal Multi-Criteria Evaluation are different activities depending on each other. They cannot be either collapsed into a single one or held separated in time. They have to be performed in an iterative process. This does not mean, obviously, that it is impossible to find cases in which algorithms and softwares can result very useful in a process of decision making based on the adoption of multicriteria methodologies. Rather this is a warning against the application of these formal protocols without an adequate quality control on the relative semantic.

Coming to the representation of different matrices in **Fig. 5.4** and in **Fig. 5.7** and the two heroic compressions illustrated in **Fig. 5.6,** there are three tasks that are crucial in relation to this process.
(1) definition of the identity of the two matrices, in terms of legends of the matrices. For the matrix shown in Fig. 5.4: what are the relevant criteria? What are the indicators and the target values used to assess the performance on each indicator? What are the alternatives to be considered?. For the matrix shown in Fig. 5.7: who are the relevant actors? What is their relative power? Who has veto power? How acceptable is, in ethical terms, present situation?;
(2) what has to be included as valid data set inside the cells of the matrix (how to measure the values taken by the various indicators in the various options/alternatives considered? how reliable are the assessment included in he various cells).
(3) how to decide what is the "wisest" course of action on the basis of a given problem structuring (the representation of options, criteria and indicators obtained in task (1) and (2).

The term "wisest solution" has been suggested by Bill Bland (personal communication) as opposed to optimal solution. The term "wisest", in fact, refers to the need of reaching an agreement on the definition of something that is perceived by the various social actors (after a process of negotiation) as ***feasible***, ***desirable***, ***satisficing***, ***reasonable*** according to previous knowledge and ***prudent*** in relation to the unavoidable existence of uncertainty and ignorance.

5.5 Soft Systems Methodology: developing procedures for an iterative process of generation of Discussion Support Systems (Multi-Scale Integrated Analysis) and Decision Support Systems (Societal Multi-Criteria Evaluation)

5.5.1 Soft System Methodology

In this section we provide a quick resume of crucial concepts introduced by Checkland and others (Checkland, 1981; Checkland and Scholes, 1990; Roling and Wagemakers, 1998) dealing exactly with the impasse typical of science for governance discussed in this and the previous chapters. Since Checkland has done an outstanding work in this direction for more than 30 years it is wise to use his own words to present his approach.

A paragraph taken from the introduction of the book of Checkland and Scholes (1990, pag. xiii) explains beautifully the basic rationale of SSM.

"*Soft Systems Methodology (SSM) was developed in the 1970's. It grew out of the failure of established methods of 'systems engineering' (SE) when faced with messy complex problem situations. SE is concerned with creating systems to meet defined objectives, and it works well in those situations in which there is such general agreement on the objectives to be achieved and the problem can be thought of simply the selection of efficacious and efficient means to achieve them. A good example would be the USA's programme in the 1960s with its unequivocal objective of 'landing a man on the Moon and returning his safely to Earth'(President Kennedy's words). Not many human situations are as straightforward as this, however, and SSM was developed expressly to cope with the more normal situation in which the people in a problem situation perceive and interpret the world in their own ways and make judgments about it using standards and values that which may not be shared by others*".

Taking advantage of the extraordinary clarity of the introductory chapters of that book I will use again groups of statements, which are related to the points discussed so far in this chapter and in the previous ones.

The special approach of SSM is crucial when dealing with science for governance

* *Thus theory must be tested out in practice; and practice is the best source of theory. In the best possible situation* ***the two create each other in a cyclic process*** *in which neither is dominant but each is the source of the other* (pag. xiv).

* *To 'manage' anything in everyday life is to try to cope with a flux of interacting events and ideas which unrolls through time. The 'manager' tries to 'improve' situations which are seen as problematical – or at least as less than perfect – and the job is never done (ask the single parent!) because as the situation evolves new aspects calling for attention emerge, and* ***yesterday's solutions' may now be seen as today's 'problems'*** (pag. 1).

* *Mankind finds an absence of meaning unendurable. We are meaning-endowing animal, on both the global long-term and the local short term level. Members of organizations, for example, tend to see the world in a particular way,* ***to attribute at least partially shared meaning to their world*** (pag. 2).

* ***But what an observer sees as wisdom may to another be blinkered prejudice*** (pag. 3).

* His definition of system = *a set of elements mutually related such that the set constitutes a whole having properties as an entity* (pag. 4); or = ***a whole with emergent properties*** (pag. 21).

* *Pruzan (1988) lists a number of the shifts entailed in a move from "classic" to "soft"* Operational Research *(though he himself does not use that phrase):* ***from optimization to learning; from prescription to insight; from 'the plan' to the 'planning process'; from reductionism to holism. . . . from an approach aimed at optimizing a system to an approach based on articulating and enacting a systemic process of learning.*** (pag. 15)

The lessons that led to the peculiar characteristics of SSM

* *The Lancaster researchers started their action by taking hard systems engineering as a declared framework and trying to use it in unsuitable situations, unsuitable, that is, in the sense that they were* ***very messy problem situations in which no clear problem definition existed.*** (about the emergence of SSM pag. 16).

* ***If the system and its objectives are defined,*** *then the process is to develop and test models of alternative systems and to select between them using carefully defined criteria which can be related to the objectives. . . .* ***Systems engineering looks at 'how to do it' when 'what to do' is already defined. . .*** *This was found to be the Achilles'heel of systems engineering, however, when it was applied in the Lancaster research programme, to ill-defined problem situations. Problem situations, for managers,* ***often consist of no more than a feeling of unease, a feeling that something should be looked at . . .*** *This means that* ***naming a system to meet a need and defining its objective precisely – the starting point of systems engineering – is the occasional***

special case *(pag. 17).*

* *What was found to be needed was a broad approach to examining problem situation in a way which would lead to decisions on action* ***at the level of both 'what' and 'how'. The solution was a system of enquiry.*** *In it a number of notional systems of purposeful activity which might be 'relevant' to the problem situation* ***are defined, modelled, and compared with the perceived problem situation in order to articulate a debate about change, a debate which takes in both 'whats' and 'hows'*** (pag. 18).

The basic features of SSM in relation to Post-Normal Science

* *. . . the description of any purposeful holon must be from some declared perspective or worldview. This stems from the special ability of human beings to interpret what they perceive. Moreover, the* ***interpretation may, in principle, be unique to a particular observer. This means that multiple perspectives are always available*** (pag. 25).

* *. . . we have a situation in everyday life which is regarded* ***by at least one person as problematical,*** *There is a feeling that this situation should be managed . . .* ***in order to bring about 'improvement'.*** *the whats and the hows of the improvement will all need attention, as will consideration of through* ***whose eyes 'improvement' is to be judged.*** *The situation itself, being a part of human affairs, will be a product of a particular history,* ***a history of which there will always be more than one account*** *. . .*
we have to learn from the relative failure of classical management science, since that is surely due to ***its attempt to be abistorical*** [note = based on the characterization of situations based on the use of typologies out of time] *. . . we are not indifferent to that logic, but are concerned to go beyond it to enable action to be taken in the full* ***idiosyncratic context of the situation, which will always reveal some unique features*** [note = all real situations are special] (pag. 28).

* *a number of purposeful holons in the form of models of human activity are represented in the form of systems which* ***are named, modelled, and used to illuminate the problem situation.*** *This is done by comparing the models with perceptions of the part of the real world being examined. What is looked for in the debate is* ***the emergence of some changes which could be implements in the real world and which would represent an accommodation between different interests.*** *It is wrong to see SSM simply as consensus-seeking. That is the general case within the general case of seeking accommodation in which the conflict endemic in human affairs are still there, but are* ***subsumed in an accommodation which different parties are prepared to 'go along with'*** (pag. 30).

* ***Which selected 'relevant' human activity systems are actually found to be relevant to people in the problem situation will tell us something about the culture we are immersed in.*** *And knowledge of that culture will help both in selection of potentially relevant systems and in delineation of changes which are* ***culturally feasible*** (pag. 30).

* *No human activity system is* ***intrinsically*** *relevant to any problem situation, the choice is always subjective. . . In the early years of SSM development, much energy was wasted in trying at the start to make "****the****" best possible choice.* ***(This at least was better than the very earliest attempts to name the relevant system, in the singular!)*** (pag. 31).

About the proposed procedure (CATWOE) to apply SSM

* *. . . pay close attention to the formulation of the names of relevant systems. These had to be written in such a way that they made possible to build a model of the system named. The names themselves became known as 'root definitions' since they express the core or essence of the perception to be modelled"* (pag. 33)
[note = in the previous chapters I proposed the expression "identity" and "multiple-identities" to indicate the set of names given to our non-reducible perceptions of a given system].

* *The positive aspect of the use of more complex models is that it might enrich the debate when models are compared with the real world. The negative aspect is that the increased complexity of the models* ***might lead to our slipping into thinking in terms of models of part of the real world, rather than models relevant to debate about change in the real world.*** (pag. 41)
[note = in Chapter 2 I suggested the expression **complicated models** to indicate models with a large

number of variables, more parameters, non-linear dynamics. Rather complexity in the view proposed in this book has to do with addressing the semantic aspect related to the use of inferential systems. Adopting the vocabulary used in this book, therefore, the authors are referring in this passage to "complicated models"].

* *Once a model of a purposeful holon exists . . . . then it may be used to structure enquiry into the problem situation. However, before using the model as a tool . . . most modellers will probably be asking themselves if their intellectual construct is adequate, or valid. Since the model does not purport to be* ***a description of part of the real world*** - but rather - ***merely a holon*** **[note = the author means with this term the representation of a given shared perception]** ***relevant to debating perceptions of the real world,*** *adequacy and validity cannot be checked against the world. Such models are not, in fact, 'valid' or 'invalid', only technically defensible or indefensible.* (pag. 41)

* *Models are only a means to an end which is to have a well structured - and shared representation of the perception of a problem situation to be used in the debate about how to- improve it. That debate is structured by using the models based on a range of worldviews to question perceptions of the situation* (pag. 43)

5.5.2 The procedural approach proposed by Checkland with his Soft System Methodology

A quick presentation of the procedural approach proposed by Checkland is given below. This presentation is taken from the book of Allen and Hoekstra (1992) "*Toward a Unified Ecology*". We decided to use this narrative because of two points: (1) Allen and Hoekstra propose in their book an epistemology framed within complex systems theory; (2) the reference to SSM as a problem solving engine is directly related, in their book, to the issue of sustainability with a specific reference to multiple land use and ecological compatibility.

The steps identified by Allen and Hoekstra (1992 – pag. 308 – 316)

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Step 1 – *Feeling the disequilibrium, recognizing that there is a problem even if it is not clearly expressed.*
If we accept that a problem is the existence of a gradient between: (a) our perception of the reality; and (b) our expectation about the reality, it becomes immediately clear that even reaching an agreement on the existence of a problem is everything but trivial. The denial of the existence of problems that would require a discussion of the identity of those in power is a well known phenomenon in human affairs (e.g. the ego denying the process of ageing, academic institutions denying the need of changing the way a disciplinary field is taught, the government denying the existence of economic problems).

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Step 2 – *After intuiting that there is a mess* ("mess" is regarded here as a technical word 'that couches the situation in terms that recognize conflicting interests' – pag. 309) *the second step is to generate actively as many points of view for the system as possible. Checkland calls this stage "painting the rich picture" or the "problem situation expressed". The distinctive feature here is not the building of a model that has a particular point of view, but rather taking into account of as many explicitly conflicting perspectives as possible. It is the richness of the picture which is important at this stage, not the restricted mental categories one might create to deal with it.*
We can use an analogy with the quality of digital images. We know that depending on the number of pixels per cell we can have a better quality in the image, no matter what type of image will be shown on the screen. In the same way, the ability of perceiving the same process or facts using a wider set of non-equivalent detectors, mechanisms of mapping, epistemic categories will provide more robustness to the

final image. This is a characteristics of the process of representation that will hold, whatever we will be decided to be the subject focused by the camera.

****

Step 3 – *The third stage is the most critical, and involves the explicit development of abstractions. It puts restrictions on the rich picture in the hope of finding a workable solution. Checkland calls this stage finding the root definitions.*
This is the stage at which we have to decide **how to identify and represent our problem situation.** A formal problem structuring requires (as noted in Chapter 3 and Chapter 4) first of all a semantic problem structuring. That is the analyst must be able to answer a family of basic questions: What is the system of interest? What is this system doing? Why is this relevant? Relevant to whom? What are the criteria used to decide that? What are the system attributes that produce the conflicts and the unease that generated the willingness to get into the first step of the process?

As noted in Chapter 2 and 3 depending on the various perceptions of the physical structure of the system of interest we should expect to find different identities for the same system. These identities will change depending on the scale or the points of view adopted.

About the existence of multiple-identities required for a useful problem structuring Allen and Hoekstra observe (ibid pag. 313) "*It is important to realize that the several different sets of root definitions are not only possible, but desirable*".

The heuristic tool suggested by Checkland for dealing with the delicate step of deciding about a set of useful "root definitions" (identities) for the problem structuring is based on the use of the acronym CATWOE. The six letters of the acronym stand for (again these a re quote from the book of Allen and Hoekstra):

C = *is the client of the system and analysis – for whom does the system work. Sometimes the "client" is the person for whom the system does not work, namely the victim.*

A = *refers to the actors in the system.*

T = *are the transformations or underlying processes. What does the system do? What are the critical changes? These critical transformations are generally performed by the actors.*

W = *Weltanschauung (World view) = identifies the implicit world view invoked when the system is viewed in a particular manner. This defines the set of phenomenon of interest.*

O = *refers to the owner of the system, who can pull the plug on the whole thing.*

E = *identifies the environment, that is what the system takes as given. By default, the environment defines the scale of the system extent by being everything that matters which is too large to be differentiated.*

In order to bridge this analysis to what presented in the previous chapters we can "translate" now this vocabulary into what is generally found in the literature of Integrated Assessment and Multi-Criteria Analysis.

Three of these letters C, A, and O refer to different categories of relevant social actors (which are not mutually exclusive, but rather overlapping). Before discussing the differences let's first of all start with the standard definition of "stakeholder" (a technical terms often used to refer to relevant social actors) found in the literature of MCA:
Stakeholders are those actors who are directly or indirectly affected by a issue and who could affect the outcome of a decision making process regarding that issue or are affected by it.

The suggested non-equivalent categories of social actors can be interpreted as follows:

* Clients = these are "the stakeholders that are ethically relevant in relation to the Weltanschauung (World View) in which the process of decision making is taking place". For example, when dealing with sustainability these Clients could be the future generations. They can be non-agents, they do not have power in the negotiation, but still their perspective can result relevant and should be included for ethical reasons. Obviously, it is essential to start the process with a clear picture of what are the stakeholders that are ethically relevant, since the integrated assessment has to include indicators able to detect the effects that our decision will have on them.

* Actors = these are "the stakeholders that are relevant agents within the mechanisms determining the set of phenomenon of interest". Also in this case, it is essential to start with a clear picture of what are the stakeholders that are agents, in order to be able to consider in our models and future scenarios the possible reactions of these agents to the changes implicit by the selected actions or policies. Agents not necessarily have a strong negotiating power in the process. For example, poor marginal farmers can decide to increase the pressure on free natural resources because of bad policies of central government. In this case, if the result of this overexploitation is just a decrease of their local sustainability and material standard of living (e.g. deforestation or soil erosion) we are dealing with an example of relevant agents without negotiating power in the process of decision making.

* Owner = these are "the stakeholders with a clear power asymmetry in the process of negotiation used to define what are the perceptions that count when defining the problem structuring". Also in this case, it is essential to start with a clear picture of the existing power structure among the considered set of: (a) relevant stakeholders (Clients) and (b) agents (Actors). In fact, going back to the scheme presented in **Fig. 5.6** and the example of Social Impact Matrix presented in **Fig. 5.7** such a relation will result essential in determining whose perceptions, goals, vetoes will be more important in the process of selection of a "semantic problem structuring" which will then be translated into a relative formal problem structuring.

The definition of these three categories (C, A, & O) has to do with relevant issued in relation tot he normative side (APPLY in **Fig. 4.2**).

The other two letters T and E refer to choices related to our representation of facts. Also in this case it is possible to relate these letters to concepts presented and discussed in previous chapters.

* **Transformations** refers to the set of modeled behaviors (e.g. inputs transformed into outputs) resulting from the choice of encoding variables and inferential systems used to describe the reality within the selected representation of relevant perceptions. That is, these are the transformations included in the simplified representation of the reality obtained through modeling. Each one of these transformations represented within individual models refer to a particular dynamics which is simulated using a simple time (following a triadic reading of nested holarchies).

* **Environment** refers to the set of assumptions about the compatibility of initiating conditions (stability of structural elements) and admissibility of boundary conditions (stability of the meaning of a given function in a given associative context). These are the assumptions required for the triadic reading (modeling in a given descriptive domain) of complex systems organized in nested hierarchies. The definitions of what should be considered as Environment has to do with choices made by the modelers about the potential obsolescence of the models used to represent transformations and therefore the scale (time differential and time horizon for the validity of the model). When the becoming reality change in relation to the selected models, the representation of transformations loses validity.

The definition of these two categories (T & E) has to do with the descriptive side (REPRESENT in Fig. 4.2).

Finally the last letter W directly related to how both the descriptive side and the normative side are affecting each other.

* Weltanschauung (World View) refers to the pre-analytical set of choices about: (a) what should be

considered as the universe of relevant facts (the universe of discourse within which analysts look for explanations and models); and (b) how to structure the representation in this universe (after deciding what has to be given priority on the rest in relation to agreed upon goals). This pre-analytical set of choices is related to the evolution of the system of knowledge within which the process is taking place. This is where the history of the social group enters into play affecting how a particular social group will end up representing their shared perception of the reality (Fig. 4.2). According to this history (the past experience of the human group) and the virtual future (aspirations and wants expressed at the level of the whole group) the modelers have to define who is belonging to the three categories of C, A, and O, when organizing the normative side, and chose how to define T and E when deciding about the descriptive side. As observed several times the definition of C, A, and O will affect the way the modelers select and define T, E. The reverse is also true, the definition of T and E, will affect the way C, A, and O are perceived and individuated. The result of this convergence in the past is what determines the starting point of this reciprocal definition now (the current weltanschauung). However, when discussing of complex time we already addressed the problem of the potential obsolescence of the validity of the pre-analytical choices required for selecting identities and multiple-identities (or "root definitions") in any problem structuring.

The definition of this category (W) therefore has to do with the challenge of keeping coherence in the process leading to a shared perception of the reality in relation to action and the relative representation. This has to do with TRANSDUCE (Fig. 4.2).

Before getting back to the list of the remaining 5 steps it is opportune to have a look at the overview of the representation of the iterative process given by Allen and Hoekstra which is illustrated in **Fig. 5.8.**
The first 3 steps belong to a large iterative loop (that indicated by black arrows). Whereas the step 3 (= reaching an agreement on the definition of a semantic problem structuring) which resonates with step 6 (= deciding about the validity of the formalization of the semantic problem structuring) belongs to an additional internal loop (that indicated by the red arrows) related to the need of a quality control on the effective convergence between the information referring to the normative and descriptive side.

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Step 4 – *The fourth stage is that of building the models. There will need to be a different model for each set of alternative root definitions.* [note = non-reducible models for non-equivalent identities]
In this step the various modelers coming from different scientific disciplinary backgrounds will bring into the process the specific know-how of their expertise. That is, thanks to this expertise it will be possible to individuate constraints and crucial mechanisms affecting the behavior of the system in relation to general patterns well known in different academic fields (economic, social, technical, ecological). Obviously, the potential contribution of scientists coming from different back-grounds will depend on the selection of relevant aspects to be included in the problem structuring.

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Step 5 – *The fifth stage returns to observations of the world and the model is checked against what happens. If the actors are people,* [note: when dealing with ecological systems this is not necessarily the standard case] *then one can ask them their opinion of the model and modify it to be consistent with their special knowledge.*
In this step there is the decision of selecting among all the possible models and all the possible indicators and all the possible metaphors and principles which could be applied to this situation only on an information space that can usefully be handled as the formal problem structuring to be adopted in the process of decision making.

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Step 6 – NOTE this step is present in the figure given by Allen and Hoekstra in the book (Fig. 9.9 on pag. 310), but then is not described in the text that mentions only 7 steps.

In this step feasible and desirable changes are explored using the analytical tools developed so far. If nothing of feasible and desirable is found in the process of negotiation it is obvious that the original problem statement is wrong (useless) and has to be revisited. There are several ways out of this impasse. Check the validity of the perceptions, check the validity of the expectations, try to change the terms of reference determining constraints and feasible solutions.

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Step 7 – *At this stage one identifies desirable and feasible changes for the system.*
Decisions about selecting and implementing a policy are taken at the end of this step.

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Step 8 – *After the implementation of a given policy it is necessary to widen the view of the whole process. Evaluation – did it work?*
Again also in this case, a more effective monitoring of the results looking for unexpected side-effects can be obtained by relaying on non-equivalent observers, which can generate new types of signals about the expected and unexpected effects induced by the choice (or policy). Increasing the diversity of non-equivalent observers performing such a monitoring can increase the ability to detect the consequences of the unavoidable ignorance-load of the semantic and formal problem structuring adopted in the decision making process.

This explains why this step leads naturally into a new step 1 for another cycle.

An important feature of the procedure suggested by Checkland stressed by Allen and Hoekstra is the ability of compressing and expanding the information space considered in the process during the various steps. The implications in terms of compression and expansion of the information space (number of attributes/variables/indicators used in the set of identities used in the various models, number of models, number of relevant issues and anticipatory systems adopted in the analysis) is shown in **Fig. 5.9**. This has to do with the challenge of handling the heroic compression illustrated in **Fig. 5.6**. Since it is impossible to even dream to perform such a compression in a satisficing way in a single step, it is wise to compress and expand several times in an iterative process. This can make easier to perform a quality control of the choices made during such a process (normative versus descriptive – technical feasibility versus social acceptability – accuracy versus relevance). This is especially true when dealing with the unavoidable existence of conflicts and power asymmetry. At this regard is particularly useful the distinction introduced by Checkland about the three relevant attributes that should be used to classify stakeholders in relation to their relevance in this process (C, A, & O).

Coming to the descriptive part, the part which is relevant for the rest of this book, it should be noted that **a continuous shift between semantic** (the use of metaphors required for the sharing of the meaning about a situation – definition of classes of models) **and formal models** (translating the meaning of the perceptions associated to a class of models in relation to a location specific situation to generate data related to variables that can be used as indicators) **is the only way out from the impasse of reductionism described so far.**

5.5.3 Looking at this procedure in terms of an iteration between Discussion Support System and Decision Support System.

The expression "discussion support system" has been suggested by Herman van Keulen to indicate the activity of handling of non-equivalent descriptive domains, sets of indicators referring to legitimate contrasting perspectives and non-reducible models during the process of selection of a problem structuring. The output of this process has been called Multi-Scale Integrated Analysis and will be the subject of the next Parts of this book. The activity referring to the generation of a MSIA refers to the loop indicated by the red arrows in **Fig. 5.8.**

The *quality* of a given problem structuring provided by scientists to the stakeholders involved in a process of decision making depends on the ability to represent in analytical terms "sustainability trade-offs" (on different scales) in relation to the set of legitimate views considered as relevant (multi-objective) and to the set of non-equivalent dimensions of viability considered as relevant (multi-dimensional). This is why such an input is called Multi-Scale and Integrated Analysis (multi-objective and multi-dimensional). Scientists should be able to characterize the performance of socioeconomic systems in relation to envisioned changes, considering in parallel short, medium and long term perspectives of the various stakeholders. To do that, they have to tailor their descriptive tools on what is required by multicriteria methods of evaluation.

In order to do that they have to **perform several quality checks on the validity and usefulness of the representative tools used in the process.**

IF we accept that the organization of the information space needed for SMCE can no longer be based on traditional (reductionist) descriptive tools (as discussed in Chapter 2 and 3), that is it can no longer be based on the assumption that it is possible to provide substantive definitions of "optimal solutions" THEN we have to look for new descriptive tools (as those presented in section 5.4) and adequate procedures (as those presented in this section).

These new tools have the goal of organizing the scientific representation of the problem, after acknowledging the existence of the serious epistemological challenges found when attempting to generate a relevant, reliable and transparent scientific input for the process of decision making. Such a scientific input has to be realized in the form of an agreed upon Multi-Scale Integrated Analysis, (i.e. a set of assessments of different typologies or costs and benefits in relation to different definitions of costs and benefits), which has to be referred to a preliminary definition of an option space (i.e. a given set of scenarios reflecting possible alternative choices).

Therefore, any procedure for obtaining a useful MSIA should be based on a genuine iterative process between scientists and the rest of social actors aimed at generating an evolving discussion on how to better represent and structure the problem to be tackled. This procedure has to deal with two major problems: (1) on the normative side – dealing with the unavoidable ambiguity in the definition of terms and identification of common goals (social incommensurability). Everyone can agree on the need of looking for peace and freedom, on the other hand there is an unavoidable ambiguity when translating these general concepts into action within a given context. That is, those considered "terrorists" by one side are the "freedom-fighter of the other side (Tim Allen, personal communication), the definition of actions required to obtain and preserve peace often bifurcates when coming to the decision of what to do next in front of an existing confrontation. (2) on the descriptive side – dealing with the unavoidable non-reducibility of models built by using variables defined in non-equivalent descriptive domain (technical incommensurability).

This section focus on the implications of this fact from the perspective of the scientist willing to get involved in such a process. An overview of the iterative process which is required to define a Multi-Scale Integrated Analysis to be generated by a "discussion support system" is given in **Fig. 5.10.** This MSIA has to be based on:

(1) *Useful representations* (Multi-Objective, Multi-Scale, Multi-Dimensional) of relevant features of the system able to reflect legitimate perspectives found among relevant social actors and information required for decision making of relevant agents. This translates into the selection of a set of models which use non-equivalent identities and boundaries for the same system which is able to represent the problem over different descriptive domains in relation to different dimensions of analysis. To start such an iterative process, a first draft of a formal problem structuring (to be criticized and changed later on) can be used to start a discussion about the semantic questions required for the problem structuring (to start the step 3 in **Fig. 5.8**).

(2) *Definition of the feasibility space* (range of admissible values) for each of the selected indicators of performance. Feasibility should reflect the reciprocal effect of constraints across hierarchical levels. The most common selection of constraints includes economic, biophysical, institutional and social constraints. This is the enrichment of information obtained during step 4 (in Fig. 5.7), when individual reductionist scientist can bring into the discussion metaphorical knowledge (validated on class of models) which can be applied to the specific situation.

(3) *Integrated representation of system performance* in relation to the selected set of incommensurable criteria. This require selecting a package of indicators referring to the desirability of feasible changes in relation to different relevant criteria. This requires assessing the value of each indicator included in the package. In this way, it becomes possible to represent: (i) what should (or could) be considered an improvement or a worsening in relation to each attribute; (ii) how the system compares with appropriate targets and other similar systems; (iii) what are potential critical, threshold values of certain variables where non-linear effect can play a crucial role. This is the first part of the activity included in step 5 illustrated in Fig. 5.8.

(4) *Strategic assessment of possible scenarios* done by addressing the problem of uncertainty and general evolutionary trends that can be expected. In relation to this point, the scientific representation has no longer be based only on steady-state view and on a simplification of the reality represented according to a single dimension at a time ("ceteris paribus"). That is, conventional reductionist analyses providing the picture of the position of the system on a Multi-Objective Performance Space (as the radar diagrams shown in **Fig. 5.5**) have to be complemented by analyses of: (a) evolutionary trends (related to adaptability implying a virtual future-present causal perspective); (b) the crucial effects of the particular history of a system determining lock-in and behavioural constraints; and (c) the parallel consideration of processes and mechanisms operating simultaneously on several levels and scales. An evolutionary analysis should make possible to classify the investigated system in relation to its position within the domain of possible evolutionary trajectories (by comparing it with other similar systems within the same state space used for the integrated assessment). Only in this way it is possible to enable the stakeholders to provide an input about the validity of the scientific representation of the issue. The quality check of the stakeholders has to deal also with the issue of overall credibility of scenarios and simulation, beside that of relevance of the analyses included in the package. This activity is still in the step 5 of **Fig. 5.8**.

(5) *Mosaic effects providing robustness to the scientific input, obtained through redundancy in the information space.* "Mosaic effects" can be obtained by bridging of non-equivalent descriptions using the forced congruence of numerical assessment across scales. This mechanism that can be used to boost the reliability of data and models will be introduced and discussed in Part 2 and Part 3. Mosaic effect can be used not only to perform a congruence check on the validity of the database used in the description but also to fill empty spaces in the data base, when gaps occur. When dealing with practical problems of sustainability of human societies the bridge across descriptive domains can be obtained by forcing the congruence of flows of: (i) money, (ii) energy, (iii) matter, and (iv) human time. The condition of congruence implies that non-equivalent descriptions (organs within humans, and humans within households) adopted when generating and calculating the set of different indicators included in the package must still exhibit coherence in relation to congruence checks (the total weight of organs and the total weight of humans must be congruent with each other). Recall the example of the multiple assessments of cereal consumption per capita in the USA in 1997, according to micro, macro, biophysical and economic analyses. By establishing bridges among non-equivalent readings we can check whether or not assessments coming from an analysis performed at a given level (the household level) result consistent - when scaled-up or scaled-down to a different level - with indications coming from the analysis based on a non-equivalent description performed at a different level. This congruence check can be obtained both in terms of: (i) numerical values,

and (ii) known trends. The generation of a "mosaic effect" patching together non-reducible models can make possible the filtering out of incoherent scenarios or biased policy solutions proposed by interested scientists and/or stakeholders, as well as forcing transdisciplinarity in the step representation. A more detailed description of this approach in Chapter 6, applications in Part 3. Again this is a type of quality check on the scientific input of representation that can be performed by scientists themselves. As observed by Checkland this has to do only with the "technical defensibility" of a given integrated representation (e.g. looking at the Jevons paradox – Chapter 1 – by performing an analysis in parallel on two scales we can immediately check that the inference that an increase in efficiency will lead to a reduction of consumptions (obtained using models based on the "ceteris paribus" hypothesis), clashes against a trend analysis performed at a different scale.

(6) *Analysis of the "sustainability dialectics"* which is unavoidably implied by multifunctionality and sustainability ("a given blanket cannot be pulled in all directions"). This analysis has to include an assessment on the uncertainty associated to various scenarios considered in relation to the criteria and alternatives indicated as more relevant in the discussion. This is where the activity of scientists has to be integrated by an interaction with social actors and where the border between descriptive and normative blurs. This is especially important in the step 6 of **Fig. 5.8**, when an overall agreement has to be reached on the validity of the existing problem structuring as "the agreed-upon scientific input" to be adopted in the process of Social Multi-Criteria Evaluation.

In conclusion, the scientific aspects of Multi-Scale Integrated Analysis which is the required input to a process of Social Multi-Criteria Evaluation can be related to the activities related to the 4 iterative steps included in the loop indicated by red arrows in **Fig. 5.8**. Even when remaining within the problems associated to the activities required in these four steps (#3, #4, #5, and #6) the scientists are forced to address, first of all, the implications of the delicate pre-analytical step of compression of the virtual infinite universe of discourse into the finite and formalizable information space represented by the scientific input to the process of decision making (**Fig. 5.6**). In the rest of this thesis I will deal only with this problem.

Technical issues and example of how to organize the scientific input in the form of Multi-Scale Integrated Analysis of Agroecosystems useful for SMCE are discussed in Part 3, specifically in Chapter 9, Chapter 10, and Chapter 11. Whereas Part 2 provides the theoretical rationale of these approaches in relation to complex systems theory.

5.6 What has all this to do with the sustainability of agriculture? – Example: the making of farm bills (institutionalizing a discussion of the social contract about agriculture)

5.6.1 What should be the role of colleges of agriculture in the new millennium?

Current basic strategy driving technical progress of humankind, which is aimed at achieving a much higher material standard of life for an increasing number of people, is becoming more and more a sort of gambling. Humankind is risking what already exists in order to have more (Giampietro, 1994a; 1994b). But even if we accept that gambling cannot be avoided by systems that are forced to evolve in time (this is what life is about), we should at least be able to define the terms of the bet (what can be gained, what can be lost) and the rules of the game (who is calling the bet and who will pay for or gain by it). Unfortunately, at present, these terms of this gambling are anything but clear, especially when dealing with the technical progress of agriculture.

These two facts combined are generating a clear paradox. Because of the big challenges and the large dose of uncertainty faced by humankind in this delicate phase of transition, science and technology are needed as never before. However, one should be always aware that technology can be either part of the solution or part of the problem. This is why, in parallel with the development of new technologies, humans have to develop, and as soon as possible, new scientific fields aimed at interfacing the activity of scientists with the activity of the rest of the society. When dealing with science for governance scientific know-how cannot be taken from the shelf. It must be always applied and "tailored" to specific situations through an iterative process of interaction of all relevant social actors.

Against this general framework, what is the role that academic institutions and in particular colleges of agriculture should play in the field of sustainability of agriculture? We can use a statement taken by the post-Newtonian quantum physicist David Bohm – quoted by Roling (1994 p. 390) "Science consists not in the accumulation of knowledge, but in the creation of fresh modes of perception" (Bohm, 1993). Coming back to the discussion presented in Chapter 4 about the problem of how to update societal perception, representation and regulation of agricultural activities, we can say that this is clearly a task that can not be performed by scientists alone. Such an updating implies learning how to elaborate better compromises among contrasting values, perceptions of risks and opportunities, aspirations. Put it in another way, any assessment of innovations, regulations and policies to be adopted in the Food System, requires the implementation of procedures of Participatory Integrated Assessment. That is, the development of useful Multi-Scale Integrated Assessment used and driven by processes of Societal Multi-Criteria Evaluation.

In this perspective, conventional agricultural research should be complemented by a new field of analysis dealing with the issue of science for governance. Basic knowledge about agricultural practices is and will always be required to make possible the continuous re-adjustment of mixes of activities in relation to different definition of performance in a multifunctional frame. However, at the same time, a truly innovative field of scientific activity is required to enable a two-ways exchange of information between academic institutions and the civil society. This is not about generating better programs of extension, but rather looking at a two-way direction of information flows. The ivory tower so useful in the past to preserve the special status of academic research has to become more open. To make this point clear let's consider the example of the making of a farm bill.

5.6.2 The case of the US Farm Bill 2002

The "US Farm Bill 2002" represents a clear change in (or a big revision of) the US federal government attitude toward the regulation and intervention in agricultural development. The passing of this farm bill has generated contrasting views and assessments on its overall quality (e.g. an example http://www.sustainableagriculture.net/summary-5-6-02.htm). We can relate this example of decision making to the discussion of analytical tools presented in section 5.4. When making this decision the US federal government must have selected this specific bill, out of a set of possible alternative bills. To do that "US decision makers" must have used a problem structuring similar to that represented both in Fig. 5.4 (in terms of impact matrix) and in Fig. 5.7 (in terms of social impact matrix). In this case: n is the set of possible alternative ways of spending a certain amount of (billions of) dollars in implementing a package of policies; and m is the set of criteria used to represent and assess the expected performance associated to the implementation of each of the alternative policies. Actually, it should be noted that the decision about the amount of money to be spent in a Farm Bill could be considered itself as a variable, rather than a constraint. In this case, different policies requiring the expenditure of different amounts of billions dollars should have been considered in the analysis. Obviously, the chosen alternative (the actual "farm bill 2002") must have been considered to be the "wisest" choice in relation to: (a) a set of m multiple goals (e.g. economic viability of the agricultural sectors, food security, quality of the food, environmental impact, social stress in rural community, protection of cultural values, etc.); (b) a set of data and models characterizing n scenarios associated to the implementation of the n alternative policies included in the problem structuring; and (c) the legitimate contrasting perspectives of the social actors considered as relevant in such an analysis.

Put in another way, in order to make this choice the government of USA must have used:

**A problem structuring*, implying decisions about: (a) what is the set of relevant social actors that have to be considered when deciding; (b) a set of criteria that are considered relevant for this choice, (c) what is the set of criteria that are relevant to some stakeholders but that can be neglected in order to satisfy other conflicting criteria; and (c) a mix of policy options which can be combined to generate the set of alternative bills considered.

**A set of Analyses (models and data) and predictions* used to characterize the effects of the possible policies on different descriptive domains through scenarios (e.g. in social terms, economic terms, ecological terms, in landscape use terms) characterized at different scales. That is, in order to make such a decision it has been necessary to have an idea of what will/could happen when adopting the package of monetary and regulatory policies #1 or #2 or 3#. The MSIA of different effects of each package must have been characterized using a set of different indicators reflecting the relevant and legitimate contrasting views defined in the problem structuring.

**A process of political negotiation* among different interests and concerns associated with the various stakeholders in the US food system. The particular choice of one of the possible policy packages (the actual farm bill 2002), in fact, implied that some stakeholders got more benefits than others (implying that some of the criteria have been given more priority than others).

Analysts of agriculture as well as social actors may have asked a number of questions about the choices made by the US government in this Farm Bill:

(i) Could US society at large and the various stakeholders in the US food system have had a better chance to have a clearer picture of what was the information space used by the decision makers for organizing such a discussion?

(ii) Could US society at large and the various stakeholders in the US food system have been involved in a more transparent process of discussion of the basic problem structuring (defining the relevant criteria and defining possible options)?

(iii) Could US society at large and the various scientists and academic institutions have been involved in a more effective Multi-Scale Integrated Analysis of possible effects of the various alternative bills?

(iv) Could US society at large and the various stakeholders in the US food system have been involved in a more transparent process of negotiation about the weight to be used when dealing with contrasting perspectives about priorities?

If the answer to any of these questions is yes, then US society at large and the various stakeholders in the US food system have lost an important opportunity to learn how to design, discuss, understand and negotiate future farm bills in a better way. The ability to design, discuss, understand and negotiate better farm bills in the future can become extremely important if the existing trends referring to the post-industrialization of a globalized world remain there.

The context is changing so fast that the validity of the social contract used to define the various roles which social actors have to play in the food system has to be monitored and negotiated on regular basis. This is why academic programs willing to deal with the sustainability problems of agriculture should give top priority to the development of new tools and procedures for dealing with MSIA of agriculture. Agriculture should no longer be considered just as another economic sector producing commodities. Rather agriculture should be associated to a multifunctional set of activities associated to land use.

At this point we can try to answer the question about the role of academic programs dealing with agriculture in the new millennium. Top priority for academic programs of agricultural colleges within the US should be that of producing scientific information relevant for the discussion of next farm bill in 2008 and that of becoming able to make a difference in the shaping of the discussion and the Societal Multi-Criteria Evaluation of the US farm bill in the year 2014. In fact, future farm bills should be able to better reflect: (a) the continuous change in societal perception about what a food system is about, and (b) the growing scientific awareness about the ecological and social dimensions of sustainability.

These two lines of research for agriculture can be related to the discussion about the two possible interpretations for the term Agroecology presented at the beginning of this chapter. The first of the two interpretations (= how to totally rethink agriculture) refers to the process of societal learning about how to better design, discuss, understand and negotiate future farm bills in developed countries and how to better design, discuss, understand and negotiate policies of technical progress in developing countries. The second interpretation of the term Agroecology is about the need of expanding the option space of the set of possible technical coefficients available to generate mixes of techniques of production in various agroecosystems. This has to do with expanding the knowledge about ecological and economic performance profiles of individual techniques of production and/or integrated systems of production. The usefulness of this second activity is associated to the beneficial effect of increasing the diversity of potential "performance profiles" to be adopted in a multifunctional framework of land uses.

Obviously, the sustainability predicament of agriculture both in developed and developing countries implies that more research is needed in both directions. For sure, however, the first direction of research is the one that will provide higher return, in the short term, because of the clear obsolescence and cultural lock-in of current mechanisms of policy interventions in the agricultural endeavor both in developed and developing countries.

Photo by Maurizio Paoletti

Fig. 5.1 The ultimate wisdom of agro-ecology: the recycling of night-soil. Nutrients are recycled from humans back to the plants . . .

Chinese ethnic fashion by Qi Chunying

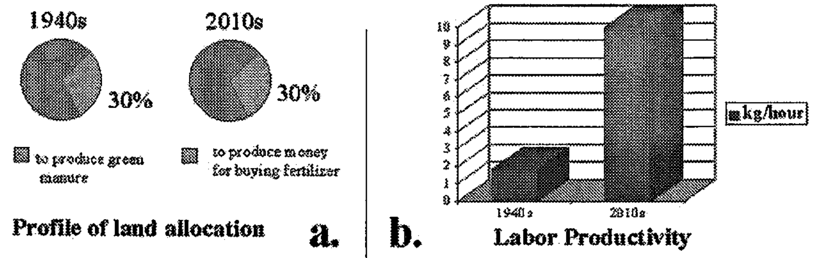
International fashion week Beijing

Photo: Wilson Chu - REUTER

Fig. 5.2 Farmers' vision of the future for their daughters

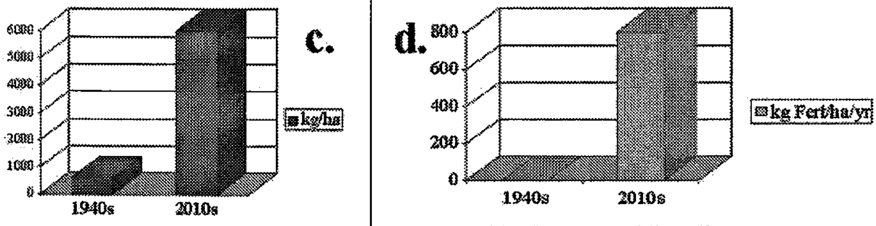
Fig. 5.3

Different indicators that can be used to characterize historical trends in rice farming in China



Profile of land allocation

Labor Productivity



Cropland productivity

Environmental Loading

Fig. 5.4 Integrated Assessment - the formalist perspective

Closing the information space into a formal problem structuring

(how to chose a car among so many options? computers can handle it . . .)

Criteria	Units	Alternatives FORD Mondeo	 HONDA Civic	 VW Golf	 NISSAN Micra
Fuel Consumption	US $	a_{11}	a_{12}	. . .	a_{14}
Maintenance cost	US $	. . .	. . .	. . .	. . .
Price	US $			a_{33}	
Road Handling	Index				
Reliability	Index	. . .	a_{52}	. . .	. . .
Safety devices	Index				
Power	HP	a_{71}			
Comfort	Index	. . .	. . .	. . .	. . .
Noise	db			a_{93}	
Design	Index		$a_{10\,3}$		
Status Symbol	Index	. . .	. . .	. . .	. . .
Colour	Index	$a_{12\,1}$			$a_{12\,4}$

Fig. 5.5 Multi-Objective Integrated Representation of car performance

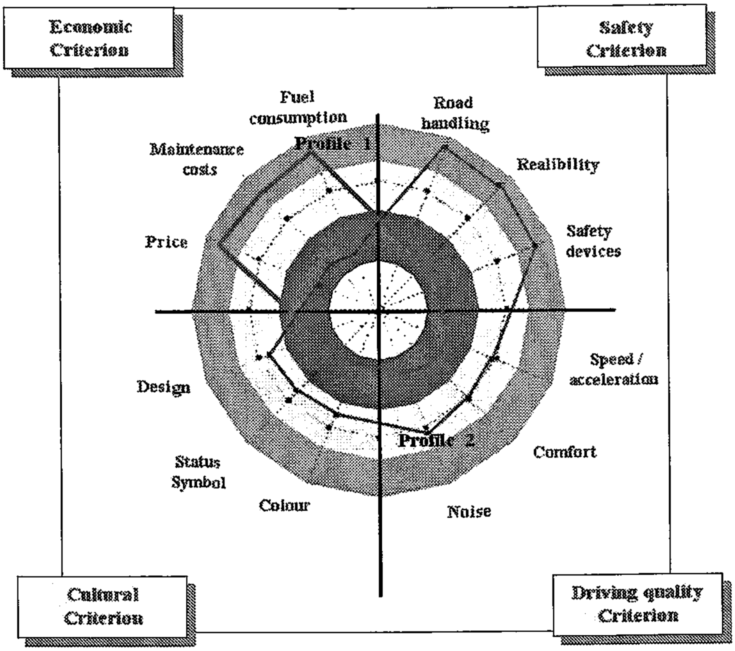


Fig. 5.6 - "Problem Structuring" as a "heroic" compression of the information space

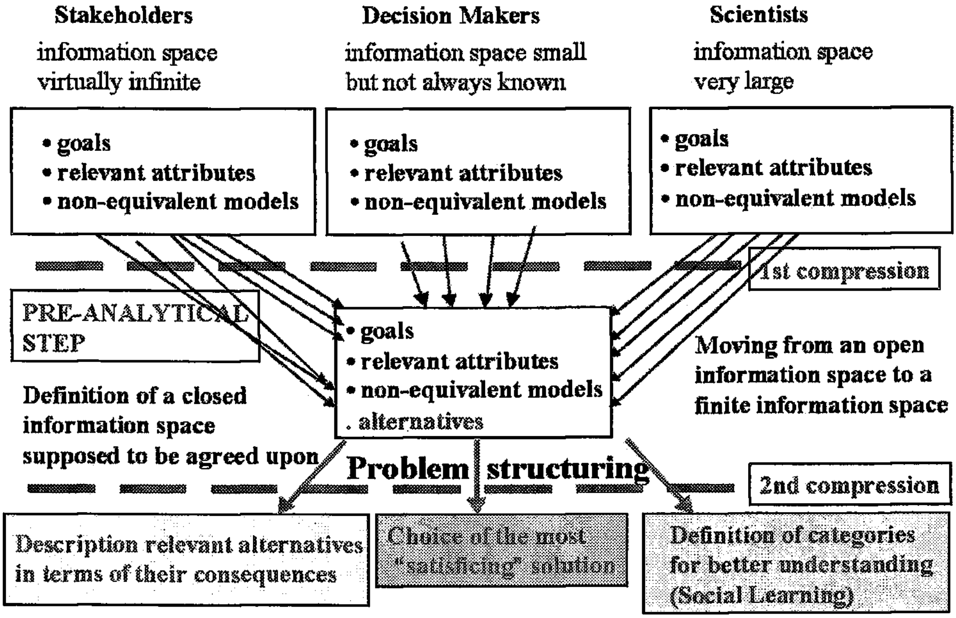


Fig. 5.7 "Multi-Criteria Evaluation" requires more information

Additional elements: Power relations, Conflict analysis, Institutional analysis

STAKEHOLDERS / OPTIONS	Ford Mondeo	VW Golf	Honda Civic	Nissan Micra	
Sandra (my wife)	Yes +	No	Yes/No	Yes ++	**Veto Power !!!**
Mario (me)	Yes +	Yes/No	No	Yes/No	**Relevant**
Olga (older daughter)	No	Yes/No	Yes ++	Yes ++	**Relevant only in fine tuning**
Sofia (younger daughter)	**It must be red**	**It must be red**	**It must be red**	**It must be red**	**Ignored, but what if...**

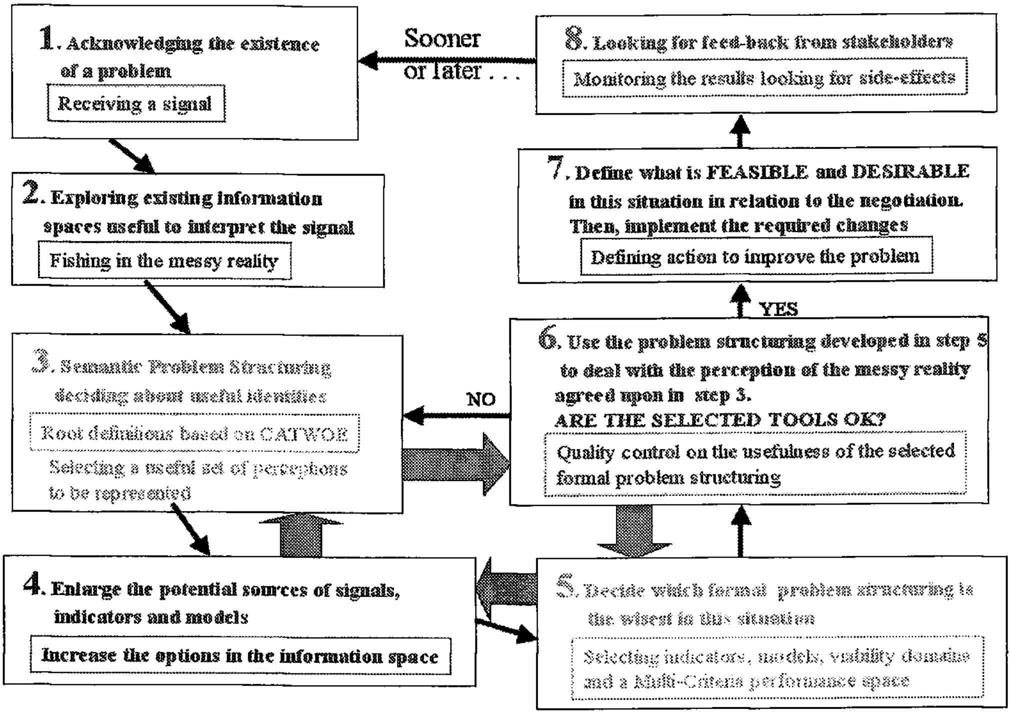


Fig. 5.8 The iterative process suggested by Checkland **adapted from Allen and Hoekstra (1992)**

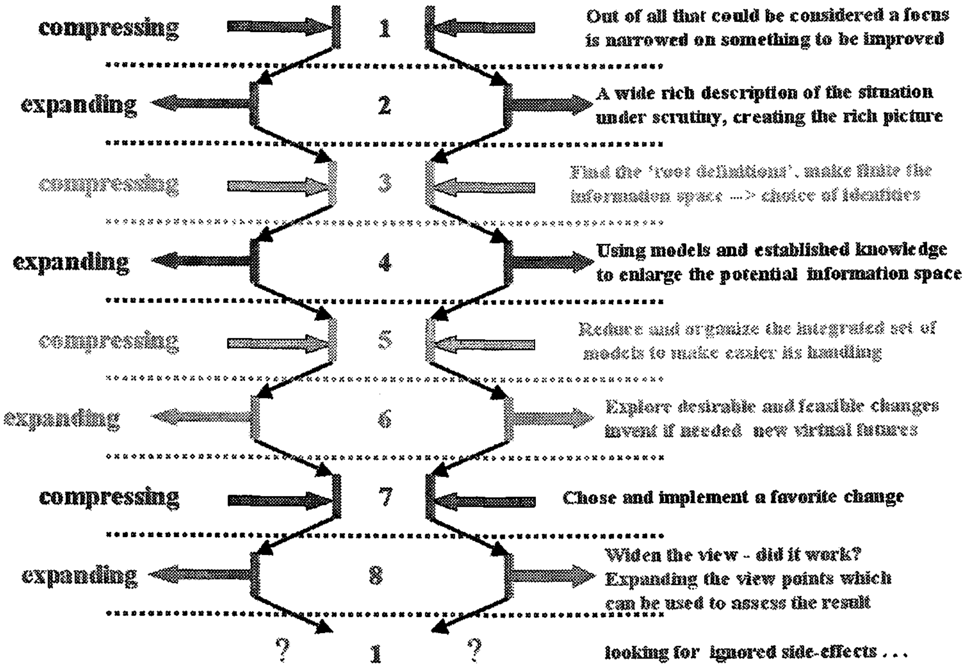
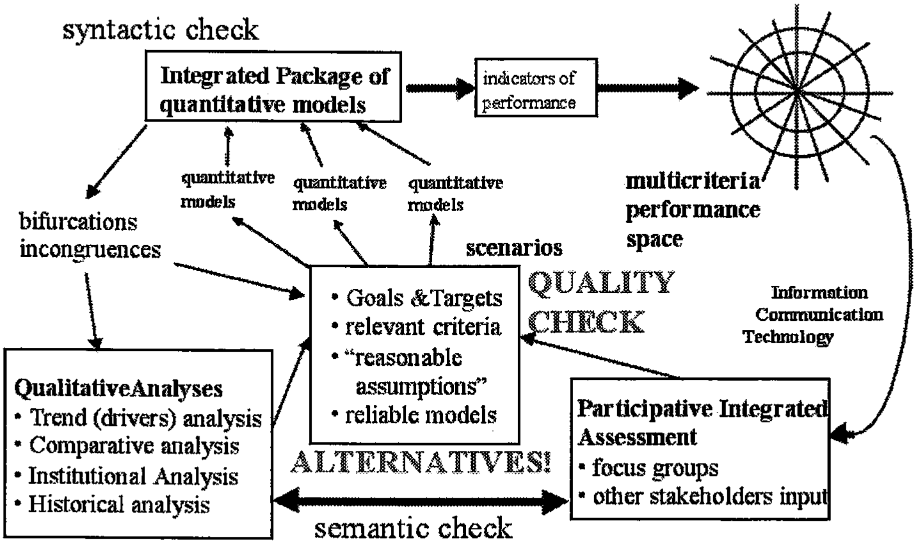


Fig. 5.9 The iterative process suggested by Checkland **adapted from Allen and Hoekstra (1992)**

Fig. 5.10

Iterative process mixing quantitative and qualitative analyses in a participatory discussion of sustainability dialectics



PART 2

Complex Systems Theory in Action: Daring to violate basic taboos of reductionism

Chapter 6*

Forget about the Occam razor: looking for Multi-Scale Mosaic Effects

This chapter first introduces the concept of mosaic effect (Section 6.1) in general terms. Then it illustrates the special characteristics of holarchic systems with examples (Section 6.2). This class of systems can generate and preserve an integrated set of non-equivalent identities (defined in parallel on different levels and therefore scales) for their constituent holons. The expected relation between the characteristics of this integrated set of identities makes possible to obtain some free information when performing a multi-scale analysis. This is the basic rationale for Multi-Scale Mosaic Effect. A multi-scale analysis requires establishing an integrated set of meaningful relations between perceptions and representations of typologies (identities) defined on different hierarchical levels and space-time domains. This entails that in holarchic systems we can look for useful mosaic effects when considering the relations between parts and the whole.

Multi-Scale Multi-Dimensional Mosaic Effects can be used to generate a robust Multi-Scale Integrated Analysis of these systems. This is discussed in details in Section 6.3. In particular examples are given of a Multi-Scale integrated analysis of the socio-economic process. Finally, this chapter closes with a discussion of the evolutionary meaning of this "special" holarchic organization. Holarchic organization, in fact, provides a major advantage in preserving information and patterns of organization. This is done by establishing a resonating entailment across identities which are defining each-other across scales. This concept is discussed- using a very familiar example: the calendar- in Section 6.5. The concept of holarchic complexity has been explored in the field of complex systems theory – under different names – in relation to the possible development of tools useful for the study of the sustainability of complex adaptive systems. An overview of these efforts is provided in Section 6.6. Different labels given to this basic concepts are for example:" integrity", "health", "equipollence", "double-asymmetry", possible operationalizations of the concept of "bio- diversity".

* Kozo Mayumi is a co-author of this chapter

6.1 Complexity and Mosaic effects

Before getting into a definition of this concept it is useful to discuss two simple examples.

* Example 1 - Koestler (1968 - Chapter 5; pag 85) suggests that human mind can obtain compression when storing information by applying an "abstractive memory" (the selective removing of irrelevant details). In Chapter 2 we described this process as the systemic use of epistemic categories (the use of a type – "dog" – to deal with individual members of an equivalence class – all the organisms belonging to the species "*canis familiaris*"), based on a continuous switch between semantic identities (= an open and expanding set of potentially useful shared perceptions), and formal identities (= closed and finite sets of epistemic categories used to represent a member of an equivalence class associated to a type) assigned to a given essence. When dealing with the perception and representation of natural holarchies (such as biological systems of socio-economic systems) this compression is made easy by the natural organization of these systems in equivalence classes (e.g. the set of organisms of a given species are copies made from the same genetic information, as well as with human artefacts, the set of cars belonging to the same model are copies made from the same blue-print).

Getting back to the ideas of Koestler, the compression obtained with language is not obtained by using

a single "abstractive hierarchy" (in our terms by using a single formal identity for characterizing a given semantic identity), but rather by relying on "a variety of interlocking hierarchies . . . with cross-references between different subjects". (ibid. pag. 87). This is a first way to look at mosaic effects:
"*You can recognize a tune played on a violin although you have previously only heard it played on the piano; on the other hand, you can recognize the sound of a violin, although the last time a quite different tune was played on it. We must therefore assume that melody and timbre have been abstracted and stored independently by separate hierarchies within that same sense of modality, but with different criteria of relevance. One abstracts melody and filters out everything else as irrelevant, the other abstracts the timbre of the instrument and treats the melody as irrelevant. Thus not all the details discarded in the process of stripping the input are irretrievably lost, because details stripped off as irrelevant according to the criteria of one hierarchy may have been retained and stored by another hierarchy with different criteria of relevance. The recall of the experience would hen be made possible by the co-operation of several interlocking hierarchies . . . Each by itself would provide only one aspect only of the original experience - a drastic impoverishment. Thus you may remember the words only of the aria "Your Tiny Hand is Frozen", but have lost the melody. Or you may remember the melody only, having forgotten the words. Finally you may recognize Caruso' voice on a gramophone record, without remembering what you last heard him sing*" (ibid. pag. 87).

In order to relate this quote of Koestler to the epistemological discussions of Chapter 2 and Chapter 3 it is necessary to substitute the expression "abstracting hierarchies" with the expression "epistemic categories associated to a formal identity used to indicate a semantic identity" discussed there. Every time we associated to a label (a name) the expected set of characteristics (a set of observable qualities) of members assumed to belong to an equivalence class, we are using "types" (an abstract set of qualities associated to those individuals assumed to belong to an equivalence class). As noted before, the relative compression in the information space obtained by using the characteristics of "types" (= you say a dog and you include them all) to describe the characteristics of individuals members perceived as belonging to the class has the unavoidable effect of inducing errors. Not all the dogs are the same. It is not possible to catch with a formal identity (a finite and closed set of relevant observable qualities – a formal definition of a dog), the open universe of semantic identities (types of dogs) that can be associated to an essence ("dogginess"). This is why humans are forced to use sub-categories (e.g. a dog fox-terrier), sub-sub-categories (e.g. brown dog fox-terrier), and sub-sub-sub categories (e.g. very young brown dog fox-terrier) in an endless chain of possible categorizations. Adopting this solution, however, implies facing two set-backs: (1) in this way we re-expand the information space required by individual observers to handle the representation (since more adjectives are required to individuate the new sub-sub-category); (2) in this way, we loose generality and usefulness of the relative characterization. The class of "very young brown dog fox-terrier having had a stressing morning because of a nasty diarrhoea and which therefore are very hungry now" is not very useful as an equivalence class. In fact, it is not easy to find a standard associative context, that would make convenient its use as a general type. This is why we do not have a word (label) for this class.

What gets us out of this impasse is the observation that within a given situation at a given point in space and time – within a specified context - (e.g. children getting out of a given school at 13.30 of a Thursday, March 23) a combination of a few adjectives ("the tall girl with the red dress") can be enough to individuate a special individual in a crowd. The girl we want to indicate is the only one belonging simultaneously to the three categories: (i) girl (individual belonging to the human species, that is woman and young at the same time); (ii) tall (individual belonging to a percentile on the distribution of height of her age class above the average); (iii) with the red dress (individual wearing a red dress). Obviously this mechanism of triangulation, based on the use of a few adjectives (the fewer the better) can only be adopted within the specificity of a given context (only if the triangulation is performed at a given point in space and time). The category "tall girl with the red dress" would represent a totally useless category if used in general to individuate someone within the USA.

The consequences of this example are very important. We can describe effectively a system using a limited set of categories (indicators) by triangulating them – relying on a mosaic effect - but only when we are sure that we are operating within a valid, finite and closed information space. When describing patterns in general ***the type is described in general terms within its standard associative context, or a special system is individuated within a specific local setting (at a given point in space and time).*** When dealing with specific description of events, ***the characteristic and constraints of the given context have to be reflected in the selection and definition of an appropriate descriptive domain.***

* Example 2 - Bohm (1995; pag 187) provides an example of integrated mapping based on mosaic effect. "*Let us begin with a rectangular tank full of water, with transparent walls. Suppose further that there are two television cameras, A and B, directed at what is going on in the water (e.g. fishes swimming around) as seen through the two walls at right angles to each other. Now let the corresponding television images be made visible on screens A and B in another room*". This is a simple example in which we deal with two non-equivalent descriptions of the same natural system (the movements of the same set of fishes seen in parallel on two TV screens). The non-equivalence between the two descriptive domains is generated by the parallel mapping of events occurring in a tri-dimensional space into two two-dimensional projections (over the two screens A and B). Again we have the effect of incommensurability already discussed about the Pythagorean theorem (Section 3.7) – in that case a description in one dimension (a single number) was used to represent the relation of two two-dimensional objects (the ratio of two squares). As a consequence of this incommensurability any attempt of reconstructing the tri-dimensional movement using just one of the two-dimensional representations could generate bifurcations. That is two teams of scientists looking at the two parallel non-equivalent mappings of the same event but looking at only one of the two-dimensional projections (either A or B) could be led to infer a different mechanism of causal relations between the two different "perceived" chains of events. In this case, the bifurcation is due to the fact that the step represent (what the scientists see over each of the two screens: A and B) is only a part of what is going in reality in the tri-dimensional thank. The images moving on the two screens are two different "narratives" about the same reality. The problem of multiple narratives of the same reality becomes crucial, for example in quantum physics, when the experimental design used to encode changes of relevant system's qualities in time may generate a fuzzy definition of simultaneity and temporal succession among the two representations (Bohm, 1987; 1995).

It is important to recall here the generality of the lesson of complexity. The scientific predicament is related to the fact that scientists, no matter how hard they think to be, can only represent perceptions of the reality. As observed by Allen et al. (2001): "***Narratives collapse a chronology so that only certain events are accounted significant. A full account is not only impossible, it is also not a narrative***". Put in another way, a narrative is generated by a particular choice of representing the reality using a sub-set of possible perceptions of it. Any set of perceptions is embedded by a large sea of potential perceptions which could also result useful when different goals were considered. This implies that providing sound narratives has to do with the ability of sharing meaning about the usefulness of a set of choices made by the observer about how to represent events. That is, the very concept of "narrative" entails the handling of a certain dose of arbitrariness about how to represent the reality. A degree of arbitrariness about which the scientist has to take responsibility (Allen et al. 2001). Getting back to our example of fishes swimming in a tank in front to two perpendicular cameras. Looking at the movements of these fishes from the camera A (on the screen A) implies filtering out – as irrelevant – all the movements toward or away from that camera. A fish moving in a straight line toward the camera A will be seen as moving on the screen B but not moving on the screen A. However, a sudden deflection from the original trajectory to a side of this fish will be perceived as a dramatic local acceleration from the camera A. This will generate a non-linearity in the dynamic of the fish within the descriptive domain represented on the screen A. This dynamic will be difficult to explain in physical terms (and to simulate by a dynamic model) by relaying only on the information given by the screen A. How did the fish manage to get this huge acceleration in the middle of the water, without touching anything, moving suddenly away from total immobility? As soon as we check the information coming from the screen B we can easily explain this perceived non-linearity. The non-linear dynamic "impossible to explain" on the descriptive domain A is simply an artefact generated by the use of a bad descriptive domain (screen A). That is, the original speed of the fish (perceived when looking at the screen B) was simply ignored in the descriptive domain A, since the movement was occurring on the direction considered as "irrelevant" according to the selected set of relevant observable qualities associated to the experimental design.

This is a very plain example of the types of problem related to the difficult interpretation of representation of changes, when multi-dimensions have to be considered. In this very simple case, we are dealing only with a relevant observable quality: the position of a given object – a fish – which is moving in time. That is, no other relevant attributes are considered when discussing of trajectories but vectors associated to speed and acceleration. Let imagine, then, the case in which we were required to deal with a much more complex situation in human affairs which would require a much richer characterization (the simultaneous use of a larger set of relevant attributes), which in turn would require the simultaneous use of non-equivalent descriptive domains.

In conclusion, when dealing with the sustainability of socio-economic system we have to decide first of all about what is relevant and/or irrelevant for: (a) explaining the past history of the system; and (b) guessing future trajectory of development; but above all (c) deciding what are the relevant observers that should be considered as clients for the tailoring of the representation provided by the analysis. In fact, any formalization of the representation of complex systems' behaviour implies: (1) a large dose of arbitrariness in deciding which are the non-equivalent descriptive domains to be considered to gather useful information (on different dimensions using different "cameras" as in this example); (2) the risk of making inferences using one of the possible models (based on what is perceived on just one of the possible screens). It is important not to miss crucial information detectable only when looking at different screens.

* Mosaic effects

The two definitions of "mosaic effect" given below are taken from the field of analysis of language (Prueitt, 1998; section 3 of the hypertext):

- "***Syntactic Mosaic effect** occurs when structural parts of a single image or text unit is separated into disjoint parts, each part judged not to have a certain piece of information but where the combination of two or more of these units is judged to reveal this information*";
- "***Semantic Mosaic effect** occurs when structural parts of a single image or text unit are separated into perhaps overlapping parts. Each part is judged not to imply a certain concept but the combination of two of more of these units is judged to support the inference of this concept*".

Both definitions are clearly pointing at a process of "emergence" (= a whole perceived as something different from the simple sum of the parts). The syntactic mosaic effect has more to do with "pattern recognition" (individuating a similarity within the reservoir of available useful patterns), whether the semantic mosaic effect has more to do with the establishment of a meaningful contextual relation within the loop "represent/transduce/apply". In both cases we have that, as done often by famous fiction detectives, we can put together a certain number of "clues", none of which can by itself identify the "murder" we are looking for (they are not mapping 1:1 to the murder) into a particular combination that provides enough evidence to clearly identify her/him.

Another important aspect that can be associated to the concept of mosaic effect is that of redundancy in the information space that can be used to increase its robustness. A good example of the "free ride" that can be obtained by an interlaced or interlocking of different systems of mapping generating internal redundancy (we are using here the expressions suggested by Koestler) is the process of solving crosswords puzzles. Due to the given and expected organizational structure of the puzzle you can "guess " a lot of missing information about individual words by taking advantage of the internal rules of coherence of the system (by the existing redundancy generated by the organization of the information space in crosswords). Examples of how to apply this principle to integrated analysis of sustainability are discussed in the rest of this chapter.

Before concluding this introductory section we can briefly recall the discussion (Chapter 2) of the innate redundancy of the information space used when describing Dissipative Adaptive Holarchies. In this cases, we are dealing with a "russian-dolls-structure" (nested hierarchies) of equivalence classes generated by replicated process of fabrication based on a common set of blue-prints (e.g. biological systems made using a common information stored in the DNA). This innate redundancy is the reason why, we can rely so heavily on type-based description related to expected identities in the first place. This means that it is easy to find labels about which the users of a given language can share their organized perceptions of types associated to the expected existence of the relative equivalence class. As discussed in Chapter 2 this mechanism used for organizing human perceptions is very deep. This entails that even when looking for the characterization (representation of a shared perception) of an individual human being, it is necessary to use typologies. For example, let's consider a famous individual human being, let's say Michel Jordan. We can obtain a lot of free information about him from the knowledge related to equivalence classes to which this individuality belongs even without having a direct experience of interaction with him. For example, since we know that Jordan belongs to the human species we can guess that he has two arms, two eyes etc. Actually, we can convey a lot of information about him just by adding after his name, the simple information "nothing is missing in the standard package of the higher category – human being – to which this individual belongs". Within this basic typology of "human-being" we can use a more specific "sub-type characterization " linked to his identity as "male of a certain age" (a smaller sub-category of that of "human beings"). This will provide us with another sub-set of expected standard characteristics (expected observable qualities) and behaviours (expected patterns) against which it will become easier (and cheaper in terms of information to be gathered and recorded) to track and represent the "special" characteristics of Mr. Jordan (e.g. he is much higher than the average male of his age, he has an excellent physical fitness). It should be noted, however, that every time we get closer and closer to the very definition of the special individual "Michel Jordan" in terms of characteristics of the organized structure generating signals, we remain trapped in the fuzziness of the definition of what should be considered as the relative type, against which to make the identification of the individual. In fact, even when we arrive to the clear characterization of an individual person we are still dealing with a holon at the moment of representing him. This is due to the unavoidable existence of an infinite regression of potential simplifications linked to the very definition (representation of shared perception) of the same holon "Michel Jordan". The universe of potential meaningful relations between perception and representation can be compressed in different ways to obtain a particular formal representation of him. This will remain true, even if we would use "first hand experimental information" about his anthropometric characteristics and about his behavioral patterns – e.g. by asking his family or by recording his daily life. Each characterization would still be based on various "types" related to Michel Jordan determining different sets of expected observable qualities and behaviours. That is, we will still end up by using different types such as: "sleeping Michel Jordan", "full strength Michel Jordan", "angry Michel Jordan", "affected by a cold Michel Jordan". Even at this point, we can still split these "types" into other "types" all related to the special sub-set of qualities and behaviours that the individual Michel Jordan when in "full strength" could take. This splitting can be related to different position in time during a year (spring versus winter) or during the day (morning versus night) or changes referring to a time scale of minutes (surprised vs pleased), let alone considering the process of aging. As noted before it is impossible to define in absolute terms a formal identity for holons (the right set of qualities and behaviors which can be associated in a substantive way to the given organized structure). Each individual holon will always escape a formal definition due to: (i) the fuzzy relation between structure and function which are depending on each other for their definition within a given identity; (ii) the innate process of becoming which is affecting them; (iii) the changing interest of the observer. The indeterminacy of such a process translates into an unavoidable openness of the information space required to obtain useful perceptions and representations (holons do operate in complex time). Put in another way, holons can only be described (loosing part of their integrity or wholeness) in semantic terms using types, after freezing their complex identity using the triadic reading over an infinite cascade of categorizations, and in relation to the characteristics of the observer. At this point a formalization of the semantic description represents an additional simplification, which is unavoidable, if one wants to use such an input for communicating and interacting with other observers/agents.

The work of Rosen, Checkland and Allen discussed in Part 1 points at the fact that an observer or a given group of observers can never see the whole picture (= the experience about reality is the result of various processes occurring at different scales and levels). Observers can only see, at a given point in space and time, a few special perspectives and parts of the whole. The metaphor of the group of blind people trying to characterize an elephant by touching it in different parts can be recalled here. Rather than denying this obvious fact, scientists should learn how to better deal with it.

In fact, if it is true that holons are impossible to formalize - a ***con*** in epistemological terms - it is also true that they are able to establish reliable and useful identities [= a valid relation between expected characteristics (types) and experienced characteristics of the members of the relative equivalence class (organized structures sharing the same template)] – a major ***pro*** in epistemological terms. This implies that, as soon as, we are dealing with a known class of holarchic systems (as always is the case when dealing with biological and human systems), we should expect that across levels, a few characteristics of the relative types can be predicted. Moreover, the characteristics of nested types are defining each other across levels. This means that, after having selected an opportune set of formal identities for looking at these systems, we can also expect to be able to "guesstimate" some hierarchical relations between parts and whole.

6.2 Self-entailments of identities across levels associated to holarchic organization

6.2.1 Looking for mosaic effects across identities of holarchies

First of all, we have to look for mechanisms of accounting (assigning a formal identity to the semantic identity of dissipative system) that will make possible to establish a link between assessments referring to lower level components and assessments referring to the whole. The choice of a useful system of accounting is a topic that will be discussed in the next chapter about Impredicative Loop Analysis. The following example has only the goal of illustrating the special characteristics of a nested holarchy. Let's imagine to have a holarchic system – e.g. the body of a human being – and let's imagine that we want to study its metabolism in parallel on two levels: (i) at the level of the whole body; and (ii) at the level of individual organs, belonging to the body. To do that, we have to define a formal identity (a selection of variables) that can be used to characterize the metabolism over these two contiguous levels.

That is, the selected formal identity will be used to characterize two sets of elements defined on different hierarchical levels: (a) the parts of the system (defined at level ***n-1***); and (b) the whole body (defined at level ***n***). This example has the goal to show that the various identities associated to elements of metabolic systems organized in nested hierarchies entails a constraint of congruence on the relative values taken by intensive and extensive variables across levels.

Let's start with two variables which can be used to describe the size of both the whole (level ***n***) and parts (level ***n-1***) in relation to its metabolic activity. The two variables adopted in this example to describe the "size" of a human body (seen as the black-box) in relation to metabolic activity are:

(1) variable #1 – kg of human mass - (1 kg of body mass is defined at a certain moisture content);
(2) variable #2 – watts of metabolic energy - (1 W = 1 Joule/sec of food metabolized). This assessment refers to energy dissipated for basal metabolism.

These two variables are associated with the "size" of the dissipative system (whole body) and reflect two non-equivalent mechanisms of mapping. The selection of these two variables reflects the possibility of using two non-equivalent definitions of size. The definition - #1 - which refers to the perception of the internal structure (body mass), and the definition - #2 - which refers to the degree of interaction with the environment (flow of food consumed). That is, this second variable refers to the amount of environmental services associated to the definition of size given by variable #1.

The very same two variables can be used for characterizing the system (human body) perceived and represented over two contiguous hierarchical levels: (a) size of the parts [at the level n-1]; and (b) size of the whole [at the level n].

In fact, after having chosen a variable #1 and variable #2 [= "formal identity"] to characterize the size of the metabolism of the human body across levels, we can measure both the size of the whole body (at the level n) and the size of lower level organs (at the level n-1) using: "kg biomass" or "MJ of food energy converted into heat". Again, the assessment #1 - 70 kg of body mass for the whole body - represents a mapping related to the black-box in relation to its structural components. Whereas, the assessment related to energy - 80W amount of energy input required over a given time horizon – a day – to retain the identity of the whole body - represents a mapping of the dependency of the identity of the system (black-box) on benign environmental processes (stability of favourable boundary conditions). The fact that this second assessment is expressed in W (Joule/sec) should not mislead the reader. Even if the unit of measurement W is a ratio (an amount of energy per unit of time), it should not be considered an intensive variable when dealing with metabolic system whose identity is associated by default with a flow of energy. In fact, according to the system of accounting adopted here, the size of these systems is associated with an amount of energy required in a standard period of reference – either a day or a year depending on the measurement scheme. That is, this is an assessment which is related to a given time window (required to obtain meaningful data), which is big enough to assume such an identity constant in relation to lower level dynamics. The value is then expressed in Joule/second, only because of a mathematical operation applied to the data. The value 80W (for the whole body) has to be considered as an extensive variable, since it maps onto an equivalent amount of environmental services (e.g. a given supply of food – an amount of energy carriers - and absorption of the relative amount of CO_2 and wastes), associated with the metabolism of the system over a given time horizon.

By combining the two extensive variables (#1 and #2) we can obtain an average density of energy dissipation per kg of body mass, which is 1.2 W/kg. This should be considered, within this mechanism of accounting, as an intensive variable (a variable #3 to be added to the set used to characterize metabolism within a formal identity of it). This variable #3 can be seen as a benchmark value (average value for the black box) which can be associated to the identity of the dissipative system considered as a whole at the level ***n***.

If we look inside the black box at individual components (at the level ***n-1***), we find that the average (W/kg, variable #3) assessed at the level ***n*** is the result of an aggregation of a profile of different values of energy dissipation per kg of lower level elements (W/kg, variable #3) assessed at the level ***n-1***. For example, the brain, in spite being only a small percentage of the body weight (around 2%) is responsible for about 20% of the resting metabolism. (Durnin and Passmore, 1967). This means that the density of the metabolic energy flow dissipated in the brain per unit of mass (an intensive variable #3) is around 12.0 W/kg. The average metabolic rate of the brain per unit of mass, therefore, is ten times higher than the average of the rest of the body. If we write an equation of congruence across these two levels, we can establish a forced relation between the characteristics of the elements (whole and parts) across levels.

Level ***n*** (the identity of the black box is known)
Total body mass – ***70.0 kg***; Endosomatic energy – 80.0 W; EMR***n*** = 1.2 W/kg

Level ***n-1*** (the identity of the considered lower level components is known)
Brain – ***1.4 kg***; Endosomatic energy – 16.2 W EMR***n-1*** = 11.6 W/kg

Level ***n-1*** (after looking for a closure we can define a weak identity for other components)
Rest of the body – ***68.6 kg*** Endosomatic energy – 63.8 W EMR***n-1*** = 0.9 W/kg

When we know the hierarchical structure of parts and the whole (how the whole body mass is distributed over the lower level parts), and the identities of lower level parts – the characteristic value of dissipation per unit of mass – intensive variable #3 $(\mathrm{EMR}\boldsymbol{n\text{-}1})_i$ – we can even express the characteristics of the whole as a combination of the characteristics of its parts:

$$\mathrm{EMR}\boldsymbol{n} = \sum x_i\,(\mathrm{EMR}\boldsymbol{n\text{-}1})_i = 1.2\ \mathrm{W/kg} = (0.02 \times 11.6)_{\mathrm{brain}} + (0.98 \times 0.9)_{\text{rest of the body}} \qquad (1)$$

That is the hierarchical structure of the system and the previous knowledge of the expected identity of parts makes possible to obtain missing data when operating an appropriate system of accounting.
Put in another way, we can either guess the EMR of the rest of the body (an element defined at the level ***n-1***) by measuring the characteristics of the whole body (at the level ***n***) and the characteristics of other elements at the level ***n-1*** (brain). In alternative, we can infer the characteristics of the whole body – at the level ***n*** – by our knowledge of the characteristics of the lower level elements (level ***n-1***), provided that the definition of identities (EMR***i***) on the level ***n-1*** guarantees the closure over the total mass. This requires that the mapping of lower level elements in kg has to satisfy the relation:

Mass "whole body" = Mass "brain" + Mass "rest of the body" (2)

This means that the selected system of accounting of the relevant system quality "mass" must be clearly defined (e.g. body mass has to be defined at a given content of water or on dry basis) on both levels to obtain closure. In this example, only two compartments were selected (i =2), but depending on the availability of additional external sources of information (data or experimental settings available) we could have decided to assign more known identities to characterize what has been labeled here as "the rest of the body". That is, we could have used additional identities for compartments at the level ***n-1*** (e.g. brain, liver, heart, kidneys – see Fig. 6.1).

This approach makes possible to bridge (by establishing congruence constraints) non-equivalent representations of a metabolic system across levels. However, this requires that the formal identities used to characterize lower level elements must have a set of attributes in common with the formal identity used to characterize the whole. That is, it is possible to adopt the same set of variables to characterize a relevant quality (e.g. size) of: (a) the black-box; and (b) its lower level components. In the example of a multi-scale analysis of the metabolism of human body – an example is given in Fig. 6.1 – the two variables are: (1) size in kg of mass – extensive variable #1; and (2) size in W of metabolic energy – extensive variable #2. The combination of these two variables makes possible to define a benchmark value - the metabolic rate of either the whole or an element expressed in W/kg – intensive variable #3 - which can be used to relate the characteristics of the parts to that of the whole.

Obviously, attributes which are useful to characterize crucial features of the whole body (emergent properties of the whole at level ***n***) - such as the ability to remain healthy – cannot be included in the definition of identity applied to individual organs (at level ***n-1***). These characteristics are in fact "emergent" on level ***n*** and cannot be detected when using a descriptive domain relative to the parts. This is why, variables that are useful for generating Multi-Scale Mosaic Effect are not useful as Multi-Scale Indicators. However, they are very useful to establish a bridge among analyses on different scales providing relevant indicators.

An additional discussion of the possible use of equations of congruence [relations (1) and (2)] applied to a larger number of lower level elements (level n-1) is given in the following section - Fig. 6.1. Obviously, the more we manage to characterize the whole size of the black box (defined at the level ***n***) using information gathered at the lower level (by using data referring to the identity of lower level elements – parts - at level ***n-1***), the more we will be able to generate a robust description of the system. In fact, in this way we can combine information (data) referring to external referents (measurement schemes measuring the metabolism of organs) operating at level ***n-1*** with non-equivalent information (data) about the black box, which have been generated by a non-equivalent external referent (measurement scheme measuring the metabolism of the person) operating at level ***n***. The parallel use of non-equivalent external referents, in fact, is what makes very robust the information obtained through a cross-scale mosaic effect (avoid the tautology of reciprocal definitions in egg-chicken process – as discussed in the next chapter).

6.2.2 Bridging non-equivalent representations through equations of congruence across levels

In this section we discuss the mechanism through which it is possible to generate a mosaic effect based on the combined use of intensive and extensive variables describing parts and whole of a dissipative holarchic system. This operation leads to a process of benchmarking based on the determination of a chain of values for intensive variables #3 across levels. With benchmarking we mean the characterization of the identity of a holon (level ***n***) in relation to the average values referring to the identity of the larger holon representing its context (level ***n+1***) and the lower level elements which are its components (level ***n-1***).

Let's use again the multi-scale analysis is given in Fig. 6.1. The two non-equivalent mappings:

* ***Extensive #1*** - This is the size of the human body expressed in mass (a mapping linking black-box/ lower level components): 70 kg of body mass;

* ***Extensive #2*** - This assessment of "size" measures the degree of dependency of the dissipative system on processes occurring outside the black-box, that is, in the context. That is, this can be translated into an amount of carriers of endosomatic energy (e.g. kg of food) which is required to maintain a given identity (a mapping linking black-box/context): 81 W of food energy. This is equal to 7 MJ/day of food energy required to cover resting metabolism.

* ***Intensive #3*** - the ratio between the value taken by these two variables is an intensive variable that can be used to characterize the metabolic process associated to the maintenance of the identity of the dissipative system. This ratio can been called Endosomatic Metabolic Rate of the Human Body (EMR_{HB}): 1.2 W/kg of food energy per kg of body mass. It is important to note that the values of EMR_i can be directly associated to the identity of the element considered. That is, these are "expected values" as soon as we know that we are dealing with a kg of mass of a given element (such as brain, liver, heart).

As illustrated in the upper part of Fig. 6.1 when considering the human body as the focal level of analysis (level ***n***) - as the black box - we can use this set of three variables (EV#1, EV#2, and EV#3) as a formal identity to characterize its metabolism. The same approach can be used to characterize the identity and the metabolism of lower level elements of the body (level ***n-1***). This implies assuming that it is possible to perceive and represent both the black-box and their components as metabolic elements on the same descriptive domain (using a set of reducible variables, even if operating different measurement schemes). This means that the data obtained using non-equivalent measurement schemes can be reduced to each other (e.g. the energy consumed by the Brain in form of ATP can be expressed in energy equivalent consumed by the person in form of kg of food). Both assessments refer to resting metabolism. Obviously, this requires having available in parallel two experimental settings (one used to determine the data set for the black-box - level ***n*** - and one used to determine the same data set but referring to lower level components - level ***n-1***. The experimental design used to measure the mass and the energy requirement of the whole body, in fact, is different from that adopted to measure the mass and the energy requirement of internal organs.

Let's use this approach to characterize the metabolism of lower level components of the human body. Obviously, the mass of – extensive variable #1 - and the amount of energy dissipated per unit of time in – extensive variable #2 - individual components must be smaller than the whole. The same rule does not apply, however, to the value taken by the intensive variable #3 describing the level of dissipation per unit of mass. Actually, this is what makes possible to establish forced relation between the value taken by the size of the compartments and their level of dissipation. Looking at Fig. 6.1:

Brain: (1) size in mass = 1.4 kg; (2) size in endosomatic energy = 16.2 W; (3) EMR_{br}= 11.6 W/kg

Liver : (1) size in mass = 1.8 kg; (2) size in endosomatic energy = 17.4 W; (3) EMR_{lv}= 9.7 W/kg

In this example both elements considered at the level ***n-1*** have an endosomatic metabolic rate much higher than the average found for the human body as a whole. This means that in terms of requirement of input per unit of biomass (e.g. the requirement of input flowing from the environment into the black box) 1 kg of brain is consuming as (is equivalent to) almost 10 kg of "average human body mass". This ratio reflect the relative value of EMR_i (11.6 W/kg for the brain versus 1.2 W/kg for the average body mass). This implies the possibility of calculating different levels of embodied ecological activity for ecosystem elements operating at different hierarchical levels (Odum, 1983; 1996). This fact can also be used to calculate biophysical limits of human exploitation of ecological systems (Giampietro and Pimentel, 1991). We can recall here the joke about the national statistics about consumption of chicken per capita. If there are parts of the body that consume much more than the average, other parts must consume much less. This implies also that the value of the ratio between levels of consumption per unit of mass and the value of the ratio between the size of the various parts must be regulated by equations of congruence.

It is important to observe here the crucial role of the peculiar characteristics of nested metabolic elements. They are made up of holons which do have a given identity (they are realization of a given essence which implies the association between expected typologies and experienced characteristics in equivalence classes). The brain of a given human being has an expected level of metabolism per kg, which we can guesstimated 'a priori', from the existing knowledge of the relative type. This level is different from the expected level of metabolism of 1 kg of heart. Both of them, however, can be predicted only to a certain extent. Individuals are just realization of types (their assessments come with error bars).

Completely different would be the situation if we disaggregate the characteristics of human body – assessed at the level ***n*** - by utilizing a selection of mappings based on the adoption of identities referring to much lower levels of organization. For example, let's imagine to use a set of identities referring to the atomic level of organization – as done in the lower part of Fig. 6.1, in the white box labeled as Chemical Elements. In this example, the whole body mass is characterized in terms of a profile of fractions of Oxygen, Carbon, Hydrogen, etc. We can even obtain closure of the size of the whole body (assessed in kg) expressed as a combination of lower level identities (assessed in kg). However, with this choice, the distance between the hierarchical levels at which we perceive and represent the characteristics of the metabolism of human body [at a level that we called ***n***], and those at which we can perceive and represent the identity of chemical element [at a level that we can call ***w***, with ***w*** << ***n***], is so large that this non-equivalent set of identities – chemical elements - used to describe the components of the human body cannot bring into our descriptive domain – on level ***n***– any free information. In fact, atoms require a descriptive domain for their characterization which is not compatible with the perception and representation of the chemical processes associated to the metabolism of food and the maintenance of the organized structure of the organs through metabolism. That is, with this choice we are not able to reduce the formal definition of these two sets of identities to each other. From our knowledge of the typologies associated to the label Oxygen, Carbon, Hydrogen [identity of chemical components in relation to lower level atomic components at the level ***w*** and level ***w-1***] we can just estimate the overall mass of the system. Nothing about the rate of its metabolism.

On the contrary, when we use for the representation of lower level elements of the human body a reliable set of identities for organs viewed as metabolic systems – at the level ***n-1*** – we can use previous knowledge about the given rate of energy dissipation associated to the functions expressed by the relative organized structure. In fact, we expect that both components (organs and the whole) do have a metabolism, so that they can share the same formal identity, even if they require different measurement schemes. This is where we can get some "free information" from the knowledge of the relative types. To take advantage of this free ride, however, we have to select two sets of identities [e.g. for the whole body and its organs] which can be characterized using the same set of variables. This implies a small distance between hierarchical levels. For example, when using the disaggregating procedure shown in the white box labeled as "***Organs of an adult man***" (70 kg of body mass) we can infer, in principle, the dissipation rate of the whole body starting from our knowledge of the dissipation rates of its parts and their relative size. Basically, this is the basic rationale that will presented later on for generating mosaic effects in the representation of the stability of socio-economic systems (e.g. Multiple-Scale Integrated Analysis of Societal Metabolism).

This mechanism, however, requires introducing an additional concept, which plays a crucial role in the process. The concept of closure over the information space (Dyke, 1988). The bonus obtained when using in parallel non-equivalent information derived from non-equivalent observations of a nested hierarchical system depends in fact on the degree of closure of the relative information space. A mosaic effect is reached when we are able to aggregate in a consistent way the various assessments referring to the parts onto the total size of the whole. In this case, the knowledge of the formal identity of the whole – at the level ***n*** – and the knowledge of the formal identities of the various parts – at the level ***n-1*** – can be related to each other to gain robustness. This robustness is associated to the congruence of the values taken by the set of different variables used to characterize the two set of identities across levels (after characterizing the existing relation of parts into the whole, in relation to the selection of formal identity).

To explain this concept, lets imagine' that we want to guesstimate the overall metabolic rate of a human body using only our knowledge of its parts (referring to the level ***n-1***). To do that, we can use the data set included in the white box labeled as "***Organs of an adult man***" in Fig. 6.1. In this case, we can express the characteristics of the whole body (level ***n***) as a combination of characteristics of 7 typologies of lower level components (level ***n-1***). Out of these 7 typologies, 6 types (Liver, Brain, Heart, Kidneys, Muscle, Fat Tissue) have a clear and known (expected) identity. The seventh compartment, which is required for obtaining the closure, however, is not clearly defined in terms of an established correspondence between an internal mapping (e.g. kg of mass) and an external mapping (e.g. energy required for its metabolism), associated to a previous knowledge of this type. Actually, we are all familiar with the label given to this last compartment which is often found at the bottom of this type of lists. The standard label for this last item is "others". Obviously, this solution implies that the identity of the compartment labeled as "others" is not associated to any previous knowledge of an established type at the level ***n-1*** . Therefore, the resulting numerical assessment is not obtained by a direct measurement (performed at the level ***n-1***) – an external referent - of a sample of members of an equivalence class. Put in another way, "others" is not, like the others, a known type with a given and reliable identity. Rather the characteristics of this virtual compartment are "inferred" by considering the difference between: (A) the information gathered about the characteristics of the whole human body gathered at level ***n***; and (B) the information gathered about the selected set of 6 identities of lower level elements, perceived and measured at the level ***n-1***. The characterization of this seventh virtual lower level element – the identity of 'others' (about which we cannot provide any "expected value" a priori) – depends on: (1) the values taken by the variables referring to the characteristics of the whole; (2) the selection of identities used to define the various compartments of the whole – the set of lower level elements used in the disaggregated representation of the whole; and (3) the relative values of the variables describing the selected set of identities of lower level elements. Getting back to the example of the 7 compartments in the white box, we could have used a different selection of 6 types (e.g. by replacing the 1.8 kg of Liver with 7.0 kg of Skeleton) and this would have provided a different definition for the "virtual identity" of the seventh compartment "others". In this case "others" would have had a mass of 17.8 kg (rather than the 23.3 kg reported in the table) and a different EMR.

This is an important aspect which can be associated to the next concept to be introduced in Chapter 7 – that of "impredicative loop analysis". One of the standard goals of the triangulation of information when dealing with the reciprocal definition of identities across levels in a metabolic holarchy is that of reducing as much as possible the noise associated to unavoidable presence of "informational left-overs". The amount of information missed when adopting the category "others" as it were a real typology can be important or not. Therefore, the analyst has to chose the most useful way to represent the system (disaggregate it into lower level elements) trying to reduce as much as possible such a problem. For example, getting back to the example of the disaggregating choices made in the white box labeled ORGANS [= 6 types plus the sixth compartment labeled "others"] we have a relatively large size of the unaccounted part of the whole in terms of mass (more than 33% of the total mass is included in "others" – that is 23,2 kg over 70 kg of the whole body). On the other hand, this mass could result not particularly relevant in terms of metabolic activity, since the resulting level of EMR is quite low (0.6 W/kg). Therefore, by making such a choice, the analyst is ignoring the characteristics of the identity of a big part of the whole in terms of mass. However, if the analysts is concerned only with identifying those organs that are keeping high the metabolic rate, this body part could result not particularly relevant in terms of energy dissipation per unit of mass (e.g. in terms of the qualities associated to extensive variable #2 , that is requirement of services – e.g. sustainable food - from the context). Obviously, any decision about what to include and what to leave out in the virtual category assigned to the "others compartment" will depend on the type of problems faced and the type of questions we want to answer with the study.

When facing a level of closure which is not satisficing for the goal of the analysis, the analyst can decide to get into the remaining parts of the whole labeled as "others" and look for additional typologies (look for additional valid and useful natural identities). In this way, it becomes possible to reduce the amount of total mass of the whole, which remains unaccounted for in terms of a definition of identities at the lower level. An example of this additional investigation (which implies gathering additional information – using additional external referents - at the level ***n-1***) is given in the blue box in the lower part of Fig. 6.1. The compartment originally labeled as "others" in the white box (which is covering 23.2 kg of mass of the whole) has been split into additional 7 compartments, characterized using an additional 6 known typologies/identities of lower level components (Skeleton, Bone Marrow, Blood, Gastro-Intestinal tract, Lungs, Lymph. Tissue). Also in this new characterization of the black-box in terms of an expanded set of lower level compartments we still face the presence of a residual compartment labeled as "others". However, after this additional injection of information about the identities of elements involved in the metabolism of the human body of an adult man - at the level ***n-1*** - we are able to characterize the metabolism of the whole using previous knowledge related to the characteristics of 12 known typologies/ identities of lower level elements. This reduce the amount of residual "unknown" body mass not accounted for in terms of expected characteristics of lower level typologies to only 3.9 kg (over 70 kg). Depending on the questions addressed by the study, the analyst can decide, at this point, whether or not this reduction is enough.

Obviously, we cannot expect that it is always possible to keep splitting the residual required information labeled as "others" into characteristics associated to known typologies (exploiting in this way pre-existing knowledge of additional lower level identities). The analysts must face the obvious fact that the possibility of using this trick has limits.

We can leave now the metaphor of the multi-scale analysis of the metabolism of the human body to get into a more general question. What can be achieved, when studyng complex adaptive holarchic systems by adopting this approach? What are the advantages of obtaining an adequate closure of the information space, based on a parallel characterization of the identities of metabolic systems organized in holarchies on two contiguous levels (e.g. level ***n*** and level ***n-1***)?

We believe that this approach can be used to achieve two important objectives:

(1) it provides a general mechanism which can be used for benchmarking (= contextualization of an element in relation to the whole to which it belongs). Obviously, any benchmarking will always reflect the previous selection of the formal identity (the set of significant variables) used to check the congruence among flows. For example, a question like: "how good is doing a farmer making 1,000 US$ per year?"

can only be answered after comparing this value (an intensive variable of added value per unit of human time, which can be associated to the identity of a household-holon), with the average household income of a given year within a given society in which such a farmer is operating (the identity of the larger holon within which the household-holon is operating). In the same way, a yield of 1,000 kg of corn per ha can result a remarkable achievement for a farmer operating in a desert area with poor soil, when not using any fertilizers, whereas it would be considered a totally unacceptable output if obtained in Iowa in the year 2000. By adopting a Multi-Scale Integrated Analysis of Agro-ecosystems it can be possible to build an integrated mechanism of mappings of flows that can be easily defined and tracked [e.g. flows of food energy, exosomatic energy, added value, water, nitrogen] in relation to: (a) the characteristics of the system generating and consuming these flows; and (b) the characteristics of the context within which these flows are exchanged. Since the very exchange of these flows is related to the definition and maintenance of an identity for the metabolic elements investigated (across various levels), such an analysis can carry useful "free" information when addressing the hierarchical structure of the system, and when linking identities and indicators referring to wholes and parts.

As noted earlier, however, in order to do that we have to be able to express these flows against a matrix (e.g. against human activity or areas) in a way that makes possible to obtain a closure of the non-equivalent representations of the various identities of compartments across levels. After having done this, we can define whether the values taken by a set of variables used to characterize the performance of a farmer (e.g. level of income, leisure time, life span) or the performance of a particular farming activity (e.g. economic labor productivity, return on the investment, demand of land, associated level of pollution per unit of land) is above or below average values referring to observable qualities of types characterizing the equivalence class to which the farmer belongs and how these values refer to the expected values associated to larger level holon determining the stability of the context.

(2) it provides a general mechanism which can be used for establishing a bridge among non-equivalent descriptive domains, and therefore to boost the coherence and reliability of an integrated package of indicators. The forced relation between parts and the whole (e.g. using the relation between total EMR of the whole body and the various EMR_i of its parts) can be applied to different typologies of flows in parallel (e.g. food produced and required per unit of land, exosomatic energy produced and consumed per unit of land, added value generated and consumed per unit of land) and against different matrices (e.g. human activity and area). This makes possible to establish a mosaic effect also among non-equivalent readings (definition of different formal identities for the dissipative systems) in relation to the feasibility of the various holons making up the investigated metabolic system. Households, counties, states, macro-economic reasons, in fact, all do produce and do consume (and must produce and must consume) flows of money, food, energy. Whenever, we map these flows across levels against the same matrix (the same hierarchical frame of unit of lands, or the same profile of allocation of human time), then we can establish links among analyses related to different disciplinary fields (e.g. producing the same flow of 10,000 US$/year/ha either by agriculture or by agro-tourism implies different requirement of labor, capital, water, and different environmental impacts). The mosaic effect can also be used to fill knowledge gaps referring to not accessible information of residuals. Put in another way, important facts ignored, or heavily underestimated, by an economic accounting of farming (e.g. ecological services lost with soil erosion) can result extremely clear, when performing a parallel analysis based on a biophysical accounting (e.g. the huge material flow associated to soil erosion). The soil lost resulting negligible in an economic accounting of profit and revenues per year at the farm level, can become an important factor when adopting a biophysical accounting of matter flows associated to crop production at the watershed level and over a time horizon of 50 years.

6.2.3 Extending the Multi-Scale Integrated Analysis to land use patterns

Linkages among characteristics of "typologies" belonging to different but contiguous hierarchical levels can be established also by using a spatial matrix which can provide closure across levels. To explore this option let's adopt the same approach used in Fig. 6.1, but this time mapping densities of flows associated to typologies of land use. An example of this analysis is given in the upper part of Fig. 6.2. Let's imagine to have a county of a developed country inhabited by 100,000 people and a Total Available Land of 1 million ha. Assuming a consumption of exosomatic energy per capita (= consumption of commercial energy) of 200 GJ/year/person (an EMR_{AS} = 2.3 MJ/hour), we can calculate a Total Exosomatic Throughput (TET) for that county of 20 PJ of exosomatic energy per year (PJ = Petajoule = 10^{15} joules). The possibility of establishing a relation between the values taken by these variables [= the characterization of a social system viewed at the focal level ***n***] and the values of variables associated to the characteristics of lower level elements defined at the level ***n-1*** [= societal compartments] is discussed in detail in the following section 6.3.

In the example of Fig. 6.2 the same rationale adopted in Fig. 6.1 is applied. The difference in this case is that the common matrix across levels (extensive variable #1) consists of assessments of land area. In practical terms, we have to divide a given amount of TAL (Total Available Land – the size of the whole system mapped in terms of units of area) – which is the equivalent of the total body mass indicated in Fig. 6.1– into a set of typologies of land use (the lower level compartments to which we assign the characteristics of a typology – the equivalent of organs). In the example of Fig. 6.2 the selected set of 5 typologies is: (1) NAL -Natural Land not managed by humans; (2) Res&Inf - Residential and Infrastructures; (3) AGL - Agricultural land; (4) MLPS - Land used for economic activities belonging to the sector of manufacturing, energy and mining; (5) MLSG - Land used for economic activities belonging to the sector of services and government. As noted earlier, we have to obtain closure with this division. That is, TAL [= 1,000,000 ha] has to be divided according a given profile of investment of TAL over the 5 typologies of land use, which provides an arrow of percentages that sums to 100. In the example of Fig. 6.2 such a profile is: (1) NAL – 50%; (2) AGL – 40%; (3) R&I– 6%; (4) MLPS – 2%; (5) MLSG – 2%.

The breaking down of the whole (TAL) into components, which is done in hectares (or other units of area), provides an internal mapping of the size of the system (TAL defined at the level ***n***) which is used also for assessing the size of lower level components (NAL + AGL +R&I + MLPS + MLSG). That is the size of component is expressed as a part of the whole. This would be the equivalent of the extensive variable #1 discussed before for the metabolism of the human body.

We need now a non-equivalent assessment of the size of the whole system (the county) in terms of the degree of interaction with the context. That is we have to select a second extensive variable (#2), which makes possible to adopt the same approach discussed before. The choice adopted in the example provided in the upper part of Fig. 6.2 is to use assessment of exosomatic energy consumption, which is required to guarantee the typical level of metabolism of the county. This is the amount of fossil energy that the county is getting from the society in relation to its socio-economic interaction. As noted earlier such a value is 20 PJ/year for the whole county. This choice reflects an attempt to keep the analogy with the example provided in Fig. 6.1 – this is the equivalent of the extensive variable #2 and with this choice we manage to respect also the same selection of unit (energy over time). However, as it will be discussed later on, this approach works also when selecting as extensive variable #2 an economic variable – e.g. assessment of a flow of added value or another biophysical variable – e.g. water.

Starting from the two values of extensive variable #1 and extensive variable #2 used to characterize the metabolism of the whole county, we can calculate the intensive variable #3 – the Exosomatic Metabolic Density (Average for the County), which is the amount of exosomatic energy consumed per unit of area, referring to the total area occupied by the county. In this example EMD_{AC} is obtained dividing TET, which is 20 PJ, by TAL, which is 1 million ha. The resulting is EMD_{AC} 20 GJ/ha/year.

At this point, we can apply the approach previously illustrated about the multi-scale analysis of the metabolism of human body. The green table in the upper part of Fig. 6.2 can be used to get some "free ride" out of the redundancy existing within this organized information space. Again, this redundancy is generated by our previous knowledge of "identities" of lower level typologies, which can be found in our descriptive domain across hierarchical levels. For example, after having structured the information space in this way, we can try to fill the values of the column of EMD_i by using the column of assessments of the amounts of energy consumed by the various sectors used to represent the economic structure of county. This economic sectors would be the equivalent of organs (elements defined at the level ***n-1***). The values taken by the extensive variable#2 referring to the identities of the lower elements (reflecting the characteristics of the economic sectors of the county) are given in the column of ET_i. The values found in the column of EMD_i are referring to the typologies of lower level sectors. That is the EMD of "Residential and Infrastructure" can be calculated by dividing the value of the relative $ET_{R\&I}$ - 6 PJ of exosomatic energy per year, which is spent in the residential sector - by the area of 60,000 hectares, which is used by this compartment. In this way we obtain a value of $EMD_{R\&I}$ which is equal to 100 GJ/ha/year.

On the other hand, we could have find the same value by using a different source of information – a non-equivalent external referent for this assessment – which is related to a non-equivalent perception and representation of events referring to the level ***n-2***. In fact, we can use additional non-equivalent information to define the characteristics of household types at the level ***n-2***. The characteristics of household types – defined at the level ***n-2***– in fact will determine the characteristics of the household sector – at the level ***n-1***. For example we can start with the average value of consumption per household in the county, related to a given typology of housing (e.g. by looking at the literature, we can find a value of 180 GJ/year/household for the typical houses found in that county). Knowing the average size of the households of that county – e.g. 3 people – we can estimate an average consumption of 60 GJ/year person associated to direct energy consumption in the household sector. After using information on the housing typology (e.g. 300 m^2 of house per person and a ratio 9/1 between the built area of the houses and the additional land included in the residential compound) we can assume – for the specific county characterized by such a residential typology - an amount of 3,000 m^2 of residential area per person. To this area we have to add an additional area (e.g. 3,000 m^2 per person) required for infrastructure (roads, parking lots, recreational areas, etc.). Put in another way, in this way, we can assess the total request of land per person for the residential/household sector of that particular county.

Using this information in our example of an hypothetical county of the USA about which lower level household typologies are known, we can characterize such a system as composed by 33,000 households (100,000 people divided by 3), generating an aggregate consumption in the residential sector of 6 PJ (180 GJ of exosomatic energy per household spent in the residential compartment), in relation to a requirement of land of 18,000 m^2 per household (that has to be included in the residential category). Using this set of data (different from what used before) we can calculate in a non-equivalent way a value of $EMD_{R\&I}$ = 100 GJ/ha/year.

In this example we have two non-equivalent ways for calculating $EMD_{R\&I}$:

(1) using information referring to the level ***n/n-1***. $EMD_{R\&I}$ is the ratio between the total size of the residential sector in terms of exosomatic energy consumption (6 PJ, e.g. as resulting from aggregate record of consumption of that sector in the county) and in terms of land (60,000 ha, e.g. as resulting from remote sensing analysis of land use in the county);

(2) using information referring to the level ***n-1/n-2***. $EMD_{R\&I}$ is calculated from our previous knowledge of: consumption level for a given typology of household, house space requirement per person, house size, ratio between the area of the house and the open space included in the housing compound, ratio between the area occupied by private housing and the area required by common infrastructures.

In a holarchic system made up of nested types, the characteristics of the types making up holons across levels must be compatible with each other. This redundancy is at the root of the existence of "free" information when dealing with representation across levels of holarchic systems.

This hierarchical structure is very robust, in fact if more typologies of housing were known in that area – at the level ***n-2*** – that is, for example: (A) individual family houses (180 GJ/year/household and 3,000 m^2/person of area of the residential compound) and (B) condominium apartments (100 GJ/year/household and 500 m^2/person of area of the residential compound), the average value (variable #3) for

$EMD_{R\&I}$ at the level ***n-1*** would have been different. Still, such a characteristic value for the residential sector - at the level ***n-1*** - can still be expressed in relation to the characteristics of the lower level typologies - at the level ***n-2***. This can be done by considering the profile of distribution of investments of space and energy (using variable #1) within the household sector over the set of possible household types characterized at the level ***n-2*** (using information gathered at the level ***n-2***) in terms of the intensive variable #3. This mechanism is at the basis of impredicative loop analysis.

Obviously, the example of redundant definition of a given value is valid also for other typologies of land use. In the same way, starting from characteristics of typologies belonging to the level ***n-2*** (e.g. typologies of industrial plants) it is possible to guesstimate the value of EMD_{MISG} and EMD_{MLPS} a characteristics referring to the level ***n-1***. To calculate such a value it is necessary to study the consumption of different typologies of industrial building and other categories of land use associated to these typologies. The important aspect of this analysis is related to the ability of disaggregating the total area under the various land use categories, in a way that makes possible later on to use equations of congruence.

This is crucial also for another reason. Known typologies (a given typology of housing or a given typology of power plants) not only makes possible to associate a defined density of flows (e.g. the amount of added value per ha, or the amount of food produced per ha, or the amount of exosomatic energy consumed per ha) per unit of land use in that category, but also to set-up a package of different indicators of performance. That is, we can add to the possibility of performing a Multi-Scale Analysis (by considering simultaneously information gathered at different hierarchical levels) also the possibility of performing a Multi-Dimensional Analysis, (by considering simultaneously the constraints affecting the flows of variables – food, exosomatic energy, added value – referring to different dimensions of sustainability). For example, in the lower part of Fig. 6.2 we have an example of a possible characterization of a farm in relation to a given profile of 4 different typologies of land use: (1) Natural area; (2) Agriculture for Subsistence; (3) Agriculture for Cash crops; (4) Housing and Infrastructures. This would be the characterization of the whole and the part in relation to an extensive variable #1.

Let's imagine now to associate to each one of these 4 typologies defined using the extensive variable land the relative mapping of relevant flows: (A) a flow of endosomatic energy – food produced by subsistence agriculture; and (B) a flow of added value – associated to the production of cash crops. That is, we are using in parallel against the same definition of size (extensive variable #1), two versions of an extensive variable #2. An ***extensive #2biophysical*** – which is referring to a biophysical mapping of the interaction with the context in terms of exchange of flows (the flow of food produced, consumed and sold by the farm). Another ***extensive #2economic*** – which is referring to an economic mapping of the interaction with the context in terms of exchange of flows (the flow of added value produced, consumed and spent by the farm).

In this example, we already can extract from this very simple data base, a set of non-equivalent indicators of performance: (i) the amount of food available for self-consumption (a relevant indicator in those areas in which the market is not reliable); (ii) the amount of food supplied by the farm to the rest of the society (relevant for determining self-sufficency at the national level); (iii) the amount of added value available to the farmers as Net Disposable Cash (a relevant indicator to determine the potential level of interaction of the household with the rest of the society in terms of economic transactions).

Because of the particular structure of this information space, we can establish a link between potential changes in the value taken by these indicators. That is, relative constraints can be studied by using biophysical, agronomic, ecological, and socio-economic variables and models. This example is important to show, how the same data set can be used to provide different results according to the adoption of different disciplinary perceptions and representations of changes.

For example, talking of the amount of food available for self-consumption we have that out of the total 90,000 kg of grain produced in this farm (50,000 kg of grain for subsistence and 40,000 kg of grain for cash) only 50,000 kg should be accounted as internal supply of food (as a relevant flow for food security for the farmers). The reverse is true when we want to assess the amount of food supply that this farm is providing for the socio-economic system to which it belongs. That is the "context of this farm" is receiving only 40,000 kg of grain out of the investment of 100 ha TAL in this farm. Even more complicated is the accounting of economic variables. If we want to assess the income of the farm we should add the value of the self-consumed grain (the 25,000 $ indicated in red) to the value of the Net-Return of cash crop (15,000 $). On the other hand, if we want to assess the level of Net Disposable Cash we have to ignore the 25,000 $ related to the value of the self-consumed crops. Still different has to be an analysis aimed at assessing the effect of the characteristics of this farming system on the GNP of the country.

The typology "natural area" (area not managed by humans) is completely irrelevant when dealing with short term perception and representation of economic performance and food security. This typology of area is perceived as not producing anything useful (nor money or food). This is probably an explanation for the fast disappearance of this typology of land use on this planet. However, as soon as we introduce a new set of relevant criteria and the consequent set of relevant indicators of performance (preservation of biodiversity, support for natural bio-geo-chemical cycles, preservation of soil, quality of the water, etc.), it becomes immediately clear that those typologies of land use that are crucial for determining a high economic performance are, at the same time, the very same categories that can be associated to the worse performance in ecological terms (see Chapter 10). It is exactly the ability to handle the heterogeneity of information related to different scales and non-reducible criteria of performance which make interesting the approach of Multi-Scale Integrated Analysis of agroecosystems.

Even in this very simple example we can appreciate that a multi-scale integrated analysis is able to handle the information related to indicators which are in a way independent from each other, since they are calculated using disciplinary representation of the reality, which are non-equivalent [e.g. the study of the stability of the loop of food energy spent to generate the labor required for subsistence is independent from the analysis of the economic loop associated to cost and return related to the cultivation of cash crops]. However, within this integrated system of accounting across levels, these two representations are indirectly connected. In fact, autocatalytic loops of endosomatic energy (investment of labor to feed the workers), added value (investment of money to pay back the investments), and exosomatic energy (investment of fossil energy to generating the useful energy required for the making of exosomatic devices) they all compete for the same budget of limiting resources: human activity and total available land. It is this parallel competition which determines a set of mutual constraint which each one of these autocatalytic loops implies on the others. As noted earlier the nature of this reciprocal constraint can be explored by considering lower level characteristics (e.g. technical coefficients) and higher level characteristics (e.g. economic, social and ecological boundary conditions).

6.3 Using mosaic effects in the integrated analysis of socio-economic processes

6.3.1 Introduction: the integrated analysis of socio- economic processes

In economic terms we can describe the socio-economic process as a process in which humans alter the environment in which they live with their activity (through labor and capital/technology) in order to increase the efficacy of the process of production and consumption of goods and services. In other words, they attempt to stabilize and 'improve' the structures and functions of their society according to a set of internally generated "values" and "goals" (= what they perceive and how they represent improvements in existing situation). In biophysical terms, the process of self-organization of human society can be seen as the ability to stabilize a network of matter and energy flows (defined over a given space-time domain) representing what is produced and what is consumed in the economic process.

To be sustainable, such a process has to be: (1) compatible with the aspirations of the humans belonging to the society; (2) compatible with the stability of both natural and human-managed ecosystems; (3) compatible with the stability of social and political institutions and processes, (4) technically feasible, and (5) economically viable. The order of these 5 points does not reflect priorities or relative importance, since each one of these conditions is crucial.

This is to say, that when we perform a biophysical analysis of human societies (e.g. using variables such as kg of iron or Joules of fossil energy) we can "see" only certain qualities of human societies (e.g. we cannot get any indication about the "economic value" of commodities) and therefore we can check only a few of the 5 conditions listed above. The same predicament applies to "economic analyses", "engineering analyses", or "political analyses". In order to be able to "see" and describe a certain set of system's qualities considered as relevant in certain disciplines, analysts will have to use a finite set of encoding variables and descriptive domains (they have to assign to the system a formal identity which is useful for applying the relative disciplinary knowledge). However, this choice can imply losing track of other system's qualities considered as relevant by other disciplines. That is, not everything which is economically viable is, as a consequence, also ecologically compatible. Not every solution which optimizes efficiency is, as consequence, also advisable for keeping low social stress or to improve adaptability, and so on.

The integrated use of non-equivalent medical analyses to deal with human health – Fig. 6.3 - can be used as a good metaphor on how to use in an integrated way scientific analyses when dealing with sustainability. For the same concept Neurath (1973) proposed the expression "*orchestration of sciences*". Getting back to the example of Fig. 6.3 which is limited only to the challenge of generating of meaningful representation of shared perception at a given point in space and time, if you want to see broken bones you have to use X-rays, but you cannot "see" in this way soft tissues (for that you need an ultrasound scan). In the same way, if you want to know whether a woman is pregnant in the first weeks, you can use a chemical test, based on her blood or urine. Going in endoscopy can be the easiest thing to do to look at a local situation, whereas Nuclear Magentic Resonance can deal also with the big picture. In these examples, X-rays, ultrasound-scan, NMR, chemical tests, endoscopy are non-equivalent tools of investigation. No matter how powerful or useful is any of them, when dealing with the behavior of complex systems (i.e. health of humans) we cannot expect that one tool (based on the adoption of a formal identity in the representation of the investigated system) can do all the relevant monitoring. In order to be able to characterize several relevant non-equivalent aspects of patient behavior, and also for economic criteria (to avoid to shoot to flies with machine guns) it is wise to develop and use several non-equivalent analytical tools in different combinations depending on the circumstances. Sustainability analyses seem to be a classic case in which it is wise to be willing to work with an integrated set of tools. This is the only way to expand the ability of scientists to cover as much as possible the relevant perceptions about sustainability that should be considered, without putting all the eggs in the same basket.

6.3.2 Redundancy to bridge non-equivalent descriptive domains: multi-scale integrated analysis

Redundancy in scientific analysis is often seen as a villain. The axiom used to justify the "holy war" of science against redundancy is the famous "Occam's razor principle" (= one should not increase, beyond what is necessary, the number of entities required to explain anything). The principle is also called the "principle of parsimony". Such a principle requires that scientific analyses should follow the goal of obtaining a maximum in the compression of the information space used in their model. That is, sound science must use as few as possible variables and equations. It is worthwhile observing here that one of the measure of complexity for mathematical objects (computational complexity) is related exactly to the impossibility of compressing the demand of information for their representation (Chaitin, 1987). That is, if you are dealing with a complex object, you cannot expect to compress much in the step of representation (amplify your predictive power), just by developing more sophisticated inferential systems (more complicated models). Without getting into a sophisticated discussions related to this topic, we want to use again a metaphor, that of geographic maps, to question the idea that redundancy should be eliminated as much as possible in scientific analyses.

Using a metaphor based on geographic map is appropriate, since, after all, numerical values taken by variables in an integrated analysis are generated by the application of a selected modeling relation to the representation of a natural system (Rosen, 1985). These assessments are nothing but "mappings" of selected qualities of the investigated natural system into a given mechanism of representation, which reflects the characteristics of the selected model.

The examples given in Fig. 6.4 and Fig. 6.5 are related to the discussion given in Chapter 3 about non-equivalent descriptive domains. The 4 different views given in Fig.6.4 (Catalonia within Europe; a specific County in Catalonia; an area of a national Park in the county, and finally roads within the Natural Park) reflect the existence of different hierarchical levels at which a geographic mapping can be provided. When the differences in scale are too large, it is almost impossible to relate the non-equivalent information presented in distinct descriptive domains (e.g. in Fig. 6.4 the upper and lower maps on the left). In order to link non-equivalent views across different scales you need a certain level of redundancy among the map. That is, in order to be able to appreciate the existing relation between two non-equivalent representations, you must be able to recognize the element (pattern) described within one of the specific descriptive domain also within the next one. For example, Catalonia within Europe – in the first map - becomes the whole object within which Pallars Sobira' County is located - in the next map. This happens, in Fig. 6.4, in all the couplets of maps linked by an arrow.

At this point, if we are able to establish a continuous between the various links across the non-equivalent maps, then, this makes possible for us to structure the information provided by the set of maps (referring to different hierarchical levels). Distant maps are non-reducible to each other (upper and lower maps on the left), contiguous maps can be bridged. The bridging of non-equivalent information across different maps will be easy or not, depending on the degree of overlapping of the information contained in it. The higher the level of overlapping, the lower the compression, but the easier becomes to establish a relation between the information contained in the two maps. On the other hand, a very little degree of overlapping (e.g. the two maps on the higher level) implies a more difficult bridging of the meaning conveyed by the maps. By establishing a continuous chain of bridges of meaning across maps we can relate the information about the lay-out of the Natural Park (which is required by someone willing to drive there) to the information about "where such a park is located". Depending on the characteristics of possible users, we have to provide such an information in relation to different definition of such a context. We can say that such a park is at the same time, in Europe, in Spain, in Catalonia, and in a given corner of Pallars Sobira' County.

It should be noted that in this case, using some redundancy in this integrated system of representations (the partial overlapping of the information in contiguous maps) is the only way of handling such a task. A huge map that would keep the same level of accuracy adopted for the representation of the area within the Natural Park, applied to the description of the entire Europe, cannot be made or operated for theoretical and practical issues (without a hierarchical structuring of the information space it would not be possible to handle the required amount of bits of information). A map as large as Europe in scale 1:1 would simply result into an excessive demand of computational capability both in the step of making the representative tool (encoding system's qualities) and using it (decoding). Moreover, nobody would find it useful since we have already the original!

In Fig. 6.5 we deal with an example of the second source of non-equivalent assessment discussed in Chapter 3 (Fig. 3.1): two logically independent systems of mapping of the same geographical entity – Europe. To recall the example given in Fig. 3.1 we are in the case of the same system (the head of a given woman) represented by using two different mechanisms of encoding (visible light for the face and x-rays for the skull). In the case of Fig. 6.5 there is a map which provides two non-equivalent formal identities: (i) a political mapping, dealing with borders and names of Countries; whereas the other map provides (ii) a physical mapping, locating and describing physical elements such as rivers and mountains. In this case, different selections of relevant attributes are used to represent the formal identity of the same system in the map. The two maps are based on two non-equivalent formal identities assigned to the same natural system (Europe), in relation to two possible meaningful relations between shared perception and representation of such a system. Whenever, we are in presence of a bifurcation which generates two non-equivalent formal identities both useful, we can no longer compress. It becomes necessary to use and handle in parallel these non-equivalent descriptions.

At this regard, we can recall the main conclusions about the 4 assessments presented in Fig. 3.1 which can be applied to the message given by Fig. 6.4 and Fig. 6.5. The 4 examples of assessment given in Fig. 3.1 cover the possibility of:
(a) life cycle assessment bridging the assessment consumption per capita at the household level (116 kg/year) and at the food system level (1,015 kg/year). This implies the need of using several maps based on the same system of encoding (same set of attributes), but referring to different scales (as in Fig. 6.4).
(b) the need of using different types of maps - based on different methods of encoding – economic variables (1,330 kg/year) and biophysical variables (1,015 kg/year) on the same scale (as in Fig. 6.5).

But in this case, the two non-equivalent descriptions (two maps based on a different selection of variables) must refer to the same hierarchical element. Otherwise, they could not be used in integrated analysis. Getting back to the various maps shown in Fig. 6.4, this implies that we can imagine two versions of the map of Europe (political and physical), as well as two versions of the map of Spain (political and physical) and Catalonia (political and physical). Put in another way, representations which are logically independent in their selection of encoding variables (e.g. political and physical maps – a bifurcation in formal identities) have to be packaged in couplets referring to the same "basic definition" in terms of space-time domain. Also in this case, this implies keeping a certain level of redundancy in the representation (e.g. in Fig.6.5 the geographic border of Europe are the same in the two maps).

This observation can appear absolutely trivial when dealing with the example of political and physical representations of geographic entities as in Fig. 6.5. However, when dealing with the parallel reading of socio-economic systems in biophysical and economic terms, it is very common to face a different "definitions" of border for the same system defined at the same level. For example, the border used to assess the GNP of a country is different from the border used to assess its demand of ecological services. The difference being generated by the effect of import and export.

6.4 Applying the metaphor of redundant maps to the integrated assessment of human systems

The following two sections present an example of the application of this rationale to a Multi-Scale Integrated Analysis of societal metabolism. A detailed presentation of the methodological approach and the data base used for generating the material presented here is available on two special issues of ***Population and Environment*** dedicated to Multi-Scale Integrated Assessment of Social Metabolism: Vol.22 (2) of the year 2000; and Vol.22 (3) of the year 2001.

6.4.1 Multi-scale analysis of societal metabolism - same variable (MJ) different levels

In this section we describe how it is possible to apply the same rationale seen about geographic maps in Fig. 6.4 to establish a bridge among different numerical values taken by the same variable, when used to represent the multiple identities of a given system resulting from its perception on different hierarchical levels. In this example we use a system of encoding of the characteristics of the system based on the variable "MJ of energy" (this is an example taken from energy analysis).

In the following example we describe a given system (Spain in 1995) in terms of energy flows and to do that we will build a system of accounting able to establish congruence among different mechanisms of mapping (different perceptions and representations of energy flows) referring to different levels. This does require the use of non-equivalent external referents. The reader should recall again the example of non-equivalent assessments of kg of cereal discussed in Fig. 3.1.

In order to be able to represent in quantitative term something we must provide "root definitions" (the identities of the elements that are modeled expressed in terms of encoding variables). More about this step can be found in Chapter 7 (impredicative loop analysis) and in Chapter 9 (applications to agricultural systems). For the moment, it is enough to say that in our representation we do include a set of energy flows associated to the various activities required to produced and consume goods and services within a socio-economic system. In order to define a clear identity for these energy flows we map them against a reference frame provided by the profile of allocation of total human activity over the set of activities performed within the society (for a more detailed explanation see the two special issues quoted before).

A conceptual distinction between exosomatic metabolism (matter and energy flows metabolized by a society outside human body) and endosomatic metabolism (food used to support human physiological processes) has been introduced by Lotka (1956) and later on proposed as a working concept for the energetic analyses of bio-economics and sustainability by Georgescu-Roegen (1975). Such a distinction obviously is based on a previous definition of a given identity for the lower level converters which are transforming inputs into outputs – i.e. humans, that are considered by this distinction in parallel on two hierarchical levels: (1) endosomatic energy refers to a perception of human metabolism at the level of individuals (physiological conversions). (2) exosomatic energy refers to a perception of human metabolism at the level of the whole society (technical conversions). The concept of societal metabolism directly addresses the hierarchical structure linking the converters and the whole. In fact, using the original vision of Lotka about exosomatic energy: ".... *it has in a most real way bound men together into one body: so very real and material is the bond that society might aptly be described as one huge multiple Siamese twin*" (ibid, p. 369). The vivid image proposed by Lotka explicitly suggests that a hierarchical level of organization higher than the individual converter should be considered when describing the flow of exosomatic energy in modern societies.

- Endosomatic energy – Endosomatic means inside the human body. It indicates energy conversions linked to human physiological processes fueled by food energy. Therefore, endosomatic energy implies a clear "identity" for energy carriers, technical coefficients (power levels are all clustered around the value of 0.1 HP), rates of throughput (energy consumption per capita per day are well known) and output/input ratios.

- Exosomatic energy – Exosomatic means outside the human body. It indicates energy conversions obtained using sources of power external to human muscles (e.g. machine or animal power), but which are still operated under the control of humans. Depending on the technology available to a given society, exosomatic conversions can imply the existence of huge gradients in power levels. For example, a single farmer driving a 100 HP tractor in the USA delivers the same amount of power of 1,000 farmers tilling the land by hand in Africa. This is qualitative difference detected by the existence of huge gradients in power level, which can be totally lost by an assessment of energy flows, since huge tractors are driven only for a few hundreds hours per year! In developed societies, exosomatic energy is basically equivalent to "commercial energy". In very poor countries, exosomatic energy is less related to the use of commercial energy, but rather to traditional forms of extra power for humans such as animal power (like mules and buffaloes), wind, water falls, fire (used for cooking food, heating or clearing land).

In both cases, we have that the very idea of metabolism requires the mapping of energy flows (MJ of food per day, or GJ of Tons of Oil Equivalent/year) against time in relation to the size of a dissipative system. Below we adopt a mapping of size of energy flows (extensive variable#2) against a mapping of the size of the societal system obtained in terms of "human time" (extensive variable#1). This variable of size can be divided using different categories. At a first sub level: producing versus consuming. Then within each of this subcategories into lower level typologies of activities (e.g. producing in the agricultural sector versus producing in the industrial sector). Such a mapping can obtain closure across levels of categorization and therefore can be easily used to build a hierarchical matrix against which frame multi-scale analysis.

There is, however another important difference that has to be briefly discussed. In the conventional linear representation of the metabolism of a society energy flows are described as unidirectional flows from left to right (from primary sources to end uses) as illustrated in Fig.6.6 and Fig.6.7. However, it is easy to note that some of the end uses of energy (indicated on the right side of these two figures) are necessary at the beginning of the chain for obtaining the input of energy from primary energy sources (indicated on the left side). That is, the problem with a linear representation – as the one adopted in these figures - is generated by the fact that the conversions losses indicated on the left side (of both Fig.6.6 and Fig.6.7 for endosomatic and exosomatic energy flows) occur "before" the primary energy sources get into the picture. That is the stabilization of a given societal metabolism is linked to the ability of establishing an egg-chicken patterns within flows of energy (Odum, 1971, 1983, 1996). Activities occurring on the left are not occurring "before" the one on the right in reality. This is an artifact of the choice made when representing such a metabolism. In the reality all these activities are occurring at the same time within an autocatalytic loop. Unfortunately, this obvious insight is completely lost by a linear representation of energy flows used to generate assessments of output and inputs. The possibility of establishing internal link among the values taken by energy variables using the concept of egg-chicken is discussed in Chapter 7 (in particular we will get back to the discussion of Fig. 6.6 and Fig. 6.7 in Section 7.3).

*** Linking non-equivalent assessments across hierarchical levels***

Let's start by writing a mathematical identity [= a redundant definition in formal terms establishing an equivalency statement among names of numbers] of the Total Exosomatic Energy Throughput of a society (e.g. TET expressed in Giga Joules of Tons of Oil equivalent consumed by a country per year). For example, we can write that TET – upper part of Fig. 6.8 - is equal to:

$$\text{TET} = \text{Endo} \times \text{Exo/Endo} \qquad \text{(i)}$$

The terms included in this identity are:

- TET is the total amount of exosomatic energy consumed by the society in a year (expressed in Giga Joules of TOE /year). This value can be obtained checking existing statistics (e.g. UN Energy Yearbook) and it was in Spain, 1995, equal to: 4,240 PJ (primary energy expressed in TOE).
- Endo is the total amount of food energy consumed by the society in a year (expressed in Giga Joules of food /year). This value can be obtained checking existing data (e.g. FAO-statistics) and it was in Spain, 1995, equal to: 196 PJ (this is food disappearing at the household level).
- Exo/Endo is the resulting ratio between the total amount of Exosomatic energy metabolized by society and the total amount of Endosomatic energy. In 1995 in Spain it was: 4,240/196 = 21.6.

Obviously, as soon as, we calculate the ratio Exo/Endo using only the two numerical values obtained from statistical sources (using the ratio "TET"/"Endo"), then we collapse relation (i) to the trivial identity TET = TET. This is why, we need to look for external referents bringing in non-equivalent source of information about the nature of this relation, when perceived and represented across hierarchical levels. This implies adopting different ways of perceiving and representing the qualities indicated by this relation.

*** Looking for additional external referents: Endosomatic flow - the physiological view**

Thanks to the peculiar characteristics of holarchies, we can also express the given "system quality" – endosomatic energy flow - using a non-equivalent mechanism of mapping, related to the previous knowledge of lower level typologies. For example, we can write:

$$\text{Endo} = \text{THA} \times \text{ABM} \times \text{MF} \qquad \text{(ii)}$$

Where:
THA = Total Human Activity (total hours per year of human activity in the society. These hours imply a proportional amount of endosomatic energy flow linked to the physiological metabolism of human body). This assessment, in turn, depends on the variable population. In fact we can write the variable THA = Population x 8760 (where 8760 are the hours of a year).
ABM = Average Body Mass (average value of the weight of humans referring to individuals in the society – expressed in kg);
MF = Metabolic Flow (average metabolic energy expenditure per kg of body mass over the year in the society – expressed in W/kg).

These average values (ABM and MF) can be calculated for any given society (or country) starting from the population structure and the record of the mix of physical activities. Put in another way, in order to be able to make these assessments, we must have the knowledge of lower level characteristics. For example, the average body mass can be estimated from:
(a) age structure of population, which reflects the profile of distribution of individuals over different age classes. An example of this analysis applied to 4 different types of societies at different degree of development is given in Fig. 6.9.
(b) data on the Average Body Mass within each age class. An example of this analysis applied to 4 different types of societies at different degree of development is given in Fig 6.10. Data related to the profiles of values of ABM on different age class in different countries are available in the field of nutrition (see for example James and Schofield, 1990).

This means that we can express the endosomatic flow per capita as:

$$\text{Endo} = \text{MJ/hour} = \text{ABM} \times \text{MF} = \sum (K_i \times \text{ABM}_i \times \text{MF}_i) \qquad \text{(iii)}$$

In which we can use 3 age classes; K_1 <15 year; 15 year > K_2 < 65 year; K_3 >65 year

It should be noted that the information on the distribution of population over the various age classes implies an additional constraint on the value that can be taken by the "dependency ratio" of the society (the fraction of population that can be included in the work force), in fact it determines the fraction of population which is included in the age bracket <15 year of age and >65 year of age.

*** Looking for additional external referents: Exosomatic flows - the technological view**

Following the same rationale used so far, we can express the value of TET as the sum of the energy consumption of different sectors of the socio-economic system:

$$\text{TET} = \text{ET}_{HH} + \text{ET}_{PS} + \text{ET}_{SG} \qquad \text{(iv)}$$

Where:
ET_{HH} = Exosomatic energy consumption of the Household Sector
ET_{PS} = Exosomatic energy consumption of the Productive Sector (including Manufacturing, Agriculture, Energy and Mining)

ET_{SG} = Exosomatic energy consumption of the economic sector including Services and Government.

Each one of the 3 assessments included in the right side of relation (iv) is expressed in terms of an extensive variable (e.g. GJ/year) and can directly be found on statistical sources, but this would imply using again the same external referent used when calculating the exo/endo ratio in relation (i). However, assessments of exosomatic energy can be handled in the same way as the assessment of Endosomatic energy in relation (ii). That is, we can express each one of these assessments as the product of an intensive and an extensive variable establishing a bridge with a meaningful relation between perceptions and representation of events at the lower level (= lower level assessments).

We have to use again the trick of using redundancy to link non-equivalent definitions of identities. That is, for each economic sector (PS is used as an example here) we can write:

$$ET_{PS} = HA_{PS} \times EMR_{PS} \qquad \text{(v)}$$

Where:

HA_{PS} = Human Activity invested in working in PS (expressed in hours of human activity) – being a total amount per year in this sector, this is an extensive variable (#1 – see section 6.2);

ET_{PS} = Exosomatic Throughput in PS (expressed in GJ of exosomatic energy per year) – being a total amount per year in this sector, that is an extensive variable (#2 – see section 6.2);

EMR_{PS} = Exosomatic Metabolic Rate of the economic sector (expressed in MJ of exosomatic energy spent in the sector per hour of human activity invested in the sector) – being a ratio: flow of "something" per unit of "something else", this is an intensive variable (#3 - see section 6.2).

Note: since we deal with dissipative systems (which imply a basic level of energy consumption per year) we are facing the special use of the concept of "extensive and intensive variables" discussed in the example of Fig. 6.1. That is, following our choice of using "Human Activity" as the extensive variable#1 defining the size of socio-economic compartments, when dealing with the assessment of flows of energy we have that:
(a) "extensive variable#2" applies to the class of assessments defining aggregate amounts of either energy or added value per year of a particular element (the size of interaction with the context).
(b) "intensive variable#3" applies to the class of assessments referring to ratios of either energy or added value per unit of human activity, as calculated within various elements (the time unit in the case of Multi-Scale Integrated Analysis of Societal Metabolism is hour).

Clearly, the same type of relation ($ET_i = HA_i \times EMR_i$) holds for each of the three sectors (ET_{HH}, ET_{PS}, ET_{SG}).

Again, relation (v) can seem useless (a mathematical identity based on redundant information) when considered in isolation, within a single descriptive domain (and using an individual data source at the time). That is, you need to know both ET_{PS} and HA_{PS} to calculate EMR_{PS} and viceversa. However, when this relation is used in combination with other relations calculated for the same socioeconomic system, but on different descriptive domains (for different elements, and/or at different levels), using different data sources, it provides a powerful mechanism for bridging information of different nature.

In fact, when related to lower level characteristics, the value of EMR_{ps} depends on (or reflects) the set of technical coefficients and the level of capitalization of the various economic activities performed within PS (characteristics of lower level elements or sub-sectors of that sector). When, the value of ET_{PS} is related to TET (the hierarchical level of the whole society), we obtain that this implies a constraint on the possible range of values that can be taken by the other two sectors (ET_{SG} and ET_{HH}) in relation to TET. In fact the equation of congruence on exosomatic energy flows requires that:

$$TET - ET_{PS} = ET_{SG} + ET_{HH} \qquad \text{(vi)}$$

By expanding the original simple identity (i) into lower and higher levels it is possible to establish a network of relations among various assessments that can be used to characterize a the metabolism of human society at different levels. An example of this "branching" across levels is given in Fig. 6.11. We can start with a simple numerical assessment that can be found as a single figure (the numerical value taken by TET in a given year for a given country) on a particular statistical source (e.g. UN Energy Statistics Yearbook). Then we can express such a numerical value as related to other numerical values reflecting the characteristics of other elements (and different figures found when using different data sources). When redundancy is used in this way, to express the same "quantity" as a function of both intensive and extensive variables reflecting relations across levels to establishes bridges across non-equivalent descriptive domains as in Fig. 6.11.

Relation (v) can be applied not only to other economic sectors and sub-sectors (e.g. SG, or the manufacturing sector within PS), but also to the characterization of the Household Sector - HH. The exosomatic metabolism of the household sector can be assessed exactly in the same way (using the same approach $ET_{HH} = HA_{HH} \times EMR_{HH}$) by dividing the energy spent in the "end use residential + private transport" by the hours of human time not allocated in paid work. This assessment can be obtained starting from the population size, dependency ratio and other social parameters determining the amount of work supply in a given society.

When working within the various elements determining the societal metabolism in this way, the more information we add to the network of relations (as when adding more pieces in the solution of a puzzle) the more we will receive "free" information from the hierarchical structure of the system. This "free information" is generated by forced congruence of flows across levels. That is, as soon as the "loose" structure of relation indicated in Fig. 6.8 or Fig. 6.11 is organized imposing forcing equations (in terms of energy and human activity) we obtain a clearer network of relations among assessments.

6.4.2 Multi-Scale Integrated Analysis of Societal Metabolism: two variables (MJ & $) and different levels - *TECHNICAL SECTION*

The approach for a Multiple-Scale Integrated Analysis of Societal Metabolism (MSIASM) has been developed to describe socioeconomic systems in parallel using non-equivalent descriptive domains (energy analysis, economics, demography, ecology), while addressing explicitly the issue of multiple scales.

As already shown in the previous section assessments of Human Activity (extensive variable #1) can be used as the common matrix against which endosomatic and exosomatic energy flows (two qualities both assessed using MJ as extensive variables#2) can be assessed at different hierarchical levels over parts and whole. Total Human Activity (the total size of the system expressed in terms of the extensive variable#1) is linearly dependent on population size (when expressed in hours THA = people x 8760). Whereas, the profile of distribution of human activity over the various compartments (how THA is invested on lower level components) depends/reflects key variables which are socially relevant (age and gender structure of the population, retirement age, compulsory education, access to higher education, participation of women in the economic process, length of work week).

Chapter 7 shows, with practical examples, that the existence of this mosaic effects across identities of human holarchies makes already possible to establish a set of internal constraints (determined by the need of obtaining congruence in the representation of flows across non-equivalent descriptive domains) on the reciprocal value that these variables can take, when considering the dynamic budget of societal metabolism. That is, autocatalytic loops of investments related to food, labor, land, exosomatic energy can be represented in a way that makes possible to characterize: (a) what are feasible costs in relation to existing returns; and (b) what are feasible return in relation to existing costs. This simultaneous non-equivalent characterization is at the basis of what we call: Impredicative Loop Analysis. However, before getting into that discussion it is important here to show the possibility of generating a mosaic effect across levels which uses in parallel two non-reducible types of extensive variable#2: (i) one related to exosomatic energy; and (ii) one related to an economic reading of societal metabolism.

That is, we want to show that it is possible to add to the integrated system of mapping across levels illustrated in the previous section also the mapping of money flow. This additional typology of mapping reflects the production and consumption of added value both: (a) at the level of the whole society; and (b) on lower level elements (economic sectors of the socio-economic system, and even economic sub-sectors). To do that, we have to perceive and represent economic entities as being characterized in their functioning by a behavior similar to that of dissipative systems. That is, economic entities must produce and consume a certain amount of added value in time in order to remain economically viable. Depending on the reference state provided by the context within which the holon is operating (what is the general level of dissipation of the context) a given density of flow of added value occurring within a given holon can result insufficient (e.g. the making of 10 US$/hour in 2003 by a farmer in Iowa) or plenty (e.g. the making of 10 US$/hour in 2003 by a farmer in China). That is, we can apply the same mechanism used to perceive/represent the relation between the identity of parts and whole to do benchmarking also applied to economic variables. To do that we can go through the same mechanism of definition of extensive and intensive variables illustrated before.

That is, we can start with a characterization of size of the social system, that will be used to structure the compartments across levels. We can use the same extensive variable #1: Total Human Activity. Then we can assess the size of the economic process (the total amount of added value associated to the production and consumption of goods and services) which represent the extensive variable#2. For example the total GNP per year, seen as a proxy for the size of the economic system according to a extensive variable#2. The relation between these two extensive variables provides an intensive variable#3 (e.g. something similar to GNP p.c. per year – rather a GNP/hour in our system of accounting), which can be used to characterize the identity of the socioeconomic context in terms of benchmarking. In this way, we can compare the performance of economic sectors within the same level (e.g. level ***n-1***). A much higher level of $/hour must be found in a hour of human activity allocated in the compartment "paid work", whereas we can expect a much lower level of $/hour in a hour of human activity allocated in "education". The same benchmarking, based on the values taken by the Intensive Variable#3 - generation of added value per hour – can be used to compare different sectors of the economy (agriculture) in relation to the same value obtained in another sector (manufacturing). This conventional economic analysis, however, can be complemented by: (a) a simultaneous comparison based on spatial analysis – e.g. level of generation of added value per ha of a given category of land use to the average value for a given province (comparing typologies of land use allocated to economic activities); and (b) a simultaneous analysis of biophysical flows.

Obviously, in this way, after calculating the given level of production and spending of added value per hour of a socio-economic system - GNP/THA ($/Hour) at the level of the country – we can characterize different compartments of the socio-economic system as handling a higher (those in the Productive Sectors of the economy) or lower (the Household Sector) density of money flow per hour of human activity or per ha of land invested there.

When accounting into Multi-Scale analysis also added value flow, together with endosomatic and exosomatic flows (using the MSIASM approach) we can use a common skeleton of equations of congruence that maps investments of "exosomatic energy" and "added value" (two non-equivalent extensive variables#2) against the same nested hierarchical structure, providing closure, of compartments obtained by dividing THA (the same extensive variable#1). The formation of the skeleton (frame) related to the extensive variable #1 is based on four logical steps.

(1) The socioeconomic system is divided into a set of relevant compartments, whose size is characterized in terms of investments of Human Activity (the common matrix that provides closure). That is THA at the

level $\boldsymbol{n}$, must be equal to the sum of HAi (the investments of human activities in the various sectors) defined at the level $\boldsymbol{n-1}$, following a nested hierarchical structure. That is, for example:
* [whole country – level $\boldsymbol{n}$] → [economic sectors level $\boldsymbol{n-1}$] → [economic subsectors level $\boldsymbol{n-2}$] → . . . → [individual economic activities level $\boldsymbol{n-x}$].

(2) Lower-level compartments must account for the *total* human activity of their upper level (e.g., subsectors making up a sector). That is:

* $THA\ \boldsymbol{n} = [\sum HA_i]\ \boldsymbol{n-1} = [\sum HA_i]\ \boldsymbol{n-2}$
With this choice the definition of economic sectors, sub-sectors and individual economic activities must include also the fraction of human activity invested in the household sector (non-working time of the economically active population and all the activities performed by the non-economically active population including sleeping).

(3) Compartments are then characterized in terms of intensive variables and extensive variables by combining two extensive#2 variables (both exosomatic energy and added value) against the same hierarchical frame provided by the compartimentalization done using extensive variable#1. That is, in this way it is possible to define for different compartments two intensive variables#3:
* intensive variable#3biophysical = "exosomatic energy per unit of human activity"; and
* intensive variable#3economic = "added value per unit of human activity"

(4) After having implemented this mechanism of characterization, it is possible to establish a relation between the size of each compartment – parts - (expressed either in terms of GNP or Exosomatic Energy) to the total of the whole society using: (i) the extensive variable#1 "total human activity," which is determined by population size of the whole society; (ii) the "fraction of total human activity" which is allocated to the particular compartment; and (iii) the two intensive variables#3. For example:
* EMRi = Exosomatic Metabolic Rate of the compartment i (exosomatic energy per unit of human activity in the compartment i);
* ELPi = Economic Labor Productivity of the compartment i (added value per unit of human activity in the compartment i)

The hierarchical frame for the relative relations (assuming α and $\alpha-1$ as two contiguous hierarchical levels) can be expressed as:

* $X_i = HA_i / HA_k$ = the *fraction* of "human activity HA_k" invested in the i-th sector.
[elements $\boldsymbol{i}$ belongs to the level ($\alpha-1$), element $\boldsymbol{k}$ belongs to the level (α)]
* $ET_i = HA_i \times EMR_i$ = the exosomatic energy spent in the i-th sector - at the level ($\alpha-1$)
* $EMR_i = ET_i / HA_i$ = the exosomatic metabolic rate in the i-th sector - at the level ($\alpha-1$)
* $GNP_i = HA_i \times ELP_i$ = the added value productivity of the i-th sector - at the level ($\alpha-1$)
* $ELP_i = GNP_i / HA_i$ = the economic labor productivity of the i-th sector - at the level ($\alpha-1$)
* $ET_\alpha = \sum (ET_i)_{\alpha-1}$ e.g. $TET = (ET_{PS} + ET_{SG} + ET_{HH})$
* $HA_\alpha = \sum (HA_i)_{\alpha-1}$ e.g. $THA = (HA_{PS} + HA_{SG} + HA_{HH})$
* $GNP_\alpha = \sum (GNP_i)_{\alpha-1}$ e.g. $GNP = (GNP_{PS} + GNP_{SG})$
In these examples, the values referring to the whole country ($TET = ET_{WC}$; $THA = HA_{WC}$; $GNP = GNP_{WC}$) - the α level - are related to the values taken by the same variable in the lower level - ($\alpha-1$) – over the compartments: PS (productive sector); SG (service and government); and HH (Household

Sector).

Information (data) about the value taken by both extensive variables (e.g. HA_i *extensive variable#1* - ET_i and GNP_i *extensive variable#2*) can be linked using intensive variables (e.g. EMR_i; and ELP_i which are two types of *intensive variable#3*) across hierarchical levels, about which it is possible to obtained non-equivalent sources of information. The relation among compartments across levels expressed in terms of relation of assessments based on HA_i *extensive variable#1* (X_i) provides the congruence requirement. The possibility of using independent external referents to assess the value taken by these variables entails that the redundancy in this set of relations should not be considered as a problem (Occam razor principle). On the contrary, such a redundancy is a plus since it makes possible to establish a bridge among non-equivalent forms of perception and representation of societal metabolism (e.g. the social, the biophysical and the economic) at different scales.

For example, changes in EMR_i and ELP_i in the same compartment (e.g. urban households) are connected because of their common reference frame –> the same HA_i. Because of the common matrix represented by the profile of investments of human activity on the different compartments (defined in the same way for the exosomatic energy accounting and the added value accounting) we can generate a Holarchic Complexity in the structure of relations among data as illustrated in Fig. 6.12. Obviously, the fact that a part of the assessments (the red assessments in Fig. 6.12) is in common for the economic and biophysical representation entails that changes in the values taken by the two non-equivalent variables (biophysical and economic) are not totally independent.

Applications of the approach of Multiple-Scale Integrated Analysis to the analysis of agricultural systems is presented in Part 3.

6.5 Holarchic Complexity and mosaic effects: the example of the calendar

Finally, it is time to discuss the possible use of the concept of holarchic complexity to provide robustness to a system of mapping. The example discussed below has to do with the encoding of time. A task that for its complex nature has been crucial in the shaping of human civilization (e.g. see Duncan, 1999). In the history of their civilization, humans where forced to develop and continuously update different systems of mappings for keeping time. What is remarkable in this example is the convergence on a solutions based on holarchic complexity.

To introduce the example let's first try to answer the following question. When we say that Cristoforo Colombo (Cristopher Columbus, in English) arrived for the first time on the American continent on "***the morning of the 12 October of 1492***", what is the meaning and the reliability of such an assessment ? Put it in another way: Does it mean that this event took place:
(i) in the daily light when the sun was still raising in its daily trajectory?
(ii) in a day which was in early autumn?
(iii) in the same year that the Christian Isabella of Castile and Ferdinando II of Aragon took the city of Granada from the Muslim Emir Al-Zagal?

If the answer to these three questions is yes, then we are confronted with a big question.

According to the assumptions of reductionist science, time encoding is obtained in simple linear terms [e.g. the time keeping obtained using a clock]. That is, a point in time can be individuated by moving along a linear trajectory based on a unique variable. In this framework time durations are defined by differences between the measurement (reading of the clock) at time T2 minus the measurement (reading of the clock) at time T1.

But if this assumption were true, we would be forced to conclude that the characterization of time: "*morning of 12 Octobre 1492*" cannot support all the information required to answer the three questions posed before. In fact, when basing our mapping of time on a uni-dimensional system of encoding (e.g. when using hours or minutes measured against the indications given by an ordinary clock) we have that the difference between:

T2 = the morning of the 1 January of 2000, and T1 = the morning of 12 Octobre 1492 represents a "quantity" of time which is 4,454,760 hours or 267,285,600 minutes (the equivalent of almost 509 years after accounting for a few spare months and days, plus the correction for leap years).

Assuming an error of 1 % (e.g. generated by the accuracy of the device measuring time and the handling of the information over long periods of time) we would obtain an error bar associated to the assessment "*morning of the 12 October 1492*" of +/- 5 years ! In this case, the information related to concepts: (i) morning, (ii) early autumn, and (iii) contemporaneousness of events in Spain in the year 1492, would be completely lost.

Let's imagine now to run the same mental experiment trying to fix this problem with the "high tech" solution. We can hypothesize that an atomic clock with an incredible degree of accuracy were available since the year 1450 (!). Would then be possible to use the linear time assessment T2 (midnight of January 1st, 2000) minus T1 ("*morning of the 12 October 1492*") to answer the three questions? First of all, even having an atomic clock it is difficult to imagine a very reliable mechanism for keeping the record of time in the form of hours and minutes over a time horizon of 500 years. Such a mechanism should be able to go through wars, riots, earthquakes. This is a list of a set of perturbations that can be expected to occur (at least one of them) in a given place over such a large time window. Because of this reason such a mechanism would require following the old say "do not put all your eggs in the same basket". That it, the only way to obtain reliability of a record over hundreds of year is making several copies of it and storing it in different places using different mechanisms – using redundancy and mosaic effect . . . Actually, if someone would try to implement this solution, by handling the flow of records coming out of a set of synchronized clocks, that person would find out that this is not an easy task at all. Actually, the challenge of recording time in terms of hours and minutes in parallel over different places in our planet is everything but simple and this is part of the fascinating history of the fight that humans had to do for mastering time-keeping.

But there is another more direct evidence of the impossibility to track the passing of time on a large scale by using an uni-dimensional mechanism of mapping. Beside the problem of keeping parallel records of aggregate time durations through war, riots, and natural disasters, and beside the problem with the accumulated effect of lack of accuracy of clocks to be kept constant over 5 centuries, there is another major problem that came into play in this case. The 4 October of 1582 the calendar was reformed by Pope Gregory. The original system of accounting of leap years was changed and 10 days were eliminated from that year.

Because of this "perturbation" when adopting a reductionist (= linear, uni-dimensional) system of mapping of time the indication "*the morning of 12 October 1492*" would no longer make any sense in relation to the first of the three questions listed before. The gradient "morning/night over the day" is much smaller that the error induced by the removing of 10 days from a year. This has nothing to do with the accuracy of the measurement scheme and the reliability of the keeping of records. The 10 day taken away by Pope Gregory would remain missing either when using an old fashioned solar clock or an atomic one. On the other hand, we all share the feeling that the indication of *the morning of 12 October 1492* is conveying useful information about the location in time of this events. That is, the first official European arriving in the new continent landed: (a) in the morning; (b) in the fall; and (c) in the same year in which Granada was occupied by the Spanish Kings. This shared belief is so strong that this date is still a national holiday in the USA and in Spain. This paradox can be explained by the mechanism of mapping of time adopted by the calendar, which is not simple or linear. For each of the three statements about the relative location in time of the event [(1) morning; (2) fall; (3) the same year of the occupation of Granada], the calendar is using non-equivalent external referents (the relative position in time is based on the use of distinct markers). That is, with the old fashioned calendar we are dealing with "holarchic complexity" in the system of mappings used to encode the passing of time. Such a system is based on an integrated encoding of the same quality (duration of time) obtained by a chain of associative contexts across hierarchical levels. In particular, there is a hierarchical structure based on at least 3 levels which are linked - for the needed respective semantic checks - to the natural frequencies of three natural processes: (1) the division of a year into sub-parts (seasons) - with an external semantic referent given by cycles of seasons related to the sun; (2) the division of a month into subparts (days) - with an external semantic referent given by cycles of the moon; (3) the division of a day into subparts (e.g. (i) am with daylight, (ii) am without daylight, and (iii) pm with daylight, (ii) pm without daylight) - with an external semantic referent given by daily revolutions of the planet Earth on itself. This subparts can again be divided into smaller parts (hours and then minutes) using clocks. Within this structure of Chinese boxes, Russian-dolls, or nested interlocking hierarchies (using the expression coined by Koestler) each of this parts can be individuated by using the larger container as the specific associative context (e.g. 30 seconds after 45 minutes after the 5th hour of Monday which is the first day of the 3rd week of the 7th month of. . .). The simplicity and the validity of each assessment depends on the validity of the assessment referring to the larger associative context of the chain. At this point, the validity of each of these statement can be checked against non-equivalent external referents. The measurement of a time duration of 15 minutes is quite simple to obtain (with a mechanical clock used as external referent) as well as the representation of "15 minutes past the hour". However, to be useful they both require a higher level (AM or PM) as reference – related to the revolution of the Earth on its axes - which in turn can be related to a date (a day within a month, etc.). What is interesting in this system of mapping is its flexibility and internal coherence which is generated by the use of non-equivalent mechanisms of encoding changes of observable qualities of external referents (sun for years, moon for months and revolving planet Earth for days). This integrated system of assessments is then forced into congruence by a set of semantic checks based on direct perceptions of changes of observable qualities of external referents, which are performed at different space-time windows selected on the basis of the hierarchical structure of the whole.

There are years in which seasons seem to behave in a crazy way. Even in normal years, the very same profile of daylight both in the am-section and pm-section of each day can change dramatically when moving from summer to winter and according to geographic location. There are even cases in which the distinctive quality implied by the very definition of day (the daily shift from night to day-light and viceversa) can totally collapse disappearing for a while as in the case of the long nights (or the long days) experienced by those living close to the poles. Still local failures of individual mappings do not affect the stability and the validity of the whole system (the usefulness of using a common calendar for the different countries of this planet). The calendar is working fine for humankind. Whereas individual organisms can be fouled by too simple mechanisms of mapping time [e.g. when they are led to sprout too early by a few warm days; due to the simple mapping "cluster of warm days" = "spring is here"], humans can be aware of being still in winter by looking at the record of days and months on the calendar even though the outside temperature is extremely pleasant.

The self-entailing structure of the various mappings (a month mapping onto a given number of days, a year mapping onto a given number of months) implies redundancy and this generates an internal robustness. The number of days (lower level mapping related to the quality daily-revolution of the planet) selected to define a month (in relation to moon cycles – about 28) must be congruent, at the year level, with the indications coming from another non-equivalent mapping obtained at that level (the passing of seasons – about 365 days). Bringing into congruence such a system of encoding which is based on non-equivalent mappings of events operating on distinct descriptive domains (= into light changes due to daily revolutions, into monthly cycles due to moon revolutions, into season changes due to cycling changes in the inclination of Earth axis) provides enough redundancy to the system for handling local failure (e.g. days without daylight, warm winters). Actually, such holarchic complexity does much more: it makes possible the patching of individual mappings without losing the functional performance of the whole. That is with this complex structure it is possible to have an evolution in time of the integrated system of mapping. In fact it is well known that the basic problem with the accounting of time for humans has been generated by the fact that the discretization in time units based on moon cycles is not fully compatible with the discretization in time units based on solar cycles (for a detailed account of this issue see Duncan, 1999). This incommensurability of "units related to moon months" with "units related to solar seasons" is what requires the presence of a step of semantic verification when errors or bifurcations occur. As already noted, after the discovery of America, the Gregorian reform of the calendar had the goal of patching the old mechanism of mapping of time, exactly because the semantic check performed on solar cycles was indicating the manifestation of a bifurcation. The position of Eastern – determined according to the system of accounting based on lunar units - was no longer congruent with the position in time expected according to the system of accounting based on solar units. In that occasion, with the reform, not only a more sophisticated mechanism of accounting of the "leap year" was put in place (the correction factor for dealing with the incommensurability between lunar units and solar units), but also 10 days were deleted from the month of October of 1582 to correct the lack of congruence (the error) generated by the previous operation of the old integrated system of mapping (the old calendar).

The robustness of an integrated systems of mapping based on holarchic complexity is so high that the date of 12 October 1492 kept its relevance even after the patching done by the Gregorian reform. The "perturbation" induced by such a correction (a local deletion of ten days and a systemic change in the accounting of leap years) was absorbed by the complex structure of the traditional calendar without major problems. In fact, the individuation of a given position in time (*the morning of the 12 october 1492*) is obtained through a triangulation of a given position in time related to non-equivalent external referents. This mechanism provides an extreme robustness, since it makes possible to be anchored to the representation of non-equivalent perceptions relative to different relevant space-time differentials. That is, the decisions taken when reforming the old calendar (= adding a lower number of "29th of February" in the next 400 years after having deleted 10 days from the year 1582) did not affect at all the indication given by the indicator "morning" over the selected difference T2 – T1. This indicator refers to an external referent relevant at a lower level scale. Therefore, this external referent is operating below the time differential of a day. At that level of the distinction between morning and night, the perturbation associate to the Gregorian reform of the calendar has been simply filtered out. Colombus arrived in the morning no matter which was the individual day of the month.

What about a potential "overwhelming error bar" on the location in time of the "12 October 1492"? This could imply - for example - loosing the meaningful indication of the season. Again this preoccupation is just an artefact resulting from the adoption of a reasoning based on the concept of simple time (system of mapping based on only one space-time differential). Within a system of mapping based on the reciprocal entailments between the position of days over months, months over seasons, and cycles of seasons over year, the effect of an aggregation of more or less "29th of February" is simply not taking place. In fact, the reciprocal forced congruence over different levels of non-equivalent encoding in relation to: (a) external referents defined over different space-time windows (sun, moon, rotation of the Earth); and (b) semantic checks (was this in day-light? is Easter coming in the right expected season?) has exactly the effect of "diffusing" possible negative effects of aggregation of errors on a single level for a too long period of time. An error at one level can keep occurring as long as its aggregate effect does not affect the validity of the next external referent in the hierarchy. This built-in-default-quality check makes possible a continuous activity of patching within the various range of tolerances specified for each level in the hierarchy. Using hierarchy theory jargon we can say that external perturbations requiring the patching and internal perturbations generated by the patching tend to be filtered out by the hierarchical structure of the whole system of mapping. This is why systems hierarchically organized have a much more reliable and robust organization. Actually, both the new mechanism for handling leap years and the deletion of 10 days were exactly introduced to keep congruence between the meaning conveyed by a given date (the location of Eastern within the formal frame of accounting of numbers) and the indications given by the set of external referents (number of moon months and solar seasons). That is, the complex structure of the calendar based on the simultaneous operation of semantic checks and formal representations was not only able to absorb the changes introduced by the reform but rather it was the cause of these changes. Its intrinsic robustness was exactly what called for the patching in the first place!

But there is another important point to be made about this example of robustness of the mechanism of mapping time obtained with the calendar. This has to do with the special nature of holarchic objects. When using an holarchic system with a robust set of identities self-entailed across levels we are forced to admit that its complex structure can also be a reason of trouble. That is the complex structure cannot result very useful when referring to specific assessments at a given point in space and time. For example, if we try to use ***"the calendar" to compare dates and events over a small descriptive domain*** we can face clear incongruences and paradoxes. For example, the existence of a geographically determined "day-line" imposed on our globe by such a system of mapping implies that people talking on the phone at the distance of a few miles across such a line can be represented as acting simultaneously but in different days. That is the very structure that makes reliable a coherent an overall mapping of time over a set of different space-time windows (***the calendar used to compare dates across centuries)*** is not very useful (should not be used) to map differences in time when dealing with events describable at a given point in space and time. When dealing with small scale events, simple time (= based on only one time-differential and only one external referent for semantic checks = a shared indication from a clock) may result more useful.

In conclusion, for a very large descriptive domain (= when dealing with the risk of losing relevance in the process of representing the collocation in time of the event "discovery of America") we need to use a system of mapping based on holarchic complexity. Over large descriptive domains the application of the reductionist paradigm would have not solved the problem of loss of significance of the expression "*morning of 12 October, 1492*" after 500 years. Rather, a "high tech" encoding of time for historic dates would have made the problem of preserving the meaning of this mapping much worse. This is an important point, since often technical progress leads some scientists to believe that the higher accuracy of an electronic clock could dispense them from the need of understanding the context in which the numerical measurement is used (recall here the "true age" of the Funtrevesaurus in Fig.3.2). In this way, hard scientists working on integrated assessment can end up by neglecting the need of a continuous semantic check about: (1) the meaning of each of the encoding variables used in the model; and (2) the implications associated to the choice of the relative measurement schemes. In many situations, it is much better to use a primitive clock (a measurement scheme with low accuracy) linked to the use of an old fashioned calendar (a robust integrated system of mapping) rather than relying on an atomic clock (a measurement scheme with high accuracy) linked to a uni-dimensional accounting of time (an inadequate system of mapping) to record aggregate durations. Obviously, when dealing with a small descriptive domains (a single scale in which both the identity of the investigated systems and the interests of the observers do not change in time) the reverse is true. An accurate clock can result much more useful than a calendar for dealing with athletic records.

To resume the main message of this section we can use a quote from Rosen (1985, p. 317): "***Functional reliability (which is different from freedom from errors) can be obtained through an artful employment of redundancy providing robustness to the functions of a network. Functional reliability at some functional level, however, implies the existence of errors at a different level***".

6.6 Holarchic Complexity and robustness of organization overview of literature

TECHNICAL SECTION

In his seminal work, Goldberger (1997) describes human health in terms of the ability of keeping harmony between the reciprocal influence of processes occurring in parallel on different scales within the complex web of physiological process in the human body. **The insurgence of a disease is seen as a process decomplexification in which one particular dynamic (a system of control operating over a given relevant space-time differential) – which is therefore related to only a given set of processes going on at one particular hierarchical level - takes over on other dynamics.** This makes dynamics expressed on other relevant space-time differentials, which were originally included in the integrated system of controls, irrelevant. In his words when this occurs "the system looses its fractal complexity". This leads to pathological manifestations of ordered behaviour (e.g. Parkinson's tremors). Using again his words: the human body looses its "organised variability" (balanced mix between functional specialization and functional integration).

The same concept is proposed by O' Neil et al. (1997) when discussing of assessment of human interference on ecological processes in relation to spatial configuration of landscapes. **When observing natural landscapes one can find a cascade of scales at which spatial patterns can be found.** The negative effects induced by humans can be detected by the disappearance of some of these spatial patterns on certain scales. Those patterns missing indicate the termination processes of self-organization operating at the relative space-time differential. In this perspective, **human management can be seen as having the effect of inducing a decomplexification of dynamics within the landscape.** In particular humans are systematic removing those dynamics (mechanisms and related system of controls) which result not economically relevant within the models assessing the economic performance of various land uses.

The concept of holarchic complexity has been discussed by Grene (1969) in relation to stable hierarchical systems. The terms used by Grene is that of **double asymmetry**. The concept of "double asymmetry" indicates the peculiar status of each element of a self-entailing hierarchy which is operating in complex time, **which is at the same time a ruler and a ruled.** That is, the existence of a double asymmetry implies that the stability of each level depends on other levels either higher or lower in the hierarchy. The number of predators affect the number of the preys and viceversa, governments determine the fate of citizens and viceversa. A dictator or a group of bandits keeping hostages would be an example of social entities lacking of double asymmetry, that is, a sick social holarchy. The need of double asymmetry leads, in the long term, to the organization of socio-economic structures that can be explained in terms of "power laws" as noted by Zipf (1948). In modern time, within the complexity literature we call systems organized in this way as "critically organized" (Bak, 1996). The concept of double asymmetry is crucial for the concept of "impredicative loop" and will be discussed with practical examples in Chapter 7.

As alredy discussed in Chapter 2, Koestler (1978) calls the phenomenon of double-asymmetry as a "Janus effect" taking place within holarchies. The etymological explanation for the choice of the term "holon" given by Koestler (1968; pag. 56) is the following: "a holon is a Janus-faced entity who looking inward, sees himself as a self-contained unique whole, looking outward as a dependent part". The term is derived (ibid. pag. 48) from the Greek word ***holos*** = whole, to which the suffix ***on*** has been added to recall words such as prot***on*** or neutr***on*** in order to introduce the idea of particles or parts. His definition of structural complexity of holarchies is also framed within hierarchy theory, that is in terms of vertical and horizontal coupling of holons. On their own level of activity, holons have to fight to preserve their identity, both by keeping together their own parts on the lower level and by preventing same-level-holons to expand too much. On the other hand, because of the fact that holons belong to a larger system that provides them with the stability of boundary conditions and the stability of lower level structural organization they have to support other level processes stabilizing the entire structure of the holarchy. Holons have to contribute to the stability of vertical levels even though this implies negative trade-offs on their own level. A classical example of this tension is represented by ethical dilemmas (personal advantage versus social advantage). In particular, let's consider the dilemma about paying tax. Individual household have a direct short-term return in skipping their tax duty (boosting in this way their horizontal interaction as holons), however, this would make weaker the community to which they belong (this will make weaker their vertical integration, the larger holon to which they belong). Another example has been discussed in Fig. 3.6 about the role of death in human affairs. For individual human beings death is a very sad event. On the other hand, from the perspective of the species "*homo sapiens*" a sound "turnover" of individual realizations within the type is essential for keeping high the physiological fitness of this species. Obviously different degrees of stress on the horizontal or vertical coupling will dictate the final compromise solution at which the holon will eventually decide to operate. The existence of several distinct relevant space-time differential which makes impossible to "see" or "represent" the relevant attributes reflecting different interests (objectives and goals) of the various relevant wholes and parts within the same representative domain. Even if it is impossible to formally account for it, every time one sees or represents a part of a holarchy one must imply the whole to which this part belong and viceversa.

Iberall et al. (1981) introduce a concept very similar to that of double asymmetry by suggesting the term "equipollence". With this expression they mean that within socioeconomic systems there is a natural tendency toward power balance among components. More powerful components, which are higher in the hierarchy of controls, are fewer in number. This is what generates on the large scale a balance in power among ruler and ruled. The same reasoning applies to the mechanisms generating stability in ecosystems given by H.T. Odum (1971; 1996). The representation of Odum is based on the requirement of a given balance between the mass and rate of energy dissipation of different components of ecosystems. An ecosystem which is in equipollence must have a given ratio between different components (due to the near closure of its matter cycles). Equipollence means that a higher level of energy dissipation which is found in ecosystem compartments higher in the hierarchy (e.g 1 kg of biomass of tigers) has to be coupled to a smaller size of such a compartment, when compared to the other stabilizing the whole structure in the lower levels (you must have a lot of kg of biomass of plants per kg of biomass of tiger). At this point we can recall Koestler's idea of "a memory for forgetting" (= our brain when storing concepts tends to remove redundant information - irrelevant details - which are considered, because of their redundancy, as storing "less valuable" information). Margaleff (1968) suggests the very same idea in relation to the functioning, the evolution and organization of eco-systems over hierarchical compartments. In their daily functioning the different components of an ecosystems, which are organized into trophic chains, literally eat each other at different speed. In this operation the more redundant information (the one belonging to the larger compartments made up of a larger number of copies of the same organized pattern) is eaten "more" in order to stabilize less redundant information stored on the top of the hierarchy (the one stored in the components making up higher levels). The equipollence of various components of ecosystems, in this frame, can be directly related to the goal of obtaining a balance between functional specialization (increasing the efficacy of metabolic processes at any particular level) and functional integration (increasing the stability of the integrated network in relation to changes on each level and in the larger context) .

The NESH network (with D. Waltner-Toews, J. Kay, D.R. Cressman as founding members) working on the concept of ecosystem health proposes a similar concept to describe sick holarchies. A holarchy is no longer healthy when it looses its ability to share stress among different holons (balancing the focus between horizontal and vertical coupling, maintaining equipollence, being able to act under double asymmetric relations). This happens when policy indications developed according to one perspective (based on the description of what goes on at one level) become dominant over other legitimate and contrasting policy indications coming from descriptions referring to other holons (what has been called decomplexification in human health). This is a sign that the continuous negotiation/interaction among holons within the holarchy (which is needed to avoid the process of decomplexification of the existing dynamics and controls) is no longer effective. Incidentally, we can remember here the point made by Bohm (1995 pag. 3) that the word 'health' in English is based on an Anglo-Saxon word 'hale' meaning 'whole'. The philosophers of science Jerome Ravetz and Silvio Funtowicz call this same phenomenon "hegemonization" which can lead (if not corrected in time) to a state of "ancient regime syndrome". When reaching the "ancient regime syndrome" adaptive holarchies loose their ability to read and interpret signals coming from the context about the need and urgency of changing their own set of identities. This is due to a systemic error which is generated by the excess of power of higher level components over the rest of the holarchy. This imbalance of power implies that gradients between "expected" and "experienced" patterns occurring in lower levels of the holarchy are ignored (filtered) in the internal communications. Holons on the top manage the whole structure relaying on their perception, which is based on the stored representation of the old identities. In fact, at the higher level the reality looks different than at the lower level. This is due to the active filtering of information that any holarchic structure implies. However, if this systemic error is not corrected in time, this mismatch between what experienced at the lower level and what imagined (or denied) at the higher level will make the holarchic structure brittle (less adaptable) and therefore more fragile to even small perturbations. A socio-economic system in "ancient-regime syndrome" is much more likely to get into catastrophic events (Tainter, 1988).

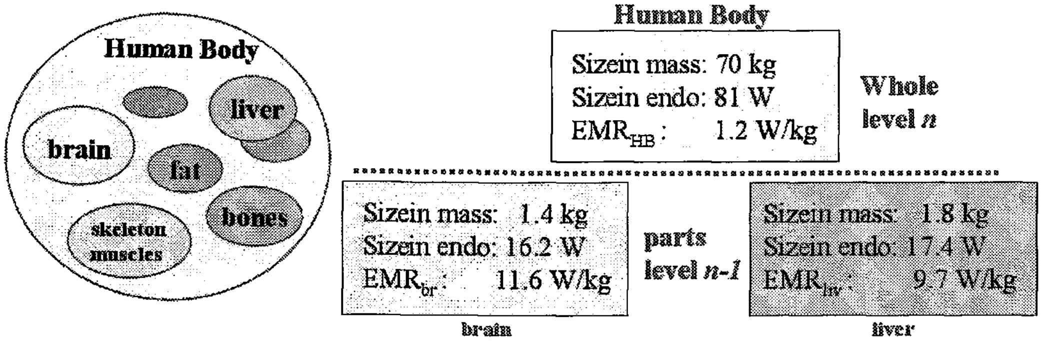
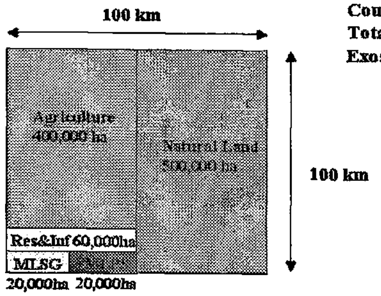


Fig. 6.1 Constraints on relative values taken by variables within hierarchically organized systems

CHEMICAL ELEMENTS	kg	%
Oxygen	44.8	64%
Carbon	13.3	19%
Hydrogen	6.3	9%
Nitrogen	2.8	4%
Calcium	1.0	1.5%
Others	1.8	2.5
Total mass	70.0	

ORGANS of an ADULT MAN (70 kg mass)	kg	W/kg	W
Liver	1.8	9.7	17.4
Brain	1.4	11.6	16.2
Heart	0.3	21.3	6.4
Kidneys	0.3	21.3	6.4
Muscle	28.0	0.6	16.8
Fat tissue	15.0	0.2	3.0
Others	23.2	0.6	14.0
Total mass	70.0		

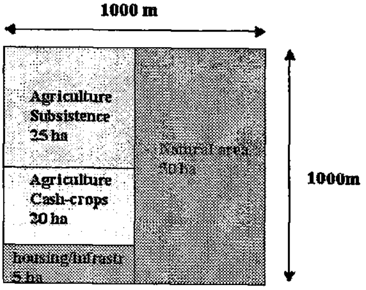
	kg
Skeleton	7.0
Bone Marrow	3.0
Blood	5.4
Gastro-intest.	2.3
Lungs (2)	0.9
Lymp. Tissue	0.7
Others	3.9
Total mass	23.2



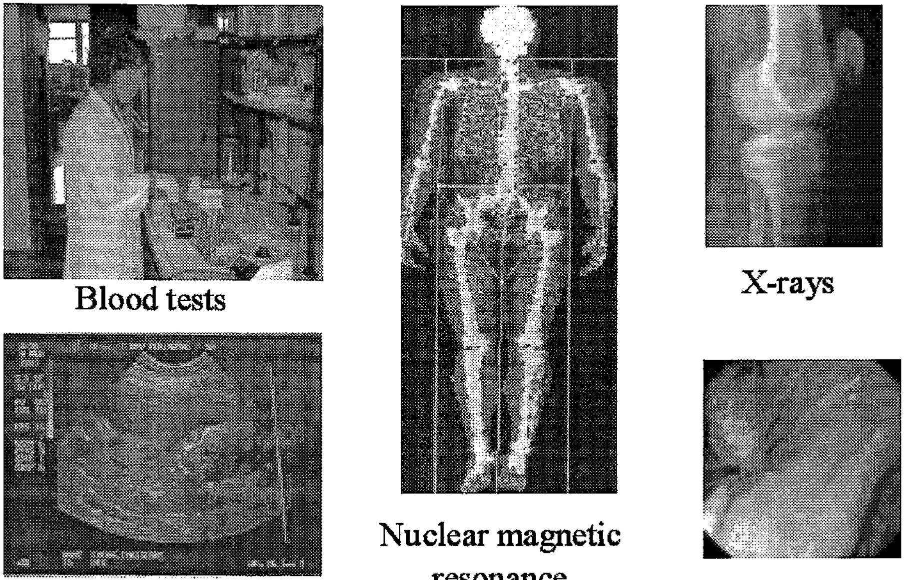
County area: 1,000,000 ha = extensive#1 (size from within)
Total Exosomatic thruput : 20 PJ/year = extensive#2 (size on interface)
Exosomatic Metabolic Density: 20 GJ/ha /year = intensive#3

Natural Land	$500{,}000 \times EMD_{NAL} = ET_{NAL}$	0 PJ
Agriculture	$400{,}000 \times EMD_{AGL} = ET_{AGL}$	5 PJ
Resid.&Infrast.	$60{,}000 \times EMD_{R\&I} = ET_{R\&I}$	6 PJ
MLSG	$20{,}000 \times EMD_{MLSG} = ET_{MLSG}$	3 PJ
MLPS	$20{,}000 \times EMD_{MLPS} = ET_{MLPS}$	6 PJ
	$TAL \times EMD_{AC} = TET_{AC}$	
	(1,000,000 ha x 20 GJ/ha = 20 PJ)	

Fig. 6.2 Constraints on relative values taken by variables within hierarchically organized systems



Land use	Food *kg*	Gross return *$*	Net Return *$*
Agric. Subsistence	50,000	25,000	0
Agric. cash-crops	40,000	20,000	15,000
Natural areas	0	0	0
Housing/infrastr.	0	0	0



Phoots by Elena Azzini

Fig. 6.3 Non-equivalent complementing views used in medicine

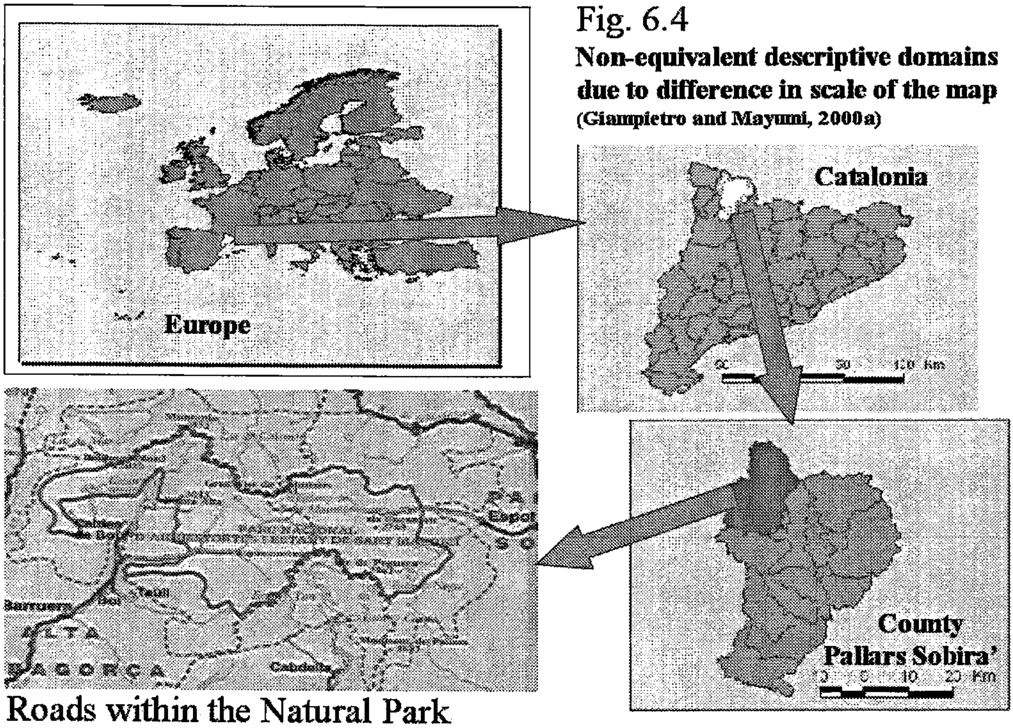


Fig. 6.4

Non-equivalent descriptive domains due to difference in scale of the map

(Giampietro and Mayumi, 2000a)

Fig. 6.5 Same hierarchical level but different categories used in the map to characterize system identity (Europe) (Giampietro and Mayumi, 2000a)

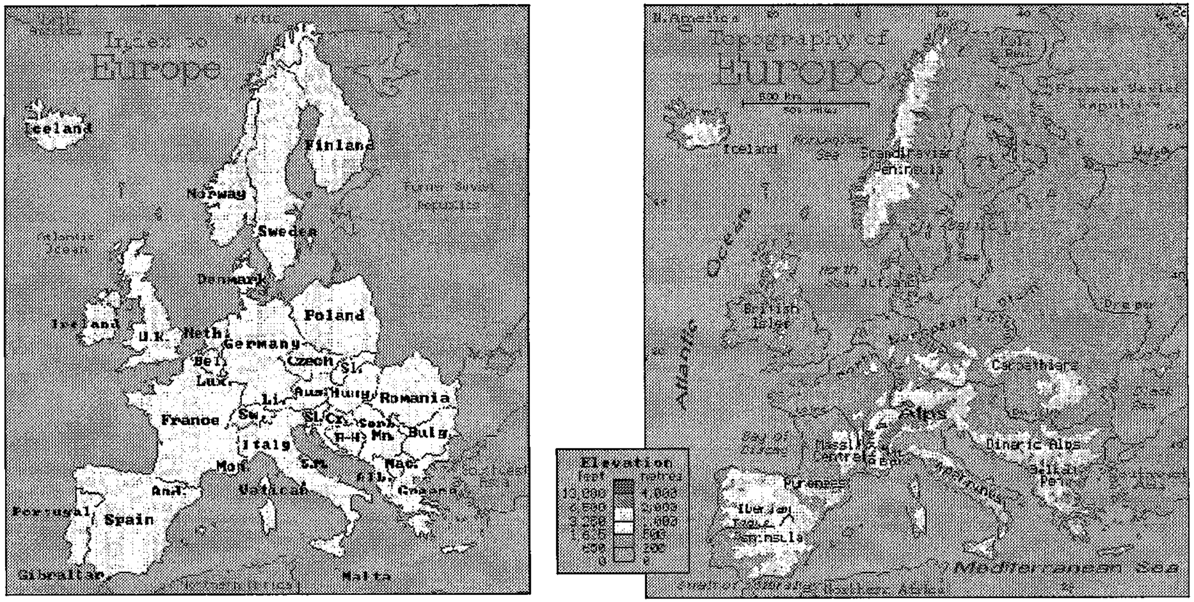


Fig. 6.6 ENDOSOMATIC ENERGY FLOW IN HUMAN SOCIETIES

(Giampietro and Mayumi, 2000a)

Characteristics of the societal endosomatic metabolism

Conversion losses	**Primary energy sources**	**Conversion losses**	**Energy vectors**	**Conversion losses**	**MIX OF END USES**
* "overhead" on investments * Compulsory investments needed in production for making accessible: * nutrients * arable land *healthy soil *seeds *fresh water, *environmental services *agricultural work	* **plants products** for example. cereals, vegetables fruits * **animal products** for example: meat milk & dairy eggs	Making agricultural products accessible to consumption * Post-Harvest Losses Investments for: *processing *packaging *transportation *storage *cooking *washing	* **Carbohydrates** * **Proteins** * **Fats** within meals ready to be eaten for example: * breakfast *lunch *dinner *other snacks	Depending on: * Quality of the diet * Body size (e.g. 1 -200 kg) * Age (e.g. 0 - 120 year) * Sex (M/F) * Level of physical activity * Health	MAINTENANCE & REPRODUCTION PHYSICAL ACTIVITY SOCIAL AND LEISURE PHYSICAL ACTIVITY WORK FOR FOOD

Fig. 6.7 EXOSOMATIC ENERGY FLOW IN HUMAN SOCIETIES

(Giampietro and Mayumi, 2000a)

Characteristics of the societal exosomatic metabolism

Conversion losses	**Primary energy sources**	**Conversion losses**	**Energy vectors**	**Conversion losses**	**MIX OF END USES**
* "overhead" on investments * Compulsory investments needed to make possible the flow of energy inputs * extraction from stocks (depending on the quality of reserves) * catching incoming renewable energy (depending on its concentration)	* **fossil energy** for example oil coal natural gas * **nuclear energy** * **renewable energy** for example: hydroelectric wind power solar heating photovoltaic cells	TWO TYPES of losses: I. Making various forms of energy (derived from primary sources) accessible to the final consumption II. Manufacturing exosomatic devices. This is a crucial step for making possible for people a massive use of exosomatic energy (losses are = making + repairing discounted on the life span of devices)	* **Electricity** * **Fuels** gasoline diesel coal Forms of energy which can be converted into useful power by the consumer: * mechanical power *heating, in relation to various tasks *processing of information	Depending on the characteristics of consumption: *level of economic activity *mix of energy vectors *level of technology *life styles *housing type *climatic conditions *availability of natural resources	RESIDENTIAL (including, heating, cooking, leisure and private travelling) PRODUCTIVE SECTORS (Industrial, Agriculture, Energy and Mining) SERVICE SECTOR (including retailers) TRANSPORT (roads, railroads, marine and air transport)

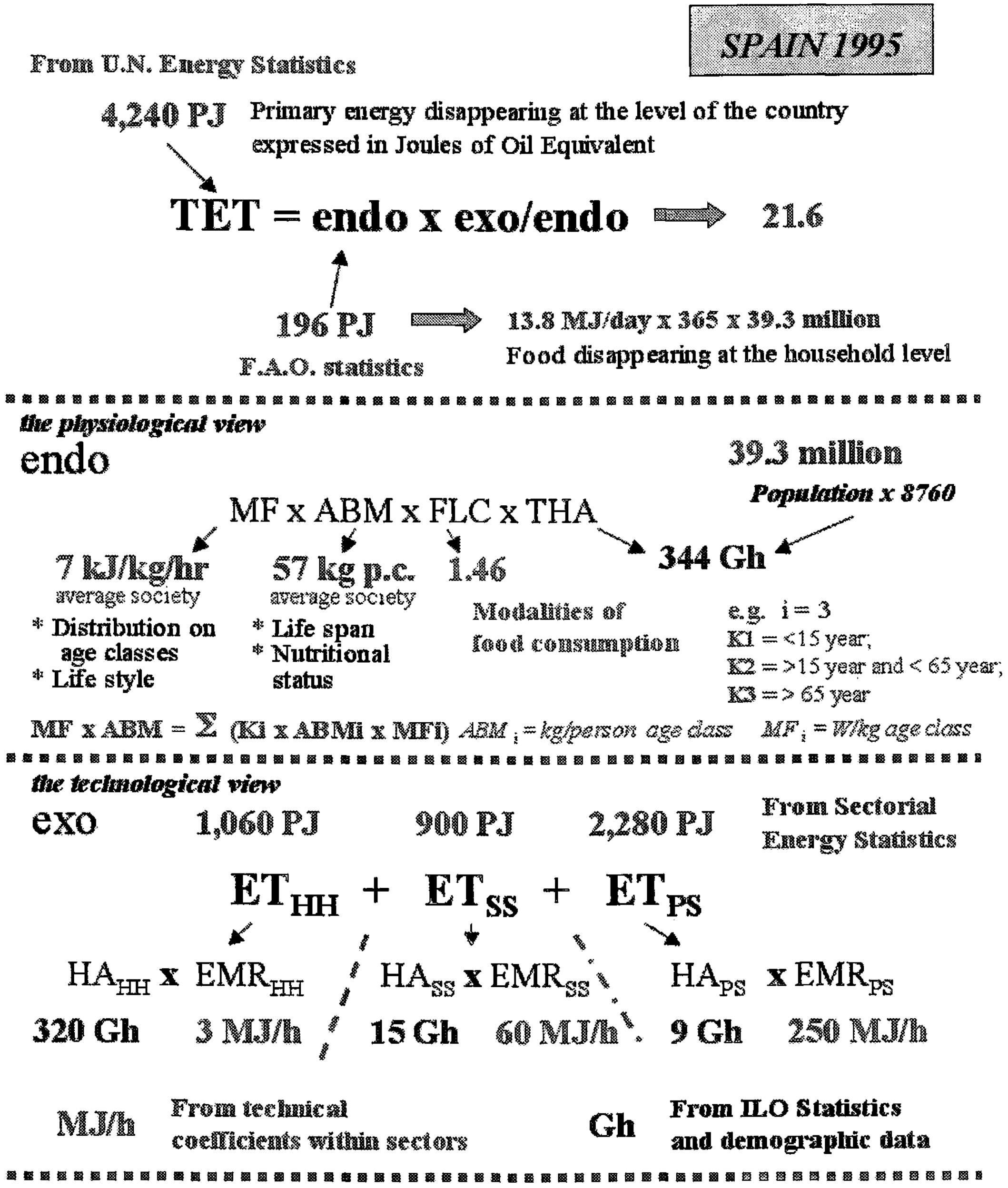


Fig. 6.8 Using redundancy to link non-equivalent assessments taking advantage of non-equivalent external referents

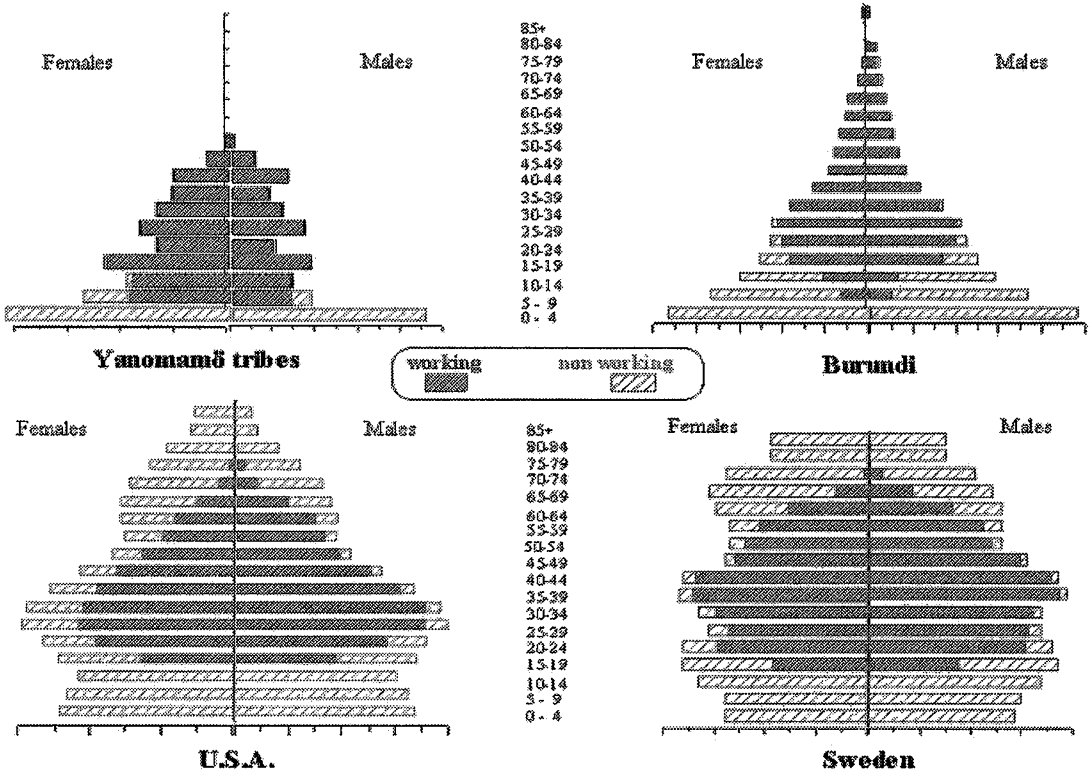


Fig. 6.9 Population structure of societies at different level of economic development (Giampietro and Mayumi, 2000a)

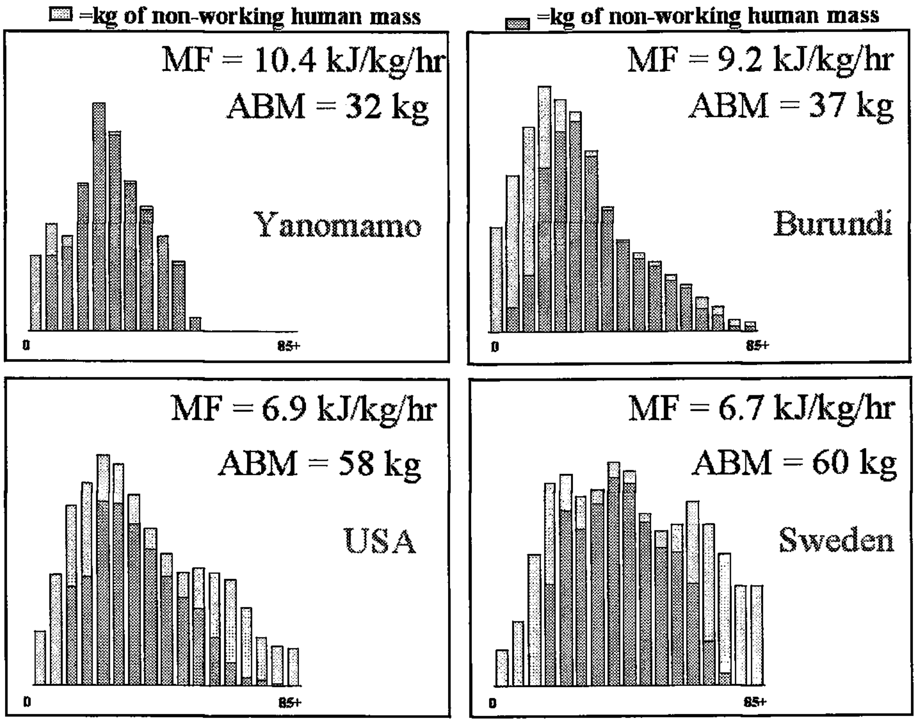
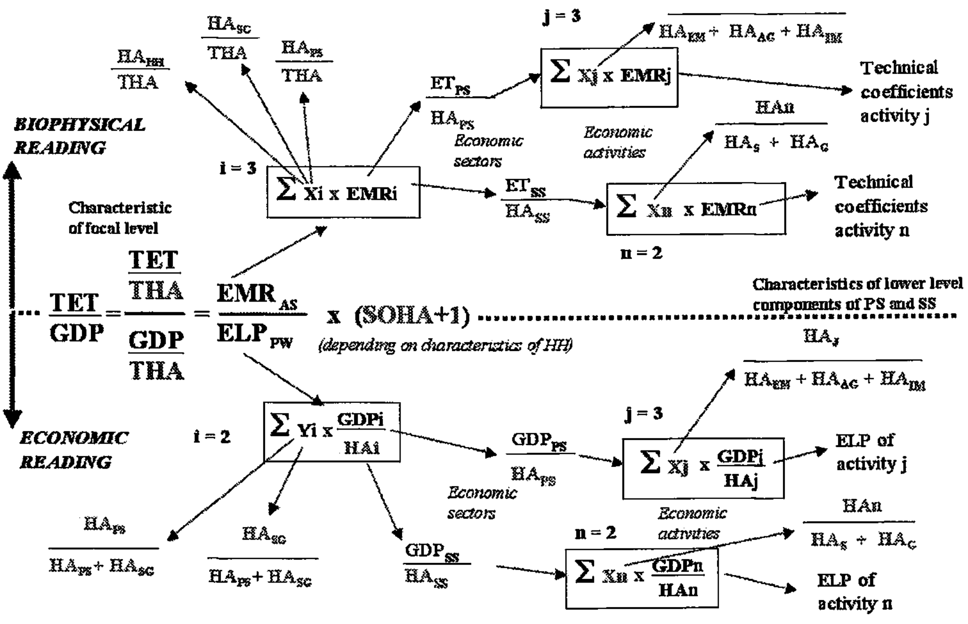
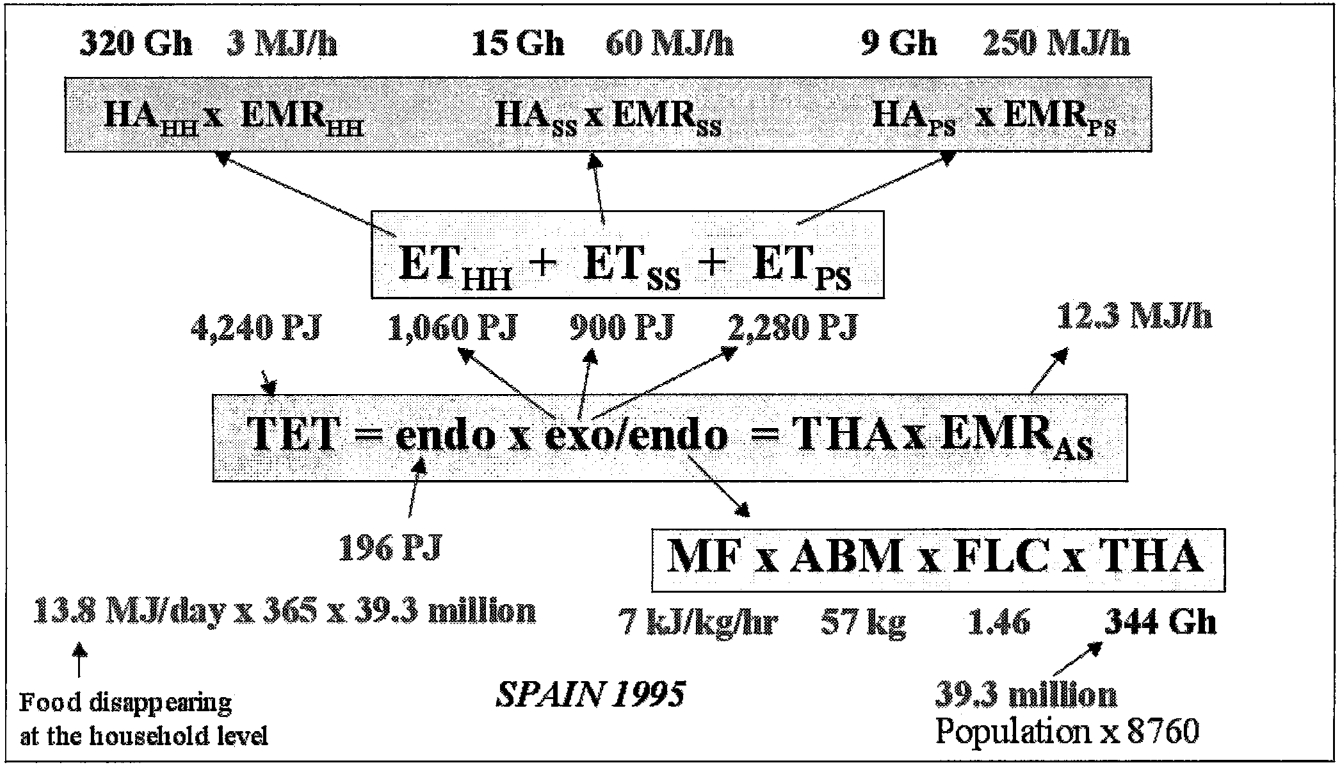


Fig. 6.10 Body Mass over age classes and average MF **(Giampietro and Mayumi, 2000a)**

Fig. 6.11 The nested hierarchical nature of relations in societal metabolism: integrating biophysical and economic variables
(Giampietro and Mayumi, 2000b)





$$THA = 344\ Gh = 320\ Gh + 15\ Gh + 9Gh \qquad TET = 4{,}240\ PJ = 1{,}060\ PJ + 900\ PJ + 2{,}280\ PJ$$

$$ExoMR_{AS} = \sum (X_i\ EMR_i) = (0.93 \times 3\ MJ/h) + (0.04 \times 60\ MJ/h) + (0.03 \times 250\ MJ/h)$$

$$EndoMR = 13.8\ MJ/\ (24 \times 1.46) = 7\ kJ/kg/hr \times 57\ kg = \sum (X_i\ ABM_i\ MF_i)$$

Fig. 6.12 Equations of congruence establishing a link between non-equivalent assessments

Chapter 7*

Impredicative Loop Analysis: dealing with the representation of chicken-egg processes

This chapter first introduces the concept of Impredicative Loop (Section 7.1) in general terms. Then, in order to make easier the life of readers not interested in hard theoretical discussions, additional theory has been skipped from the main text. Therefore, second section (section 7.2) provides examples of applications of Impredicative Loop Analysis (ILA) to three metabolic systems [(i) pre-industrial socio-economic systems, (ii) societies basing their metabolism on exosomatic energy, and (iii) terrestrial ecosystems]. The third section (section 7.3), illustrates key features and possible applications of ILA as a heuristic approach to be used to check and improve the quality of multi-scale integrated analyses. That is this section shows that ILA can be used as a meta-model for the integrated analysis of metabolic systems organized in nested hierarchies. The examples introduced in this section will be integrated and illustrated in details in Part 3 dealing with Multi-Scale Integrated Analysis of agroecosystems. The chapter ends with a technical appendix (last 2 sections) discussing theoretical aspects of ILA. The first of these two sections (section 7.4) provides a critical appraisal of conventional energy analysis – an analytical tool often found in scientific analyses of sustainability of agro-ecosystems. Such a criticism is based on hierarchy theory. The second section (section 7.5) deals with the perception and representation of autocatalytic loops of energy forms from a thermodynamic point of view (non-equilibrium thermodynamics). In particular, we propose an interpretation of ILA, which is based on the rationale of "negative entropy" which was provided by Schrödinger and Prigogine in relation to the class of dissipative systems. These last two sections are technical ones, and even though they do not require any mathematical skill to be followed, they do require some familiarity with basic concepts of energy analysis and non-equilibrium thermodynamics. In spite of this problem, in our view, these two sections are important since they provide a robust theoretical back-up to the use of ILA as a meta-model for dealing with sustainability issues.

*** Kozo Mayumi is a co-author of this chapter**

7.1 Introducing the concept of impredicative loop

Impredicativity has to do with the familiar concept of chicken-egg problem, or what Bertrand Russel called "vicious circle"(quoted in Rosen, 2000 p. 90). According to Rosen (1991) **impredicative loops** are at the very root of the essence of life, since **living systems are the final cause of themselves.** Even the latest developments of theoretical physics – e.g. superstring theory – represents a move toward the very same concept. Introducing such a theory Gell-Mann (1994) makes first reference to the *bootstrap principle* (based on the old saw about the man that could pull himself up by his own bootstraps) and then describes it as follows: "*the particles, if assumed to exists, produce forces binding them to one another; the resulting bound states are the same particles, and they are the same as the ones carrying the forces. Such a particle system, if it exists, gives rise to itself*". (Gell-Mann, 1994 p. 128). The passage basically means that you have to assume the existence of a chicken to get the egg that will generate the chicken and vice-versa. As soon as the various elements of the self-entailing process – defined in parallel on different levels - are at work, such a process is able to define (assign an identity) to it-self. The representation of this process, however, requires considering processes and identities that can only be perceived and represented by adopting different space-time scales.

A more technical definition of impredicativity provided by Kleene and related more to the epistemological dimension is reported by Rosen (2000, p. 90): "*When a set **M** and a particular object **m** are so defined that on the one hand **m** is a member of **M**, and on the other hand the definition of **m** depends on **M**, we say that the procedure (or the definition of **m**, or the definition of **M**) is impredicative. Similarly when a property **P** is possessed by an object **m** whose definition depends on **P** (here **M** is the set of objects which possess the property **P**). An impredicative definition is circular, at least on its face, as what is defined participates in its own definition*" (Kleene, 1952 pag. 42).

It should be noted that impredicative loops are also found in the definition of the identity of crucial concepts in many scientific disciplines. In biology, it is well known the example of the definition of the mechanism of natural selection (= "***the survival of the fittest***", in which the "***fittest***" is then defined as "***the surviving one***"). The same mechanism is found in the basic definition of the first law of dynamic (**F** = **m** x **a**) in which the force is defined as "what generates an acceleration over a mass", whereas an acceleration is described, using the same equation, as "the result of an application of a force to a given mass". Finally, even in economics we can find the same apparently tautological mechanism in the well known equation P x Y = M x V (price level times real GNP equal to amount of money times velocity of money circulation) in which the terms 'define'/'are defined by' each other.

Impredicative loops can be explored by explicitly acknowledging the fact that they are in general occurring across processes operating (perceived and represented) in parallel over different hierarchical levels. That is, definitions based on impredicative loops refer to mechanisms of self-entailment operating across levels and which therefore require a set of representations of events referring to both parts and wholes in parallel over different scales. Exactly because of that, as it is discussed in the technical section 7.4, they are out of the reach of reductionist analyses. That is, they are out of the reach of analytical tools developed within a paradigm that assumes that all the phenomena of the reality can be described **within the same descriptive domain, just by using a set of reducible models referring to the same substantive definition of space and time.** However, this **does not imply that impredicative loops cannot be explored by adopting an integrated set of non-equivalent and non-reducible models.** That is, by using a set of different models based on the adoption of non-equivalent descriptive domains (= non-reducible definition of space and time in formal terms – as discussed by Rosen, 1985 and in the technical section at the end of this chapter) it is possible to study the existence of an integrated set of constraints. These constraints are generated by the reciprocal effect of agency on different levels (across scales) and are referring to different relevant characteristics of the process (across disciplinary fields). The feasibility of an impredicative loop, with this approach, can be checked on different levels by using non-reducible models taking advantage of the existence of mosaic effects across levels (Giampietro and Mayumi, 2000a; 2000b; Giampietro et al. 2001).

However, this approach requires giving up the idea of using a unique narrative and a unique formal system of inference to catch the complexity of reality and to simulate the effects of this multi-scale self-entailment process (Rosen, 2000). Giving up this reductionist myth does not leave us hopeless. In fact, the awareness of the existence of reciprocal constraints imposed on the set of multiple-identities expressed by complex adaptive holarchies [= the existence different dimensions of viability e.g. chemical constraints, biochemical constraints, biological constraints, economic constraints, socio-cultural constraints] can be used to do better analyses.

7.2 Examples of Impredicative loop analysis of self-organizing dissipative systems

7.2.1 Introduction

With the expression *Impredicative Loop Analysis* we want to suggest that the concept of Impredicative Loop can be used as a heuristic tool to improve the quality of the scientific representation of complex systems organized in nested hierarchies. The approach follows a rationale which represents a major bifurcation from conventional reductionist approach. That is, the main idea is that first of all it is crucial to address the semantic aspect of the analysis. This implies accepting a few points which are consequences of what presented in Part 1:

(1) the definition of a complex dissipative system, within a given problem structuring, entails considering such a system to be a whole made of parts and operating in an associative context (which must be an admissible environment). In the step of representation this implies establishing a set of relations among a set of formal identities referring to at least 5 different hierarchical levels of analysis: ***(i) level n-2***: sub-parts; ***(ii) level n-1***: parts; ***(iii) level n***: the whole-black-box; ***(iv) level n+1***: an admissible context; and finally ***(v) level n+2***: processes in the environment that guarantee the future stability of favourable boundary conditions associated to the admissible context of the whole. An overview of such a hierarchical vision of an autocatalytic loop of energy forms is given in **Fig. 7.1.** This representation can be directly related to the discussion given in Chapter 6 about multi-scale mosaic effects for metabolic systems organized in nested hierarchies.

(2) it is always possible to adopt multiple legitimate non-equivalent representations of a given system, which are reflecting its ontological characteristics. Therefore, the choice of just one particular representation among the set of potential representations, does reflect not only characteristics of the observed system, but also characteristics of the observer (goals of the analysis, relevance of system's qualities included in the semantic identity, credibility of assumptions about the models, congruence of non-equivalent perception of causal relations in different descriptive domains).

(3) a given problem structuring (the definition of what is the system and what it does in its associative context) reflects an agreement about how to perceive and represent a complex adaptive holarchy in relation to the choice of: (a) a set of semantic identities (what is relevant for the observer about the observed), and (b) an associated set of formal identities (what can be observed according to available detectors and measurement schemes), which will be reflected into the selection of variables used in the model. It is important to notice that such an agreement about: (i) what is the system, and (ii) what the system is doing in its context; is crucial in order to get into the following step of selection of formal identities (individuation of variables used as proxies for observable qualities. Before reaching such an agreement about how to structure in scientific terms the problem of how to represent the system of interest **experimental data do not count as relevant information.** That is, before having a valid (and agreed upon) problem structuring that will be used to represent the complex system using different models referring to different scales and different descriptive domains **data "per se" do not exist.** The possibility of using data requires a previous validated definition of: (i) what should be considered relevant system qualities; (ii) which observable system qualities should be used as proxies of these relevant qualities; (iii) what is the set of measurement schemes that can be used to assign values to the variables, which, then, can be used in formal models to represent system's behaviour. The information provided by data therefore always **reflects the choices made when defining the set of formal identities** adopted in the representation of the reality by the analyst.

Sometime scientists seem to be aware of the implications of these pre-analytical choices, sometimes they are not. Actually, the most important reason for introducing complex systems thinking is exactly that of increasing the transparency about "hidden implications" associated to the step of modelling. The approach of Impredicative Loop Analysis is exactly aimed at addressing this issue. **The meat of ILA is about forcing a semantic validity check over the set of formal identities adopted in the phase of representation by those making models.**

In order to obtain this result, it is necessary to develop meta-models which are able to establish typologies of relations among parts and wholes, which can result relevant and useful when dealing with a class of situations. Useful meta-models can be applied, later on, to special (individual) situations belonging to a given typology. These "meta-models" to be useful, have to be based on a standard characterization of the mechanism of self-entailment among identities of parts, whole and context, defined on different levels. Actually this is exactly what it is implied by the very concept of impredicative loop.

Looking for "meta-models", however, implies accepting the consequence that any impredicative loop does have multiple possible formalizations. That is, the same procedure for establishing relations among identities of parts and whole within a given impredicative loop, can be interpreted in different ways by different analysts, even when applied to the same system considered at same point in space and time. Meta-models, by definition, do generate families of models based on the adoption of different sets of congruent formalization of identities. Obviously, at the moment of selecting an experimental design (or a specific system of accounting) we will have to select just one particular model to be adopted (in order to gather experimental data) and stick with it. Experimental work is based on the selection of just one of the possible formalizations of the meta-model, applied at a specific point in space and time.

This transparent "arbitrariness" of models which are built in this way should not be consider a weakness of this approach. On the opposite, in our view, this should be considered as a major strength. In fact, after acknowledging from the beginning the existence of an open space of legitimate options, analysts coming from different disciplinary back-grounds and/or from different cultural contexts and/or from different value systems are forced to deal, first of all and mainly, with the preliminary discussion of semantic aspects associated to the selection of models. This certainly facilitates a discussion about the usefulness of models and enhances the awareness of crucial epistemological issues to be considered at the moment of selecting experimental designs.

Below we provide 3 practical example of dissipative systems: (i) a pre-industrial societies of 100 people on a desert island; (ii) a comparison of the trajectory of development of two modern societies that base the metabolism of their economic process on exosomatic energy (Spain and Ecuador); (iii) the dynamic budget stabilizing the metabolism of terrestrial ecosystems. For the moment we just describe how it is possible establish a relation between characteristics of parts and the whole of these systems in relation to their associative context. Common features of the three analysis will be discussed in Section 7.3. More general theoretical aspects are discussed in Section 7.5.

7.2.2 Example 1 - Endosomatic Societal Metabolism of an isolated society on a remote island

Goals of the example.

As noted earlier the ability of keeping a dynamic equilibrium between requirement and supply of energy carriers (e.g. how much food must be eaten versus how much food can be produced in a pre-industrial societies) entails the existence of a biophysical constraint on the relative sizes and relative characteristics of various sectors making up such a society. The various activities linked to both production and consumption must be congruent in terms of an analysis based on a combined use of intensive and extensive variables across levels (mosaic effects across levels - Chapter 6). That is, we can look at the reciprocal entailment among the definition of size and the definition of characteristics of a metabolic system organized on nested hierarchical levels (parts and whole). Then we can relate this to the aggregate effect of this interaction on the environment. This is what we call an impredicative loop analysis.

Coming to this first example, we want to make immediately clear to the reader, that the stability of any particular societal metabolism does not depend only on the ability of establishing a dynamic equilibrium between requirement and supply of food. The stability of a given human society can be checked in relation to a lot of other dimensions – i.e. alternative relevant attributes and criteria. For example: Is there enough drinking water? Can the population reproduce in the long term according to an adequate number of adult males and females? Are the members of the society able to express a coordinate behavior in order to defend themselves against external attacks? Indeed, using an analysis that focuses only on the dynamic equilibrium between requirement and supply of food is just one of the many possible ways for checking the feasibility of a given societal structure.

However, given the general validity of the laws of thermodynamics such a check cannot be ignored. As a matter of fact, the same approach (checking the ability of obtaining a dynamic equilibrium between requirement and supply) can be applied in parallel to different mechanisms of mapping that can establish forced relations among flows and sizes of compartments and wholes across levels, in relation to different flows (as already illustrated in Chapter 6), to obtain integrated analysis. The reader can recall here the example of the various medical tests to be used in parallel to check the health of a patient – **Fig. 6.3**. In this first example of impredicative loop analysis we will look at the dynamic budget of food energy for a society. That is, this is like if we were looking at bones – using X-rays – of our patient. Other types of impredicative loop analysis (e.g. next 2 examples) could represent non-equivalent medical tests looking at different aspects of the patient (e.g. ultrasound-scan and blood test). What it is important is to have the possibility, later on, to have an overview of the various tests referring to non-equivalent and non-reducible dimensions of performance. This is done, for example, in **Fig. 7.6**, which should be considered as an analogous to **Fig. 6.3**.

The example.

As soon as we undertake an analysis based on energy accounting we have to recognize that the stabilization of societal metabolism requires the existence of an autocatalytic loop of useful energy (the output of useful energy is used to stabilize the input). In this example, we characterize the autocatalytic loop stabilizing societal metabolism in terms of reciprocal "entailment" of the two resources: "human activity" and "food" (Giampietro, 1997a). The terms autocatalytic loop indicates a positive feed-back, a self-reinforcing chain of effects (the establishment of an egg-chicken pattern). Within a socioeconomic process we can define the autocatalytic loop as follows. (1) The resource "human activity" is needed to provide control over the various flows of useful energy (various economic activities both in producing and consuming), which guarantee the proper operation of the economic process (at the societal level). (2) The resource "food" is needed to provide favorable conditions for the process of re-production of the resource "human activity" (i.e. to stabilize the metabolism of human societies when considering elements at the household level). (3) The two resources, therefore, enhance each other in a chicken-egg pattern. In this example we are studying the possibility of using the impredicative loop analysis related to the self-entailment of identities of parts and whole, which are responsible for stabilizing the autocatalytic loop of two energy forms: (i) Chemical energy in the food <--> (ii) Human activity expressed in terms of muscle and brain power.

Within this framework our heuristic approach has the goal of establishing a relation between a particular set of parameters determining the characteristics of this autocatalytic loop as a whole (at the **level *n***), and a particular set of parameters that can be used to describe the characteristics of the various elements of the socioeconomic system at a lower level (**level *n-1***). These characteristics can be used to establish a bridge with technological changes (observed on the interface of the **level *n-1*/level *n-2***) and to the effect of changes on environmental impact at the interface (**level *n*/level *n+1***) – see **Fig. 7.1.**

In this simplified example, we deal with an endosomatic autocatalytic loop (only human labor and food) referring to a hypothetical society of 100 people on an isolated, remote island. The numbers given in this example "per se" are not the relevant part of the analysis. As noted earlier any data set is not relevant, without a previous agreement of the users of the data set about the relevance of the problem structuring (in relation to a specific analysis performed in a specific context). We are providing numbers - which are familiar for those dealing with this topic - just to help the reader to better grasp the mechanism of accounting. **It is the forced relation among numbers (and the analysis of the mechanism generating this relation) which is the main issue here.** Different analyst can decide to define the relation among the parts and the whole in a different way, and therefore this could lead to a different definition of the data set. However, when adopting this approach they will be asked by other analysts about the reasons of their different choices. This will require, then, discussing about the meaning of the analysis.

The following example of ILA presenting a useful metaphor (meta-model) for studying societal metabolism has two major goals:

#1 - to illustrate an approach that makes possible to establish a clear link between the characteristics of the societal metabolism as a whole (characteristics referring to the entire loop – **level *n***) and a set of parameters controlling various steps of this loop (characteristics referring to lower-level elements and higher level elements – either defined at **level *n-1*** or at **level *n+1***). Moreover, it should be noted that the parameters considered in this analysis are those generally considered, by default, as relevant in the discussion about sustainability (e.g. population pressure, material standard of living, technology, environmental loading). This example clearly shows that these parameters actually are those crucial in determining the feasibility of the autocatalytic loop, when characterized in terms of impredicative loop analysis.

#2 - to illustrate the importance of closing the loop when describing societal metabolism in energy terms, instead of using linear representations of energy flows in the economic process (e.g. as done with input/output analyses). In fact, the conventional approach usually adopted in energy analysis, based on conventional wisdom keeps its focus on the consideration of a unidirectional flow of energy from sources to sinks (the gospel says "while matter can be recycled over and over, energy can flow only once and in one direction . . ."). As discussed later on, in Section 7.4, a linear representations of energy flows in terms of input/output assessments cannot catch the reciprocal effect across levels and scales that the process of energy dissipation implies (Giampietro and Pimentel, 1991a; Giampietro et al., 1997). It is in fact well known that, in complex adaptive systems, the dissipation of useful energy must imply a feed-back which tend to enhance the adaptability of their system of control (Odum, 1971, 1983, 1996). Assessing the effect of such a feed-back, however, is not simple because this feed-back can only be detected and represented on a descriptive domain which is different (larger space-time scale) from the one used to assess inputs, outputs and flows (as discussed at length in section 7.4 and 7.5). This is what Gerogescu-Roegen (1971) describes as the impossibility to perform an analytical representation of an economic process when several distinct "time differentials" are required in the same analytical domain. Actually, he talks of the existence of incompatible definitions of "duration" for parallel input/output processes (the replacement of the term "duration" with the term "time differentials" is ours). Our ILA of this 100 people of the remote island does provide practical examples of this fact.

The representations given in **Fig. 6.6** of how endosomatic energy flows in a society is a classic example of the conventional linear view. Energy flows are described as unidirectional flows from left to right (from primary sources to end uses). However, it is easy to note that some of the end uses of energy (indicated on the right side) are necessary for obtaining the input of energy from primary energy sources (indicated on the left side) in the first place. That is the stabilization of a given societal metabolism is linked to the ability of establishing an egg-chicken patterns within flows of energy. In practical terms, when dealing with the endosomatic metabolism of a human society a certain fraction of "End Uses" (e.g. in **Fig. 6.6**, the "physical activity work for food") must be available and used to produce food. The expression autocatalitic loop actually indicates the obvious fact that some of the end uses must re-enter into the system as input in order to sustain the overall metabolism. This is what implies the existence of internal constraints on possible structures of socioeconomic systems. In practical terms, when dealing with the endosomatic metabolism of a human society a certain fraction of the "End Uses" (in **Fig. 6.6**, the "physical activity work for food") must be available and used to produce food before the input enters into the system (as indicated on the lower axis of **Fig. 7.2**).

Assumptions and numerical data for this example

We hypothesize a society of 100 people that uses only flows of endosomatic energy (food and human labor) for stabilizing its own metabolism. In order to further simplify the analysis, we imagine that the society is operating on a remote island (survivors of a plane crash). We further imagine that its population structure reflects the one typical of a developed country and that the islanders have adopted the same social rules regulating access to the work force as those enforced in most developed countries (that is, persons under 16 and those over 65 are not supposed to work). This implies a dependency ratio of about 50%, that is, only 50 adults are involved in the production of goods and social services for the whole population. We finally add a few additional parameters needed to characterize societal metabolism. At this point the forced loop in the relation between these numerical values is described in **Fig. 7.2**:

* **Basic requirement of food.** Using standard characteristics of a population typical of developed countries, we obtain an average demand of 9 MJ/day per capita of food, which translates into 330,000 MJ/year of food for the entire population.

* **Indicator of material standard of living.** We assume that the only "good" produced and consumed in this society (without market transactions) is the food providing nutrients in the diet. In relation to this assumption we can define, then, two possible levels of material standard of living, related to two different "qualities" for the diet. The two possible diets are: ***(1) Diet A***, which covers the total requirement of food energy (3,300 MJ/year per capita) using only cereals (supply of only vegetal proteins). With a nutritional value of 14 MJ of energy per kg of cereal, this implies the need of producing 250 kg of cereals/year per capita. ***(2) Diet B***, which covers 80% of the requirement of food energy with cereals (190 kg/year p.c.), and 20% with beef meat (equivalent to 6,9 kg of meat/year p.c.). Due to the very high losses of conversion (to produce 1 kg of beef meat you have to feed the herd 12 kg of grains), this double conversion implies the additional production of 810 kg of cereals/year. That is, Diet B requires the primary production of 1,000 kg of cereals per capita (rather than 250 kg/year of diet A). Actually the value of 1,000 kg of cereal consumed per capita in indirect form in the food system, is exactly the value found in the USA nowadays (see the relative assessment in **Fig. 3.1**).

* **Indicator of technology.** This reflect technological coefficients. In this case: (i) labor productivity and (ii) land productivity of cereal production. Without external inputs to boost the production, these are assumed to be 1,000 kg of cereal per hectare and 1 kg of cereal per hour of labor.

* **Indicator of environmental loading.** A very coarse indicator of environmental loading can be assessed by the fraction "land in production"/"total land of the island". Since the land used for producing cereals implies the destruction of natural habitat (replaced with the monoculture of cereals). In our example the indicator of environmental loading is heavily affected by the type of diet followed by the population (material standard of living) and the technology used. Assuming a total area for the island of 500 hectares, this implies an index of EL = 0.05 for Diet A and EL = 0.20 for Diet B (EL = hectares in production/total hectares of available in the island).

* **Supply of the resource human activity.** We imagine that the required amount of food energy for a year (330,000 MJ/year) is available for the 100 people for the first year (let's assume it was in the plane...). With this assumption, and having the 100 people to start with, the conversion of this food into endosomatic energy implies (it is equivalent to) the availability of a total supply of human activity of 876,000 hours/year (= 24 hours/day x 365 x 100 persons).

* **Profile of investment of human activity of a set of typologies of "end uses" of human activity** (as in **Fig. 7.2**). These are: ***(1) "Maintenance and Reproduction"*** = It should be noted that in any human society the largest part of human activity is not related to the stabilization of the societal metabolism (e.g. in this case producing food), but rather to "Maintenance and reproduction" of humans. This fixed overhead includes: (a) sleeping and personal care for everybody (in our example a flat value of 10 hours/day has been applied to all 100 people leading to a consumption of 365,000 hours/year out of the Total Human Activity available). (b) activity of non-working population (the remaining 14 hours/day of elderly and children, which are important for the future stability of the society, but which are not available – according to the social rule established before – for the production of food, now). This implies the consumption of another 255,000 hours/year (14 x 50 x 365) in non-productive activities. ***(2) "Available Human Activity for work"*** - The difference between "Total supply of human activity" (876,000 hours) and the consumption related to the end use "Maintenance and Reproduction" (620,000 hours) is the amount of available human activity for societal self-organization – in our example 256,000 hours/year. This is the budget of human activity available for stabilizing societal metabolism. This budget of human activity, expressed at the societal level, however, has to be divided between two tasks: (1) guaranteeing the production of the required food input (for avoiding starvation now) - "Work for Food"; and (2)

guaranteeing the functioning of a good system of control able to provide adaptability in the future and a better quality of life to the people - "Social and Leisure".

At this point, the circular structure of the flows in **Fig. 7.2** enters into play. The requirement of 330,000 MJ/year of endosomatic energy input (food at time t) entails the requirement of producing enough energy carriers (food at time t+1) in the following years. That is a biophysical constraint on the level of productivity of labor in the activity producing food. Therefore this characteristics of the whole (the total demand of the society) translates into a not-negotiable fraction of investment of "Available Human Activity" in the end use "Work for Food" (depending on technology and availability of natural resources). This implies that the "disposable" fraction of "Available Human Activity" which can be allocated to the end use "Social and Leisure" is not a number that can be decided only according to social or political will. **The circular nature of the autocatalytic loop implies that numerical values associated to the characterization of various identities defining elements on different hierarchical levels (at the level of individual compartments – extensive – segments on the axis - and intensive variables – wideness of angles) can be changed, but only respecting the constraint of congruence among flows over the whole loop. These constraints are imposed on each other by the characteristics and the size - extensive (#1 and #2) and intensive (#3) variables – of the various compartments.**

Changing the value of variables within formal identities within a given impredicative loop

Let's imagine to change, for example, some of the values used to characterize this autocatalytic loop of energy forms. For example let's change the parameter "material standard of living", which - in our simplified model - is expressed by a formal definition of quality of the diet. The different mix of energy vectors in the two diets (vegetal versus animal proteins), imply a quantitative difference in the "biophysical cost" of the diet expressed both in terms of a larger work requirement and in a larger environmental loading (higher demand of land). The production of cereals for a population relying 100% on diet A requires only 25,000 hours of labor and the destruction of 25 hectares of natural habitat ($EL_A = 0.05$), whereas the production of cereals for a population relying 100% on Diet B requires 100,000 hours of labor and the destruction of 100 hectares of natural habitat ($EL_B = 0.20$). However, to this work quantity required for producing the agricultural crop, we have to add a requirement of work for fixed chores. Fixed chores are preparation of meals, gathering of wood for cooking, getting water, washing and maintenance of food system infrastructures in the primitive society. In this example we use the same flat value for the two diets = 73,000 hours/year (2 hours/day per capita = 2 x 365 x 100). This implies that if all the people of the island decide to follow the Diet A, they will face a fixed requirement of "Work for Food" of 98,000 hours/year. Whereas, if they all decide to adopt a Diet B, they will face a fixed requirement of "Work for Food" of 173,000 hours/year. At this point, for the two options we can calculate the amount of disposable "Available Human Activity" that can be allocated to "Social and Leisure". It is evident that the amount of time that the people living in our island can dedicate to: (a) running social institutions and structures (schools, hospitals, courts of justice); and (b) develop their individual potentialities in their leisure time in social interactions, is not only the result of their free choice. Rather, it is the result of a compromise between competing requirements of the resource "Available Human Activity" in different parts of the economic process.

That is, after assigning numerical values to social parameters such as population structure and a dependency ratio for our hypothetical population, we have a total demand of food energy (330,000 MJ/year) and a fixed overhead on the "Total supply of human activity", which implies a flat consumption for "Maintenance and Reproduction" (620,000 hours/year). Assigning numerical values to other parameters such as: (i) material standard of living (Diet A or Diet B), and (ii) technical coefficients in production (e.g. labor, land and water requirements for generating the required mix of energy vectors), implies defining additional constraints on the feasibility of such a socioeconomic structure. These constraints take the form of: (1) a fixed requirement of the resource "Available Human Activity" which is absorbed by "Work for Food" (98,000 hours for Diet A and 173,000 hours for Diet B). (2) a certain level of environmental loading (the requirement of land, water as well as the possible generation of wastes linked to the production), which can be linked, using technical coefficients, to such a metabolism (in our simple example we adopted a very coarse formal definition of identity for environmental loading which translates into $EL_A = 0.05$ and $EL_B = 0.20$).

With the term internal biophysical constraints we want to indicate the obvious fact, that the amount of human activity that can be invested into the end uses "Maintenance and Reproduction" + "Social and Leisure" depends only in part on the aspirations of the 100 people for a better quality of life in such a society. The survival of the whole system in the short-term (the matching of the requirement of energy carriers input with an adequate supply of them) can imply forced choices – e.g. in **Fig. 7.3**. Depending on the characteristics of the autocatalytic loop, large investments of human activity in "Social and Leisure" can become a luxury. For example, if the entire society (with the set of characteristics specified above) wants to adopt Diet B, then for them it will not be possible to invest more than 83,000 hours of human activity in the end use "Social and Leisure". On the other hand, if they want together with a good diet also a level of services typical of developed countries (requiring around 160,000 hours/year per 100 people), they will have to "pay for that". This could imply renouncing to some politically important rules reflecting cultural identity and ethical believes (what is determining the Fixed Overhead for Maintenance and Reproduction). For example, to reach a new situation of congruence they could decide either to introduce child labor, or increase the work load for the economically active population (e.g. working 10 hours a day for 6 days per week) – **Fig. 7.3**. In alternative, they can accept a certain degree of inequity in the society (a small fraction of people in the ruling social class eating diet B and a majority of ruled eating diet A). We can easily recognize that all these solutions are operating in these days in many developing countries and were adopted, in the past, all over our planet.

Lessons from this simple example

The simple assumptions used in this example for bringing into congruence the various assessments related to a dynamic budget of societal metabolism are of course not realistic (e.g., nobody can eat only cereals in the diet, and expected changes in the requirements of work are never linear). Moreover, by ignoring exosomatic energy we do not take in account the effect of capital accumulation (e.g. potential use of animals, infrastructures, better technology and know how affecting technical coefficients), which are relevant for reaching new feasible dynamic points of equilibrium of the endosomatic energy budget. That is alternative points of equilibrium can reached, beside changing population structure and size, also by changing technology (and the quality of natural resources). Actually, it is easy to make models for pre-industrial societies that are much more sophisticated than the one presented in **Fig. 7.2.** Models that take into account different landscape uses, detailed profiles of human time use, as well as reciprocal effects of changes on the various parameters, such as the size and age distribution of society (Giampietro et al., 1993). These models, after entering real data derived from specific case studies, can be used for simulations, exploring viability domains and the reciprocal constraining of the various parameters used to characterize the endosomatic autocatalytic loop of these societies. However, models dealing only with the biophysical representation of endosomatic metabolism and exosomatic conversions of energy are not able to address the economic dimension. Economic variables reflects the expression of human preferences within a given institutional setting (e.g. an operating market in a given context) and therefore are logically independent from assessment reflecting biophysical transformations.

Even within this limitation, the example of the remote island clearly shows the possibility to link the representation of the conditions determining the feasibility of the dynamic energy budget of societal metabolism to a set of key parameters used in the sustainability discussions. In particular, characterizing societal metabolism in terms of autocatalytic loops makes it possible to establish "relations" among changes occurring in parallel in various parameters, which are reflecting pattern perceived on different levels and scale. For example, how much would the demand of land change if we change the definition of the diet? How much would the disposable "available human activity" change if we change the dependency ratio (by changing population structure or retirement age)? In this way, we can explore the viability domain of such a dynamic budget (what combination of values of parameters are not feasible according to the reciprocal constraints imposed by the other parameters).

A technical discussion of the sustainability of the dynamic energy budget represented in **Fig. 7.2** and **Fig. 7.3** in terms of potential changes in characteristics (e.g. either the values of numbers on axis or the values of angles) requires using in parallel trend analysis on non-equivalent descriptive domains. In fact, changes which are affecting the value taken by angles (intensive variables) or the length of segments on axes (extensive variables) require considering non-equivalent dynamics of evolutions reflecting different perceptions and representations of the system. These relations are those considered in the discussion about mosaic effect across levels in Chapter 6.

For example, if the population pressure and the geography of the island imply that the requirement of 100 hectares of arable land are not available for producing 100,000 kg of cereal (e.g. a large part of the 500 hectares of the island are too hilly), the adoption of Diet B by 100% of population is simply not possible. The geographic characteristics of the island (let's say defined at the **level *n+2***) can be, in this way, related to the characteristics of the diet of individual members of the society (let's say at the **level *n-2***). This relation between shortage of land and poverty of the diet is well known. This is why, for example, all crowded countries depending heavily on the autocatalytic loop of endosomatic energy for their metabolism (such as India or China) tend to have a vegetarian diet. Still, it is not easy to define such a relation when adopting just one of these non-equivalent descriptive domains.

To make another hypothesis of perturbation within the ILA shown in **Fig. 7.2**, let's imagine the arrival of another crashing plane with 100 children at board (or a sudden baby boom in the island). This perturbation translates into a dramatic increase of the dependency ratio. That is, a higher food demand, for the new population of 200 people, which have to be produced by the same amount of 256,000 hours of "Available Human Activity" (related to the same 50 working adults). In this case, even when adopting Diet A, the larger demand of work in production will force such a society to dramatically reduce the consumption of human activity in the "end use" related to "Social and Leisure". The 158,000 hours/year, which were available to a society of 100 "vegetarians" (adopting 100% Diet A) for this "end use" - before the new crash of the plane full of children - can no longer be afforded. This could imply that the society would be forced to reduce the investments of human activity in schools and hospitals (in order to be able to produce more food), at the very moment in which these services should be dramatically increased (to provide more care to the larger fraction of children in the population) This could appear an "uncivilized behavior" to an external observer (e.g. a volunteer willing to save the world in a poor marginal area of a developing country). This value judgment, however, can only be explained by the ignorance of such an external observer of the existence of biophysical constraints which are affecting first of all the very survival of that society. Survival, in general, gets a higher priority than education.

The information used to characterize the impredicative loop which is determining the societal metabolism of a society, translates into an organization of an integrated set of constraints over the value that can be taken by a set of variables (both extensive and intensive). In this way, we can facilitate the discussion and the evaluation of possible alternative solutions for a given dynamic budget in terms of trade-off profiles. We earlier defined sustainability as a concept related to social acceptability, ecological compatibility, stability of social institutions, technical and economic feasibility. Even when remaining within the limits of this simple example, we can see the integrative power of this type of multilevel integrated analysis. In fact, the congruence among the various numerical values taken by parameters characterizing the autocatalytic loop of food can be obtained by using different combinations of numerical values of variables defined at different hierarchical levels and reflecting different dimensions of performance. There are variables or parameters - e.g. technical coefficients - that refer to a very location specific space-time scale (the yield of cereals at the plot level in a given year), others – e.g. dependency ratio – that reflect biophysical processes (demographic changes) with a time horizon of changes of 20 years. Finally there are other variables or parameters – e.g. regulation imposed for ethical reasons such as compulsory school for children – which reflect processes related to the specific cultural identity of a society.

For example, data used so far in this example about the budget of the resource "human activity" (for 100 people) reflect standard conditions found in developed countries (50% of the population economically active, working for 40 hours/week x 47 weeks/year). Let's imagine, now, that for political reasons, we will introduce a working week of 35 hours (keeping 5 or 6 weeks of vacation per year) – a popular idea nowadays in Europe. Comparing this new value to previous work-load levels, this implies moving from about 1,800 hours/year to about 1,600 hours/year per active worker (work absences will further affect both). This reduction is possible only if this new value is congruent with the requirement imposed by technical coefficients (the requirement of "work for food") and the existing level of investments/consumption in the end uses "Maintenance and Reproduction". If this is not the case, depending on how strong is the political will of reducing the number of hours per week, the society has the option of altering some of the other parameters to obtain a new congruence. One can decide to increase the retirement age (by reducing the consumption of human activity by "maintenance and reproduction", that is by reducing the amount of non-working human activity associated to the presence of elderly in the population), or to decrease the minimum age required for entering in the work force (a very popular solution in developing countries, where children below 16 years generally work). Another solution could be that of looking for better technical coefficients (e.g. producing more kg of cereals per hour of labor), but this would require both a lag-time to get technical innovations and an increase in investments of human work in research and development.

Actually, looking for better technical coefficients is the standard solution to all kinds of dilemmas about sustainability looked for in developed countries (since this makes possible to avoid facing conflicts internal to the holarchy). This is what we called in Part 1 the search for "silver bullets" or "win-win-win" solutions. However, any solution based on the adding of more technology does not come without side effects. It requires adjustments all over the Impredicative Loop. Moreover, this solution could imply an increase in the environmental impact of societal metabolism (e.g. in our example increasing the performance of monocultures, could increase the environmental impact on the ecosystem of the island). Again, when we frame the discussion of these various options, within the framework of integrated analysis of societal metabolism over an impredicative loop, we force the various analysts to consider, at the same time, several distinct effects (non-equivalent models and variables) belonging to different descriptive domains.

To make things more difficult, the consideration in parallel of different levels and scales can imply reversing the direction of causation in our explanations. That is, the direction of causality will depend on what we consider to be the "independent definitions of identity" (parameters) and the "dependent definitions of identities" (variables) within the impredicative loop – e.g. **Fig. 7.4**. For example, looking at the 4 quadrants shown in **Fig. 7.4** we can have that physiological characteristics (e.g. average body mass) can be given (e.g. in the example of the plane full of western people crashing on the island we are dealing with an average body mass of more than 65 kg for adults). On the other hand, if the Average Body Mass is considered as a dependent variable (e.g. in the long terms when adopting the hypothesis of "small and healthy" of physiological adaptation to reduced food supply), we can expect that, as occurring in pre-industrial society, in the future we will find, on this island, adults with a much smaller average body mass. In the same way the demographic structure can be a variable (when importing only adult immigrants, whenever a larger fraction of work force is required) or a given constraint, when operating in a social system where emigration or immigration are not an option. The same applies to social rules (e.g. slavery can be abolished and declared immoral when no longer needed or used to boost the performance of the economy and the material standard of living of the masters). In the same way, what should be considered as an "acceptable level of services" is also another system quality that can be considered as a dependent variable (e.g. if you are in a marginal social group forced to accept whatever is imposed on you) by the system. It becomes an independent variable, though, for groups that have the option to force their governments to do better, or that have the option to emigrate. Technical coefficients can be seen as driving changes in other system qualities, when adopting a given time scale (e.g. population grew because better technology made available a larger food supply), or they can be seen as driven by changes in other system qualities when adopting another time scale (e.g. technology changed because population growth required a larger food supply). Every time the analyst decides to adopt a given formalization of this impredicative loop based on a pre-analytical definition of what is a parameter and what is a variable (which in turn implies choosing a given triading filtering on the perception of the reality), such a decision implies exploring the nature of a certain mechanism (and dynamics), by ignoring the nature of others. The reader can recall the different explanations for the death of a person (**Fig. 3.5**) or the example of the plague in the village in Tanzania (**Fig. 3.6**).

This fact, in our view is crucial, and this is why we believe that a more heuristic approach to multi-scale integrated analysis is required. Reductionist scientists use models and variables which are usually developed in distinct disciplinary fields. These reductionist models can deal only with one causal mechanism and one optimizing function at the time, and in order to be able to do so, they bring with them a lot of ideological baggage very often not declared to the final users of the models.

We believe that by adopting Impredicative Loop Analysis we can enlarge the set of analytical tools that can be used to check non-equivalent constraints (lack of compatibility with economic, ecological, technical, social processes), which can affect the viability of considered scenarios. This approach can be used to generate a flexible tool bag for making checks based on different disciplinary knowledge, while keeping at the same time an approach that guarantee congruence among the various assessments referring to non-equivalent descriptive domains (some formal check on congruence among scenarios).

7.2.3 Example 2 – Modern societies based on exosomatic energy

Impredicative loop analysis applied to the self-entailment among the set of identities [= (a) energy carriers (**level *n-2***); (b) converters used by components (on the interface **level *n-2*/level *n-1***); (c) the whole seen as a network of parts (on the interface **level *n-1*/level *n***); and (d) the whole seen as a black box interacting with its context (on the interface **level *n*/level *n+1***)] required to represent the metabolism of exosomatic energy in modern societies as illustrated in Fig. 7.1. The way to deal with such a task is illustrated in **Fig. 7.5** (more details in the theoretical section 7.4). The 4 angles refer to the forced congruence among two different forms of energy flowing in the socio-economic process: **(1) Fossil energy used to power exosomatic devices**, which **is determining/ is determined by (2) Human activity used to control the operation of exosomatic devices** – for more on this rationale, see also Giampietro (1997).

There two sets of 4-angle figures which are shown in **Fig. 7.5**. Two of these 4-angle figures are in red (dotted and solid line) and represent two formalizations of the impredicative loop generating the energy budget of Ecuador at two points in time (1976 and 1996). The other two 4-angle figures (blue and dark green) represent two formalizations of the impredicative loop generating the energy budget of Spain at the same two points in time: 1976 (blue lines) and 1996 (dark green lines). This figure shows clearly that by adopting this approach it is possible to address the issue of the relation between qualitative changes (related to the re-adjustment of reciprocal value of intensive variables within a given whole) and quantitative changes (related to the value taken by extensive variables – that is the change in the size of internal compartments and the change of the system as a whole). The approach used to draw **Fig. 7.5** is basically the same used in **Fig. 7.2** in terms of the basic rationale. That is "the set of activities required for food production" within the autocatalytic loop of endosomatic energy has been translated into "the set of activities producing the required input of useful energy for machines" (energy and mining + manufacturing)".

For a more detailed explanation of the formalization used in the 4-angle figures shown in **Fig. 7.5** see Giampietro, 1997, Giampietro et al. (2001) and the two special issues of *Population and Environment* [2000, Vol. 22(2): 97-254; and 2001, Vol. 22(3): 257-352]. Moreover, a detailed explanation of this type of analysis will be discussed in Chapter 9 when discussing the concepts of demographic pressure and socio-economic pressure on agricultural production.

Economic growth is often associated to an increase in the total throughput of societal metabolism and therefore to an increase in the size of the whole system (when seen as a black box). However, when studying the impredicative loop which is determining an integrated set of changes in the relative identities of different elements (e.g. economic sectors seen as the parts) and the whole, we can better understand the nature and the effects of these changes. That is, the mechanism of self-entailment of the possible values taken by the angles (intensive variables), reflect the existence of constraints on the possible profiles of distribution of the total throughput over lower level compartments. In the example given in **Fig. 7.5**, Spain changed, over the considered period of time, the characteristics of its metabolism both in: (a) **qualitative terms** (***development*** – different profile of distribution of the throughput over the internal compartments – changes in the value taken by *intensive#3 variables*); and (b) **quantitative terms** (***growth*** – increase in the total throughput – changes in the value taken by *extensive#2 variables*).

On the other hand, Ecuador, in the same period of time, basically expanded only the size of its metabolism (the throughput increased as result of an increase in redundancy = more of the same – increase in *extensive variable#2*), but maintaining the original relation among intensive variables (the same profile of distribution of values of *intensive variables#3*, reflecting the characteristics of lower level components = growth without development). In our view, an analytical approach based on an impredicative loop analysis can provide a powerful diagnostic tool when dealing with issues related to sustainability, environmental impact associated to growth and/or development (e.g. when dealing with issues such as the mythological Environmental Kuznet Curves). In fact, in these situations it is very easy to extrapolate wrong conclusions (e.g. dematerialization of developed economies) after being misguided by the reciprocal effect of changes among intensive and extensive variables – Jevons' paradox – see **Fig. 1.3** - leading to the generation of "tread mills" as discussed in Chapter 1 - **Tab.1.1.**

7.2.4 Example 3 – The net primary productivity of terrestrial ecosystems

The crucial role of water flow in shaping the identity of terrestrial ecosystems

Before getting into the discussion of the next example of Impredicative Loop Analysis applied to the mechanism of self-entailment of energy forms associated to the identity of different types of terrestrial ecosystems, it is useful to quote an important passage of Tim Allen about the crucial role of water in determining the life of terrestrial ecosystems.

"*Living systems are all colloidal and, for the narrative we wish to tell, water is the constraining matrix wherein all life functions. Unfortunately, most biological discussion turns on issues of carbon chemistry, such as photosynthesis, and the water is taken from granted. Think then of the amount of water that is in your head as you think about these ideas. Your thoughts are held in a brain that is over 80% water. Might it not be foolish to take that water from granted. Water is the medium in which life is constrained. Mars is a dead planet because it has insufficient liquid water. The controls of Gaia (Lovelock, 1986) on this planet works through water as a medium of operation. There is no life on Mars because there is no water to get organized. When we take water seriously, as a matrix of life, living systems are an emergent property not of carbon and its chemistry, but an emergent property of planetary water. Thus I misspeak when I tell my students that terrestrial animals are zooplankton that have brought their water with them. Rather they are pieces of ocean water that has brought its zooplankton with it. In the time between the next to last breath of a dying organisms and when it is unequivocally death, the carbon chemicals within the corps are essentially unchanged. The difference between life and death is that the water ceases to be the constraining element and it leaks away.* ***The water looses its control. Trees are one of water's ways of getting around on land and into the air***". Allen et al. (2001 pag.136).

This passage beautifully focuses on the crucial importance and the role that water (and its activity driven by dissipation of energy) plays in the functioning of terrestrial ecosystems. From this perspective, one can appreciate that the net primary productivity of terrestrial ecosystems (the ability to use solar energy in photosynthesis to make chemical bonds) depends on the availability of a flow of energy of different nature (the ability to discharge entropy to the outer space, associated to the evapotranspiration of water). That is the primary productivity of terrestrial ecosystems, which establishes a storage of free energy in the form of chemical bonds in standing biomass, requires the availability of a different form of energy at a higher level. According to the seminal concept developed by Tsuchida, the identity of Gaia is guaranteed by an engine powered by the water cycle which is able to discharge entropy at increasing rate – see Tsuchida and Murota, (1985). This power is required to stabilize favourable boundary conditions of the various terrestrial ecosystems operating on the planet.

When coming to agricultural production in agro-ecosystems the situation is even more complicated. In fact, in order to have agricultural production there additional types of energy forms and conversions which are required. At least 3 distinct types of energy flows (each of which implies a non-equivalent definition of identities for converters, components, wholes and "admissible environments") are required for the stability of an agroecosystem:

(A) natural processes of energy conversions powered by the sun and totally out of human control. These can include, for example: heath transfer due to direct radiation, evapotranspiration of water, generation of chemical bonds via photosynthesis, interactions of organisms belonging to different species within a given community in order to stabilize existing food-webs (i.e. for the reciprocal control predator/prey or "plants/herbivores/carnivores/detritus-feeders" within nutrient loops in ecosystems);

(B) natural processes of conversion of food energy within humans and domesticated plants and animals controlled by humans to generate useful power. This metabolic energy is used to generate: (i) human work and animal power needed in farming activities, as well as (ii) plants and animal products (such as crops, fibers, meat, milk and eggs);

(C) technology driven conversions of fossil energy (these conversions require the availability of technological devices - capital - and know how, beside the availability of fossil energy stocks). Fossil energy inputs are used to boost the productivity of land and labor (e.g. for irrigation, fertilization, pest control, tilling the soil, harvesting). This input to agriculture is coming from stock depletion (mining of fossil energy deposits) and therefore implies a dangerous dependency of food security on non-renewable resources.

These three types of energy flows have a different nature and therefore cannot be described within the same descriptive domain (not only the relative patterns are defined on non-reducible descriptive domains, but also their relative sizes are too different). Therefore it is important to be able to establish at least some sort of bridge among them. An integrated assessment has to deal with all of them, since they are required in parallel - and in the right range of values: intensive variable#3 - for sustaining a stable flow of agricultural production.

Relevant implications of this fact are:

(1) When describing the process of agricultural production in terms of output/input energy ratios (using conventional energy analyses), the analyst tends to focus basically only on those activities and energy flows that have a direct importance (in terms of "costs" and "benefits") for humans. That is, the traditional accounting of output/input energy ratios in agricultural production refers to outputs directly used by humans (e.g. harvested biomass and useful by-products) and inputs directly provided by humans (e.g. application of fertilizers, irrigation, tilling of soil). That is, such an accounting refers to a perception of "usefulness" obtained from within the socio-economic system (from within the black box). However, not necessarily these two flows should also be relevant for the perspective of the ecosystem in which the agricultural production takes place. Actually, it should be noted that **the two flows of energy considered in conventional energy assessments as "input" and "output" of the agricultural production are only a negligible fraction of the energy flowing in any agroecosystem.** Any biomass production (both controlled by humans and naturally occurring) requires a very large amount of solar energy to keep favorable conditions for the process of self-organization of plants and animals. There are large scale ecological processes occurring outside human control that are affecting both the supply of inputs and the stability of favourable boundary conditions to the process of agricultural production. That is, what is "useful" to stabilize the set of favourable conditions required by primary production of biomass in terrestrial ecosystems – the flow of useful activity of ecological processes 0 can be perceived and represented only by adopting a triading reading of events on higher levels (**level *n*/*n*+*1*/*n*+*2***). This is a triadic reading different from that adopted to represent the process of agricultural production at the farm level (**level *n*-*1*/*n*/*n*+*1***). These mechanisms operating at higher levels are totally irrelevant in terms of short term perception of utility for humans and tend not to be included in assessments based on monetary variables. A tentative list of ecological services required for the stability of primary productivity of terrestrial ecosystems and ignored by default by monetary accounting include: (a) an adequate air temperature; (b) an adequate inflow of solar radiation, (c) an adequate supply of water and nutrients; (d) healthy soil which makes the available water and nutrients accessible to plants at the right moment, (e) the presence of useful biota able to guarantee the various steps of reproductive cycles (e.g. seeds, insects for pollination).

(2) **the two flows of energy considered in conventional energy assessments as "input" and "output" of the agricultural production are** two flows referring to energy forms which require the use of different sets of identities for their assessment. The majority of energy inputs in modern agriculture belong to the type "fossil energy used in converters which in general are machines" (what we called before exosomatic energy). Whereas the majority of energy output consist of the produced biomass, which belongs to the type "food energy used in physiological converters" (what we called before endosomatic energy). Therefore, this is a ratio between numbers which are reflecting assessments logically independent (they refer to two different autocataltyc loops of energy forms – as discussed in the two previous examples). This ratio divides apples by oranges . . . An operation, that can be legitimately done to calculate indicators (e.g. dependency of food supply on disappearing stocks of fossil energy) or for benchmarking (comparing environmental loading, or capital intensities of two systems of production), but not to study indices of performance about evolutionary trajectories of metabolic systems.

Just to provide an idea of the crucial dependency of human food supply on the stability of existing bio-geo chemical cycles on this planet it is helpful to use a few figures. The total amount of exosomatic energy controlled by humankind in 1999, for all its activities (agriculture, industry, transportation, military activities and residential) is around 11 TW (1 Terawatt is 10^{12} joule/second) which is about 350 x 10^{18} Joules/year (BP-Amoco Energy Statistics, 1999). Whereas, only for keeping the water cycle the natural processes of Earth are using 44,000 TW of solar energy (about 1,400,000 x 10^{18} Joules/year), **4,000 times the energy under human control!** Coming to assessments of energy flows related to agricultural production, the amount of solar energy reaching the surface of the Earth, per year, as average is 58,600 GJ/ha (1 Gigajoule is 10^{9} joules), which is equivalent to 186 W/m^2. This is almost 500 times the average output of the most productive crops (e.g. corn, around 120 GJ/ha/year). Remaining in the example of corn production, the amount of solar energy needed for water evapotranspiration is about 20,000 GJ/ha/year, **which again is more than 150 times the crop output produced assessed in terms of chemical bonds stored in biomass.** [* This assessment is based on the following assumptions: (1) 300 kg of water/kg of Gross Primary Production (GPP); (2) 2.44 MJ of energy required kg of evaporated water (1 MJ = Megajoule is 10^{6} joules); (3) GPP = yield of grain x 2.62 (rest of plant biomass) x 1.3 (pre-harvest losses)].

This deluge of numbers confirms completely the statement of Tim Allen reported earlier about the crucial role of water when compared to carbon chemistry in the stabilization of terrestrial ecosystems. Using again a metaphor used by Prof. Allen to explain the behaviours of terrestrial ecosystems we should think of water as the electric power, whereas carbon chemistry is the electronic part of controls.

The goal of this sections full of figures is to make clear to the reader that several different output/input energy ratios can be calculated when describing agricultural production and the functioning of terrestrial ecosystems. Depending on what we decide to include among the accounted flows [different classes of energy forms] - either as output or input - we can generate a totally different picture of the relative importance of various energy flows or about the "efficiency" of the process of agricultural production. Conventional output/input energy analysis tends to focus only on those outputs and inputs that have a direct economic relevance (since they are linked to short-term and direct benefits and costs of the agricultural process). This choice, however, carries the risk of conveying a picture that neglects the importance of "free" inputs, which are provided by natural processes to agriculture. This picture ignore how the autocatalytic loop is seen from the outside (from the ecosystem point of view).

Without the supply of these free inputs (such as healthy soil, fresh water supply, useful biota, favorable climatic conditions) human technology would be completely incapable of guaranteeing food security. The idea that technology can (and will) be able to replace these natural services is simply ludicrous when analyzed under an energetic perspective as perceived by natural ecosystems. This is why we need an alternative view of the relation among the identity of parts and whole of terrestrial ecosystems that reflects the internal relation between identity of parts and wholes, according to the mechanism of self-entailment of energy forms within ecological processes. The example presented below represents an attempt in this direction. The ILA rationale is applied to the analysis of a self-entailment of energy forms stabilizing the identity of terrestrial ecosystems.

An ILA of the autocatalytic loop of energy forms shaping terrestrial ecosystems

Our Impredicative Loop Analysis of the identity of terrestrial ecosystems tries to establish a relation between: (1) what is going on in them in terms of primary productivity (the making and consuming of chemical bonds) inside the black box (using the total amount of chemical bonds are extensive variable#1). This is an information that can be linked to the analysis of agricultural activities; and (2) the external power associated to the cycling of water linked to this primary productivity, which is a measure of the interaction of such a black box with the context (this measures the dependency of Gross Primary Productivity on favourable conditions for the transpiration of water, which is an extensive variables#2 according to the mechanism used to generate mosaic effect across levels for dissipative systems illustrated in Chapter 6). Obviously, we cannot attempt to include the mechanisms occurring "outside" the investigated system to stabilize boundary conditions (the set of identities stabilizing the power associated to the cycling of water). By definition there is always a **level *n+2*** which is labeled as "environment" and therefore must remain outside the grasp of scientific representation within the given model. We just establish a set of reciprocal relations among key characteristics of the identity of terrestrial ecosystems (without considering the interference of humans). To do that, we benchmark the identities of various elements mapped used a specified form of energy (i.e. amount of chemical bonds – as extensive variable#1) against another form of energy (i.e. the amount of water which is evapotranspirated per unit of Gross Primary Production (GPP) – as extensive variable#2). If in this way, we can find typologies of patterns that can be used to study the relations among characteristics and size of the parts and the whole of terrestrial ecosystems, then, it becomes possible to study the effects of human alteration of terrestrial ecosystems associated to their colonization, in terms of distortion from the expected pattern. Applications of this analysis are discussed in Chapter 10 (section 10.3).

An example of ILA applied to terrestrial ecosystems is given in **Fig. 7.6**. The self-entailment among flows of different energy forms considered there refers to "Solar energy used for evapotranspiration" which is linked to "generation and consumption of chemical bonds in the biomass". That is, the 4 angles of **Fig. 7.6** refer to the forced congruence among two different forms of energy flowing in terrestrial ecosystems: **(1) Solar energy to power evaporation of water associated to photosynthesis**, which **is determining/ is determined by (2) biomass generated through photosynthesis, whose activity is used to organize and control the evaporation of water.**

Put in another way, the chicken-egg loop stabilizing terrestrial ecosystems is described in **Fig. 7.6** as an autocatalytic loop of two energy forms: (i) **"photosynthesis" making biomass** (storage of energy in the form of chemical bonds), which makes possible to **use solar energy through "evapotranspiration of water"**; and (ii) **solar energy invested in "evapotranspiration of water"** bringing nutrients to the leaves and **making possible the photosynthetic reactions required for making biomass.** Also in this case, it is possible to represent such a chicken-egg loop using a 4 angle representation:

* angle α --> due to the characteristic of the terrestrial ecosystem a certain fraction of the energy made available to the ecosystem through photosynthesis (extensive variable#1) is used by the plants themselves. The fraction lost to autotrophic respiration – an overhead of the plants - defines the Net Primary Productivity (NPP) of an ecosystems, given a level of GPP (internal loss at the level n-1).

* angle β --> the characteristics of the Heterotrophic compartment of the terrestrial ecosystem defines the distribution of the total biomass among different sub-compartments (the shape of the Eltonian pyramid, food web structure and/or when adopting non-equivalent representation of ecosystems – e.g. network analysis - different graphs). The combined effect of this information will determine the ratio SB/NPP [SB = Standing Biomass]. This is still described using fractions of the extensive variable#1;

* angle γ --> due to the characteristic of the terrestrial ecosystem there is a certain demand of water to be used in evapotranspiration per unit of total standing biomass (total standing biomass includes the biomass of heterotrophic and autotrophic organisms). This depends on the turnover of different types of biomass (with known identities in different compartments) and the availability of nutrients and way of transportation of nutrients. This establishes a link between investment of extensive variable#1 and returns of extensive variable#2 at the level n-1 (over the autotrophic compartment).

* angle δ --> this angle represent the ratio between two non-equivalent flows of energy forms (two independent assessments) that can be used to establish a relation between: (1) the size of the dissipative system "terrestrial ecosystem" seen from the inside – extensive variable#1, which is defined in size (total standing biomass, and turnover time "GPP/SB) using a chain of identities energy carriers--> transformers--> whole (chemical bonds generated by photosynthesis making up flows of biomass across components – total size GPP). The internal "currency" expressed in GPP makes possible to describe the profile of investments of it, inside the system over lower level compartments (e.g. autotrophs and heterotrophs); and (2) the size of the dissipative systems as seen from the context – extensive variable#2. This is the size of the energy gradient which is required from the context to stabilize the favourable boundary conditions associated to the given level of GPP (incoming solar radiation and thermal radiation into the outer space – which is supporting the process of water evapotranspirations – plus availability of enough water supply).

Obviously, we cannot fully forecast what are the most important limiting factors or what are the mechanisms more at risk in the future to stabilize such a power supply. But this is not an issue relevant here. Given a known typology of terrestrial ecosystems, we can study the relation between the relative flow of GPP and the solar energy for water transipration associated to it, in terms of the relative characteristics (extensive and intensive variables) of parts and whole, represented as stabilizing an impredicative loop of energy forms. The mapping of these two energy forms (extensive variable#1 and extensive variable#2) can provide a reference value – a benchmark – against which assess the size of the ecosystem (at the **level *n***), and the size of their relative components (at the **level *n-1***) in relation to the representation of events – intensive variables#3, associated to the identity of parts and lower level elements - the consumption and generation of energy carriers/chemical bonds – at the **level *n-2*.**

A detailed analysis of the self-entailment among characteristics of each one of the 4 angles (how the identity of lower level components affects the whole and viceversa) is the focus of "theoretical ecology" applied to the issue of sustainability. Our claim, is that ILA can provide a useful additional approach to study such an issue. We propose the theoretical discussion provided in the technical session 7.5, and a few examples provided in Chapter 10 in Part 3 to support our claim. It is important to observe that studying the forced relations between the characteristics of identities of elements (and the size of the relative equivalence class) determining this impredicative loop in terrestrial ecosystems has to do with how to define concepts like "ecosystem integrity", "ecosystem health" and how to develop indicators of ecological stress. Even from this very simplified example, we can see that the concept of impredicative loop can help to better frame these elusive concepts (integrity or health of natural ecosystems) in terms of a standard mechanisms of self-entailment among biological identities which are defining each-other on different levels and on different scales. Integrity and health can be associated to the ability of maintaining harmony among the multiple-identities expressed by ecological systems (the ability to respect the forced congruence among flows exchanged across metabolic components organized in nested hierarchies) – see also last section of Chapter 6. Healthy ecosystems are those able to generate meaningful "essences" for their components (more on this in Chapter 8).

As in the previous example of the 100 people on a desert island, the perceived identity of terrestrial ecosystems is represented in **Fig. 7.6** in the form of an autocatalytic loop of energy forms which is related to the simultaneous perception (and definition) of identities of lower level components, higher level components and the congruence between functional relation and organized structures on the focal level. Again, looking at energy forms is just one of the possible way to look at this system (whenever we are using x-rays and we miss soft tissues). However, making explicit such a holarchic structure, in relation to a useful selection of formal identities, can be useful to study the effect of perturbations. For example, agriculture implies an alteration of the relation between key parameters determining the impredicative loop described in **Fig. 7.6.** Monocultures, by definition, translate into a very high Net Primary Productivity with little Standing Biomass as average over the year, and a reduced fraction of Heterotrophic Respiration over the total GPP. An analysis of the stability of ILA applied to agroecosystems can be used to look for indicators of stress. A discussion of these points is given in Chapter 10 – e.g. Fig. 10.13, Fig. 10.14, Fig. 10.15. The main point to be driven home from the ILA approach now is that whenever we deal with parameters which are reciprocally entailed in a chicken-egg loop, we cannot imagine that it is possible to generate dramatic changes in just one of them, without generating important consequences over the whole loop. That is, whenever we decide to dramatically alter the holarchic structure of a terrestrial ecosystem we have to expect non-linearity in the resulting side-effects (the breaking of its integrity). The use of Impredicative Loop Analysis to study this problem should help in searching for mechanisms that can lead to catastrophic events across different scales that can result useful for such a search (for more see Chapter 10).

7.2.5 Parallel consideration of several impredicative loop analyses

An overview of the three impredicative loop analyses presented in **Fig. 7.2**, **Fig. 7.5**, and **Fig. 7.6** is given in **Fig. 7.7**. Actually, these three formalizations of Impredicative Loops refer to three possible ways of looking at energy forms relevant for the stability of agroecosystems. It is very important to note that these three formalizations cannot be directly linked to each other, since they are constructed using logically independent perceptions and characterization of parts, whole and contexts (non-equivalent descriptive domains). The meta-model used for the semantic problem structuring is the same, but they have been formalized (when putting numerical assessment in it) by referring to definitions of energy forms, and useful energy which are specific for the set of identities adopted to represent the autocatalytic loop. However, they have some aspect in common and this makes possible to use them in an integrated way, when discussing, for example, of scenarios analysis.

These three applications of the same meta-model, useful for catching different aspects of a given situation, required a tailoring of the general ILA on the specificity of a given situation. In this way it becomes possible to build a set of integrated models reflecting different dimension of analysis for a specific problem. That is, scientists that want to use this approach to deal with a specific issues of sustainability of an agroecosystems have to decide about what are the relevant characteristics of the endosomatic autocatalytic loop (which is associated to physiological, demographic and social variables), exosomatic autocatalytic loop (which is associated to both biophysical and socio-economic variables), critical factors affecting the self-entailment of energy forms in a specific terrestrial ecosystem (which makes possible to establish a link with ecological analysis). The process through which scientists can decide about how to make these choices has been discussed in Chapter 5. According to what said in Chapter 5, we should always expect that different scientists asked to perform a process of multi-scale integrated analysis aimed at tailoring these 3 meta-models in relation to a specific situation (e.g. by collecting specific data about a given society perceived and represented at a given point in space and time as operating with a given terrestrial ecosystem) will come up with different variables and models to represent and simulate different aspects. The same can be expected about the direction of causality found in the analysis. Disciplinary bias (pre-analytical ideological choice implied by disciplinary knowledge) is always at work!

Put it in another way, the predicament described in **Fig. 7.4** (= what are the independent and what are the dependent variables?), as well as all the other problems described in Chapter 3 can never be avoided, even when we explicitly introduce in our analysis multiple identities defined on multiple scales. What can be done when going for a multi-scale integrated analysis based on the parallel use of Impredicative Loop Analysis is to take advantage of mosaic effects. If the analyst is smart enough, she/he can try to select variables which are shared by couples of ILAs. In this way, it becomes possible to look for bridges among non-equivalent descriptive domains. In this way, as illustrated in **Fig. 5.9**, it becomes possible to generate integrated packages of quantitative models, which are able to provide a coherent overview of different relevant aspects of a given problem. In particular, they can be used to filter out incoherent scenarios generated by simulations based on the "ceteris paribus" hypothesis. That is they can be used to check the reliability of predictions based on reductionist models.

7.3 Basic concepts related to Impredicative Loop Analysis and applications

7.3.1 Linking the representation of the identities of parts to the whole and viceversa

The examples of 4-angle figures presented in the previous section (e.g. **Fig. 7.7**) are representations of autocatalytic loops of energy forms obtained through an integrated use of a set of formal identities defined on different hierarchical levels (**Fig. 7.1**).

To explain the nature of the link bridging the representation given in **Fig. 7.1** and the representation given in **Fig. 7.7**, it is necessary to address key features associated to the analysis of the dynamic energy budget of a dissipative system - **Fig. 7.8a**. This alternative view provides yet another set of attributes that can be used to represent autocatalytic loop of energy forms in hierarchically organized dissipative systems. That is, the same network of elements represented in **Fig. 7.1** can be perceived and represented in a non-equivalent way by dividing the components described at the **level *n-1*** into two classes - **Fig. 7.8.a**: (1) those which do no interact directly with the environment - aggregated in the compartment labelled as "indirect" in; (2) those which interact directly with the environment (e.g. by gathering inputs from the environment) aggregated in the compartment labelled as "direct". In this view, the black box – seen as a whole (at the **level *n***) - can receive an adequate supply of required input thanks to the existence of favourable conditions (at the **level *n+1***) and the work of the direct compartment (at the **level *n-1***). This input feeding the whole can then be expressed in terms of an energy form, accounted for by using an extensive variable (which we called in Chapter 6 extensive variable #1). This variable is then used to assess how this total input is invested – within the black box - over its lower level compartments. This variable measure the size of the whole in relation to its parts. Therefore, we can represent that the total input – assessed using an extensive#1 variable - is dissipated within the black box in three distinct flows (indicated by the 3 arrows in dark green in **Fig. 7.8.a**):

(1) a given overhead for the functioning of the whole;

(2) for the operation of the compartment labelled as indirect;

(3) for the operation of the compartment labelled as direct.

The favourable conditions perceived at the **level *n+1***, which make possible the stability of the environmental input consumed by the whole system, in turn are stabilized because of the existence of some favourable gradient generated elsewhere (**level *n+2***), which are not accounted for in this analysis. As noted, the very definition of "environment" is associated to the existence of a part of the descriptive domain about which we do not provide causal explanations with our model. Favourable gradients, however, must be available – in order to have the metabolism in the first place. These favourable gradients – assumed as granted - are exploited thanks **to the tasks performed by the components belonging to the direct compartment** (the representation of energy transformations occurring at the **level *n-1***). The return between the energy input made available to the whole system (at the **level *n***) per unit of useful energy invested by the direct compartment into the interaction with the environment (at the **level *n-1***), will determine the strength of the autocatalytic-loop of energy associated to the exploitation of a given set of resources.

This integrated use of non-equivalent representations of relations among energy transformations across levels is at the basis of the examples of Impredicative Loop Analysis shown so far. The 4-angle figures are examples of coherent representation of relations among formal identities of energy forms, which are generating an autocatalytic loop over 5 contiguous hierarchical levels (from **level *n-2*** to **level *n+2***). The transformation associated to the upper level - environment - is assumed by default.

The general template for performing this congruence check is shown in **Fig. 7.8.b**. The 4-angle figure combines intensive (angles) and extensive (segments) variables used to represent and bridge the characterization of metabolic process across levels. The figure establishes a relation between a set of formal identities (= given sets of variables) used to represent inputs to parts, parts, whole and their interaction with the environment across scales.

The two angles on the left side (α and β) refers to the profile of distribution of the total available supply of energy carriers (or human activity, or colonized land), indicated on the upper part of the vertical axis, over the three flows of internal consumption, according to the mapping provided by an extensive variable#1. The angle α refers to the fraction of the total supply that is invested in overhead (e.g. for structural stability of lower level components). The angle β refers to the profile of distribution of the fraction of the total left after the reduction, which is implied by the angle α, between direct and indirect components. What is left of the original total – after the second reduction implied by the angle β - for operating the direct compartment, at this point, is the value indicated on the lower part of the vertical axis. This represents the amount of extensive variable#1 (using still a mapping related to the internal perception of size) that is invested in the direct interaction with the environment.

The two angles on the right (γ and δ) are used for a characterization of the interaction of the system with the environment (the relation between the blue and red arrows in **Fig. 7.8a** and **Fig. 7.8b**).

It is important to select a set of formal identities used to represent the autocatalytic loop (what variables have to be used in such a representation in terms of extensive#1 and extensive#2) which is able to fulfil the double task of making possible to relate the perception and representation of relevant characteristics of parts in relation to the whole (= what is going on inside the black box) with characteristics that are relevant to study the stability of the environment (= what is going on between the black box and the environment). Obviously, both extensive variable#1 and extensive variable#2 have to be observable qualities (external referents have to be available to gather empirical information).

Therefore the choice of identities to characterize an impredicative loop does not have the goal to establish a direct link between the dynamics inside the black box with dynamics in the environment. As repeated now for several times, this is simply not possible. The selection of two extensive variables (#1 and #2) that can be related to each other simply makes possible to establish bridges among non-equivalent representations of the identity or parts and wholes using variables that are relevant in different descriptive domains and in different disciplinary forms of knowledge. The logically independent ways of perceiving and presenting the reality, which are bridged in this way, must be relevant for a discussion of sustainability.

For example, the three impredicative loop analyses presented in **Fig.** 7.7 reflect three logically independent ways of looking at autocatalytic loop of energy forms according to the scheme presented in **Fig. 7.8b.** These three formalizations cannot be directly linked to each other in terms of a common formal model, since they are constructed using logically independent perceptions and characterization of identities across scales. However: (a) they share a meta-model used for the semantic problem structuring. This meta-model can be used to organize the discussion about how to tailor the selection of formal identities for parts, whole and environment (when putting numerical assessment in it) to specific local situations; (b) they cover different aspects that are all relevant to a discussion of sustainability in relation to different dimensions of analysis (physiological and socio-demographic the first, techno-economic the second, and ecological the third); (c) they share some of the variables used for the characterization of the ILA.

7.3.2 An ILA implies handling in parallel data referring to non-equivalent descriptive domains

Before getting into the description of key features and possible uses of ILAs (the typology of 4-angle figures introduced in the previous section), it is important to warn the reader about an important point. The 4-angle figures presented so far all share the same features: (i) graphic congruence in relation to the extensive variables (rectangular shape of the 4 angle figure); and (ii) all angles have a reasonable wideness. These two features are obtained because the data represented across the 4 quadrants are not in scale, that is, the representation of angles and segments has been rescaled to keep the 4-angle figure in a regular shape. It should be noted that the choice of re-scaling the representation of data over an ILA is often an obliged one. In fact, if we want to compare the characteristics of parts to the characteristics of wholes, by using the same combination of intensive and extensive variables, we should expect to find big differences in the values found at different levels for: (a) segments (in extensive terms parts can be much smaller than wholes – the brain compared with the body) and (b) angles (in qualitative aspects of different specialized parts - a specialized part can have a value for an intensive variable which is much higher than the average value found for the whole – the brain compared with the body). In this situation, if we decide to keep the same scale of reference for the representation of variables both extensive – segments - and intensive – angles - used to characterize parts and wholes we should expect to obtain graphs very difficult to read and use. An example, of the difference between two 4-angle figures based on a regular scale and a re-scaled representation is given in **Fig. 7.9.**

The two 4 angle figures in **Fig.** 7.9 reflect the situation of the hypothetical farming system - size of 100 ha (extensive variable#1 referring to ha of land) - described in the lower part of **Fig. 6.2.** The two figures on the top represent a non-scaled graphical representation of the data set given in the lower part of **Fig. 6.2.** Two dynamic budget are considered: (a) the dynamic budget of food [EV#2] – **Fig. 7.9a** - and (b) the dynamic budget of money [EV#2] – **Fig. 7.9b.** The two figures on the bottom present the same couple of ILAs but after re-scaling the values taken by the variables across quadrant. With this choice the two reductions of the total available amount of extensive variable #1 divided among internal components - which is associated to the two angles on the left (α and β angle in **Fig. 7.8b**) - are reasonable: (i) a first overhead of 50%; and (ii) an allocation between direct and indirect of 10%. In this situation, it is still possible to follow the numerical values on the graph keeping the same scale across quadrants. However, if we had used Human Activity as the extensive variable#1 for studying the same two dynamic budgets, we would have found that the two reductions referring to the two angles on the left (α and β angle in **Fig. 7.8b**) would have been: (i) a first overhead of 90%; and (ii) an allocation between direct and indirect around 50%. This would have made impossible to handle a useful graphic representations based on the representation of extensive variables using the same original scale.

A second qualitative difference which is relevant between the 4 figures shown in **Fig. 7.9** is between the two figures on the left (**Fig. 7.9a** and **Fig. 7.9c**), in which there is no congruence between: (a) the requirement of extensive variable#2 (food) consumed by the whole (at the **level *n***); and (b) the supply of extensive variable#2 produced by the compartment – land in production (at the **level *n-1***). On the contrary, the two figures on the right, which are based on an extensive variable#2 which is money (**Fig. 7.9b** and **Fig. 7.9d**) are based on the assumption that what is consumed by the whole system (at the **level *n***) is actually produced by the compartment – land in production (at the **level *n-1***). A few quick comments about these differences are:

* LEFT SIDE - The budget related to food is not in congruence (this farming system is producing more food that it consumes). This can be used to classify this system in terms of a typology. For example, this pattern can be associated to an "agricultural system net producer of food". The same ILA of land use (determination of a relation among identities of parts and whole defined across levels in relation to spatial flow of food) could have applied to a city. In this case, the difference would have been very negative. This would have classified the system in the typology: "urban system, heavy food importer". As discussed in the applications of Part 3, ILA can be used to define typologies (both in terms of pattern of land use or human time use). In the case of land use, this can help the characterization in quantitative terms of land use categories which can be associated to socio-economic variables. This could help integrating economic analysis to ecological analysis. Coming back to the example of ILA, given in **Fig. 7.9** according to: (i) existing demographic pressure (food eaten per ha); (ii) respect of ecological processes (level of ecological overhead – which is very high in this example); (iii) available technique of production (technical coefficients expressed at the **level *n-1***), this farming system can be characterized as having a low level of productivity of food surplus (= 400 kg of food surplus produced per ha of this typology of farming system). That is, from the perspective of a crowded country needing to feed a large urban population, this would not be a typology of farming system to sustain with "ad hoc" policies. Moreover, in this way, it is possible to individuate key factors determining this characteristics: (a) the small difference between γ **angle** expressed at the **level *n-1*** (the yield of 2,000 kg/ha obtained in the Land in Production) and δ **angle** expressed at the **level *n*** (the level of consumption of the farming system, in terms of food consumption per hectare); and (b) the huge ecological overhead (the difference between Total Available Land and Managed Available Land). Obviously, we cannot ask too much to this very simplified example. This figure is useful only to indicate the ability of this approach to establish a relation among different dimensions of sustainability.

* RIGHT SIDE – The budget related to money flow is assumed to be in congruence. That is the flow of added value considered in the compartment Land In Production at the **level *n-1*** (added value related to the value of the subsistence crops + added value related to the gross return of the cash crop) has been used to estimate an average income for the farmers of this farming systems at the **level *n***. This is just one of many possible choices. A different selection of economic indicators – for example using a combination of two indicators: (1) "net disposable cash for farmers" and (2) "degree of subsistence" – would have provided a quite different characterization of this farming system. In fact, only 15,000 $ of net disposable cash are generated in the simplified example considered in **Fig. 6.2**. Whereas, in terms of income the account should be of 25,000 $ when including also the value of subsistence crops. Changing hierarchical level, would also imply a change in the mechanism of accounting. For example, the assessment of the net return of cash crops (15,000 $) is obtained by subtracting the cost of production (5,000 $ paid for inputs). However, when considering the perspective of the socio-economic system to which the farm belongs, this amount of money becomes part of the GDP.

7.3.3 The coupling of mosaic effect to ILA

The example given in **Fig. 7.10** is related to a study aimed at characterizing typologies of farming system in high-land Laos (data from Schandl et al. 2003). The analysis refers to farming system of shifting cultivation in the forest. The total size of the farming system (EV#1) is expressed in this example in terms of hectares of colonized land (1,800 ha). This area is then divided into lower level compartments according to a set of categories providing closure. In this case, the different categories used for the analysis are: (1) land for food (280 ha), which is divided in 3 sub-categories (rainfed rice, pasture, garden); (2) land for housing (10 ha); (3) Land for Cash (360 ha), which is divided in 2 sub-categories (cash crops, and timber); (4) Forest (1,150 ha). The identity assigned to these categories makes possible to establish a technical coefficient (in terms of an Intensive Variable #3) establishing a given flow of biomass associated per hectare at the land use indicated. Examples are given in the yellow boxes, in which the yields (expressed in ton/ha per year) of the various land uses associated to the production of useful biomass are reported.

At this point, it is possible to apply the ILA approach to such a system, as done in **Fig. 7.11.** In the upper right quadrant 3 types of useful flows of biomass (rice, wood and vegetables) are indicated. The angles of this quadrant define for these flows a density in terms of production. The total amount can be obtained in terms of length of segments by multiplying the area of the various land use category times the relative yields. However, the density of internal production does not coincide with the supply of useful biomass that is available for the socioeconomic context of this farming system. In fact, a certain fraction of this internal supply is reduced because of internal overhead of the system. A fraction of the internal supply of rice and vegetables, in fact, is eaten by the inhabitants of the farming system. This reduction due to the endosomatic metabolism of the farming system is indicated in the upper left quadrant under the label SUBSISTENCE FOOD. An additional reduction of the flow of biomass is related to the exosomatic metabolism of the farming system (the consumption of wood for FIREWOOD AND CONSTRUCTION). This additional internal overhead reduce the amount of biomass that can be exported per year out of this farming system. In conclusion, the supply of useful biomass per hectare that the socio-economic context of Laos can expect from this typology of farming system is indicated by the values of biomass flows expressed in the angles in the lower right quadrant (e.g. in the quadrant labelled – EXPORTED: 0.03 ton/ha for rice, 0.1 ton/ha wood, and 0.05 ton/ha for fresh vegetables).

Put in another way, the amount of rice that the government of Laos can expect from this typology of farming system for feeding the cities does not depends only on the yield obtained per hectare in the relative category of land use (e.g. land in production of rice – 1.6 ton/ha). Additional and crucial factors are: (a) the overhead of internal consumption (86% reduction of internal supply), and (b) the fraction of the total colonized land which is invested in the category "rice production" (220 ha out of a total land of 1,800 ha). Again we can reiterate the concept that when dealing with a metabolic system organized in nested compartments the intensity of flows in individual compartments (or sub-compartments) has always to be assessed in relation to the hierarchical structure of the whole in relation to the parts. The characteristics of a farming system refer to the whole (at the level n), whereas technical coefficients refer to the level n-1.

Two additional relevant points about this example are about:

(1) **transparency** – as soon as this attempt to characterize this typology of farming system was discussed with the various researchers of a research project (SEAtrans EC-Project) using both figures **7.10** and **7.11,** every single participant to the meeting jumped into it. In the following discussion, every single term and assessment written in these figures was scrutinized in search for additional specifications. Both the selection and the label of categories was questioned, with suggestions aimed at accommodating the various perspectives of different analysts (e.g. establishing a link between monetary variables and biophysical accounting). People coming from different countries and different disciplinary backgrounds were finally able to share meaning about how to perceive and represent the system under investigation.

(2) **distinction between types and realizations** – The definition of an Extensive Variable #1 translates into a definition of a size for this metabolic system in terms of total area (expressed in this case in hectares of colonized land). However, when dealing with "types" we can only indicate a size but not a specified boundary. That is, in this type of analysis we can only deal with functional boundaries (referring to types). Only individual realizations can have a real specified boundary. A functional boundary should be

understood as any boundary determining the area required by the various land use categories included in the autocatalytic loop associated to the definition of total colonized land.

7.3.4 The multiple choices about "how to reduce and how to classify"

In the first part of the Faust of Goethe, Mephistopheles make fun of the academic approach adopted at that time to study the phenomenon of life (!) only in terms of "reduzieren" and "classifizieren". On the other hand, as discussed in Part 1 when exploring the epistemological predicament faced by scientific analysis, when dealing with the representation of the complexity of the reality, there are no alternatives. In order to be able to handle semantic identities within models scientists have to use formal identities. Formal identities must be associated to a closed and finite set of attributes. The way out of this impasse is the awareness that: (1) any time we reduce and classify the reality into models we are loosing a part of the reality; (2) it is wise to always reduce and classify simultaneously in several non-equivalent ways in order to increase the richness and the reliability of the resulting integrated analysis.

Coming to technical aspects of this approach we can look at the two examples given in **Fig. 7.12** that represent two non-equivalent ways of reducing and classifying the size of "countries" (i.e. Spain in 1995 and USA in 1994) when seen as metabolic systems organized over hierarchical levels. The main point of this example is that the same system admits and requires different choices about how to perceive and represent its identity in terms of parts and whole, depending on the goal of the analysis.

In the example of the upper part of **Fig. 7.12** (based on data presented in **Fig. 6.8**) the reduction and classification of the identity of the metabolic system has been obtained by the choice of the variables used for mapping the size of the whole and the parts. In this case, the EV#1 is human activity, that is used to assess the size of the whole (total human activity in a year = population x 8760 hours in a year), and the size of the lower level compartment. The EV#2 is exosomatic energy expressed in MJ of oil equivalent (see the discussion given in Chapter 6). In this way, using the concept of mosaic effect it becomes possible to associate the identity of lower level elements (e.g. the typologies of patterns of consumption in the household sectors, the typologies of patterns of production in the economic sectors) to the average values of the whole. As discussed in Chapter 6 this is useful to study how changes in technical coefficients at a given hierarchical level (e.g. in a sub-sector of the economy – which in this representation would be the **level *n-2***) can be related to changes in the characteristics of the whole. Also in this case, as seen in the example of **Fig. 7.11**, not necessarily changes in technical coefficients – more efficiency defined in terms of IV#3 at the hierarchical **level *n-2*** – are translated into changes in the EMR of the whole – IV#3 at the hierarchical **level *n***. This is another way of looking at the effect of changes across levels that lead to the generation of Jevons paradox described in Chapter 1.

In the example given in the lower part of **Fig. 7.12** (based on data that are presented in **Fig. 9.4**), we are still dealing with a definition of size (EV#1) based on Human Activity, but this time the choice of categories is made with the goal of including in the analysis socio-economic and demographic data. In particular, in this way it becomes possible to visualize the effect of socio-economic pressure (a concept that will be introduced in Chapter 9), in terms of biophysical constraints on the density of flows associated to different elements. In relation to food production we can "see" the seriousness of this biophysical constraints, just by looking at **Fig. 7.12**. That is, the requirement of food is associated to the size of the whole box determining the total of human activity. In fact, as noted in Chapter 6, the endosomatic metabolism is related to the amount of human activity (2,277 Giga hours in a year), which is proportional to the population (260 millions). On the other hand, the ability to provide an internal supply of food is related to the amount of working hours allocated in agriculture (the tiny red box made up of 5 Giga hours). In order to be self-sufficient in terms of food production the USA in 1994 had to have an agricultural sector able to produce in a year with 5 Giga hours invested in production, the amount of food consumed to sustain 2,277 Giga hours of human activity. As illustrated in Chapter 9, the same approach can be applied to an analysis of the reciprocal density of flows of added value. The flow of added value associated to the production and consumption of goods and services in a year in the USA – related to total human activity, that is 2,277 Giga hours - has to be produced by the 235 Giga hours of work, which are invested in the economic sectors generating added value (the categories selected to obtain closure in this case are: Services & Government, Productive Sectors minus agriculture, and Agriculture). Put in another way the density of the flow of added value per hour of human activity (the value of GDP per hour) can be related, with this method, to the Economic Labor Productivity of the various economic sectors and sub-sectors. The Economic Labor Productivity of an element in this approach is defined as the added value generated by the element divided by the working hours invested in that element.

Also in this case, as noted in the previous example of the characterization of a typology of farming system in Laos, whenever an analysis of this type is performed with other people sitting around a table, there is a lot of explaining and a lot of discussions to be made. Different scientists coming from different geographic, social, ideological and disciplinary contexts will carry different but legitimate opinions about how to reduce and classify parts and whole when representing flows and congruence constraints.

7.3.5 Examples of applications of ILA

At this point we can try to resume the general feature of ILA. This approach requires considering various relevant types (used to represent parts and whole), which are then characterized across contiguous levels using a common set of variables. In particular, the characterization of parts at the lower level and the whole at the focal level is obtained using a standard set of three variables: (i) an extensive variable#1 (the common matrix which makes possible to define compartments across levels while maintaining closure); (ii) an extensive variable#2 (characterizing the types in relation to the level of interaction with the context); and (iii) an intensive variable#3 (a combination of the previous two). By using this trick it becomes possible to generate mosaic effects across levels (when assuming a situation of congruence) or look for biophysical constraints associated to the particular role that a parts is playing within the whole (when big differences in throughputs are studied over elements playing a different role in the system). Examples of applications are given below.

(a) The bridging of types across different levels

Before getting into an analysis of examples of applications, it is important to illustrate the mechanism through which it is possible to establish a self-entailment over the formal identities used to represent types belonging to the same nested metabolic systems on two contiguous levels. Such a mechanism not only can be used to help scientists to better discuss about how to represent relevant aspects of the sustainability of an autocatalytic loop, but also it makes possible to perform an operation of "partial scaling" in relation to the value taken by the variables shared by the two sets of types (the parts and the whole). To explain this point, let's use the example given in **Fig. 7.13**.

In the example of ILA presented in **Fig. 7.13**, the extensive variable#1 is ***hours of human activity*** and the extensive variable#2 is ***US$ of GDP***. Intensive variable#3 is the flow of $ of added value per hour of human activity (either in consumption or production, depending on the compartment and the hierarchical level considered). There is a strict analogy between this dynamic budget and that presented in **Fig. 7.2** about the society of 100 people on the desert island. An analysis by quadrants is given below:

* **Upper-right quadrant (angle δ)** – in this quadrant we have a characterization of the whole obtained by a combination of the three variables discussed before. The intensive variable#3 is the amount of added value – extensive variable#2 (measured using a given currency referring to a given year) that is produced and consumed by the dissipative whole over a period of reference (a year) per unit of human activity – the extensive variable#1. Let's imagine first to apply this analysis to a country. Then, the intensive variable#3 will result equivalent to GDP per capita. Let's imagine to have a hypothetical value of 20,000 $/year. In this system of accounting, this would be expressed in terms of a level of added value dissipation of 2.3 $ per hour of human activity (including sleeping, children and retired activities, plus leisure of adults). To convert the value of GDP p.c. into the value of Intensive Variable#3 one has to divide GDP p.c. by the

hours in a year: 8,760 (box with orange background).

* **Upper-left quadrant (angle α)** – this quadrant represents how the structural stability of lower level compartments (i.e. body mass of humans) associated to the whole of human activity imposes an overhead on the amount of disposable human activity that can be used to generate and control useful energy. This concept has been discussed before and for a more detailed theoretical discussion see Giampietro, (1997). The important point in this discussion is that, when dealing with the characterization of this quadrant it is possible to:
(i) define a known and predictable set of types (age classes) in which we will find humans, a set of types associated to a perception of events referring to the **level *n-2*** (see the discussion about mosaic effect across scale in Chapter 6.4.1 – **Fig. 6.8**, **Fig. 6.9**, and **6.10**).
(ii) this set of types can be used to get the closure of the total size of the system (expressed either in number of individuals or in kg of body mass).
(iii) the profile of distribution of kg of body mass (or individuals) over the set of types can be used to establish link with a definition of compartments of human activity at the **level *n-1*** (e.g. "physiological overhead" versus "disposable human activity"). The assumptions used to calculate a physiological overhead on Total Human Activity starting from the profile of distribution of individuals over age classes (or kg of body mass over age classes) have been discussed about the example of the 100 people on the remote island (**Fig. 7.2**) in the previous section. This represent a first reduction of the original endowment of human activity.

* **Lower-left quadrant (angle β)** – this quadrant represents how the disposable amount of human activity - defined at the **level *n-1*** - is divided over different compartments. Also in this case, we have to start with a set of typologies of activities (the compartments in which we will divide investments of human activity) that provides closure. Also in this case, a profile of allocation of human activity over the specified set of typologies will provide an assessment of the "internal losses" of this resources in providing control to internal compartments. In this example, an analysis referring to the country level, we select 5 typologies of human activity (box with orange background): (1) Leisure, (2) Service; (3) Industry; (4) Agriculture; (5) Energy and mining. At this point, depending on the choice of extensive variable#2 used in the ILA, only a fraction of these activities has to be included in the representation on the last quadrant (when defining the direct compartment). For example, dealing with added value – as in this case – we will include in the typologies characterizing the direct compartment all those economic sectors producing added value (Service, Industry, Agriculture, Energy and Mining). Obviously, if the ILA were based on food as extensive variable#2 (as in the example of **Fig. 7.9c**), we would have to include only the type "agriculture" in the right quadrant. In that case, we could split the agricultural sector into a sub-set of agricultural activities to better characterize the value taken by the intensive variable#3 in determining the angle γ. An example of this is given in **Fig. 7.15** discussed below.

* **Lower-right quadrant (angle γ)** – this quadrant characterize relevant typologies determining the interaction of the direct compartment with the context. This representation deals with the ability to stabilize the flow of input required by the whole. To do that, this angle establishes a relation between the characteristics of the typologies making up the direct compartment in relation to the characteristics of the whole. In order to do that, we need to have information related to: (a) the **level *n-1***: the profile of investment of human activity (extensive variable#1) over the set of types used to represent the direct compartment. and (b) the **level *n-2***: the characteristics of the intensive variable#3 over the selected set of types making up the direct compartment. In the example provided in **Fig. 7.13**, the 4 compartments -Service, Industry, Agriculture, Energy and Mining – are characterized in terms of their ability of generating added value per hour of labor invested in them. In this way, we can compare: (1) the average level of consumption of the society [= I.V.#3 a given flow of added value (2.3 $/hour) which is including both the working and non-working human activity]; to (2) the capability of producing enough added value when working in those economic sectors producing profit (23.0 $/hour). Such a capacity obviously

depends not only on the labor input, but also on the capital invested in these sectors and the availability and quality of natural resources. But this is not a relevant issue in ILA. The goal of this approach is just that of establishing a mechanism of accounting of flows across levels and across disciplinary fields. By combining the known profile of investment of hours of work in the various compartments and the known return of labor in each compartment we can estimate an Average Return of Labor - ARL - (in this example, 23.0 \$/hour) for the whole society (information referring to the interface **level *n*/level *n-1***). Whereas the values used to characterize the various returns of labor in different economic sub-sectors - ARL_i- are based on information referring to the interface **level *n-1*/level *n-2*.** The relation that can be used to bridge these two pieces of non-equivalent information has been discussed already in Chapter 6 (section 6.4.1) and is: $ARL = \Sigma\ (x_i \times ARL_i)$. The characteristics of ARL_i expressed in the intensive variable#3 (e.g. X \$/hour) for the hypothetical society considered in this example are given in the box with the orange background. Obviously the difference between the average rate of the flow of \$/hour expressed at the level of the whole (2.3 \$/hour, represented by the δ angle) and the average rate of the flow of \$/hour expressed at the level of the economic compartment generating added value (ARL = 23.0 \$/hour) must reflect the losses of total human activity over the two angles on the left (in this example, the working hours in the direct compartment are only 10% of Total Human Activity). This is a very general feature found when performing ILAs of developed society. No matter what extensive variable#2 is considered in the analysis of the dynamic budget (e.g. food, exosomatic energy, added value), because of the very high value taken by the α angle, and the very high value taken by the β angle (linked to the profile of distribution of investments among various compartments at the **level *n-1*** - e.g. leisure, the various sub-sectors of the service sector, and the various sub-sectors of the productive sectors), in developed countries there is always a major reduction in size (measured in terms of hours of human activity) for specialized compartment. For example, agriculture in developed countries absorbs only 2% of the working time, which is already only 10% of the total human activity. This translates into a huge biophysical constraint in terms of productivity of labor as discussed in Chapter 9. The same applies to the energy sector, where in general one can find that only 1% of the working time, which is already only 10% of the total human activity, is capable of handling all the energy conversions required to supply the huge amount of useful energy required by modern societies. This in turn requires massive investment of capital, technology and a large use of natural resources to boost the density of flows in these specialized compartments.

Before, leaving this example, we can observe that the same type of analysis could have been applied at the level of a household operating within a given farming system. The meaning of the four angles would remain the same:

* **Angle** δ - in the analogy GDP p.c. would become the average income per capita (also in this case, using ILA this should be expressed in \$/hours (using a factor based on the household size and the hours over a year);

* **Angle** α – the profile of distribution of individuals over age classes can be used to assess a dependency ratio, and a physiological overhead, that indicate the amount of disposable human activity available for the household;

* **Angle** β – a set of typologies used to represent the range of human activities (obtaining closure) can be defined for this farming system (e.g. those indicated in the box with a yellow background). The actual profile of allocation of the disposable human activity of the household over this set of activities will define the value taken by the β angle.

* **Angle** γ – the combined use of two types of information: (a) the characterization of the typologies included in the set in terms of the value taken by the intensive variable#3; (b) the profile of distribution of human activity in the direct compartment over the set of activities; makes possible to calculate the value

taken by the δ angle (or viceversa).

Examples with real data of this type of applications are discussed below.

(b) Mosaic Effect across levels: looking for biophysical constraints and for useful benchmarking

In the previous example we made the point that an ILA can be seen as a systemic search for mosaic effect (self-entailment of identities of types defined on contiguous levels) over autocatalytic loops (representation of dynamic budgets) across levels. In this section we want to illustrate possible applications of this approach, in particular in relation to two possible goals.

* The search for biophysical constraints and bottlenecks;
* Benchmarking, for comparisons and classifications of typologies in relation to different contexts.

To do this we will use an example taken, this time, from a real application of ILA to farming system analysis. We will check the situation of a household type using two ILAs in parallel. The first is based on ***land area*** used as extensive#1 variable - **Fig. 7.14.** The second is based on ***human activity*** as extensive#1 variable - **Fig. 7.15.** In both examples, the extensive#2 variable is related to an assessment of a flow of added value (the variable here is Yuan, which is the Chinese currency). The data set is taken by the study presented in Pastore et al. 1999.

The analysis presented in **Fig. 7.14** establishes a bridge between **land use typologies** and implications that an aggregate mix of these land use typologies has on the socio-economic side. In particular, this analysis is an attempt to explain the option space seen by a particular household-type found in the farming system considered in that analysis (a mainly off-farm household type).

* **the δ angle** – the intensive variable#2 – in this example represents the level of net disposable cash spent by the household over the year (a different observable qualities from income, which still use as I.V.#3 - Yuan/hour. This observable quality of the household can be associated to the level of economic interaction that the household manages to keep with its context in terms of economic transactions related to goods and services. Since, this analysis is aimed at finding bottleneck for this household type in relation to availability of land, the mapping of flows in this ILA is made against land area. That is, I.V.#3 is Yuan/ha/year. What is extremely clear from the beginning about this household type is that this dynamic budget is not working in a situation of congruence. That is, the amount of Net Disposable Cash spent per ha and per year at the level of the whole area occupied by the household is much higher than the amount of Net Disposable Cash made available by the economic activities performed over the same period of time by the household in that area. To understand the reason of this deficit, we can go through the analysis of the other 3 angles.

* **the α angle** – the profile of distribution of land use over possible typologies can be used to assess what fraction of the available land is in cash production. This reduction is pretty high (30%), but this is due to the very limited amount of the total farm (0.47 ha!) rather than to the choice of doing heavy investments in alternative land uses. That is the total available to start with is so small, that even a small amount of alternative uses (0.14 ha!) represents a 30% of the total.

* **the β angle** – in this analysis we decided to use the β angle to assess the reduction of E.V.#1 related to Net Disposable Cash due to the need of paying taxes and to buy production inputs. This choice reflects the peculiarity of the farming system considered (taxes have to be paid in form of a certain amount of rice sold to a politically imposed price, much lower than market price; inputs are subsidized according to different mechanisms). For this reason, in this study, the amount of Net Disposable Cash obtained from cash crops has been calculated by multiplying the value of gross return (7,500 Yuan/ha) on a reduced amount of land in cash crop production (0.23 ha) to account for the costs, rather than using an assessment of net return (5,200 Yuan/ha) over the actual area in production (0.33 ha). With this assumption, for us, it was easier to discuss of possible scenarios. Obviously, both options of how to account this reduction

present pros and cons and it is not possible to provide a substantive discussion of which of the two should be preferred.

* **the γ angle** –The final supply of Net Disposable Cash from cash crop production depends on: (i) the limited availability of land; (ii) technical coefficients and economic variables; (iii) the choices made by farmers, when modulating the value taken by the two angles on the left. By using an ILA we can have a look at possible combinations of this mix, separating what can be decided from what is a real constraint imposed on farmer choices. It should be noted, that in this example, this household type already invests a very limited amount of land in subsistence (together with housing and infrastructure – let alone ecological preservation – less than 0.15 ha). This implies that there is no much room for maneuvering. This household type must go for off-farm work, not only to get a decent economic condition, but also to cover its food security.

The existence of a clear biophysical constraint on the dynamic budget is evident. In this case, it is possible to study the possible effects of changes induced on intensive variables: in the price of the various crops, cost of the inputs, technical coefficients, mix of crops to ease such a constraint. Obviously, when dealing with very severe biophysical constraints, not even the cultivation of very valuable crops, with heavy subsidies can get this typology of household out of trouble. Off-farm jobs can be the only solution.

The analysis presented in **Fig. 7.15** establishes a bridge between different profiles of investment of human activity on **work typologies** and relative effects on the socio-economic side. In particular, this a non-equivalent analysis of the option space seen by the same household type considered in the previous ILA -**Fig. 7.14**.

* **the δ angle** – the intensive variable#2 - represents the level of net disposable cash spent by the household over the year. The mapping of flows in this ILA against human activity implies that the intensive variable#3 is Yuan/hour/year. During the study the system experienced a quasi-steady-state situation in relation to the dynamic budget considered in this example (the requirement and supply of Net Disposable Cash were close enough to avoid big changes in the status of debts or saving). That is, the amount of Net Disposable Cash spent per hour of household activity over the year was close to the amount of Net Disposable Cash made available by the economic activities performed by the household in that period. In order to understand the mechanism generating this balance, we can go through an analysis of the other 3 angles. It should be noted that in this ILA we adopt a representation that keeps the same scale across the axes. In order to do that, however, we had to skip the large loss (Reduction I) associated to Physiological Overhead (- 72%). This makes possible to better use the power of resolution of the 4-angle figure. This trick is possible, however, only when comparing household types operating within the same farming system (systems sharing the same level of Physiological Overhead).

* **the α angle** – this angle has been used to characterize the profile of distribution of Disposable Human Activity in terms of two classes: non-working and working. With this choice, the α angle can be directly used as an indicator of performance for the farming system. In fact, the level of saturation of the disposable human activity is a very powerful indicator of performance within the social dimension (Giampietro and Pastore, 2000). It reflects the level of attendance of children at school, the time dedicated to social interaction, and reductions in work loads for adult workers;

* **the β angle** – in this analysis we decided to use the β angle to assess the reduction of Working Time due to the need of working in subsistence activities and chores. This choice reflects the peculiarity of the farming system considered (South-East China), in which these two typologies of work absorb a consistent fraction of the available work.

* **the γ angle** – In this type of ILA the final supply of Net Disposable Cash depends on: (a) the identity of the option space = the set of possible work types considered, and their Average Return of Labor (expressed in Yuan/hour). (b) the profile of investment of available work over this set of possible works. It should

be noted, that we found a profile of investments of hours of work over all the options of the set. That is, the available human activity for work is not invested only in those work-types that guarantee the highest Average Return per hour. This fact, indicates the existence of different typologies of constraints preventing the maximization of economic profit. Those work types that have a very high return per hour, in general cannot be performed for a large number of hours. This can be explained either by the existence of biophysical constraints (e.g. it is not possible for a Chinese household sharing a pond with other households to invest 8,000 hours/year of human activity in the "work type aquaculture") or by an economic mechanism (e.g. as soon as, a very productive work type of activity is amplified it reaches soon a scale at which the market value of the relative product drops).

An ILA makes possible to analyze the dynamic budget of a household in terms of benchmarking. We can start by comparing the value of the δ angle – e.g. the average income per capita – against the analogous value for the country, or against the difference urban/rural household, or against the value reached by other households belonging to different farming systems in the same area or different typologies of households belonging to the same farming system within the same area. In the same way, we can compare the average return of labor associated to the various work typologies (wages for typologies of jobs, returns for typologies of crops) with analogous values found in different areas of the same province, same country or similar countries operating in a different regional areas, but sharing the same farming system characteristics.

In all these cases, it is extremely important to have a tool able to characterize differences perceived at different levels and in relation to different relevant qualities. That is, the same income can be generated by a different combination of subsistence crops + net disposable cash. This can imply a different saturation index of disposable human activity and/or different level of food-security, reflected also in a different attendance of children at school, or a different level of surplus of food generated within the country to feed the cities, or a different ratio of income from on-farm and off-farm activities, or a different intensity in the use of inputs for boosting the agricultural production, or a different mix of typologies of land uses. It is important to build a network of analytical tools able to keep coherence in all these descriptions and to provide a Multi-Scale Integrated Analysis of changes, effects and trends.

The last example of ILA analysis is about a bottleneck that seems to be operating on the societal side, which, however, is directly connected with biophysical realities. The case study illustrated in **Fig. 7.16** is based on a data set collected during a 3-year study in Laos (Schandl et al. 2003). The question investigated by this analysis is about the mechanism through which demographic pressure drives a reduction in the period of rotation adopted in shifting cultivation in Laos. We used field data reflecting average values referring to three typologies of shifting-cultivation: (i) a 10-year rotation cycle – the old traditional method used when demographic pressure was low; (ii) a 5-year rotation cycle – the temporary solution forced by demographic pressure in several areas of Laos; (iii) a 3-year rotation cycle – the solution adopted in those areas affected by high demographic pressure and considered as a possible solution to have a first stabilization of the farming activities in Laos. A solution, that, however, implies a few unsatisfactory features (low productivity of labor and high environmental impact). In this ILA we followed the same scheme illustrated in **Fig. 7.14.**

* **the δ angle** – Assuming an average size for the household of 6 people, with a requirement of rice per capita of 250 kg/year, and assuming a demographic pressure that makes possible to use 5 hectares of land per household, we obtain a flow of rice to be stabilized per ha (I.V.#3 = 300 kg/ha).

* **the α angle** – this angle represents the first reduction associated to land conservation measure (ecological overhead). In this case, we can easily associate to this concept the fraction of land which is included in the rotation, but that it is not directly used for production in a given year. With this assumption we obtain that the three typologies of cycles imply a reduction of : (i) 90% (10-year rotation); (ii) 80% (5-year rotation); (iii) 67% (3-year rotation);

* **the β angle** – this second angle represents the second reduction associated to taxes and cost of inputs. In this case – shifting cultivation in Laos - these two factors are not relevant for the analysis (there are no taxes and no inputs in this typology of farming systems), this angle has no effect in determining the amount of land in production accounted for supply of food.

* **the γ angle** – this third angle describes how the characteristics of the part (the productivity of the small amount of land which is actually in production) will determine the average value for the whole (the flow of rice per ha described by the angle γ). When using the values of I.V.#3 characteristics of the three cycles of shifting cultivation – assessed at the **level *n-2*** (that is, at the field level), we got an unexpected result. The differences in densities of the yields at the field level [= I.V.#3 at the **level *n-2***] - (i) 3,000 kg/ha; (ii) 1,500 kg/ha; (iii) 900 kg/ha – are compensating exactly the differences associated to the reductions implied by the difference in the years of rotation. Put in another way, in biophysical terms, the amount of land that has to be colonized by the three cycles over the time window of the full cycle to guarantee the same flow of rice is the same. The hectares required to get congruence (5) are the same for the three cycles.

This example indicated clearly that the problem with a 10-year rotation is not associated to an excessive demand of land for production. Rather, the problem is associated to an excessive demand of information and control to keep coherence in the societal mechanism of allocation of land to farmers. In this farming system, in fact, the various parcels used by farmers (summing up to the 5 ha) are not contiguous. On the contrary, they tend to be scattered and mixed in a given area, depending on social events (wedding, deaths, moves). When dealing with a long rotation period, it is almost impossible to keep record at the societal level, by tracking back the previous uses of a given piece of land. Moreover, the specific case of Laos, is a case of a country that in the last decades has been through a lot of social perturbations (wars, revolutions, dramatic economic reforms). A typology of exploitation of natural resources which requires the ability of expressing patterns of activities over a large area and over a large time window [e.g. the 10 years cycle] can become a mission impossible.

(c) Using ILA for Scenarios analysis: exploring the assumption "ceteris paribus"

Before concluding the presentation of possible applications of ILA analysis we would like to mention a line of applications that has not been fully explored yet, but that in our opinion has huge potentialities. The overview provided in **Fig. 7.13** shows how to establish a relation among the characteristics of different types defined on different hierarchical levels. This mechanism establishing relations among types can be used to discuss the possibility of tracking the effect of changes occurring at one hierarchical level over a different hierarchical level. For example, we can study how the average value of the I.V.#3 – at the **level *n*** – (e.g. GDP p.c.) – will be affected by changes occurring at the **level *n-1*.** Relevant changes for this analysis are:

(1) changes in the given characteristics of types. That is given the same set of 5 possible activities (leisure, service, industry, agriculture, energy & mining) we can have improvements in the economic performance (e.g. higher returns per hour);

(2) changes in the profile of distribution over the type. That is, a change in the weight in the mix of activities determining the GDP of a country (less investments in agriculture and more in the industrial sector);

(3) change in the set of types considered to characterize sectors at the **level *n-1*.** That is, some of the typologies of activities can be deleted because they became obsolete (e.g. charcoal making), or new typologies of activities can be included in the set (e.g. web sites designer).

Obviously, the same analysis can be made using biophysical variables – activities will be represented as performing biophysical transformations, qualitative changes will be interpreted as better technological coefficients, and emergent properties of the whole as a new set of definitions for useful tasks for the system (functions). In general, when dealing with emergence, we are dealing with the introduction of new typologies of activities, at the **level *n-1***, which are able to express new features at the level of the whole. These new features can be generated, at the beginning, by a stretch in the profile of distribution over the old set (by an anomalous amplification of just one of the specialized types) and by a quick change in technical coefficients in the particular typology under stress (the one undergoing a fast process of amplification). We can talk of real emergence when new relevant characteristics of the whole require the use of a new set of attributes (new observable qualities of the whole) that cannot be detected on lower level elements (parts). Real emergence in evolution requires the development of new useful narratives for the complex observer/observed. Obviously, nobody can claim to be able to predict emergence and therefore what will happen in the future. This would require the possess of a reliable crystal ball.

However, when dealing with issues related to the future and to evolution Impredicative Loop Analysis can be used for qualitative trend analysis. For example, ILA can be used to characterize in quantitative terms the difference between growth and development. The 4 examples provided in **Fig. 7.5**, comparing the situation of Spain and Ecuador at two points in time – 1976 and 1996 – can be used to explain what has generated the differences in the value of extensive and intensive variables. The difference between growth and development can be studied by looking at the relative pace of growth of extensive variable (e.g. the increase in GDP versus the increase in population size). Everybody knows that to study changes in the level of economic development of a country one has to study changes in GDP per capita (an intensive variable) rather than changes in GDP in absolute terms. The GDP of a country can in fact increase due to a dramatic increase in population also when the GDP per capita is slightly decreasing. When everybody is getting poorer. By performing in parallel several ILAs, based on different selections of extensive variable#1 and extensive variable#2, and by using different definitions of direct and indirect compartments, it is possible to study this mechanism [= how changes in intensive variables (versus extensive variables) can be associated to evolution (versus growth)] at different hierarchical levels of the system and in relation to different dimensions of the dynamic budget.

This approach, makes also possible to compare in quantitative terms trajectories of development. For example, at the level of individual economic sectors, an assessment of I.V.#3 (= throughput of MJ of exosomatic energy per hour of human activity) has been used to analyze and compare the trajectory of development of Spain (Ramos-Martin, 2001) with that of other countries. In this case average reference values for typologies of economic sectors found analyzing the trajectory of OECD countries [= those belonging to the Organization for Economic Cooperation and Development] have been used as benchmarking. The set of reference values [e.g. 100 MJ/hour for the service sector; 300 MJ/hours for the productive sector, and 4 MJ/hour for the household sector] made possible to individuate peculiarities of the Spanish situation. In this particular example, the power of resolution of this approach made possible to detect a "memory effect" left in the Spanish system by the dictatorship of Franco. If on one side, a certain compression of consumptions under the Franco's regime made possible for Spain to have a quick capitalization of the economy. On the other hand, this left the household sector of Spain at a very low level of capitalization (= the Exosomatic Metabolic Rate – I.V.#3 – the ability of human activity of consuming exosomatic energy when out of work, can be used as a proxy for the level of capitalization of the compartment). In fact, the EMR of the household compartment - I.V.#3 at the **level *n-1***- was 1.7 MJ/hour, in 1976. This was by far the lowest level in Europe in that year (including Greece and Portugal), Ramos-Martin, (2001). At that time a fast growth of this parameter (almost doubled in 1996) could have been guessed, by looking at the European benchmark (around 4 MJ/hour). Big gradients in the characteristics of analogous sectors tend to indicate top priorities in development strategy.

Another application of ILA to scenarios analysis is related to the check for feasibility domains. With feasibility domain we mean the definition of admissible ranges of values taken by variables, in relation to the reciprocal relations imposed by the dynamic budget. This requires considering in parallel different dimensions of feasibility using non-equivalent ILAs. In fact, often, models developed within a given disciplinary knowledge suggest the possibility of generating changes at one particular level (e.g. the possibility of improving technical coefficients in engineering, the possibility to improve the productivity of land by implementing economic policies, the possibility to change unpleasant situations by implementing social policies). However, the effect of this change is envisioned within a given narrative. By using different ILAs based on the adoption of alternative narratives (= different definitions relevant typologies and expected relations between changes in extensive and intensive variables) we can increase the robustness of these scenarios.

Even when talking about systems, which still do not exist, the mosaic effect across scales and across descriptive domains can be used to check the internal coherence of our hypotheses. As soon as we define, technical coefficients, the relation among parts and wholes, what has to be considered direct and indirect in relation to different typologies of dynamic budget, it becomes possible to look for biophysical constraints and bottlenecks, as well as to look at the feasibility of becoming for the whole complex. A feasible process of becoming requires the ability of changing the identity of parts and whole in parallel at different paces. This can be done for w while with smooth adjustments, but it should be expected that sooner or later a catastrophic re-arrangement will occur. In terms of stability analysis, if we find congruence or lack of congruence on the axes representing a dynamic budget, we can conclude about: (1) the degree of openness [= the system is exporting inputs in surplus or importing input in shortage], or (2) the degree of becoming [= the system is reinvesting surplus to enlarge the size of its own metabolism. This enlargement of the size of the metabolism can be represented either in terms of development [= the system is changing the profile of distribution of its activity over the given set of types – by amplifying the scale of some of the activities, while reducing in percentage the relevance of others], or in terms of growth [= the system is simply increasing in size of the same set of types, by keeping the same profile of distribution].

Finally, a last possible application of ILA to understand deep changes associated to dramatic evolutionary processes is "role analysis". A typical example (that will be discussed later on in Part 3) is the dramatic change in the role that the agricultural compartment plays in crowded developed societies. In the first half of 1900 this compartment was crucial not only in its obvious role of the specialized compartment guaranteeing the dynamic budget of food. It was also providing economic returns for both capital and labor invested there, which were higher than those obtained as average by the economy as a whole. In the last decades of that century, however, this economic role changed. In the dynamic budget of added value across levels and parts, investing capital and labor in agricultural activities is no longer raising the average of the economy. On the contrary, nowadays, investing in that sector implies lowering the average at the **level *n*.** In spite of this fact, because of a cultural lock in, the mechanism of controls used to regulate the agriculture still is based on a economic narrative.

TECHNICAL APPENDIX

7.4 Theoretical foundations (1): Why Impredicative Loop Analysis?

Learning from the failure of conventional energy analysis - *TECHNICAL SECTION*

In order to better explore the meaning and the possible use of impredicative loops in multi-scale analysis we will explore a well known example of failure of reductionist science, when trying to deal with systems organized over multiple hierarchical levels. The failure of conventional energy analysis based on a characterization of dissipative systems in terms of a linear input/output approach. In this section, we claim that this failure can be explained by a systemic choice made by the analysts to denying the existence of chicken-egg processes. Our main point is that any attempt to deal with the representation and the assessment of a set of energy flows and energy conversions across levels and scales in linear terms (in terms of input/output) can be equate to a statement that it is possible to define what energy is in a "substantive way". That is, this implies believing that assessments of energy flows (and conversions) are independent from the choices made by the analyst on how to characterize a certain set of interactions over a given descriptive domain (rather than another).

The main message of complexity to this regard is clear. When dealing with the sustainability of complex adaptive systems scientists must accept to deal with: (1) an unavoidable non-reducibility of models defined on different scales and reflecting different selection of relevant attributes. This is associated to an incomparability of perceptions and the relative non-equivalent representation of events. ***Scientists should acknowledge the impossibility to have a substantive and unique description of the reality that can be assumed to be as "the right" one***; and (2) incommensurability among the priorities used by non-equivalent observers when deciding how to perceive and represent nested hierarchical systems operating across scales. That is, non-equivalent observers having different goals will provide logically independent definitions of what are the relevant attributes to be considered in the model. ***Scientists should acknowledge that it is impossible to have a substantive and an agreed-upon definition of what should considered as "the most useful" narrative to be adopted when constructing a model.***

7.4.1 *Case study: an epistemological analysis of the failure of conventional energy analysis*

Attempts to apply energy analysis to human systems have a long history. Pioneering work was done by, among others, Podolinsky (1883), Jevons (1865), Ostwald (1907), Lotka (1922; 1956), White (1943, 1959), Cottrel (1955). However, it was not until the 1970's that energy analysis became a fashionable scientific exercise, probably because of the oil crisis surging in that period. In the 1970's, energy input/output analysis was widely applied to farming systems, national economies, and more in general to describe the interaction of humans with their environment (e.g., H.T. Odum, 1971; 1983; Rappaport, 1971; Georgescu-Roegen, 1971; Leach, 1976; Gilliland, 1978; Slesser, 1978; Pimentel and Pimentel, 1979; Morowitz, 1979; Costanza 1980; Herendeen, 1981). At the IFIAS workshop of 1974 (IFIAS, 1974), the term energy analysis, rather than energy accounting, was officially coined. The second energy crisis in the 80s was echoed by the appearance of a new wave of interesting work by biophysical analysts (Costanza and Herendeen, 1984; Watt, 1989; 1992; Adams, 1988; Smil, 1991; Hall et al, 1986; Gever et al. 1991; Debeir et al. 1991) and a second elaboration of their own original work by the "old guard" (Odum, 1996; Pimentel and Pimentel, 1996; Herendeen, 1998; Slesser and King, 2003). However, quite remarkably, after less than a decade or so, the interest in energy analysis quickly declined outside the original circle. Indeed, even the scientists of this field, soon realized that using energy as a numeraire to describe and analyze changes in the characteristics of agricultural and socioeconomic systems proved to be more complicated than one had anticipated (Ulgiati et al., 1998).

We start our critical appraisal of the epistemological foundations of conventional energy analysis using one of the most well known case studies of this field: the attempt to develop a standardized tool kit for dealing with the energetics of human labor. This has been probably the largest "fiasco" of energy analysis due to the huge effort dedicated by the community of energy analysts to this subject (for an overview of issues, attempts and critical appraisal of results see: Fluck, 1981, 1992; Giampietro and Pimentel, 1990, 1991a; 1991b; Giampietro et al., 1993).

Very quickly, looking at the vast literature on the energetics of human labor one can find an agreement about the need of knowing at least three distinct pieces of information, which are required simultaneously, to characterize in useful terms indices of "efficiency" or "efficacy". The three pieces of information are:

(1) **The requirement - and/or availability - of an adequate *energy input* needed to obtain the conversion of interest** (an inflow of energy carriers – in the case of human labor a flow of nutrients contained in food = energy carriers compatible with human metabolism).

(2) **The ability of the considered converter to *transform the energy input into a flow of useful energy to fulfil a given set of tasks*** (in this case a system made up of humans has to be able to convert available food energy input into useful energy at a certain rate, depending on the assigned task).

(3) **The achievement obtained by the work done - *the results associated to the application of useful energy* to a given set of tasks** (in this case this has to do with the usefulness of the work done by human labor in the interaction with the context).

If we want to use indices based on energy analysis to formalize the concept of performance, we have then to link these three pieces of information to numerical assessments, based on "observable" qualities – **Fig. 7.17**. For this operation we need at least 4 non-equivalent numerical assessments related to:

(1) flow of a given energy input (*characterized and defined in relation to the given identity of the converter using it*) which is required and consumed by the converter. In the case of the study of human labor, it is easy to define what should be considered as food (energy carriers) for humans. Something that can be digested and then transformed into an input for muscles. If the converter were a diesel engine, food would no longer considered as an energy input.

(2) the power level at which useful energy is generated by the converter. This is a more elusive "observable quality" of the converter. Still this information is crucial. As stated in a famous paper by Odum and Pinkerton (1955), when dealing with the characterization of energy converters we have to always consider both the pace of the throughput (the power) and the output/input ratio. A higher power level tend to be associated to a lower output/input ratio (e.g. the faster you drive, the lower the mileage of your car). It does not make any sense to compare two output/input ratios if they refer to different throughput rates. In fact, we cannot say that a truck is less efficient than a small motorbike on the basis of the information given by a single indicator. That is, by the simple assessment that the truck uses more gas per mile than the motorbike. However, after admitting that the power level is another piece of information that is required to assess the performance of an energy converter, then, it becomes very difficult to find a standard definition of "power level" applicable to "complex energy converters" (e.g. to human workers or sub-economic sectors). This is especially true when these systems are operating on multiple tasks. Obviously, this is reflected into an impossibility to define a standard experimental settings to measure such a value. Moreover, power level (e.g. 1,000 HP of a tractor versus 0.1 HP of a human worker), does not map onto either energy input flows (how much energy is consumed by the converter over a given period of time used as reference – e.g. a year) nor onto how much applied power is delivered (how much useful energy has been generated by a converter over a given period of time used as reference – e.g. a year). In fact these two different pieces of information depend on how many hours the tractors or the human worker have worked during the reference period and how they have been operating.

(3) the flow of applied power generated by the conversion. The numerical mapping of this quality clearly depends heavily by the previous choices about how to define and measure power levels and power

supply. In fact, an assessment of the flow of applied power represents the formalization of the semantic concept of "useful energy". Therefore, this is the measured flow of energy generated by the converter which is used to fulfil a specified task. However, the definition of such a task can only be given at the hierarchical level of the whole system to which the converter belong. Put in another way, such a task must be defined as "useful" by an observer which is operating at a hierarchical level higher than the level at which the converter is transforming energy input into useful energy. What is produced by tractor has a value which is generated by the interaction with a larger context (e.g. the selling of products on the market). That is, the definition of "usefulness" refers to the interaction of the whole system – black box (to which the converter belongs as a component) with its context. This quality requires a descriptive domain different from that used to represent the conversion at the level of the converter (Giampietro, 2003). This introduces a first major epistemological complication: ***the definition of usefulness of a given task*** (based on the return that this task implies for the whole system) ***refers to a representation of events on a given hierarchical level*** (the interface ***n/n+1***) ***which is different from the hierarchical level used to describe and represent (assess indices of efficiency) the conversion of the energy input into useful energy*** (the interface ***n-1/n***).
(4) the work done by the flow of applied power (what is achieved by the physical effort generated by the converter). Work is another very elusive quality that requires a lot of assumptions to be measured and quantified in biophysical terms. The only relevant issue here for the moment is that this represents a big problem with energy analysis. Even if the two assessments #3 and #4 use the same measurement unit (e.g. MJ) they are different in terms of what are the relevant observable qualities of the system. That is, **assessment #3 (applied power) and assessment #4 (work done) not only do not coincide in numerical terms, but require a different definition of descriptive domain.** In fact, the same amount of applied power can imply differences in achievement, because of differences in design of technology and in know how when using it. The problem is that **it is impossible to find a "context independent quality factor" that can be used to explain these differences in substantive terms.**

The overview provided in **Fig. 7.17** should already make clear (according to what discussed in Chapter 2 and Chapter 3) that numerical assessments of energy input and output within a linear framework cannot escape the unavoidable ambiguity and arbitrariness implied by the hierarchical nature of complex systems. **A linear characterization of input/output using the 4 assessment discussed so far requires the simultaneous use of at least two non-equivalent and non-reducible descriptive domains.** Therefore, at least two of these 4 assessments would result logically independent. This opens the door to an unavoidable degree of arbitrariness in the problem structuring (root definitions of the system). Any definition or assessment of energy flows (both as input and/or output) will in fact depend on an arbitrary choice made by the analyst about what should be considered as the focal **level *n*.** That is: what should be considered as a converter, what should be considered as an energy carrier, what should be considered as the whole system to which the converter belongs, what has to be included and excluded in the characterization of the environment, when checking the admissibility of boundary conditions and the usefulness of work done. A linear representation in energy analysis force the analyst to decide "from scratch" in a total situation of arbitrariness about the set of formal identities (the finite set of variables used to describe changes in the various elements of interest) that are adopted in the model to represent energy flows and conversions. This choice of a set of formal identities for representing: energy carriers, converters, black-box, the finite set of characteristics related to the definition of an admissible environment, is then translated into the selection of the set of epistemic categories (variables) that will be used in the formal model – **Fig. 7.1**. It is at this point that the capital sin of the assumption of linear representation becomes evident. No matter how smart is the analyst, any assessment of energy inputs (the embodied energy of the input) or energy output (what has been achieved by the work done) will be unavoidably biased by the arbitrary pre-analytical choice of root definitions. In terms of hierarchy theory we can describe this fact as follows.

There is an unavoidable preliminary triadic filtering needed to obtain a meaningful representation the reality. That is, we have to select: (i) the interface between the focal **level *n*** and the lower **level *n-1*** to represent the structural organization of the system; and (ii) the interface between the focal **level** n and higher **level** $n+1$ to represent the relational functions of the system. Ignoring this fact, simply leads to a list of non-equivalent and non-reducible assessments of the same concepts. A self-explanatory example of this standard impasse in the field of energy analysis is given in **Table 7.1** – which reports several non-equivalent assessments of the energetic equivalent of one hour of labor.

That is, every time we choose a particular hierarchical level of analysis for assessing an energy flow (e.g. an individual worker over a day) we are also selecting a space-time scale at which we will describe the process of energy conversion (over a day, a year, the entire life). This, in turn, implies a non-equivalent definition of what is the context (environment) and what is the lower level (where structural components are defined). Human worker can be seen as individuals operating over a 1 hour time horizon (muscles are the converters in this case), or as households or as entire countries (machines are the converters in this case). The definitions of identities of these elements must be, then compatible with the identity of energy carriers (individuals eat food, developed countries eat fossil energy). This implies that, whatever we choose as a model, the various identities of energy carriers, parts, whole and environment have to make sense in their reciprocal conditioning. Obviously, a different choice of hierarchical level considered as the focal level (e.g. the household to which the worker belong) requires adopting a different system of accounting for inputs and outputs.

7.4.2 The impasse is more general: the problematic definitions of energy, work, and power in physics

In the previous case study we defined as problematic a formal definition of energy, power and work when dealing with an energetic assessment of human labor. Since this is a point carrying quite heavy epistemological implications we would like to elaborate a little bit more on it. That is, in order to be able to calculate within energy analysis ***substantive*** (= absolute, of general validity outside specific situations) indices of performance based on concepts such as ***efficiency*** (maximization of an output/input ratio) and/or ***efficacy*** (maximization of an indicator of achievement in relation to an input), we should be able to define, first of all, three basic concepts: "energy", "work" and "power" in general (substantive) terms. That is, we should be able to agree on definitions which are independent from the special context and settings in which these three concepts are used. However, if we try to do that, we are getting into an even more embarrassing situation.

Energy

Much of the innate indeterminacy of energy analysis, especially when applied to complex systems, has its roots in the problematic definition of energy in physics. As Feynman et al. (1963, Chapter 4, p. 2) pointed out: "it is important to realize that in physics today, we have no knowledge of what energy *is*... it is an abstract thing in that it does not tell us the mechanism or the *reasons* for the various formulas." In practice, energy is perceived and described in a large number of *different forms*: gravitational energy, kinetic energy, heat energy, elastic energy, electrical energy, chemical energy, radiant energy, nuclear energy, mass energy, etc.. A general definition of energy, without getting into specific context and space-time scale dependent settings, is necessarily limited to a vague expression, such as "***the potential to induce physical transformations***". Note that the classic definition of energy found in conventional physics textbooks, that is "*the potential to do work*", refers to the concept of "free energy" or "exergy" (which is another potential source of confusion), which both still require: (i) a previous formal definition of work; and (ii) a clear definition of operational settings, to be applied.

Work

The ambiguous definition of energy (= the ability of changing "something" defined elsewhere) is found also when dealing with a general definition of "work" [= a definition applicable out of any specific space-time scale dependent settings]. The classic definition found in dictionary refers to the ideal world of elementary mechanics: "*work is performed only when a force is exerted on a body while the body moves at the same time in such a way that the force has a component in the direction of the motion*". Others express work in terms of "equivalent to heat", as is done in thermodynamics: *"the work performed by a system during a cyclic transformation is equal to the heat absorbed by the system".* This calorimetric equivalence **offers the possibility to express assessments of work in the same unit as energy**, that is in Joules. However, the elaborate description of work in elementary mechanics and the calorimetric equivalence derived from classic thermodynamics are of little use in real life situations. Very often, in order to characterize the performance of various types of work we need *qualitative* characteristics that are impossible to quantify in terms of "heat equivalent". For example, the work of a director of an orchestra standing on a podium can not be described using the above definition of elementary mechanics nor can it be measured in terms of heat. An accounting of the Joules related to how much does her/him sweat during the execution of a musical score will not tell anything about the quality of her/his performance. "Sweating" and "directing good" do not map onto each other. Indeed, it is virtually impossible to provide a physical formula or general model defining the quality (or value) of a given work (what has been achieved after having fulfilled a useful task) in numerical terms from within a descriptive domain useful to represent energy transformations based on a definition of identity for energy carriers and energy converters. In fact, formal measurements leading to energetic assessments refers to transformations occurring at lower level (e.g. how much heat has been generated by muscles at the interface level ***n/n-1***) whereas an assessment of performance - how much the direction has been appreciated by the public – refer to interactions and feed-backs occurring at the interface level ***n/n+1***). This standard predicament applies to all real complex systems especially to human societies (Giampietro and Pimentel, 1990, 1991a).

Power

The concept of power is related to "the time rate of an energy transfer" or, when adopting the theoretical formalization based on elementary mechanics, "the time rate at which work is being done". Obviously this definition cannot be applied without a previous valid and formal mapping (in the form of a numerical indicator) of the "transfer of energy" or of the "doing the work". At this point, it should be obvious that the introduction of this "new" concept, based on the previous ones, does not get us out of the predicament experienced so far. Any formal definition of power will run into the same epistemological impasse discussed for the previous two concepts, since it depends on the availability of a valid definition of them in the first place.

It should be noted, however, that the concept of power **introduces an important new qualitative aspect (a new attribute** required to characterize the energy transformation) not present in the previous two. While the classic concepts of energy and work, **as defined in physics**, refer to quantities (assessments) of energy without taking into account the time required for the conversion process under analysis, the concept of power is, by definition, related to the rate at which events happen. This introduces a qualitative dimension which can be related to either: **(1) to degree of organization of the dissipative system; or (2) the size** of the system performing the conversion of energy **in relation to the processes that in the environment guarantee the stability of boundary conditions.** That is, in order to deliver power at a certain rate, a system must have two complementing but distinct relevant features. (1) an "adequate organized structure" to match the given task (e.g. capability of doing work at a given rate – an individual human cannot process and convert into power 100,000 kcal of food in a day), as well as (2) the capability of securing a sufficient supply of energy input for doing the task (e.g. to get advantage from the power of 100 soldiers for 1 year you must be able to supply them with enough food). In short: "gasoline without a car" [case (1)] or "a car without gasoline" [case (2)] is of no use.

This is the point that exposes the inadequacy of the classic output/input approach. In the sense that in real dissipative systems it is not thinkable to have an assessment of "energy flows" without addressing properly the set of relevant characteristics of the process of transformation (which implies addressing the existence of expected differences in power defined and measurable on different hierarchical levels and associated to the identity of the dissipative system in the first place). This means that the three theoretical concepts: **"Energy", "Work" and "Power" must be simultaneously defined and applied - within such a representation - in relation to the particular identity of a given typology of dissipative system (whole, parts and expected associative context).**

At this point, if we accept the option proposed in this book of using non-equivalent descriptive domains in parallel, we can establish a reciprocal entailment on the various definitions of identity of the various elements (converter, whole system, energy carriers, environment) used to characterize the set of energy transformations required to stabilize the metabolism of a dissipative system.

In this case we have two couples of self-entailment among identities defined on different levels:

Self-entailment #1:
* the identities adopted for representing the set of various converters – what is transforming an energy input into a flow of useful energy (on the interface ***level n*** and ***level n-1***). These identities are associated to the power level of the converter

define/are defined by:

* the identities adopted for representing the set of energy carriers – what is considered to be a material flow which is associated to the definition of an energy input (on the interface ***level n-1*** and ***level n-2***);

Self-entailment #2:
* the identities of the set of energy forms considered as useful energy on the focal level – what are the energy forms considered as useful – according to the organized structure of the system. This is a system dependent <u>characterization of the autocatalytic loop from within</u> (on interface between ***level n-1*** and ***level n***). The usefulness of the whole organized structure and the combination of energy forms is decided in relation to their ability, validated in the past, to fulfill a given set of tasks.

define/are defined by:

* the compatibility of the identities of the whole system in relation to its interaction with the larger context – what are the favourable boundary conditions related to the definition of identities of energy inputs, converters and the dissipative whole that are required to make the metabolism. This is a context dependent <u>characterization of the autocatalytic loop from outside</u> (on the interface between the ***level n*** and ***level n+1***). This compatibility can be used to define the usefulness of tasks in relation to the availability in the environment of the required flow of input and sink capacity for wastes.

When using simultaneously these two self-entailing relations among identities, which depend on each other for their definitions, we can link non-equivalent characterizations of energy transformations across scales. An overview has been given in **Fig. 7.1** and in **Fig. 7.8**. This establishes 2 bridges:

* **Bridge #1** – ***conversion rates represented on different levels must be compatible with each other*** – this implies a constraint of compatibility **between the definition of identity of the set of converters** defined at the **level n-1** (triadic reading: ***n-2 / n-1 / n***) and the definition of the set of tasks for the whole defined at the **level n+1** (triadic reading: ***n-1 / n / n+1***). This constraint addresses the ability of the various converters to generate "useful energy" (the right energy form applied in the specified setting) at a given rate which must be admissible for the various tasks. This bridge #1 deals with qualitative aspects of energy conversions ("parts of parts" versus "parts" AND "parts" versus "whole").
* **Bridge #2** – ***the flow of energy input from the environment and the sink capacity of the environment must be enough to cope with the rate of metabolism implied by the identity of the black-box*** – this implies a constraint of compatibility **between the size of the converters** defined at the ***level n-1*** (triadic reading:

n-2 / n-1 / n*)** **and the relative supply of energy carriers and sink capacity** related to processes occurring at the ***level n+1. The set of identities of the inputs (from the environment to the converters) and wastes (from the converters to the environment) is referring to a representation of events valid also at the **level n-2.** In fact, these energy carriers will interact with internal elements of the converters to generate the flow of useful energy and will be turned out into waste by the process of conversions. However, the availability of an adequate supply of energy carriers and of an adequate sink capacity is related to the existence of **processes occurring in the environment, which are needed to maintain favourable conditions** at the **level *n+1.*** Put in another way, the ability to maintain favourable conditions in face to a given level of dissipation can only be defined by considering **level n+1** as the focal one (triadic reading: ***n / n+1 / n+2***).

This consideration, however, implies the epistemological predicament discussed in Part 1. When dealing with quantitative and qualitative aspects of energy transformations over an autocatalytic loop of energy forms **we have to bridge at least 5 hierarchical levels (from level *n-2* to level *n+2*).**

By definition **the environment** (processes determining the interface between the **level *n+1/n+2*) is something about which we don't know enough.** Otherwise it will become part of the modeled system. This means that when dealing with the stability of "favourable boundary conditions" we can only hope that they will remain favourable as long as possible. On the other hand, **the existence of favourable boundary conditions is a must for dissipative systems.** That is, the environment is and must be in general assumed to be an "admissible environment" in all technical assessments of energy transformations.

If we accept this obvious point, we have also to accept that the existence of "favorable boundary conditions" – interface **level *n+1/n+2*** - is an assumption which is not directly related to a definition of "usefulness" of the tasks. The usefulness of tasks has been validated because of the admissibility of boundary conditions. That is, a technical definition of usefulness (efficiency, efficacy) does address only the effect of processes occurring on the interface **level *n/n+1*** and therefore has a limited relevance for discussing sustainability (recall here Jevons' paradox discussed in Chapter 1). The existing definition of the set of useful tasks at the **level *n*** simply reflects the fact, that these tasks were perceived as useful in the past by those living inside the system. That is, the established set of useful tasks was able to sustain a network of activities compatible with boundary conditions (**'ceteris paribus' at work !**). However, this definition of "usefulness" for these tasks (what is perceived as good at the **level *n*** according to the perceived favourable boundary conditions at the **level *n+1*)** has nothing to do with a full evaluation of the ability or the effect of these tasks in relation to the stabilization of boundary conditions in the future (in relation to processes occurring at level n+2). For example, producing a given crop that provided an abundant profit last year, not necessarily implies that the same activity will remain so useful also next year. Existing "favourable boundary conditions" at the **level *n+1*** require the stability of the processes occurring at the **level *n+2*,** (e.g. the demand for that crop remains high in face to a limited supply, as well as natural resources such as nutrients, water, soil, and pollinating bees will remain available also for the next year). This is an information about which we do not know and cannot know enough in advance. This implies that analyses of "efficiency" and "efficacy" which are based on data referring to characterizations and representations relative to identities defined on the 4 levels ***n-2; n-1; n; n+1*** (on the ceteris paribus hypothesis and reflecting what has been validated in the past) **are not very useful to study co-evolutionary trajectory of dissipative systems.** In fact they: (1) do not address the full set of relevant processes determining the stability of favourable boundary conditions (they miss a certain number of relevant processes occurring at the **level *n+2***); and (2) deal only with qualitative aspects (intensive variables referring to an old set of identities), but not quantitative aspects such as the relative size of components: how big is the requirement of the whole dissipative system – extensive variable assessing the size of the box from the inside - in relation to the unknown processes that stabilize the identity of its environment at the **level *n+2.*** As observed earlier, the processes that are stabilizing the identity of the environment are not known by definition. This is why, when deal with co-evolution we have to address the issue of "emergence". That is, we should expect the appearance of new relevant attributes (requiring the introduction of new epistemic categories in the model – new relevant qualities of the system so far ignored) to be considered as soon as the dissipative system (e.g. human society) discovers or learns new relevant information about those processes occurring at **level *n+2***, that were not known before.

In conclusion an operational definition of the three concepts "energy", "work" and "power" can only be obtained after adopting a structure of Chinese boxes (non-equivalent descriptive domains overlapping) in which the set of values taken by "intensive" and "extensive" variables used to represent (and assess) them are brought into congruence through a process of reciprocal entailment among definitions.

7.5 Theoretical foundations (2): what is predicated by an impredicative loop?

Getting back to the basic fuzzy definition of holons using thermodynamic reasoning

TECHNICAL SECTION

The new paradigm associated to complexity, which is rocking the reductionist building, is the son of a big epistemological revolution started in the first half of 19th century by classic thermodynamics (e.g. among others Carnot and Clausius) and continued in the second half of the 20th century by non-equilibrium thermodynamics (e.g. by the ideas of Schroedinger and the work of Prigogine's school). Both revolutions used the concept of "entropy" as banner. The equilibrium thermodynamics represented a first bifurcation from mechanistic epistemology by introducing new concepts such as irreversibility and symmetry breaking when describing real world processes (e.g. unilateral directionality of real time). The non-equilibrium paradigm represents a final departure from reductionist epistemology since it implies the uncomfortable acknowledgment that scientists can only work with system-dependent and context-dependent definitions of entities within models. In particular the concept of "negative entropy" - a concept that has been introduced by Schroedinger (1945) to explain the existence of life) is not a substantive concept. Rather this is a "construction" (an artifact) associated with the given identity of a dissipative system which is operating at a given point in space and time [= within a particular setting of boundary and initiating conditions]. The concept of negative entropy is crucial in our discussion, since this is a concept that imposes in the scientific analysis that the perception and representation of "quality" for both energy inputs and energy transformations has to reflect particular typology of metabolism (pattern of dissipation) of a specific dissipative system. That is, the concept of negentropy must refer to a given identity of dissipative system which is assumed to operate within a given associative context (an admissible environment). According to this fact, food is an energy input for humans but not for cars. This fact has huge implications for energy analysts. In fact, saying that 1 kg of rice has "an energy content of 14 MJ" can be misleading, since this "energy input" is not an energy input for running a car which is out of gas. In the same way the definition of what should be considered as "useful energy" depends on the goals of the system, which is expected to operate within a given associative context. Fishes are expected to operate inside the water to get their food, whereas birds cannot fly to catch preys below the ground.

These can seem trivial observations, but they are directly linked to a crucial statement we want to make in this chapter. It is not possible to characterize, by using "substantive formalisms" [= applicable to all conceivable dissipative systems operating in reality] qualitative aspects of energy forms. That is, it is impossible to define a "quality index" which is valid in relation to all the conceivable scales (from sub-atomic particles to galaxies) and when considering all the conceivable attributes that could result relevant for energy analysis (all possible observable qualities relevant in relation to the goal and the expected associative context). In order to characterize the behavior of dissipative systems one has always to specify the pre-analytical choices made by the analyst to perceive and represent energy transformations within a finite and closed information space. As noted earlier, this is a missione impossible since these systems are: (i) open (they are what they eat) – and this blurs the distinction between system and environment across scales; (ii) becoming in time (they are all special because of their history) – and this requires a continuous updating of the set of typologies used to characterize them (why and how are they special for the observer).

In our view, this is why classic thermodynamics first, and non-equilibrium thermodynamics later on, gave a fatal blow to the mechanist epistemology of Newtonian times. However, we cannot replace the hole left by the collapse of Newtonian mechanistic epistemology just by using a set of new terms derived from non-equilibrium thermodynamics (e.g. disorder, information, entropy, negentropy) and keep using them, as if they were "substantive" concepts [= definable in strictly physical sense as context-independent]. We should always recall the caveat presented by Bridgman: "*It is not easy to give a logically satisfying definition of what one would like to cover by 'disorder'... Thermodynamics itself, I believe, must presuppose and can have meaning only in the context of a specified 'universe of operations', and any of the special concepts of thermodynamics, such as entropy, must also presuppose the same universe of operations*" (Bridgman, 1961).

The big problem with this point is that the approach suggested by Bridgman cannot be followed in a universe in which not only the observed system, but also the observer is becoming something else in time. In fact, an observer with different goals, experiences, fears and knowledge will never perceive and represent energy forms, energy transformations and a relative set of "indices of quality" in the same way as a previous one (for more on this point see Chapter 8).

This entails that concepts derived from thermodynamic analysis and energy indices of quality (such as output/input energy ratios, exergy based indices, entropy related concepts, embodied assessments associated to energy flows) can be seen as very powerful metaphors. However, like all metaphors, they require always semantic checks before their use. That is, all these concepts are very powerful to help a discussion about the usefulness of alternative narratives when dealing with sustainability issues. They should not be used to provide normative indications about how to deal with sustainability predicament in an algorithmic way (on the basis of the application of a set of given rules written in protocols). Put in another way, it is not always sure that optimizing an index of "efficiency" or "efficacy" reflecting one of the possible formalizations of a problem is the right thing to do. There is not a "magic" associated to thermodynamics that can provide analysts with an epistemological silver bullet, not even the concept of entropy.

7.5.1 A short history of the concept of entropy

Originally the concept of entropy popped out, even if in an implicit form, when dealing with qualitative aspects of energy transformations within thermal engines. Sadi Carnot (in "Reflections on the Motive Power of Fire" - 1824) proposed the existence of a set of predictable relations between the work produced by a steam engine and the characteristics of the heat transfer associated with its operation (Mendoza, ed. 1960). Emile Clapeyron, in 1834, restated Carnot's principle in analytical form (Mendoza, ed. 1960). That is, after framing the representation of a set of energy conversions within a predictable setting (thanks to the structural organization provided by the engine used for the experiments), it becomes possible to predict relations between losses, overheads and useful output. Clausius restated both the first law ["the energy of the universe is constant"] and the second law ["the entropy of the Universe tends to a maximum"] assuming "the universe" as an isolated system (Clausius, 1867, p. 365). Details on this historical birth process of the term entropy are important since they show that the concept of entropy was alien to the prevailing mechanistic epistemology at that time (for more see Mayumi and Giampietro, 2004).

Georgescu-Roegen introduced another crucial theoretical issue about entropy, by proposing a ***fourth law of thermodynamics***. This law refers to the impossibility of a full matter recycling for a dissipative system. The point raised by Georgescu-Roegen is very important for the discussion of sustainability, since this is where the opinions of "prophet of dooms" and "cornucopians" bifurcate. Georgescu-Roegen defines the idea of an economy that can recycle and substitute using capital and technology any limiting resource as an idea of a perpetual motion of the "third kind". That is, he equates the idea of a perpetual economic growth to the idea of having a closed thermodynamic system that can perform work at a constant rate *forever* or that can perform *forever* work between its subsystems. He then claims that perpetual motion of the "third kind" is impossible. This claim has generated an intense debate in the field of Ecological Economics: (Bianciardi et al. 1993; Kümmel 1994; Månsson 1994; Bianciardi et al. 1996;

Converse 1996, 1997; Ayres 1999; Craig 2001: Kåberger and Månsson 2001). In fact, if the theoretical framework of thermodynamics is strictly followed, it is relatively easy to reach the following result, which contradicts Georgescu-Roegen's statement: it is *possible* to construct a *closed* engine which will work in a complete cycle, and produce no effect except the raising of a weight, the cooling of a heat-reservoir at a higher temperature, and the warming of a heat-reservoir at a lower temperature (Mayumi 1993). Actually and paradoxically this closed system is nothing but a Carnot engine. The Carnot engine with fluid is indeed a closed system because heat can be exchanged during two isothermal processes (expansion and compression) through the base of the cylinder.

This is where the epistemological predicament implied by complexity enters into play. A Carnot engine is a ideal type of engine. In the reality each working engine is a special realization of such a type, which requires lower level components guaranteeing structural stability. Because of this, it will have "special" differences from the general template used for its making. These differences due to peculiar characteristics of lower level components (the material structure) and stochastic events associated to the history of such an organized structure, imply that our knowledge of the type has a limited applicability for dealing with individual special realizations. This is why 'material entropy' is critically important. The main point of Georgescu-Roegen is that energy can be represented in models as a homogeneous substance. That is, energy representations of events are based on types. According to these energetic models, energy conversions from one energy form into another can be easily accomplished according to the laws included in the model. On the other hand, when looking at the same transformations in terms of matter (at a different level), we always find that material elements are highly heterogeneous and every element has some unique physicochemical properties. This feature of matter explains the reason that the practical procedures for unmixing liquids or solids differ from case to case and consist of many complicated steps. Seemingly, the only possible way of reaching a quantitative measure of material entropy is to calculate indirectly the amounts of matter and energy for returning to the initial state of matter in bulk in question given available technology.

Getting back to our historical overview, we can say that in the first century of its life the concept of entropy was charged with various meanings by different "users". Perhaps due to predominant addiction to formalism and because of the obvious ambiguity of the term, the label entropy became associated with non-equivalent concepts such as "irreversibility", "arrow of time", "expected trends toward disorder", "expected directional changes in the quality of energy forms" and even to "quantitative assessments of information flows among communicating systems" (for more see Mayumi and Giampietro, 2004). In any case, there is a common connotation associated with the label entropy until the first half of the XXth century. The concept of entropy (no matter how defined) was always associated with a clear "prophet-of-doom" flavor. The universe is condemned to the heat-death, disorder will prevail, irreversibility and frictions are the unavoidable bad guys that are here to disturb the beautiful order of our universe and the work of scientists . . .

The innate ambiguity associated to the concept of entropy, however, is so pervasive that it even made possible to overcome this negative connotation. A dramatic change in the perception of the role of entropy in the evolution of life arrived, in fact, in the second half of the XXth century. The twist was primed by the ideas of surplus entropy disposal by Erwin Schroedinger (Schroedinger 1967, in an added note to Chapter VI of "What is life" written in 1945) and then by the work of the Prigogine school in non-equilibrium thermodynamics (Prigogine 1961; Glansdorf and Prigogine, 1971, Nicolis and Prigogine, 1977, Prigogine, 1978, Prigogine and Stengers, 1984). With the introduction of the class of dissipative systems the concept of entropy got finally out from the original outfit of the "villain". Self-organization and emergence are both strictly associated with the ability of exporting surplus entropy generated within the system into the environment. Schneider and Kay reformulated the second law and suggested that "as systems are moved away from equilibrium they will take advantage of all available means to resist externally applied gradients" (Schneider and Kay, 1994). Actually, looking at the evolution of biological systems Brook and Wiley (1988) arrived to see *Evolution as Entropy* (as stated in the title of their famous book). For an expert in thermodynamics such a title can appear as an insult because entropy is a state function in classic thermodynamics! But this is the "magic" of entropy, as it were. First of all, in that book Brook and Wiley were using a definition of entropy derived from information theory, secondly, they were exploring new frontiers (looking for new meanings) associated with the paradigm shift about how to perceive evolution. In this task, the ambiguity of the term might have been a blessing for them. In fact, after having accepted that irreversibility and frictions are no longer the bad guys, the information entropy concept within their framework became the essential element which sustains and drives the evolution of the complex organization of dissipative systems.

Actually, at this point, it can be noted that the epistemological predicament associated to complexity (the impossibility to establish a formal mapping when dealing with the identity of complex systems) is one of the main issues dealt with in recent thermodynamic discussions. For example, we can recall the point made by **Bridgman** (1961) about the clear fact that the definition of energy in thermodynamics is not necessarily logically equivalent to the definition of energy given in wave-mechanics in quantum physics: "*from this point of view it is therefore completely meaningless to attempt to talk about the energy of the entire universe*" (ibid pag. 77). There is not a common and reducible set of definitions of energy that can be applied to all possible ways of perceiving and representing energy on different scales and in different context. The dilemma about the existence of non-reducible definitions of the identity of energetic systems and the relative assessment of energy forms directly recalls the historic impasse experienced in physics (e.g. by Boltzmann when attempting the unification of statistical representation and classic thermodynamics and in quantum physics when attempting to handle the dual nature of particles). Such an issue has been directly investigated by **Rosen** in his "Anticipatory Systems (1985). Actually, this is the issue that led him to introduce the concept of Complex Time. In Chapter 4 of his book, he provides an overview of "encodings of time", in which he shows that the formal definitions of time differentials within different representative frames (even when applied to conservative systems) are non-equivalent and non-reducible to each other. To prove this fact, he explores the various formal definitions of "time differentials" in: Newtonian dynamics, Thermodynamics and Statistical analysis, Probabilistic time, Time in general dynamical systems, where also the pace at which the observer can perform measurement matters. Concluding this chapter Rosen says: "*we have abundantly seen that the quality we perceive as time is complex. It admits a multitude of different kinds of encoding. ... Each of these capture some particular aspects of our time sense, at least as these aspects are manifested in particular kinds of situations. While we saw that certain formal relations could be established between these various kinds of time, none of them could be reduced to any of the other; nor does there to appear to exist any more comprehensive encoding of time to which all of the kinds we have discussed can be reduced*" (ibid. Pag. 271).

The impossibility of obtaining a substantive and formal definition of time is related to the impossibility of obtaining a substantive and formal definition of energy applicable across different scales to different situations.

This discussion supports the concern expressed by **James Kay** about the existing confusion in the definition and use of the concept of entropy in existing literature: "*I have not seen a good general treatment of the relationship between entropy change, entropy generated in a system, and environment and exergy change. There are a lots of examples of this being sorted out for specific cases, but not in general and not for biological systems (except for some specific cases). This is the reason that dissipation and degradation are used in sloppy ways as it is never quite clear if one is talking about entropy change, entropy generation, exergy change, gradient change, or heat transfer and if it is* ***for the system, or system plus environment***" (Kay, 2002). The last statement (underlined by us) is, in our view, crucial and we will discuss more below.

7.5.2 The metaphor of "negative entropy" of Schroedinger and Prigogine

We want now briefly apply the rationale of hierarchical reading of energy transformations occurring within an autocatalytic loop of energy forms (the theoretical basis of ILA) to the famous scheme proposed by Prigogine to explain in entropic terms the biophysical feasibility of dissipative systems. This follows the intuition of Erwin Schroedinger ("What is life" in 1945), that living systems can escape the curse of the second law thanks to their ability to feed on "negentropy". Put in another way, living systems are open systems which can preserve their identity thanks to a metabolic process, which requires the compatibility of their identity with the identity of their context.

This original idea has been developed by the work of the school of Prigogine in non-equilibrium thermodynamics. They introduced the class of dissipative systems, in which the concept of entropy is associated to that of self-organization and emergence. In this way, it becomes possible to better characterize the concept of metabolism of dissipative systems. The ability of generating and preserving in time a given pattern of organization, which would result improbable according to the laws of classic equilibrium thermodynamics depends on two self-entailing abilities: (1) the ability of generating the entropy associated to the energy transformations occurring within the system (those transformations required to generate the pattern); and (2) the ability of discharging this entropy into the environment at a rate which is proportional of that of internal generation. Put in another way, the possibility to have life, self-organization and autocatalytic loops of energy forms is strictly linked to the ability of open dissipative systems of generating and discharging entropy into an admissible environment (Schneider and Kay, 1994). Actually, the more they can generate and discharge the higher the complexity of patterns that can be sustained.

Using the vocabulary developed so far, we can say that open systems can maintain a level of entropy generation which is admissible in relation to their identity of metabolic system (= a given pattern of energy dissipation which is associated to an ordered structure of material flows and stocks characterized in relation to the expected favourable environment). Using the vocabulary developed by Schroedinger and Prigogine, this requires compensating the unavoidable generation of entropy associated to internal irreversibility (dS_i) with an adequate import of "negentropy" (dS_e) from the context. The famous scheme proposed by Prigogine to represent this idea is commonly written as:

$$\mathbf{dS_T <=> dS_i + dS_e} \qquad (1)$$

Which implies that the identity of the system defined at the interface **level *n*/ level *n-1*** (associated to the two flows of entropy: (i) internally generated - $\mathbf{dS_i}$ - and "imported/exported" - $\mathbf{dS_e}$) must result congruent (or compatible) with the identity of the larger dissipative system in which they are embedded – the picture of the dissipative system as obtained from the **level *n+1* / level *n*** ($\mathbf{dS_T}$).

Applying this rationale to autocatalytic loop across hierarchical levels

Let's now imagine to visualize the application of this scheme to the representation of a nested hierarchical system made of metabolic systems as illustrated in **Fig. 7.18**. For example, lets imagine that the **level *n*** refers to the perception and representation of the metabolism of an organ (e.g. a liver) operating within an individual human being (**level *n+1***) that is operating within a household (**level *n+2***), that is operating within a given village (an environment with favourable characteristics). It should be noted that a structure such as the one represented in **Fig. 7.18** is mandatory according to the basic scheme proposed by Prigogine.

Several evident problems with this approach can be immediately detected even by a cursory look at this figure. The representations of the autocatalytic loop in **Fig. 7.1** and **Fig. 7.8** was based on two parallel non-equivalent mappings of matter and energy flows on different levels. (a) a view of the autocatalytic loop - **from within** - defined over three contiguous levels (***n-2/n-1/n***) used to explain how the black box is operating. (b) a view of the same autocatalytic loop – also defined over three contiguous levels (***n/n+1/n+2***) – **from outside** - related to the compatibility of the behavior of the black-box in relation to the characteristics of the environment. Whereas, if we want to formalize (by assigning empirical data) to relation (1) we have to use just one descriptive domain.

Let's imagine that all this information (referred to a view from inside and from outside - **Fig. 7.1**) can be compressed thanks to the magic power of the entropy concept and as a result of a "smart" selection of three mappings: **dS_T, dS_e, dS_i** (letters written in green) as done in **Fig. 7.18**. The green letters and arrows refer to a hypothetical formalization of Prigogine scheme to characterize the effect of entropic processes related to **level *n***. These 3 numerical assessments are referring to the interface **level *n*/level *n+1*** but they must include also information about mechanisms generating internal irreversibility (represented on the interface **level *n-2*/level *n-1***) . Because of the nested structure, these three green mappings must result congruent with the other triplet of mappings: **dS_T, dS_e, dS_i** (letters written in red), this time used to characterize in numerical terms the effect of the red arrows of "entropies" related to the application of Prigogine scheme on **level *n+1***. These assessments are referring to the interface **level *n+1*/level *n+2*** but they must include also information about mechanism generating internal irreversibility (represented on the interface **level *n-1*/level *n***). Obviously, these three red mappings must result also congruent with the other triplet of mappings: **dS_T, dS_e, dS_i** (letters written in blue), used to characterize in numerical terms the blue arrows related to the reading of the scheme on **level *n+2***. These assessments are referring to the interface **level *n+2*/level *n+3*** but they must include also information about mechanism generating internal irreversibility (represented on the interface **level *n*/level *n+1***).

To spare additional suffering to the reader we stop here our stroll through this nested chain of representations of entropic processes associated to metabolic elements. In real situations, however, we have to expect a much longer journey across levels (when going from heat assessments associated to the movement of molecules within the body of consumers, to the processes generating the curves of demand and supply within economic systems, to arrive to the thermal engine of the water cycle discharging entropy for Gaia into the outer space, as suggested by Tsuchida and Murota!). It is obvious that the idea of being able to keep coherence in such a chain of formalizations across scales is ludicrous. This is why the epistemic triadic filtering (Chapter 2 and Chapter 3) is required.

The epistemological troubles related to the parallel representation of events which are occurring on different time scales are related to the impossibility to handle in formal way the complex nature of time (a la Rosen). That is, going back to **Fig. 7.1**, we can see that, over the three levels **level *n-2*/*n-1*/*n***, the mechanism of conversion of energy input (green arrow) into useful energy (red arrow) requires assuming that the energy carriers associated to the representation of the green arrow (e.g. the food) enters into the converter (e.g. the farmers working in agriculture) **before** the red arrow is generated. However, when dealing with the representation of the typology of the black box (when describing the interaction between the black box and its environment) – at the **level *n*/*n+1*/*n+2*** - it is the red arrow that is considered to be the causal source of the arrival of the energy carriers into the black box. That is, it is the red arrow (e.g. work in agriculture) that is generating the flow represented by the green arrow (e.g. the food harvested by the farmers). This applies also to an economic representation of the autocatalytic loop determining a farm: "*For example, an agricultural field is maintained as quite an improbable ecological community functioning in a particular context. Such an organized structure persists because the growth of crops generates enough money to allow the farmer to put in a new crop next year. If the market changes, the farmer shifts the realization by turning to a different crop. Thus the field persists as a production unit. The makings of the pattern reinforce themselves in a loop of structure feeding process, a loop that amounts to the whole process of ecological engineering.*" (Allen et al. 2003). We saw in Chapter 3 that the identification of a given direction of causality in nested holarchies is impossible when dealing with systems operating on multiple scales and levels. For example, the concept of "consumer democracy" assumes that consumers when choosing goods on the market are determining what types of good will be produced in the future (they provide an explanation to the question: **why** certain goods remain and other disappear). On the other hand, when looking at **how** goods are produced (technical aspects of the productive process), the selection of goods on the market can only be done after that these goods have been produced. Technical aspects provide an explanation to how certain goods arrive on the market.

Coming back to **Fig. 7.18**, as soon as we look for the simultaneous validity of all the formalizations of the triplets of **dS_T, dS_e, dS_i**, (of various colors) referring to non-equivalent sets of representation of events perceived on different hierarchical levels, it becomes clear that this task would require the simultaneous adoption of assumptions about identities of elements and definition of space-time scales, which are inconsistent with each-other. The metabolism of a liver can be represented in term of its "eating" glucose molecules as energy carrier (on a time horizon of hours). Whereas the metabolism of a human being can be represented in term of its "eating" a variety food products (on a time horizon of a year). Finally, the metabolism of a household can be represented in term of its "eating" a variety of energy carriers (electricity, gasoline, coal) over several years – associated to changes in age structure and the turnover of technical devices. Moreover, the typologies of energy carriers of a household will depend on the characteristics of its associative context (e.g. if it is operating in a subsistence society or in an industrialized countries), whereas the energy carriers for a liver are the same in rich and poor countries.

In the situation represented in **Fig. 7.18** it is meaningless to look for a formal and substantive mechanism of accounting based on the concept of entropy, or exergy, or whatever other new thermodynamic function we want to introduce to address qualitative differences in energy flows. Qualitative differences of energy assessments are not "substantive", but they always depends on the preliminary decision about how to perceive and characterize an autocatalytic loop across levels and scale. If we insist in looking at thermodynamic analysis to provide substantive quality assessment to energy forms we simply keep trying to answer questions that cannot be answered. For example, what do we mean, when we refer to the various triplets of "entropies" shown in the nested chain in **Fig. 7.18** with internal entropy production? What "entropic assessment" related characterization of the system do we have in mind? – e.g. rate of change of entropy, rate of generation of entropy, rate of disposal of entropy. Moreover, such an assessment should be related to which substantive definition of "system"? - e.g. what is "the system" when dealing with a nested hierarchy of elements necessarily open on the top? How to deal with the representation of the energy dissipation of individual elements in the middle? – e.g. should we be using a descriptive domain reflecting the perception and representation of events from within or a descriptive domain reflecting the perception and representation of events from its context, that in reality is another within for another context? As noted earlier, both are needed and relevant, but they are not reducible to each other, since they are overlapping but only when adopting non-equivalent definitions of time and space (= definition of time and space differentials in relation to measurement scheme and the expected validity of the assumption of quasi-steady state). Finally, how to decide about what are the relevant forms of energy to be included or neglected from the accounting on different levels? Should we account for gravitational energy when accounting of energy consumptions of households living in coastal areas? Very few include such a input (but Odum school), even though tides can represent relevant agents determining the characteristics of the admissible environment of these households.

Interpreting the scheme proposed by Prigogine in metaphorical terms

Let's now try to interpret in a metaphorical sense the scheme proposed by Prigogine to characterize autocatalytic loops of energy forms within nested metabolic systems:

(i) dS_i – refers to the representation of the mechanism of internal entropy production, which is associated to the irreversibility generated to preserve system identity. This assessment necessarily must be obtained using a representation of events related to a perception obtained within the black-box - on the interface **level *n-2/n-1/n*.** This can be done by using a mapping of an energy form which makes possible to represent how the total input used by the black box, is then invested among the various parts. But this implies assuming a space-time scale for perceiving and representing events, which must be compatible with the identity of both energy carriers and energy converters. For example, this energy mapping can be related to the amount of chemical bonds made available through gross primary production to an ecosystem (and then divided within the various compartments of an ecosystem) – as done in **Fig. 7.5** - or the total amount of energy made available to organs operating within humans – as done in **Fig. 6.1**.

(ii) **dS_e** - refers to the representation of imported negative entropy. The term "negentropy" entails the adoption of a mechanism of mapping of energy which is directly related (it must be reducible) to the mechanism chosen when representing $\mathbf{dS}_i$. In fact, the term "negentropy" requires establishing a bridge between the assessment of two forms of energy: (i) one used to describe events within the black-box in terms of $\mathbf{dS}_i$ (the mapping used to assess the effect of internal mechanisms associated to irreversibility) – e.g. extensive variable#1 such as chemical bonds obtained through photosynthesis or food energy eaten by people; and (ii) one used to describe the interaction of the black-box with its context – e.g. extensive variable#2 such as solar radiation used to evapotranspirate the water associated to the photosynthesis generating the given amount of Gross Primary Productivity (this would be the energy form associated to $\mathbf{dS}_e$ when dealing with gross primary productivity as the energy form associated to $\mathbf{dS}_i$). The amount of entropy assessed when considering extensive variable#1 must be compatible with the room provided by the extensive variable#2.

That is, the concept of a sum of $\mathbf{dS}_i$ and $\mathbf{dS}_e$ can be referred to the coupling of two forms of energy within an autocatalytic loop. The first energy form is used to represent relevant mechanisms inside the black-box (those associated to the stabilization of the identity of the box as a metabolic system). The second energy form is used to represent the interaction of the black box with its associative context (the energy form checking whether or not the hypothesis about admissibility of boundary conditions holds). It represents the view of the metabolism from the outside.

(iii) $\mathbf{dS}_T$ – refers to the admissibility of the identity of a known typology of dissipative system (e.g. a human being, a dog, a car) with the actual context in which it is operating across the various levels, as it is required to represent the autocatalytic loop.

As noted earlier the simultaneous check of this compatibility - a formalization in a substantive way of the relation among the three dS - is not possible. However, the metaphorical message is the same as the one found when discussing of ILA. An **autocatalytic loop of different energy forms entails the congruence across levels of formal identities defined on different descriptive domains.** This implies describing such an interaction in terms of a forced relation among known identities of energy forms defined over 5 contiguous hierarchical levels (from **level *n-2*** to **level *n+2***). If we structure our information space in a way that makes possible to perform a series of congruence checks on the selected representation of the autocatalytic loop of energy forms, we can build a tool kit that can be used to look for biophysical constraints to the feasibility of this process.

However, this require accepting two negative side effects: (1) the same autocatalytic loop can be represented in different legitimate ways (by using different combinations of formal identities). For legitimate we mean a selection of identities that provides congruence among the representations of flows; (2) there is an unavoidable degree of ignorance associated to the representation. In fact, the very set of assumptions (e.g. about the future stability of the relation between investment and return, and admissibility of the environment on **level *n+2***), which make possible to represent the system, guarantee that such a representation is affected by uncertainty ("ceteris are never paribus" when coming to the representation of autocatalytic loops). The concept of entropy, in this case, translates into a sort of "yin yang" predicament. The triadic reading on contiguous levels, which is possible thanks to the self-entailment of identities across contiguous levels makes possible to perceive and represent an autocatalytic loop. On the other hand, it also implies that such a representation is just one among many alternatives and that it is affected by uncertainty, ignorance (= a sure obsolescence).

7.5.3 Conclusion: the peculiar characteristics of adaptive metabolic systems

Thermodynamic analysis, even when adopting a mysterious and esoteric terms such as "entropy", cannot be used to deal in substantive terms with the sustainability of complex adaptive holarchies. On the other hand, entropy provides a very powerful metaphor related to the peculiar characteristics of adaptive metabolic systems. The main semantic messages associated to this concept are: (1) openness of these systems in terms of interaction with the context (therefore one has to expect a fuzzy definition of what is the border between system and environment). There is a distinction between the functional boundary of types (associated to the expected domain of influence of a pattern) and a real boundary associated to a particular realization (which therefore is not particularly relevant in scientific terms); (2) organization in nested hierarchies (therefore one should expect to find different useful identities for the same system when observing it at different scales and/or when using different detectors); (3) the possibility to use "**types**" to perceive and represent characteristics of "**individuals**" (complex adaptive systems must be organized in equivalence classes of organized structures sharing the same template); (4) awareness that our knowledge of types entails a certain degree of uncertainty. Because all dissipative systems are special; (5) unavoidable emergence of novelties (complex adaptive systems must become something else in time) – which implies the existence of an unavoidable degree of ignorance in our forecasting of future states or events (it is impossible to predict future scenarios); (6) unavoidable degree of arbitrariness in any formal representation (any representation of these systems reflect the perception associated to the peculiarity of an "observer/observed complex") which cannot be considered as substantive.

This is a crucial point that will be developed in the following chapter about the unavoidable arbitrariness of the choices made by scientists observing the reality, which translate into the need of selecting useful narratives for surfing on complex time. **Scientists can only measure and study observer-dependent representations of complex adaptive systems, which are simplified versions of the reality and which get obsolete in time.** This translates into the existence of legitimate, but contrasting views about the usefulness of a given representation, which are directly related to legitimate, but contrasting interests of non-equivalent observers.

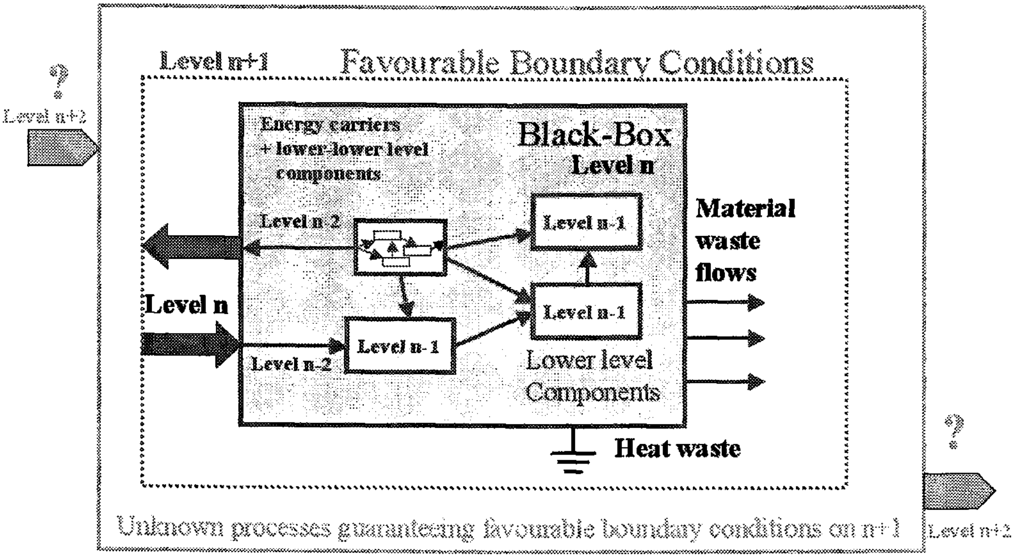
Looking at this list of semantic messages carried out by a metaphorical interpretation of the concept of entropy, we can easily understand why this concept is so popular in the debate over sustainability. In fact, if on one side entropy cannot provide us with a "magic bullet" made up of analytical tools which make possible to formalize, measure and individuate in substantive terms the "best course of action" in relation to sustainability of complex systems. On the other side, we have to admit that such a concept has a tremendous potential to help interdisciplinary researchers to look at old problems by using different questions. The only caution is that one should always be aware that thermodynamics, in spite of its look as a "very-hard-science" is just another possible narrative available to humans to make sense of their shared experience of the reality (Funtowicz and O'Connor, 1999).

The same set of considerations suggesting that a substantive formalizations of Prigogine scheme is impossible (because of the epistemological predicament of complexity discussed so far) provide also a way out from the formal impasse. Scientists can take advantage of the robustness of mosaic effects of self-entailing identities of adaptive complex systems across scales. To this regard, the metaphorical message given by the triplet of entropic assessments proposed by Progogine is that it is possible to establish relations of congruence among non-equivalent definitions of formal identities across contiguous levels (Impredicative Loop Analysis). This relation of congruence will impose constraint on the value taken by assessments of energy and matter flows in relation to the particular choice of formal identities assigned to: (a) system, (b) components, (c) energy carriers, and (d) transformations in relation to what has be assumed to be an admissible environment.

Put in another way: (1) a known typology of metabolic system can be associated to a specific typology of autocatalytic loop of energy forms – we can expect an association between known identities and experienced patterns. (2) this autocatalytic loop can be represented on contiguous hierarchical levels using formal identities of types, in a way that imposes a set of reciprocal constraints on the value taken by the various assessments of energy flows associated to a given selection of identities (to a given choice of how to represent such a phenomenon). That is, we can expect to find mosaic effect across levels.

These points are very relevant for developing analysis of biophysical constraints affecting the organization of nested dissipative systems. This is the reason why we believe that an integrated use of these concepts can be at the basis of useful procedures of multiple-scale integrated analysis of complex dissipative holarchies.

Fig. 7.1 Hierarchical levels that should be considered to study autocatalytic loops of energy forms



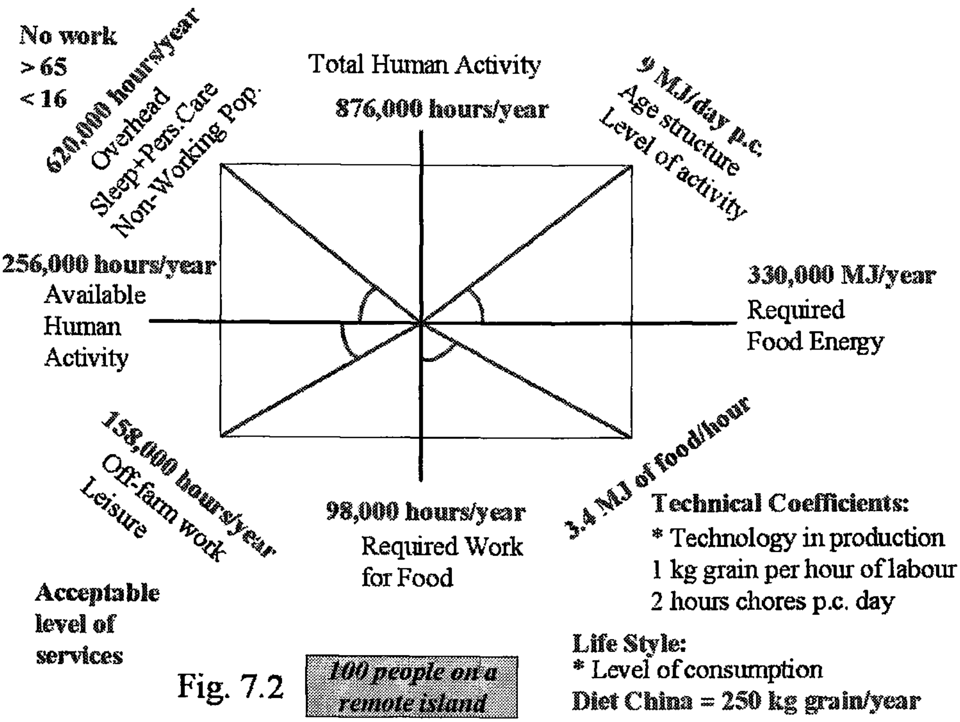


Fig. 7.2

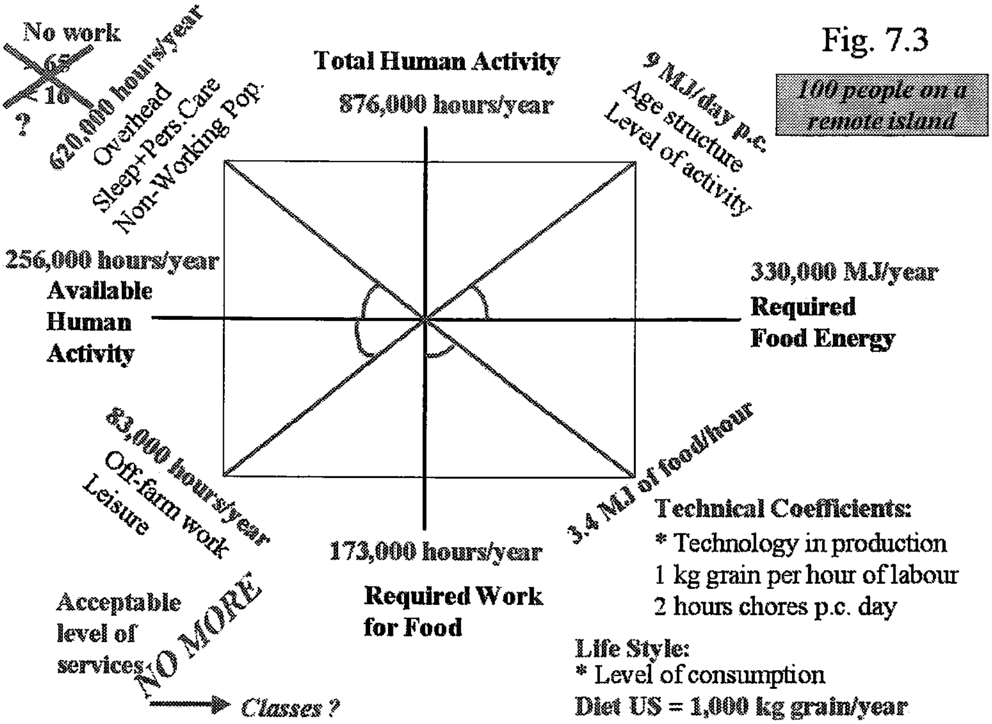


Fig. 7.3

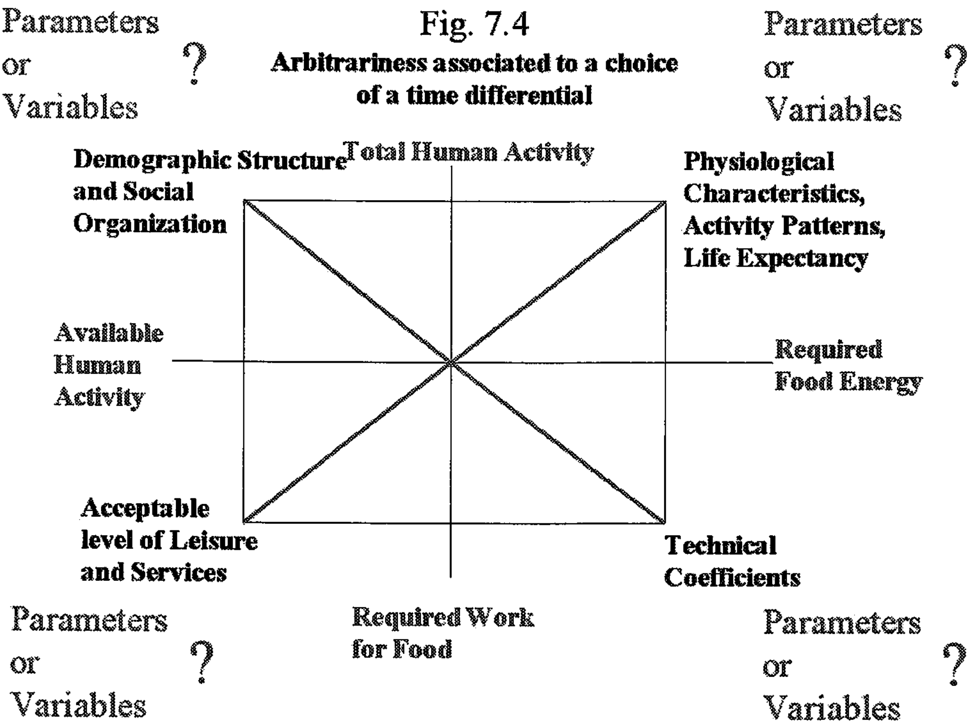


Fig. 7.4

Arbitrariness associated to a choice of a time differential

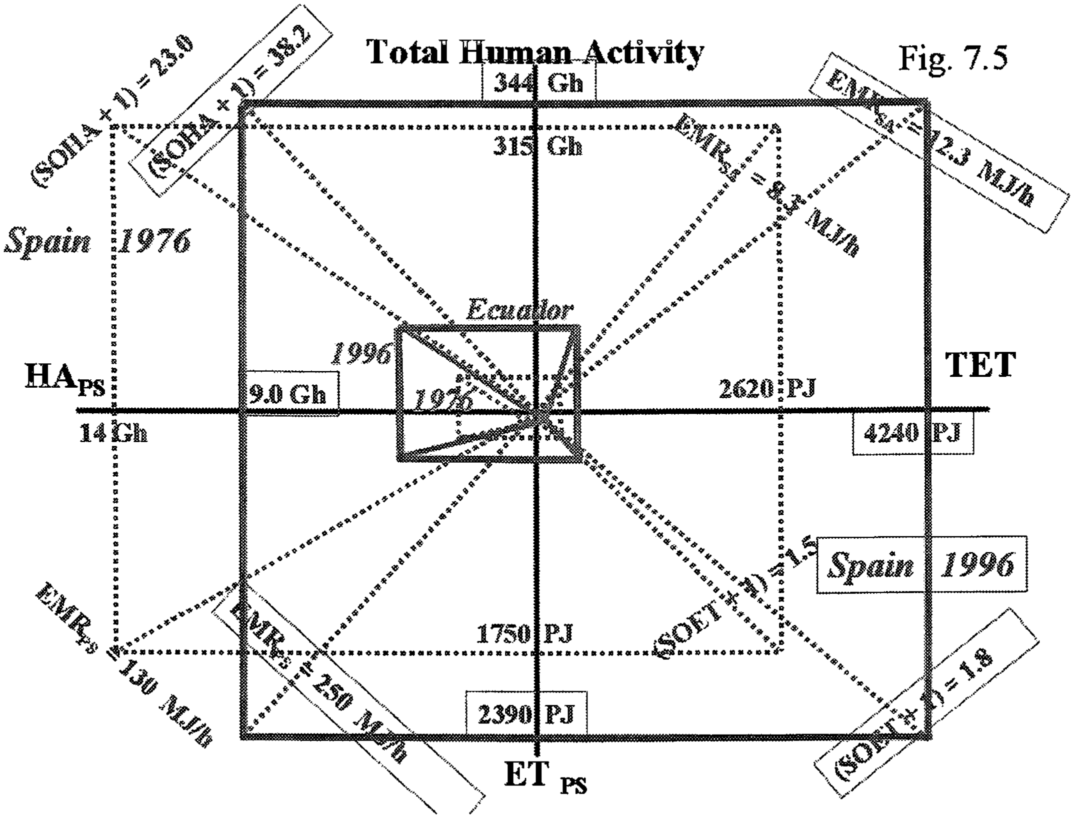

Total Human Activity
344 Gh
315 Gh
(SOHA + 1) = 23.0
(SOHA + 1) = 38.2
EMRSA = 12.3 MJ/h
EMRSA = 8.3 MJ/h
Spain 1976
Ecuador
1996
1976
HAPS
9.0 Gh
14 Gh
2620 PJ
TET
4240 PJ
(SOET + 1) = 1.5
Spain 1996
1750 PJ
EMRPS = 130 MJ/h
EMRPS = 250 MJ/h
2390 PJ
(SOET + 1) = 1.8
ET PS

Fig. 7.5

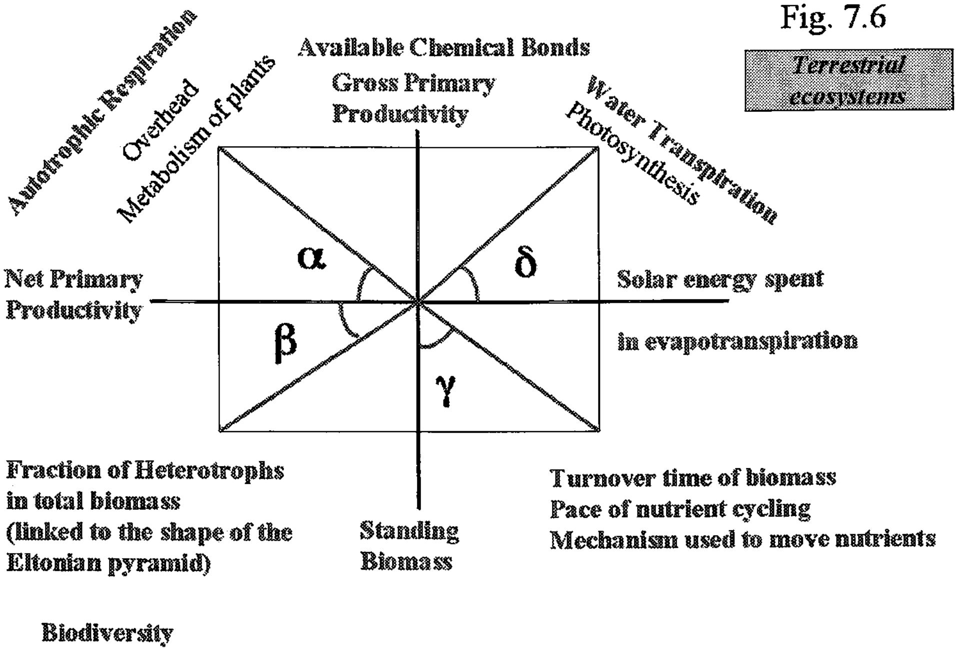
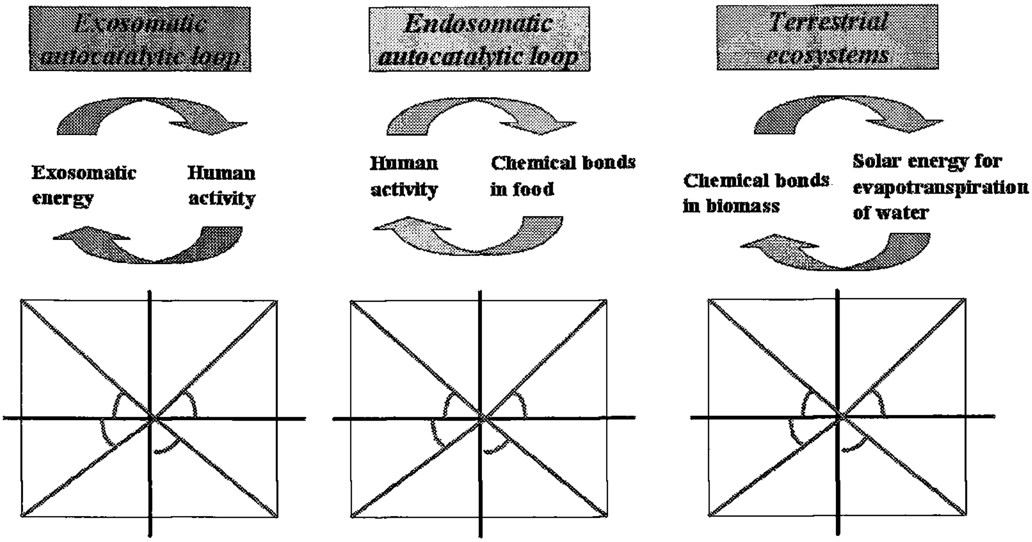

Available Chemical Bonds
Gross Primary Productivity
Autotrophic Respiration
Overhead Metabolism of plants
Water Transpiration
Photosynthesis
Terrestrial ecosystems
α
δ
β
γ
Net Primary Productivity
Solar energy spent
in evapotranspiration
Fraction of Heterotrophs
in total biomass
(linked to the shape of the
Eltonian pyramid)
Standing Biomass
Turnover time of biomass
Pace of nutrient cycling
Mechanism used to move nutrients
Biodiversity

Fig. 7.6

Fig. 7.7 The nested hierarchy of energy forms self-entailing each-other identity



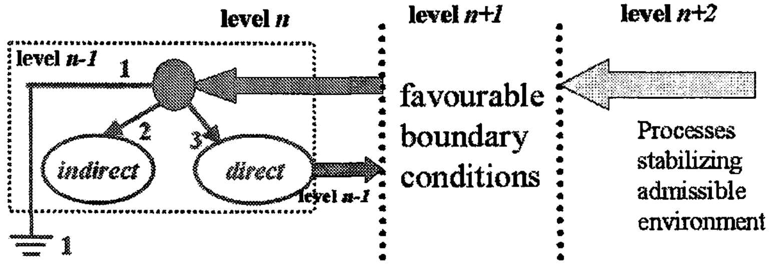


Fig. 7.8a

ILA: the rationale of the meta-model

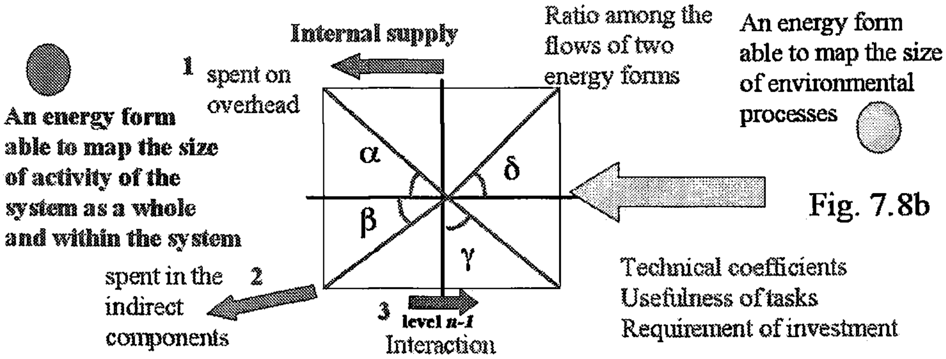


Fig. 7.8b

Fig.7.9a

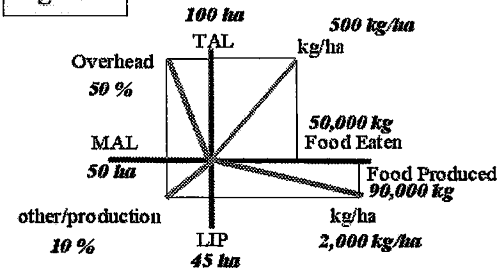


Fig.7.9b

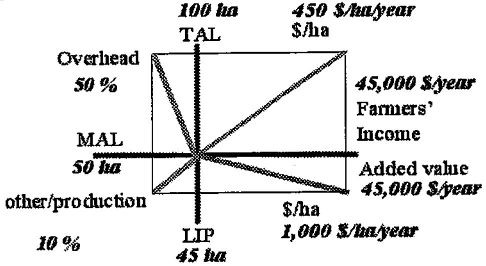


Fig.7.9c

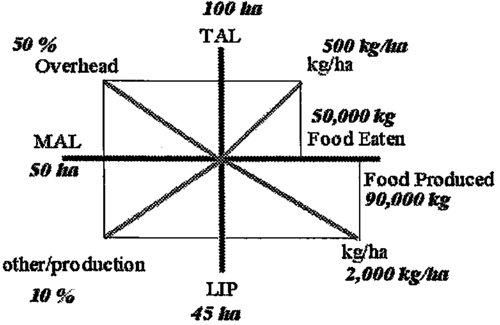


Fig.7.9d

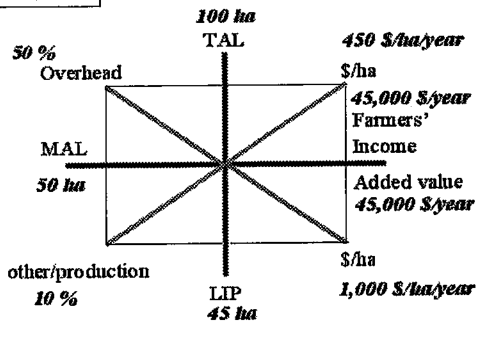


Fig. 7.10 Examples of categories of land use useful to characterize a typology of farming system in high-land Laos

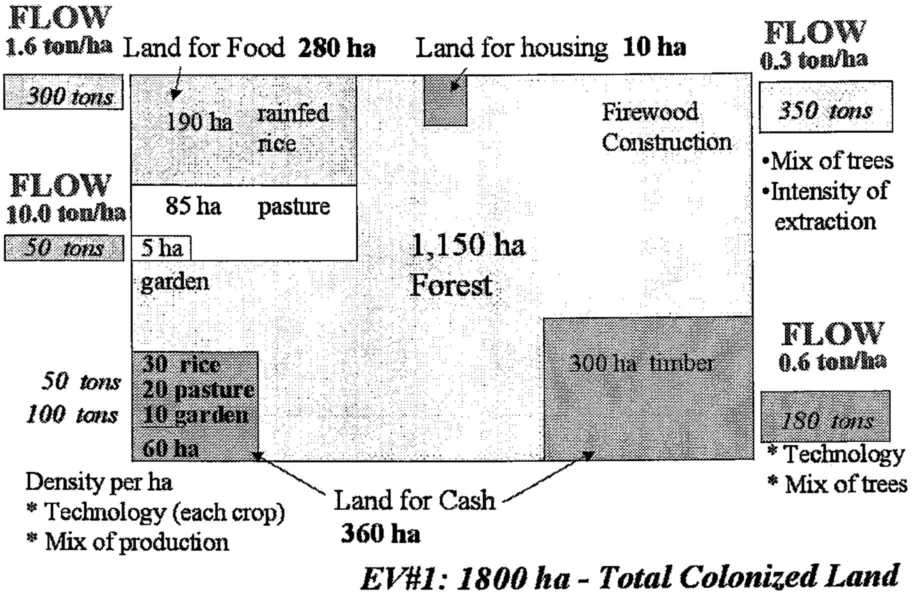


Fig. 7. 11 Defining the density of flows for the whole in relation to the definition of the parts (based on the data given in Fig. 7.10)

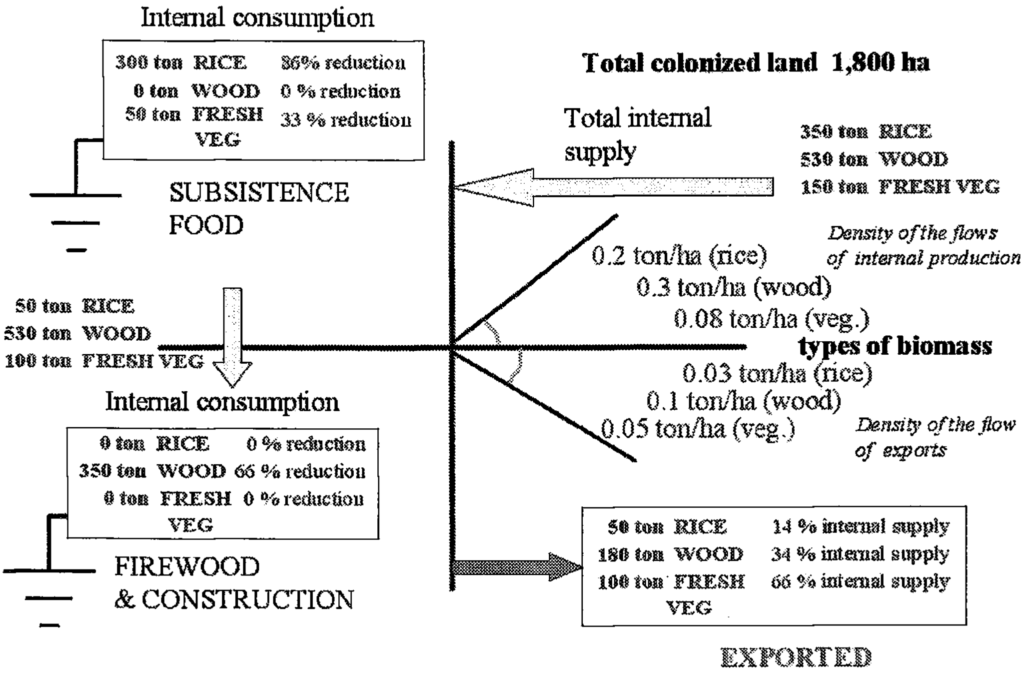


Fig. 7.12 Examples of "*reduction*" (choice of EV#1 and EV#2) and "*classification*" (choice of categories providing closure) for representing societal metabolism.

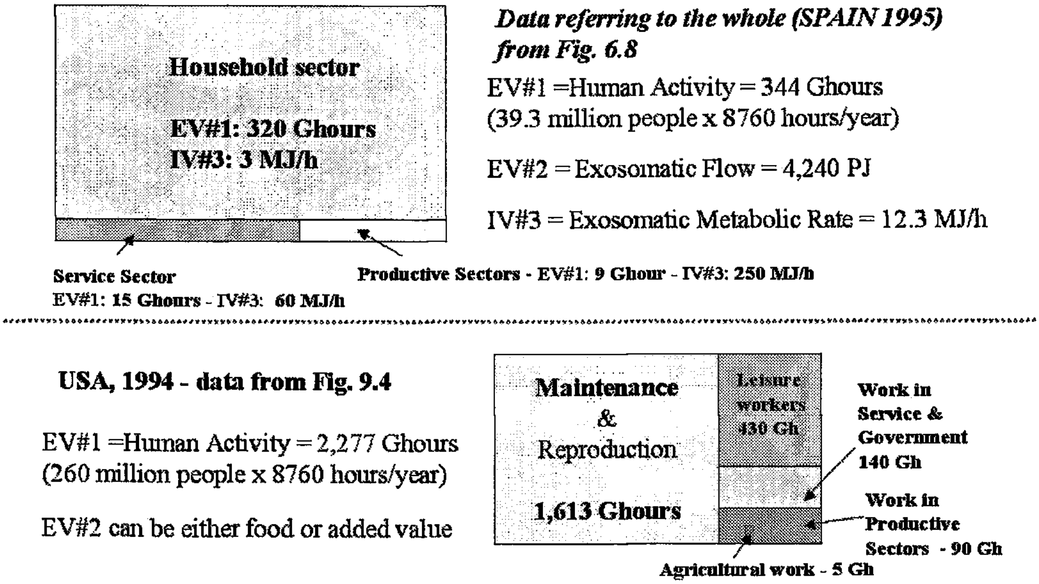


Fig. 7.13 Relation among types in an Impredicative Loop

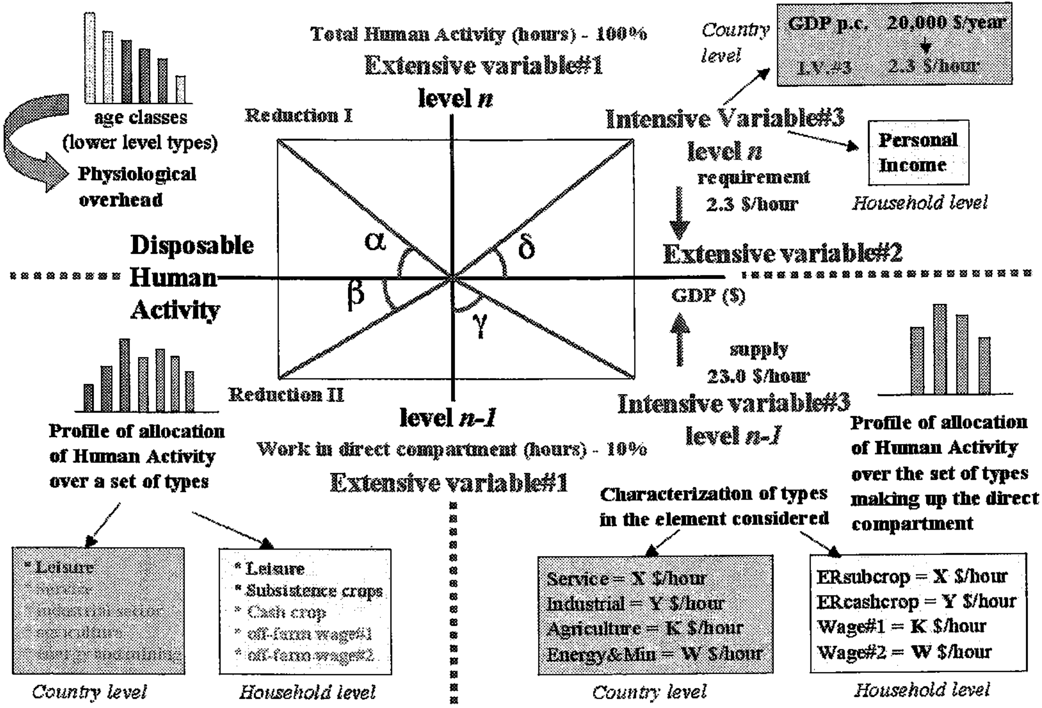


Fig. 7.14 Application of ILA to farming system analysis
[EV#1: hectares of land, EV#2: Yuan - South East China]

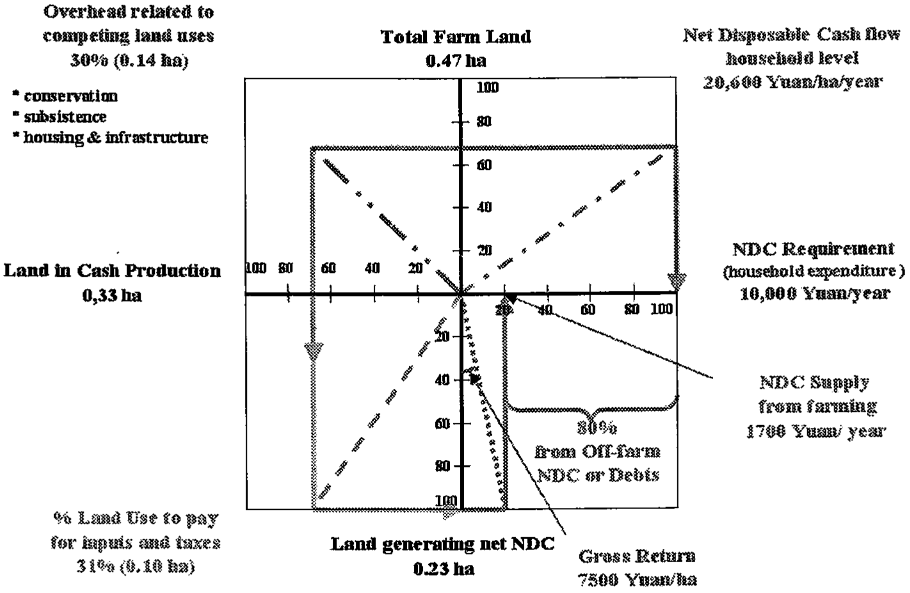


Fig. 7.15 Application of ILA to farming system analysis [EV#1:Hours Human Activity, EV#2: Yuan - South East China]

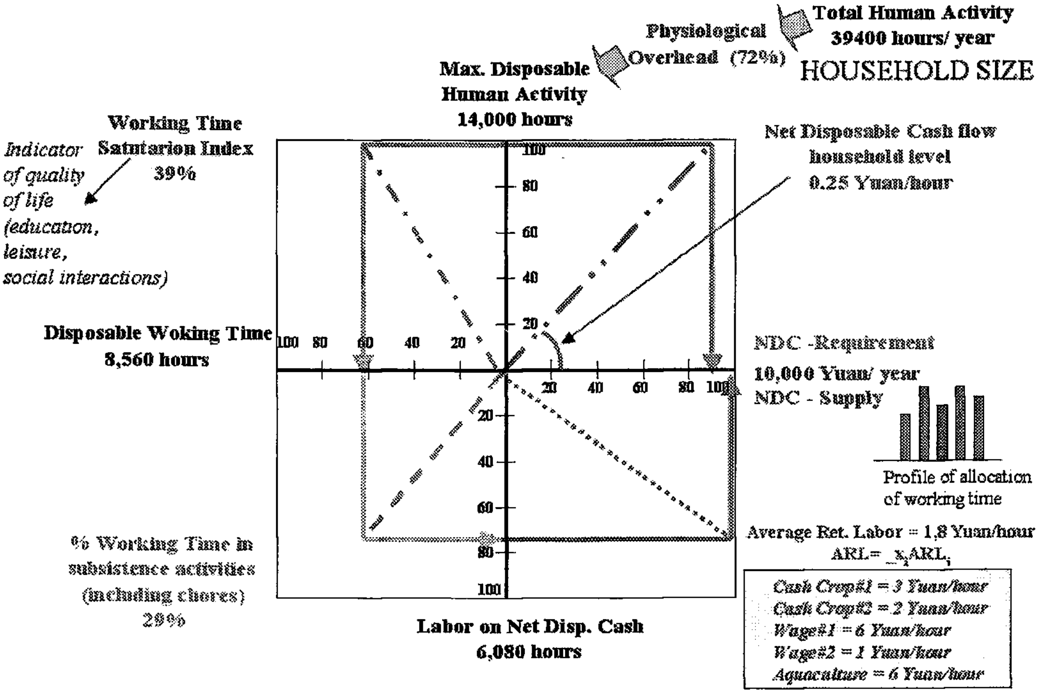


Fig. 7.16 Application of ILA to farming system analysis [EV#1:land area, EV#2: food - Shifting Cultivation, Laos]

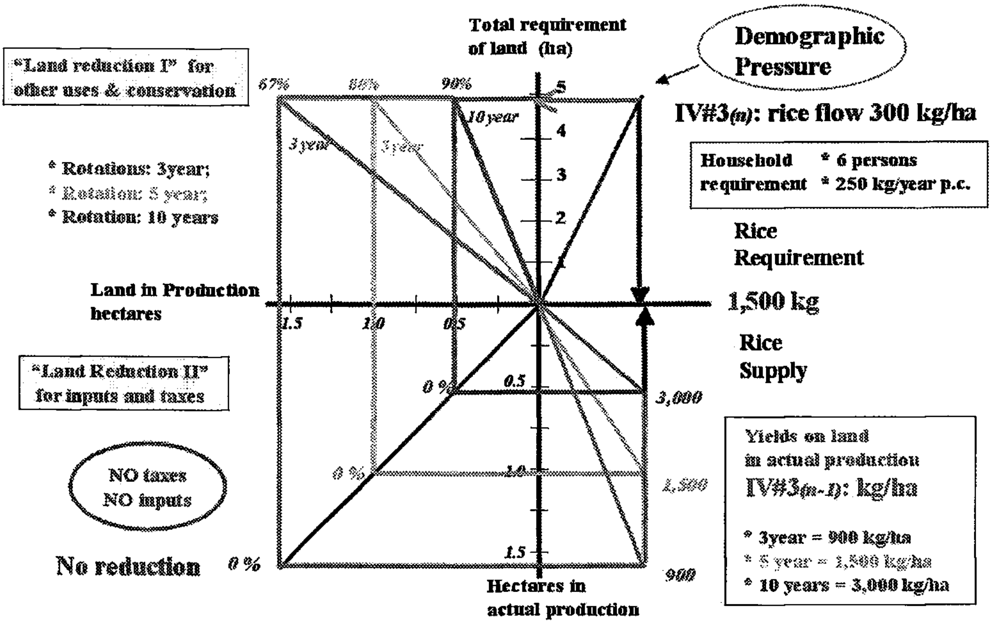


Fig. 7.17 Energetics of human labor: characterizing the performance of energy conversions across hierarchical levels

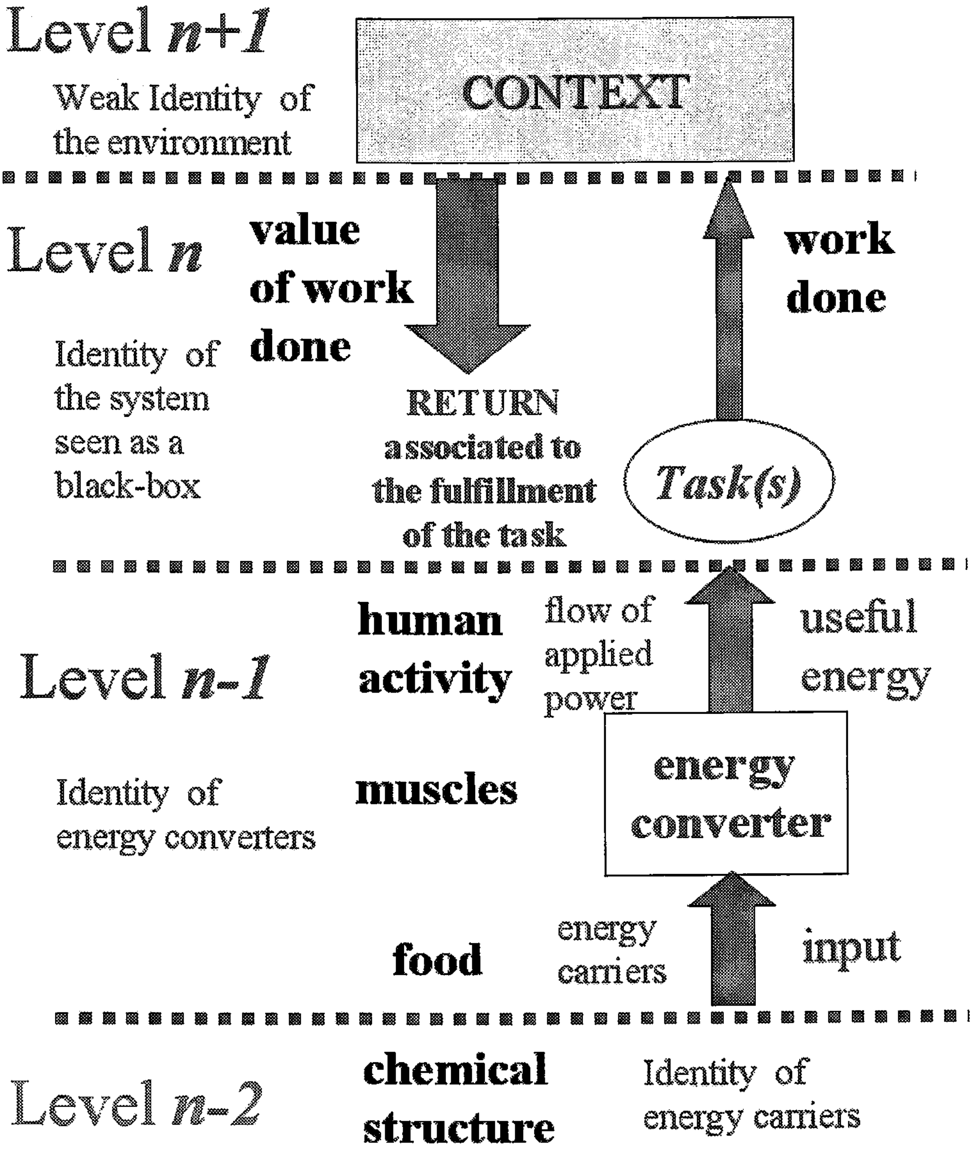
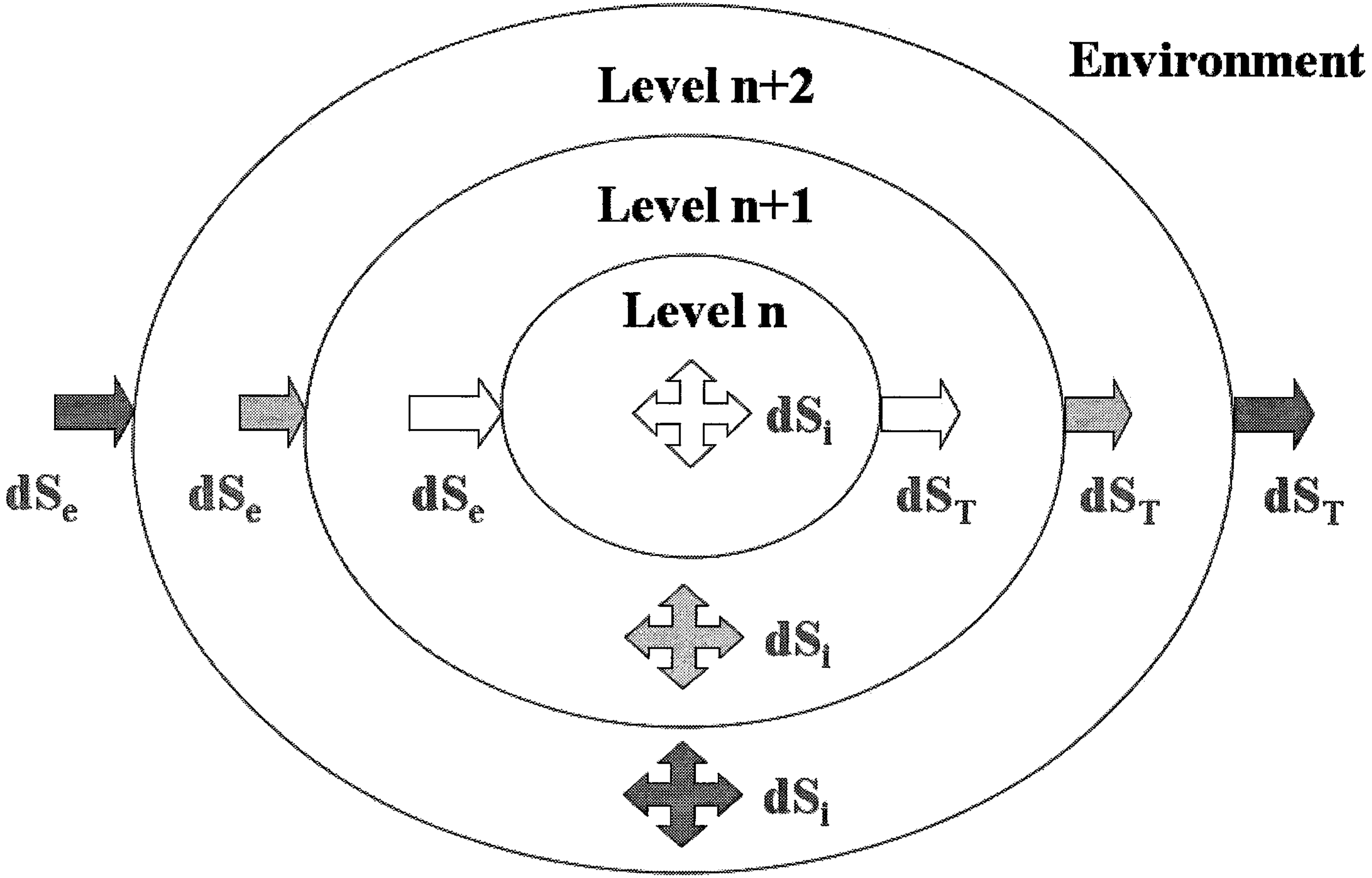


Fig. 7.18 Hierarchical levels that should be considered to study entropy exchanges according to Prigogine's scheme



Chapter 8*

Sustainability requires the ability to generate useful narratives capable of surfing complex time

This is the last chapter dealing with epistemological issues. Actually, after reading Chapter 6 and Chapter 7 in which the concepts of ***mosaic effects across levels*** *and* ***impredicative loop analysis*** *were introduced, the reader fed-up with epistemological discussions can skip this chapter and move directly to Part3. The question answered by this chapter is the following one. If we refuse the charge that the expression "sustainable development" is an oxymoron, then, we should be able to describe what is that remains the same (sustainable) when the system becomes something else (development). We understand that to some practitioners this question could appear too theoretical. However, the message proposed so far is that those analysts willing to deal with the issue of sustainability cannot just apply formal protocols. Complexity requires the adoption of flexible procedures of analysis that always imply an explicit semantic check. For this reason, we believe that, those that are serious about developing analytical tools for dealing with sustainability, should address first of all – as done in this Chapter - the peculiarity of this predicament.*

Coming to the content of this chapter, Section 1 introduces a few concepts that can be used to better frame the challenge implied by sustainability. The basic rationale proposed by Holling when representing evolutionary patterns (using the concepts of resilience, robustness, the cyclic movement among interrelated types – the adaptive cycle) is briefly introduced and translated into the narrative adopted so far in this book using the vocabulary presented in Part 1. Then, Section 2, which is a technical section, deals with the concept of "essence". Something that cannot be formalized and that can be associated to the existence of multiple identities. The concept of essence requires a special discussion, since this is the elusive concept generating the epistemological predicament implied by complexity. In this section, first we provide several examples to show the relative unimportance of DNA in the definition of "essences" in biological systems. Then using theoretical insights provided by the work of Rosen and Ulanowicz, we propose a mechanism which can be used to obtain a formal reading – images - of the un-formalizable concept of essence within the analytical frame provided by network analysis. The final section – Section 3 – deals with the definition of useful narratives in relation to the concept of complex time. Building on the concepts discussed in the previous two sections, we claim that useful narratives can only be "defined by" and "defined in relation to" a given complex observed/observer. Because of this, they have to be continuously updated during the never-ending process of evolution which includes both the observer and observed system. In particular, the requirement of a careful timing for updates becomes crucial when dealing with the reflexivity of human systems. That is when: (a) observer and (b) observed are at the same time (a) observed by the observed; and (b) observing another observer, in a reciprocal process of interaction. This situation implies that both sides of the observer/observed complex can suddenly change their identity, implying

that validated narratives can suddenly loose their usefulness.

*** Kozo Mayumi is a co-author of this chapter**

8.1 What remains the same in a process of sustainable development?

8.1.1 Dissipative systems must be becoming systems

Dissipative systems are necessarily "becoming systems" (Prigogine, 1978), since they have to continuously "negotiate" their identity with their context in time. As discussed in the previous chapter the very existence (success in preserving its own identity) of a dissipative system implies the local destruction of favourable gradients on which its metabolism depends (a consequence of the second law of thermodynamics). Therefore, dissipative systems tend to destroy the expected stable associative context to which their current identity (type) is associated. Because of this fact, a reliable and predictable associative context must be a context which is stabilized by another process of dissipation (which requires in turn favourable boundary conditions on a higher level) occurring elsewhere (see **Fig. 7.18**). This is the first mechanism that generates trouble in the representation of these systems. As noted before (Chapter 7) the stabilization of the identity of these systems can only be obtained through Impredicative Loops in which processes of dissipation occurring in parallel on different levels should be considered in terms of reciprocal entailment among identities defined on non-equivalent descriptive domains. When representing these systems we have to select one (among many possible ones) window of three levels (triadic reading), and assume: (a) on the lower-lower level, that structural stability is given; and (b) on the higher level, that favourable boundary conditions are stabilized by some benign process ignored by the model.

To make things more difficult, adaptive dissipative systems must use templates (e.g. DNA or social institutions) to guarantee the stability of their own identity (elements across levels). This implies the required stability of "types" expressed over a 'time window' larger than the life-span of individual components providing structural stability to the functions expressed by types. Realizations of an equivalence class have a shorter life span than that of the validity of the template used for making them. That is, organized structures sharing the same template undergo a process of turn-over within a given set of expected types. Unfortunately, a mechanism of replication based on templates generates an additional problem of sustainability. Self-replicating dissipative systems are affected by an innate "Malthusian instability" according to the expression coined by Layzer (1988). As soon as a dissipative pattern associated to the existence of favourable boundary conditions finds a good niche (= room for expansion), it tends immediately to expand its size by amplification (making more copies of the template). This means adding more individuals organized structure belonging to the class sharing the characteristics of the type associated to the pattern. The sudden enlargement of the domain of activity of the pattern means jeopardizing the very survival of the mechanisms of replication. In fact, by making more copies of themselves (by making more of what seems to work under the existing perception of favourable boundary conditions), adaptive dissipative systems tend to amplify on a larger scale the rate of destruction of local favourable gradients. Probably, a few readers have already recognized in this mechanism, the ultimate driver generating the problems of sustainability of human affairs discussed in chapter 1 (Jevons' paradox leading to the generation of various "tread mills").

Any dissipative system which keeps growing in size just by amplifying the same basic process of dissipation will sooner or later get into troubles. We can recall here the story of Zhu Yuan-Chang's chessboard: if you put one kernel of rice on the first square, two on the second, four on the third, and keeping doubling the number each square, there would be an astronomical number of kernels required for one position even before the 64th square is reached. This metaphor says it all. Using the expression proposed by Ulanowicz (1986) hypercycles (positive autocatalytic loops), when operating without a coupled process of control (and damping) do not survive for long, they just blow up. The expected troubles at one level (= too much of an efficient type) implies that part of the surplus has to be invested in exploring new types (even if non efficient) able to diversify the set of relations expressed by the whole (on different levels).

Dissipative systems which use a template to replicate themselves, when taking advantage of existing favourable gradients, must re-invest a part of their "energetic profit" to become something else. This is the deep reason why mutations in DNA should not be considered errors, but a crucial mechanism associated to the ability of biological systems to evolve. We addressed this key feature of adaptive dissipative systems when representing – in **Fig. 7.8a.** – these systems as made up of two compartments: direct compartment (where we can define the efficiency of the return on the investment) and indirect compartment (where the system invests in adaptability). As noted in Section 3.6.3 (**Fig. 3.7**), adaptive dissipative systems in order to stabilize their own process of dissipation have to balance their investments in "efficiency" (making stronger the actual set of identities) with investments in "adaptability" (expanding the option space of the set of virtual identities). This is what leads to the concept of "sustainability dialectics". That is, it is not possible to formalize in a substantive representation of an optimizing function the expected trade-off between these two types of investments. Existing identities must not be too greedy, maximization of profit or efficiency, implies reducing the option of expressing alternative virtual identities. The only certain point that can be driven home from the unavoidable process of becoming of complex adaptive system is that a strategy looking for a maximization of "efficiency" (obtained under the 'ceteris paribus' hypothesis) is not the wisest thing to do if one is concerned with the long term stability of the system.

8.1.2 The perception/representation of becoming systems requires the parallel use of the concepts of identity and individuality

In the 70s Buzz Holling proposed a few concepts for the analysis of the sustainability of changes in ecological systems. These concepts were "resilience", "resistance" (or "robustness") and "stability". The use of these concepts to represent the issue of sustainability of ecological systems has remained very popular among those trying to make formal analyses of sustainability both for human and ecological systems - an overview given by Holling himself, about the use of these concepts is available in Holling and Gunderson (2002). It should be noted, however, that in spite of the large popularity of this narrative, and the crucial importance of these concepts for the understanding of the evolution and behaviour of ecosystems, very little effort has been invested by those using these concepts in getting engaged into an epistemological discussion of them. If you ask different ecologists about the definition of these terms you would get different answers. By looking at the literature in this field one can find several definitions of resilience that are non-equivalent and non-reducible. Very often they are even listed as a set of interchangeable optional definitions, without addressing that they are mutually incompatible and exclusive. It is obvious, that the success of these terms is associated to their deep ambiguity, which can handle the different meanings that ecologists attach to them. A mathematician, on the other hand, would ask you to better specify the mathematical meaning of concepts like stability or resilience before getting into any discussion of their syntactic. Obviously, this is not the way for advancing in a critical epistemological appraisal of them. If we keep the terms too ambiguous, anyone can use them without problems, but in this way one has to renounce to a discussion about their semantic (what is the external referent that should be used to share the meaning about them). On the other hand, if the definition is too formal (as done by the mathematicians) everything is reduce to syntax. But exactly because of this, after having done that, it is no longer possible to discuss about the semantic usefulness of the relative concept. Robert Rosen spent a large part of his academic career in dealing with the epistemology of such a discussion. Therefore, this section has the goal to share with the reader some of Rosen insights.

Any theoretical discussion about the epistemology of these terms requires first of all answering the following question. "***When dealing with the analysis of the evolution of a given adaptive dissipative system, if we want to do measurements and make formal models about it, what remains 'the same' when the system becomes something else?***"

Just to get our discussion started, let's try to describe the three concepts of "resilience", "resistance" (or "robustness") and "stability". Two non-equivalent ways of defining these terms are listed below: (a) the definitions found in a dictionary (Merriam-Webster on line), and (b) the semantic meaning conveyed by these terms according to a narrative and a vocabulary taken by the work of Robert Rosen (1985; 1991; 2000). Obviously, we do not claim that what is posted below is "the right" interpretation of these terms. This is not the issue here. These definitions are needed to share with the reader the meaning assigned to these terms (share a common understanding with the reader) in the rest of the chapter.

RESILIENCE

From the dictionary

= the capability of a strained "entity" to recover its original condition (e.g. size, shape, structural characteristics) after a deformation caused by stress.

Narrative – using Rosen terminology

(referring to the idea of multiple equilibrium states for a dynamical system).

→ A given system has a certain identity. That system faces a perturbation (a non-admissible environment) that makes its present state no longer viable (= boundary conditions which are not compatible with the mechanism keeping the metabolism associated to a given type alive). The system can access alternative states (since it has multiple identities). In one of these alternative states the very same boundary conditions which were not-admissible for the previous identity becomes admissible. In this way, the system can preserve its individuality. This system must have the ability to switch among different viable states in relation to different definitions of "admissible environment". In this way, it can preserve the ability to get back to the original state (type) when the perturbation is over. Examples are: tree-branch bending under heavy wind (when the relevant state considered for defining its identity is only the position of the branch). A bacteria forming a spore (relevant state considered: the original organizational structure of the bacteria, which comes back when the perturbation is over). An ephemeral plant making seeds when the environment becomes too dry (as before).

ROBUSTNESS (or RESISTANCE)

From the dictionary:

having or showing firmness (firm = having a solid structure that resists stress, not subject to change or revision, not easily moved or disturbed).

Narrative – using Rosen terminology

→ A given system has a certain identity. That system faces a perturbation (that would generate a non-admissible environment). But the system can react to it, by fighting the process which is generating a hostile environment. This can be obtained using a set of controls (a tool-kit of alternative behaviours linked to anticipatory models based on previous experience of the same perturbation) – expressing a behaviour which is based on an anticipatory model "knowing" about the potential perturbation - or just having a size large enough or enough redundancy to overcome and dissipate the perturbation into an admissible noise. This requires also the ability to: (1) "expect" possible perturbations; and (2) control enough power (being able to express the dissipative pattern at a size large enough), to combat the exogenous perturbation. Examples are: immune systems in mammals, storage of water in plants when facing shortage of rain in the desert.

STABILITY

From the dictionary:

The property of a body that causes it when disturbed from a condition of equilibrium (or a steady motion) to develop forces or moment that restore the original condition.

If we want to translate this definition into a narrative based on Rosen terminology we should get into something very "generic":

→ the ability of retaining your individuality in the face of perturbations no matter how you do it.

This definition could be accepted as a variant of that of "resilience" or also as a variant of that of "robustness". This is due to an open ambiguity in the definition of the terms used. In order to decide how to deal with this ambiguity, we should, first of all, be able to answer the following questions: What is the time threshold considered for retaining identity? What has to be considered a perturbation big enough to be distinct from normal noise? What is defining a given individuality of a system that can change its identity in time? What is that defines a given type which is expressed by different individualities? Are we more interested in the preservation of types (same pattern stabilized by a turn-over of lower level structural elements) or individualities (path-dependent organized structures that changed their identity in time)?

The impossibility to answer in a general (substantive) way these questions implies that often it is not possible to make a substantive distinctions between the concepts of "resilience", "robustness" and "stability". Depending on what is the subject of our analysis (an individuality or a type) we can find different "threshold values" for assessing recover time and for defining the degree of perturbation and different useful strategies. To make things more difficult, the specification of these concepts is virtually impossible in nested hierarchical systems in which each of these concepts has to be defined on different scales (space-time domains), even though the "resilience", "robustness" and "stability" of each level is affecting the others.

This deep epistemological ambiguity can explain why, these concepts escape formalization. This means also that in order to better characterize this discussion in a different way we have to introduce new "epistemic categories". The introduction of new epistemic categories requires first of all the ability of sharing the meaning assigned to new labels and terms. This is the reason why this book invests a large part of its text to deal with epistemological foundations and why, in the rest of this chapter, the reader will find a lot of pictures and examples taken from daily life experience, used to introduce concepts. Without introducing new concepts with examples familiar to everyone, it is impossible to share the meaning of new epistemic categories. On the other hand, without using new relevant concepts to be considered in analysis of sustainability (concepts that are ignored in reductionist science) it would be impossible to discuss of how to do integrated assessment of agroecosystems in an innovative way.

Without a clear understanding of the difference in the meaning of concepts such as resilience, robustness and stability - or better **without having reached an agreement on the meaning that we want to assign to these labels/words in relation to the goals of our analysis** - it is impossible to reach an agreement on how to represent the process of becoming (making analysis of sustainability). Let alone to discuss of strategies useful for improving the persistence of some of the characteristics of evolving systems, that we (and who decides who is we?) would like to preserve.

To conclude this overview of the widespread confusion found in the field of analysis of sustainability of becoming systems we can list additional concepts (variants of the previous ones) often used in literature, which are associated to the ability to resist to perturbation: (a) ***redundancy/scale*** (= because of this quality the system can first resist and then even thrive on smaller scale perturbations. It does it by incorporating them in the identity as functional activities) - e.g. the use of wild fires by terrestrial ecosystems. (b) ***diversity*** (= because of this quality the system has the ability to work with multiple options – both in terms of possible behaviours or organizational states).

All the concepts listed so far are often confused, in their use, with each other, in the same way as the various strategies (redundancy, diversity and adaptability) are often ill-defined and used without a clear articulation of specific conditions and situations. Even worse is the situation with the term "adaptability" which directly points **at the process of becoming obtained by changing identity to preserve a given individuality**. In a way the concept of adaptability could also be associated to the concept of ***persistence*** (if only we were able to answer in formal terms the question: persistence of what?). Due to the relevance of the concept of "adaptability" (which implies a clear acknowledgment of the distinction and an innate tension between identity and individuality) we include below two non-equivalent definitions for adaptability and two metaphors useful to illustrate the concept.

ADAPTABILITY

From the dictionary:

= To make fit for a specific new use [***goal***] or new situation [***context***] often by modification.
(NOTE: the square parentheses and their content have been added by us).

Narrative – using Rosen terminology
→ the ability of adjusting our own identity in order to retain fitness in face of changing goals and/or changing constraints. Fitness means the ability to maintain congruence among: (a) a set of goals, (b) the set of processes required to achieve them; and (c) constraints imposed by boundary conditions. Since adaptive dissipative systems are "history dependent" they preserve their individuality if they manage to remain alive in the process of becoming (the series of adjustments of their identity in time).
This definition can be confronted to the definition of sustainable development proposed in Chapter 4 [section 4.2.2].
Useful Metaphors about Adaptability (from the Bloomsbury Thematic Dictionary of Quotations – available on internet):

- "If the hill will not come to Mahomet, Mahomet will go to the hill" (Francis Bacon)
- "President Rabbins was so well adjusted to his environment that sometimes you could not tell which was the environment and which was President Robbins" (Jarrel Randall)

The point to be driven home from all these examples of definitions is that the set of concepts proposed by Holling to deal with the evolution of adaptive systems entails an unavoidable severe epistemological challenge. Such a challenge is linked to the dilemma about: (i) how to define the identity of the system; (ii) how to define its context; and (ii) how to handle the fact that they change on different hierarchical levels at different paces. What is especially relevant in this discussion is the implicit constant requirement of both **a syntactic** and **a semantic appraisal** of the terms used in these statements. When talking of adaptability and resilience, everything depends on: (a) what is considered to be the relevant set of characteristics used to determine (identify, perceive, represent) the identity of the system in the first place through observable qualities – type definitions; and (b) what is considered to be the individuality of the system. The same individuality can remain – persist - even when its identity change in time as illustrated in the example of **Fig. 8.1**. The 4 pictures given in **Fig. 8.1** can be imagined to be 4 views of Bertha, the old lady on the bottom-left picture, referring to 4 points in time of her life. As noted in chapter 3 a peculiar way of expressing "individuality" of a holarchic system requires a preliminary choice made by the observer about an identity to be assigned to that individuality to make sense of the perceptions (signals carried by incoming data) referring to a given descriptive domain. The particular identity selected to organize our perceptions about a given individuality must be useful for the goal of the analysis. Differences in the choice of identity can be related to a different choice of scale or to a different choice of relevant attributes (as discussed in Chapter 3, e.g. **Fig. 3.1**). In the case shown in **Fig. 8.1** we have an individuality (Bertha) that goes through a predictable trajectory of identities (types). Whenever the observer knows ahead that this will occur, she/he has to select the right set of observable qualities (epistemic categories) associated to the right type (= the expected set of observable qualities useful to describe the individuality at a given historic moment).

This means that the characterization, perception, and representation of a given individuality of a becoming system over a large space-time domain (e.g. Bertha over her life span) requires the skilful handling of different identities. The same will occur if we want to study the multiple types that such an individuality could take (e.g. an overview of various members of different ages that are found in Bertha's family at a given point in time). Actually, when looking at the series of picture given in **Fig. 8.1,** we cannot know a priori if this series of pictures is representing the same person (individuality) at different points in time (e.g. taken at 30 year interval) or if this series of picture was taken in the same day looking at a genealogical line made up of: a grand-grand mother, her daughter, that is mother of a daughter that is mother of a daughter. In both cases, we are dealing with a set of 4 types which are useful to describe a female human being. This implies that the selected type of identity used for the representation of a particular individual of female human being be appropriated to the goal of the analysis. This requirement translates into the need of using different models for representing and simulating the relative perception of changes associated to the selected type(s). Selecting just one among the possible relevant identities included in this set, implies also selecting the relative appropriate model for simulating the expected behaviour of the type. As already discussed in Part 1, formal models can refer to only one formal identity at the time. If we decide to represent Bertha when 95 year old, then we cannot imagine to use a model which has been calibrated on the behaviour of the type representing Bertha when 30 year old. In parallel, a model for simulating the behaviour of a children cannot be used to simulate the behaviour of an elderly, even though they both represent women living in the Netherlands in the year 2000 (this is the home land of Bertha).

That is, only after having specified one of the possible identities (i.e. the particular choice of triadic reading and the set of relevant attributes used to define the system) we can look for a model able to catch the set of expected causal relations used to predict expected changes in attributes. The scientist can attempt to make sense of experimental data only after having selected a given formal identity for the system and an inferential system able to simulate perceived changes in this formal identity (see Rosen, 1985 – the chapter on modelling relation). The data set consists of different numerical values taken by a set of variables selected to encode changes in a set of relevant attributes, which are observable qualities associated to the choice of a measurement scheme, which are associated to the selection of a given formal identity. Because of this long chain of choices, all models are "identity-specific" and therefore they are bound to clash against complexity. Real natural systems are individualities operating on multiple scales, or are multiple-types expressed simultaneously by a population of individualities. This is what entails the existence of multiple non-equivalent ways of mapping the same natural system when considering as relevant different sets of observable qualities (see Chap.2, Chap.3, Chap.6 and Chap. 7).

As discussed in Part 1, the unavoidable existence of multiple valid models for the same reality is not only related to the complexity of the observed system, but also to the complexity of the observer. The existence of non-equivalent and non-reducible models for the same system is entailed by the simple fact that "*life is the organized interaction of non equivalent observers*" (Rosen, 1985). In spite of being non-equivalent and non-reducible to each other, the various models used by non-equivalent observers can be all relevant for the study of the sustainability of becoming systems.

The main point made by Rosen about "complex time" (Rosen, 1985) is that any formalization of concepts such as resilience, robustness and adaptability into a mathematical system of inference has to deal with the existence of at least three relevant but distinct *time differentials*. The "complexity of time" in the process of making and using integrated set of models related to sustainability issues has to be contrasted with the simple time which is operating (only!) within the simplified representation of reality obtained within reductionist models (= formal systems of inference), when used one at the time. The three relevant time differentials are associated to the following processes:

(1) the time differential selected for the dynamics simulated by the set of differential equations (this is what is called in differential equations **dt**).

(2) the expiration date of the validity of the set of models used to simulate causality and the set of variables used to describe changes in the state space in relation to a given selection of relevant identities adopted in the problem structuring. When dealing with becoming systems we have to explicitly address the unavoidable existence of a time horizon determining the reliability of the set of epistemic tools used to perceive, represent and simulate their behaviour. The causal relation among observable qualities does change in time due to the process of becoming of these systems. This implies that functional forms and relations adopted in any given set of differential equations useful to simulate a becoming system at a given point in time should be updated sooner or later. The ability to observe and to measure changes in observable qualities also evolves in time. That is, better proxies and better measurement schemes can become available to encode changes in relevant qualities of the system. This is another reason which can require changing and updating the procedures adopted in the process of modelling. We call the time differential **dτ**, at which the validity of the choice done in the process of modelling becomes obsolete.

(3) the time horizon compatible with the validity of the problem structuring according to the

"weltanschauung" of science and with the particular set of interests of the stakeholders in relation to a specific problem of sustainability. That is, any problem structuring implies a finite selection of: (a) goals of the scientific analysis; (b) relevant qualities; (c) credible hypotheses about causal entailments; (d) observable qualities/selection of encoding variables; (e) related measurement protocols and data; (f) inferential systems; which must be all compatible with each other. Out of a virtually infinite information space (including all the epistemological tools available to humans) scientists have to decide how to compress this intractable mass of information into a finite information space with which it is possible to do science (see Chapter 5). This process of compression of infinite to finite is called "problem structuring", and it establishes an agreed upon "universe of discourse" on which we apply our models to make sense of our potential actions. This choice will constrain what we perceive as happening in the world and "what" we decide to represent (actually what the scientists eventually represent) when defining the identity of the system to be investigated. As discussed at length in Chapter 5 this process of compression of infinite sets of identities, causal relations and goals into a finite set is in turn constrained by an underlying "weltanschauung" in which the scientific activity is performed and by the structure of power relation among the actors. The speed at which the basic "weltanschauung" is evolving (what the social consciousness defines as "relevant issues and facts") can imply the obsolescence of some of the pre-analytical choices associated to a given problem structuring. Changes at this level can imply important consequences on the speed at which the identity of the universe of discourse is evolving. This is especially clear in periods of "paradigm shift". As noted in Chapter 4, the quality of the process generating a given problem structuring refers not only to the accuracy in the measurement and the calibration of models on data. The "relevance" of the set of qualities that should be included in the representation of system identity as well as the relevance of the set of causal relations that should be addressed by the model do change in time. We call the pace of this process of evolution, in relation to the definition of complex time as "time differential" **$d\theta$**. When dealing with the perception and representation of sustainability the relevance of this third time differential can become crucial.

In conclusion, we can define **complex time** as the parallel existence of non-equivalent relevant time differentials to be considered explicitly by the modellers (both inside and outside the model!) when dealing with the implications of changes occurring in the observer/observed complex in relation to the validity of the model.

Why a discussion about the existence of a "complex time" should be relevant for those reading this book? The answer is, because these concepts are crucial for discussing of sustainability. It is very interesting to note that the distinction between "identity" (referring to the first two time differentials dt and $d\tau$) and "individuality" (referring to the second two time differentials $d\tau$ and $d\theta$) has been discussed by Rosen using the metaphor of suicide (Rosen, 1985 pag. 403). A suicide is a person terminating her/his individuality in order to resist the pressure of the context that would force a sudden change in her/his "current identity". For example, there are people that take their life for avoiding: (a) aging, (b) life without a loved one, (c) facing a failure. What is interesting in this case study, is that when dealing with the complex "observed/observer" the preservation of the current "identity" (just one among a set of possible ones) is obtained by eliminating (freezing) the "observer" (blocking the time differential $d\theta$) since nothing can be done about the changes on the ontological side (reality is forcing changes on the observed). The matter of the fact is that all becoming systems (biological and social entities) are history-dependent systems observing and making models of themselves. They must change their identity in time on both sides of the observation process (both as observed and as observer). When the speed of the process of becoming pushes too close the various time differentials (but especially $d\tau$ and $d\theta$), then the predicament of Post-Normal Science can become overwhelming. That is, the very identity of both the observed system and observer system becomes fuzzy since they are affecting each-other definition at a speed that makes impossible to have a robust validation. This can represent a serious problem of governance, related to a relatively new plague (widespread by mass-media) which we can call "butterfly-effect" or "pheromone-attention syndrome" determined by the hypercyclic interaction observed/observer. Media focus on what is of concern for stakeholders and stakeholders are concerned with what is focused on by media. The result is that what is on the spot of the public attention and/or in the debate about sustainability is often randomly generated by lower level stochastic phenomena – what happened to be the initial problem structuring of a given problem given by media. Then this original input is then amplified by lock-in effects (someone with a camera happened to be in a specific place catching a relevant fact . . .). Nobody, however can check how relevant is that particular fact, which is amplified by the spot lights, compared with other relevant facts ignored in the debate simply because they happened in the shadow.

8.1.3 The impossible use of "dynamical systems" analysis to catch the process of becoming

Adaptive holarchies can retain their individuality only if they are able to keep alive the mechanism generating coherence in the expression of their identity across the three time differentials defined in Complex Time. This implies the ability to keep harmony in the pace at which the various identities and individualities and their perceptions and representations are changing in time. This requires a deep interlocking of "ontological" and "epistemological" interactions (Chapter 2). The term "expression of an identity" refers to the concept of self-entailment between (a) establishing processes able to "realize" viable equivalence classes of organized structures sharing the same template at different levels (an ontological achievement); and (b) integrated processes across hierarchical levels able to determine "essences" in terms of the validity of mutual information used by interacting agents, which is associated to the perception, representation and running of anticipatory models at different levels (an epistemological achievement). This is a mechanism that cannot be fully represented using conventional formal systems of inference.

For example, the formalization of concepts such as resilience and stability is in general attempted from within the field of dynamical systems analysis. Actually, this field provides powerful images (e.g. basin of attractions) that are often used with semantic purpose. For example, "the shape of the basin of attraction" is a very popular metaphor. Resilient systems are depicted as having a shallow and large basin. Robust but fragile systems are associated to basins very deep and small in domain. An example of these two metaphors is given in **Fig. 8.2** (taken from Giampietro et al. 1997). These visualizations are certainly useful, but they do not avoid the original unsolved problem. Any formalization of "resilience", "robustness", "stability" or "whatever else label" we want to use within the field of dynamical systems requires the previous definition of a given "state-space". With a state-space we mean a finite and closed (in operational terms) information space made up of variables, referring to observable characteristics of the system, that can be measured at a given point in space and time through a measurement scheme. The implications of this fact are huge. To represent a basin of attraction you need numbers, which in turn requires assessments (measurement schemes), which in turn must refer to given typologies (types defined as a set of attributes), which are represented using a set of epistemic categories (variables). Put in another way, if we plan to develop **formal analytical tools** to study the evolution of adaptive dissipative system, we need measuring key characteristics of them through an interaction within an experimental setting that makes possible to encode observable qualities into numerical variables. These measurements are location specific. That is, they are and must be "context" and "simple time" dependent. "Simple time" is what is perceived from **within the representation of reality** (the model) obtained within a closed and finite information space, and what we generate within the artificial settings of an experimental scheme. Because of this, the dt of the model is reflecting: (a) the choice of a triadic reading associated to our perceptions; and (b) the filter on possible signals implied by the measurement scheme. That is, such a dt will reflect the pre-analytical choices made when choosing the particular model.

The validity of simple models requires two assumptions related to the definition of identity for the system: (1) the existing associative context will remain valid (e.g. the environment is and will remain admissible also at a different point ins pace and time). That is, the validity of the model implies the absence of changes in relation to **$d\tau$**; (2) the choice of relevant attributes used to define the identity is agreed upon by all the observers (e.g. it is impossible to find a relevant user of this model that does not agree with its assumptions). That is, the validity of the model implies that the general agreement about its usefulness and relevance does not change in relation to **$d\theta$**.

However, considering as valid these two assumptions – as required by dynamical systems analysis - puts the modeller in the unpleasant situation of defining concepts (resilience, robustness, stability) associated to the identity of static dynamical systems perceived as operating out of complex time. These systems can have multiple attractors. They can be even able to switch from one attractor to another at command. They can jump, they can get chaotic and engage in any type of fancy mathematical behaviour. But yet **the identity of their information space does not evolve in time** - see the work of Rosen (2000) and Kampis (1991) for a more elaborated discussion of this point. They are not alive, they are not becoming something else, they **are not adding new essences and new epistemic categories (emergence)** to their original information space. Finally, and most important, **they are not adding new meanings (for the observer) to their identity.** Put in another way, the real problem with complex systems is not about the fact that they are exhibiting a non-linear behaviour. In fact the technical feature of linearity or not linearity of dynamical systems refers only to changes occurring within the known state space and the simple time defined on **dt.**

Even when moving away from dynamical systems analysis to more advanced inferential systems based on the use of computers (e.g. cellular automata) the problem of a sound representation of the behaviour of complex systems is not fully solved. These new mathematical objects can establish bridges between patterns and mechanisms operating on different levels, and this is a major step forward. However, also in this case, the mathematical tool makes only possible to better clarify the mechanism associated to "emergence". They can explain how a pattern expressed at one scale can be associated to pattern defined on different scales. We can find - using the output given by a computer -new properties that can be interpreted by the modeller in terms of additional insight provided by the algorithm. But the real challenge, in this case, remains that of finding the "right" set of external referents that can provide meaning to this analysis on multiple levels. In our view there is a big risk associated with this new generation of "sophisticated formalisms". Many practitioners tend to apply them to the analysis of sustainability, under the incorrect assumption that more complicated models and more powerful computers could handle the complexity predicament just by providing more syntactic entailment . .

. Put in another way, the risk that we see is that this new frontier of development of more powerful inferential systems can represent yet another excuse for denying a relatively simple and plain fact: **becoming dissipative systems organized in holarchies have, and must have, a non-computable and non-formalizable behaviour to remain alive** (Rosen, 2000). Modellers should just accept to deal with this fact.

8.1.4 The nature of the observer/observed complex and the existence of multiple identities

Let's imagine that an extraterrestrial scientist belonging to an unknown alien form of life would suddenly arrive on Earth to learn about the characteristics of "holons-human beings". She/he/it would be confronted with the fact that human beings can be classified in non-equivalent ways. These different ways could be seen as different "attractor types" using the vocabulary of dynamical system analysis or different "types" associated to "identities" using the vocabulary developed in Chapter 2 and 3. For example, a given human being can be characterized as a "system" belonging to an equivalence class, which can be defined by adopting a set of observable qualities – or attributes (temperature of the body and organs, pH of the blood, number of legs and arms, etc.). These characteristics have to be common to all the members of the equivalence class. In this case, a set of variables, which are proxies of the set of observable qualities associated to the class, must take a range of numerical values contained within a feasible domain of the class (individuals with six legs and individual with 20 eyes are not included in the class of humans). These expected "features" and relations among variables associated to a given identity implies the definition of expected relation between numbers (if the specimen is human it must have the expected number of arms, legs, eyes and ears); and a chain of "tolerance ranges" in the relative numerical assessments used to represent them. The value taken by the proxies used to assess each relevant quality must be included in a range (spread of the values around the average). The error bars associated to the measurement scheme must be compatible with the domain of feasibility for the variable. A very generic definition of identity for human beings can be based on a set of attributes common to the majority of human types (e.g. temperature of the body and organs, pH of the blood, two legs and two arms, existence of typologies of organs).

Within this very generic definition of human beings we can imagine a large set of possible typologies of realizations. Therefore it is possible to define more specific "typologies" by constraining such a large domains with additional epistemic categories. For example, a human observer can combine the generic definition of "human being" (defined using the attributes listed before) with three relevant epistemic categories related to age (e.g. children, adults, and elderly) and two additional relevant epistemic categories related to gender (e.g. males and females). In this way, it is possible to obtain the definition of 6 basic "types" for humans: boys, girls, men, women, old men, old ladies. This selection of types can be further expanded at will, by adding new "relevant" categories (e.g. short, medium, tall; blond hair versus black hair; dressed versus undressed, etc.). **The number of relevant human types found in this way will ultimately depend on the number of categories which are considered useful by the observers in organizing their perceptions.**

Therefore, we cannot know the set of "human types" that alien observers would find. This would be determined by their selection of relevant characteristics sought in humans (are humans dangerous? are they good as food?). The consequent selection of the epistemic categories used by aliens for the definition of human types (e.g. level of presence of cobalt in their hairs, amount of radioactive radiation emanating from the body) will reflect their choices about how to organize their perception about humans.

Depending on the size of the sample that the extraterrestrial will use, they could find very little variability in human types (e.g. a cluster of homogeneous human types found when sampling just 10 students in a class-room, or 20 soldiers in a platoon) or a larger variability (e.g. when sampling the population of an entire continent). That is, by expanding the size of the sample and/or the diversity of detectors used to gather information about humans, the observers will change the universe of potential types. For example, alien observers can find:

* **a given set of attractors related to the existence of multiple equilibria (in terms of dynamical systems analysis) or multiple identities.** A massive project for studying humans on this planet based on a large sampling of humans at a given point in time would provide a set of well defined categories to be used to characterize humans. These categories should be based as much as possible on the existence of equivalence classes occurring naturally in such a big sample. As noted in Chapter 2 and 3 the process of self-organization of dissipative holarchies does generate naturally equivalence classes, types and essences. Therefore, smart aliens in order to increase their anticipatory power, when modeling humans, should be able to pick-up a set of epistemic categories that would make possible to get a maximum in compression for their representation of the characteristics of humans. If this is true, we can only imagine that, after a period of learning about humans, they probably could end up by representing human types using some of the same categories used by humans themselves. In this case, they will converge on the definition of a set of multiple identities existing in the holarchies making up humans (e.g. human organs, individual humans, baby-girls, adult men, households). Depending on the available set of types used in pattern recognition (to categorize the individuals in the sample), an observation made at a particular point in time but over a large space domain (e.g. at a particular day over an entire continent) – a synchronic analysis – will provide a profile of distribution of individuals over the given set of possible types. That is, the system "human being" can be perceived and represented using a set of different identities at a given point in time.

* **a cyclical attractor (in terms of dynamical systems analysis) or a given trajectory across identities** such as, for example the set of identities represented in **Fig. 8.1** and **Fig. 8.3**. The 4 pictures given in **Fig. 8.3** can be imagined to be 4 views of Gina, the old lady on the bottom-left picture. In analogy with **Fig. 8.1**, these can be interpreted as 4 views of the same individuality represented at 4 points in time of her life. When comparing the 4 pictures given in **Fig. 8.1** with the 4 pictures given in **Fig. 8.3** we can note that even though we are dealing with two distinct individualities (Bertha and Gina), the set of 4 typologies through which these two individualities go in time and the sequence among the types (girl, adult woman, lady and old lady) are the same. If the project of investigation of the extraterrestrial expedition had followed a certain number of households over a long time scale – e.g. centuries - using the set of typologies adopted in **Fig. 8.1** and **Fig. 8.3** they would have found a predictable pattern in the order in time in which these typologies of identities appear in the life cycle of individual persons. That is, a diachronic analysis of human beings (e.g. history of a royal dynasty or important families such as Kennedy's or Bush's families) makes possible to look at a different set of typologies linked to a turnover of lower elements into a role. This can be seen as an emergent pattern, when considered at a higher hierarchical level (on a time scale larger than that related to the life span of an individual). The perception of this pattern, however, requires the adoption of a larger time horizon, which has to include to the whole cycle of lower level holons in the role defined at the higher level. This pattern overlook the perspective of the individualities involved in its expression. When looking at this pattern (what the sequence of identities has in common in **Fig. 8.1** and **Fig. 8.3**) we have to ignore the details, which are relevant to recognize either Bertha or Gina as individual persons. The process of ageing described using types is non-equivalent to that used to describe the individuality of persons! Put in another way, in order to "see" the turnover time of individual realizations within the relative "type" [= babies getting adult, adult getting old and dead people replaced by new born babies], we have to ignore information which is crucial when dealing with individual realizations. To make things more difficult, there are processes related to the structural stability of both types and individualities [= the physiological processes keeping alive over a time scale of seconds each of the persons represented in the 8 pictures in **Fig. 8.1** and **Fig. 8.3**], which are defined at yet another scale (lower-lower level!).

Two things are remarkable in this discussion: (1) the unavoidable arbitrariness in deciding what should be considered as a holon-human being (especially when considering that holons are made of other holons made of other holons); and (2) coming to the problem of mapping and measurement, the only meaningful things that can be measured by an extraterrestrial expedition willing to know more about humans are the qualities of "types" and not the qualities of any special individual human being.
That is, when dealing with the perception and representation of learning adaptive holarchies, **what is considered as "real" by naive empiricists** (= special individual realizations materially defined in terms of structures) **is not a relevant piece of information for scientific analysis and models.** The input given by "real entities" to the process of measurement (extraction of data from the reality) is useful only when such an input is processed in terms of typology within a valid interpretative scheme. In this case, the input is useful since it provides information about the characteristics of relevant types or essences of which the real entity is just a realization. Science deals with types (= patterns defined over a space-time window which are useful to organize our perceptions in terms of epistemic categories). The space-time domain of validity of a definition of "type" is larger than that of individual realizations. On the other hand, data and measurement can only be referred to individual realizations seen and measured at a particular point in space and time. This is why we tend to see "types" as "out of time", since they refer to a standardized perception of a given relation type/associative context.

8.1.5 How to interpret and handle the existence of multiple identities

The two series of pictures provided in **Fig. 8.1** and **Fig. 8.3** refer to the perception and representation of a given individuality going through a transition across a set of predictable identities. That is, different "identities" (types associated with equivalence class) defined as: "girl", "adult woman", "lady", and "old lady" are the expected "states" that a given individuality (person) will take during her expected trajectory of evolution in her life-time. Obviously to each of these types we must be able to apply the generic set of mappings defined for all human beings (= temperature of the body and organs, pH of the blood, two legs and two arms, existence of organs). That is, to be a valid set of integrated identities girls, adult women, ladies and old ladies must all belong to the class human beings in the first place.

In conclusion, when dealing with the representation of persons we need three different pieces of information related to the perception and representation of the process of becoming shown in **Fig. 8.1** and **Fig. 8.3**. These three types of information are:

(1) a family of models able to represent the functioning of human beings (described in general terms) and that can be applied to each of the 4 identities. This would be, for example, the set of descriptions of physiological processes within the human body (e.g. those associated to respiration), which can be obtained by adopting a set of descriptive domains common to all the 4 types. This requires a preliminary selection of relevant identities of lower-lower level elements associated to the respiration of humans which refer to specific choices of triadic filtering, identification and representation of organized structures (e.g. alveoli, capillary, hemoglobin molecules). At this point, we can generate numerical assessments of values taken by variables and parameters. Examples of this type of information are given in **Fig. 8.4**. The various dynamics represented in the various examples pasted in **Fig. 8.4** are all expressed using a simple dt of general validity for the "type" supposed to operate "by default" in the right associative context (admissible environment, favourable boundary conditions).

(2) a family of metaphors able to catch the similarity implied by the sequence of types into the cycle. That is, we should find a metaphorical knowledge able to tell us **what all girls have in common when compared against adult women, ladies and old ladies in relation to the process of aging of a person.** At the same time, the metaphor should also tell us what adult women have in common when compared against girls, ladies and old ladies in relation to the process of aging of a given person, and so on. Obviously, in this case, we need a meta-model able to deal with the semantic of these relations. That is the meaning of the relation among the 4 typologies included in the figure has to remain valid even when applied to different individualities (e.g. in this case, different persons) or a different type of essences (e.g. the process of ageing of a dog). In this case, the problem is with the definition of the "quality to be measured" – the choice of attributes associated to the identity used to characterize a given equivalence class to which the individual realizations (the specimen under investigation) are supposed to belong.
As discussed in the previous chapters, essences referring to adaptive metabolic systems (humans and biological/ecological systems) are always defined over a very large space-time window, since they require the simultaneous adjustment of the mechanisms determining the feasibility of the various equivalence classes on different hierarchical levels. This requirement of mutual information across scales implies that the set of qualities required to have sustainability in evolutionary terms has nothing to do with the type of information illustrated in **Fig. 8.4.**

A very interesting example of metaphoric knowledge related to the cyclic sequence of types within a role – exactly what is shown in **Fig. 8.1** and **Fig. 8.3** - has been provided by Buzz Holling (Holling, 1995; Gunderson and Holling, 2002), and it is shown in **Fig. 8.5**. The metaphor proposed by Holling is interesting since it requires abandoning a formal representation based on exact models to move to a semantic description of events. This can be immediately realized by the fact that this metaphor got a lot of different names by different authors: "adaptive cycle", "cycle of creative-destruction" (recalling a similar idea of the economist Schumpeter), "4-box-figure-8 adaptive cycle" or the "lazy 8". This metaphor will be explored in detail in the next section.

(3) information about the history of the system that makes possible to characterize the special

individuality of this evolving system. All complex adaptive systems (learning holarchies) have and must have a history in order to be able to generate an integrated set of reliable identities. **It is their special history that makes possible to trace their individuality.** However, **it is exactly the keeping record of history that entails the development of narratives** (selecting what relevant aspects should be included as records in the storage of information and what should be excluded). **Keeping records means, in fact, selectively removing those details of a given history which are considered as non relevant.** This has important implications. This implies that the very decision of what represents the real "individuality" of a system, when this system has changed its identity in time, becomes an arbitrary decision. **Defining what is the individuality of a becoming system is a matter that cannot be dealt in objective, "substantive" terms. This is an operation that cannot be neither described or performed from outside the complex "observed/observer".** For example, it is a person that became totally crazy (unable to retain the awareness of her/his own identity) still the same person? For a citizen asked to vote this person as President of the USA, the answer is a clearly not. For a mother asked to take care of this person the answer is yes in most of the cases. The problem here is generated by the fact that a voter and a mother are generating different narratives about the history of: (a) a public officers, candidate for a new term; (b) her own children, that had a car accident.

As a matter of fact, we can disclose to the reader that the set of pictures presented in **Fig. 8.1** are not referring to the same person, exactly as the set of pictures presented in **Fig. 8.3**. Rather they are two non-equivalent combinations of mappings. Bertha's line – **Fig. 8.1** – represents 4 generations of women (Bertha is the old lady, whereas Ria, her daughter, is the lady to her right. Sandra – the adult woman - is the daughter of Bertha's daughter Ria. Finally Sofia is the grand-daughter of her daughter Ria. On the contrary, Gina's line – **Fig. 8.3** – presents only 2 persons. Gina, is the lady on the lower level, shown in two pictures taken at 30 years of distance. Whereas, in the upper level there is Marinella, the daughter of Gina, that is also shown in two pictures taken at 30 years of distance. By giving this information to the reader we changed the know-how of the reader/observer of these two figures. At this point, are our readers no longer feeling that the 4 pictures of each of these figures are representing the same individuality? More specifically, in which sense the reader can say that we are dealing with 4 individualities when looking at **Fig. 8.1** and only with 2 individualities when looking at **Fig. 8.3**? To make this statement the reader must trust what has been written by these authors. Why this distinction should be relevant for someone that does not know personally the persons represented in these two series of pictures? For sure, there is something in common in these pictures that makes possible to recognize the same individuality (same line) in each of the series of the two figures. For the monarchy the concept of "individuality of the line" is essential. If it is true that there is something in common between the 4 pictures within each of the two figures (a common line), it is also true that there is something in common among the typologies of the two lines. Something that makes possible to predict expected changes within an expected pattern of types for each of the two lines. In any case, predictions about the relation of multiple individualities, identities or essences found when observing a complex reality can be formalized only with a great care and having a deep awareness that alternative formalizations can be legitimate and valid. Moreover, uncertainty is always at work. Not even the most general characterization about the class human beings can be extrapolated to individual cases expecting full reliability. For example, an adult person could lose a leg because of a car accident and therefore not even a simple prediction [about the number of legs] in the next type (at the time t+1) starting from the knowledge of the number of legs in the type (at the time t) is necessarily granted.

When we recognize that the same pattern of "types" referring to the same individuality is going through different stages, we have to expect that human systems operating at different stages of their life cycle will adopt different definitions of optimal strategies for sustainability. This is a crucial peculiarity that human holons have because of their reflexivity. This is what leads to the need of answering tough questions when dealing with the sustainability of human holons. Sustainability of what? Defined on which time horizon? [= are we sustaining an identity associated to a given type, an essence or an individuality]? Why supporting an identity should be more important than supporting an individuality (e.g. maximization of profit which induces social stress)? or why the interest of individualities should be more important that the preservation of essences (e.g. loss of cultural diversity because of widespread fast economic growth)? We are back to the unavoidable existence of contrasting indications and contrasting optimizing strategies (recall the non-equivalent explanations of death found in **Fig. 3.6**) for agents belonging to contexts defined at different stages of the cycle. The optimal strategy for the young girl is that of growing and getting as fast as possible the characteristics of older types (becoming a woman!). Whereas, the optimal strategy for adult women is that of avoiding to get the characteristics of older types!

8.1.6 The metaphor of "Adaptive Cycle" proposed by Holling about evolution

To analyze the nature of the unavoidable ambiguity in determining a distinction between identity, essence, and individuality, let's get back into a brief discussion of the metaphor proposed by Buzz Holling under the name of adaptive cycle. What shown in **Fig. 8.5** is a very sophisticated application of this metaphor to the analysis of sustainability of ecological system. A detailed description of this meta-model can be found in Holling and Gunderson (2002). A reading of this text (or more in general of the work of Holling in this direction) gives a clear idea of the powerful insights that can be gained by adopting it. We want to focus here only on the aspects related to the preliminary choice of a set of 4 identities (types) that have to be over-imposed in time on a given individuality that the use of this metaphor entails. It should be noted that such a metaphor has a very general applicability, the cyclic attractors can be used to explain various sequences of predictable states taken by an individuality. This individuality could be an ecosystem and the four types can be the four seasons (in this case the 4 pictures will be spring/summer/autumn/winter) using a small time window, or the stages of development (in this case the 4 pictures will be the stages that go from early colonization to senescence). In alternative the individuality could be a given person (or an organism) and the 4 types will be different stages of the life cycle (as in the examples given in **Fig. 8.1** and **Fig. 8.3**).

For reasons that will be explained in the next section we applied the representation of this cycle based on the use of an integrated set of 4 types to the description of the development of a model of a car (individuality). This view is shown in **Fig. 8.6.** In fact, also the evolutionary cycle of a new model of a car can be expected to go through predictable stages according to Holling's scheme. Whenever there is an "opening" for a new model of car, a car maker can decide to go for it. The first template of such a model does not need to be very sophisticated. In step 1 what is needed is just something that is able to fill an empty niche. Whatever that does the job is OK. We can recall here the story of the Ford Model T that was launched in 1908. At the beginning the real issue for the US buyers was: "having a car" getting out of the state "not having a car". No options were available. This is the basic reason that made possible for Henry Ford to say the famous line "consumers can have it in all the colours they want as long as the colour is black . . .". Since the filling of the niche was a success (buyers were buying more than the car maker was able to supply) next problem was that of producing enough. That is next changes in the model were related to the improvements related to the process of fabrication of members of the equivalence class. By 1914, the moving assembly line enabled Ford to produce far more cars than any other company. However, a very large size of the niche (Ford built 15,000,000 automobiles with the Model "T" engine!) implied new problems. (1) Diversification of performance (since a large niche is geographically covering different expected associative contexts). Sooner or late the use of a huge amount of cars entails the requirement of performing different functions; and (2) Fighting competition within the niche (since a large niche – many buyers willing to invest in cars – tend to attract competitors). This is the third stage, when the Ford Model T was made in different colours and versions. Finally, we arrive to the final stage of maturity, when the basic structural organization of the template becomes obsolete. A new set of tasks and a new set of local associative contexts are now faced by the members of this equivalence class (cars).

A different selective pressure is operating due to changes occurred in the larger context. However, these changes in the larger context have been induced exactly because of the large success of the original model, which was able to amplify so much the domain of activity of this class. At this point, nobody would invest resources in building a new assembly line for making additional members of this obsolete equivalence class. On the other hand, as long as the production lines - existing capital – are still operating, it can pay to add a few possible gadgets to the template, to keep alive the production. In the phase of senescence car models tend to get into micro niches empty from competitors, which would not invest to get there.

This very same cycle across different stages for a model of a car is shown in **Fig. 8.6**. The model of car considered there is FIAT 500 of the Italian car maker FIAT. Four different identities adopted by the same individuality over a predictable cycle, that can be associated to differences in history, boundary conditions and goals. First, an idea is realized about a possible model filling an empty niche. Then when a positive experience confirms the validity of the original idea it is time to patch the original process of realization according to operational problems (scaling up). In this way, it is possible to occupy as much as possible the niche (take advantage of favourable boundary conditions to expand the domain of application of the type). When the size of the new pattern is large enough to guarantee enough protection against perturbations for the basic identity, then it becomes possible to explore new functions and tasks that can be associated to complement the original ones to expand the viability of the equivalence class in slightly different associative contexts. In fact, the large scale of operation of the original pattern tends to feed-back in the form of a new definition of the context of the original essence. At this point, it is important to look for a different model (a new set of organized structures mapping onto a new set of tasks). However, because of the existing investment – lock-in – for a while can be convenient to keep using the old process of fabrication of members of the obsolete equivalence class (for defining this situation we can use expressions like: "Concorde syndrome" or "sunk cost").

We can gain a crucial insight from the metaphor of the "lazy 8" of Holling if we add a third axis to the plane shown in **Fig. 8.5**. This three dimensional view is shown in **Fig. 8.7**. As illustrated both in **Fig. 8.5** and in **Fig.8.6** during the adaptive cycle, after the phase of release and before the phase of reorganization (before spring so to speak), **there is the option for the process to become something different**. That is, the phase of re-organization of a given type within a given associative context can lead to a phenomenon of emergence. In this case, the small changes accumulated at the level of the type and the small changes accumulated in the identity of the associative context can move the interacting type-associative context into a new self-entailment across identities. That is, we can look at the emergence of a new association between type and associative context across the various constraints operating at different levels. In this case, the self-organizing holarchy can jump into a different mechanism of self-entailment among identities across scales. The example given in **Fig. 8.7** shows first the cycle related to the model of the car "FIAT Topolino", which reached the last stage in the 50s making possible the launch of a new model in the late 50s. Then the "Fiat 500" took over going through the cycle to reach senescence in late 70s, when a new model "FIAT 126" took over (with a large engine – 700 cc of displacement - and better technical characteristics). But the larger engine was not enough to keep up with the changes occurring in the Italian socio-economic context. This is what led to the definition of a new type (FIAT Cinquecento), with an even larger engine – 900 cc of displacement.

Two important observations are needed in relation to this example.

(1) the three-dimensional representation given in **Fig. 8.7** shows the evolution in time of a car that is obtained by establishing congruence between processes occurring on the ontological side (the making and using of cars) and processes occurring on the epistemological sides (the decisions about producing and the decisions about the buying of cars) across hierarchical levels. The different 4 stages through which a given model of car - e.g. the "FIAT Topolino" – is expected to go through, represent different ways of obtaining congruence among these two set of processes. Therefore, in this figure we see the same pattern of movement across stages (the 4 types indicated in the adaptive cycle), which is repeated in time in relation

to the trajectory of development of different individualities – models of car. In this example the three models of car are: (i) "FIAT Topolino"; (ii) "FIAT 500"; and (iii) "FIAT 126". That is, we can define the individuality as **the model** and the 4 different types as **versions of this model**.

If we want to represent using numerical variables the changes in relevant system qualities associated to this process of evolution we have to deal with the meaning of the third axis. That is, when describing evolutionary trajectories of models of cars, the identity of the information space - the variables used to represent the characteristics of the different models (the type of information similar to that given in **Fig. 8.4** about the respiration of persons) - has to be changed. That is, the movement from a model – an individuality - to another (from "FIAT Topolino" to "FIAT 126") entails/requires a change in the identity of the descriptive domain (the set of numerical variables) used to represent the process of becoming over the 4 selected types. The reader can recall here the example of the Benard cell discussed in Part 1. When a vortex is established (emergence of a pattern at a higher hierarchical level) this requires the use of new epistemic categories (an encoding variable associated to the category "anti-clockwise") by the observer. In order to describe in useful terms the identity of the new system. – a vortex – we have to use a new variable that was meaningless in the representation adopted in a molecular description. In the same way, we cannot use epistemic categories common to all the three basic models "FIAT Topolino", "FIAT 500" and "FIAT 126" (e.g. number of wheels = 4; transparency of windows = yes; possibility to stop by breaking = yes) to describe and compare changes associated to movements across the 4 types. In order to distinguish a FIAT126 from a competitor faced in its niche (how and why the FIAT126 is changing over the set of 4 stages), we have to use for its characterization a set of observable variables that were absent in the identity used to describe the FIAT Topolino.

(2) The possibility of jumping into a new individuality during the stage of reorganization is related to the level in the holarchy at which the process is operating. This is a crucial point and can be related to the predicament of science for governance. The "lazy 8" metaphor can be applied to different hierarchical levels found in a holarchy. By enlarging the scale of analysis (moving up in the levels) we can imagine to apply the adaptive cycle rather than to different versions of the same model (as done in **Fig. 8.6**), to different models referring to the same essence of car. This implies addressing what is the meaning of a car in a given context (= the semantic definition of cars to which the various models refer to). To clarify this concept, let's get back to the beginning of the car era, with the Ford Model T and with the FIAT Topolino. At the beginning the major task of the car industry was that of making possible for people to move around using a car. In this stage, comfort and safety were not very relevant. At the beginning of the auto industry, those pioneers that dared to use cars were expected to take chances. Therefore, the role of FIAT 500 was that of increasing the ability to supply an increasing number of cars to those looking for it, at the cheapest possible price. The FIAT 126 remains within the same basic definition of essence of the FIAT 500, but the new model had to include in the definition of the minimum standard of quality for a car, a new set of attributes of performance, at that point expected by vehicles circulating on modern roads (e.g. a decent cruise speed on high-way, new safety devices required by law). This is where the displacement of the engine had to be increased and several additional changes in the body of the car became necessary. At a different level we can think of a different "lazy-8" adaptive cycle based on the movement through different models referring all to the same essence of car.

That is, we can go for a higher level perception/representation of Holling metaphor, this time applied to models of car, rather than to versions of the same model – **Fig. 8.8.** If we look at the same process at a higher hierarchical level we can see that the last "emergent" model at the end of the "lazy-8" adaptive cycle – the new model FIAT Cinquecento – got extinct very soon. This new model never managed to get into the 4 stages of different versions expected for a new model. The explanation for the extinction of this model can be found in the obsolescence of the relative essence. That is, a dramatic change in the "role" that car started to play within the socio-economic Italian context. At the end of the 90s the process of industrialization and the huge supply of cheap popular cars that the car maker FIAT provided in the previous 40 years implied a different "meaning" for small utilitarian vehicles – **Fig. 8.9**. The old definition of role supporting the chain of 4 models illustrated in **Fig. 8.8** (a satisficing combination of attributes for those looking for a car) was split into two different roles for a car – **Fig. 8.9**. The essence of utilitarian car, then, was no longer associated to the role of having a cheap car, but rather associated to a satisficing combination of attributes **for a person owning already more than one car**. Then the new meaning of a small car was that of a car to be used when getting into the heavy traffic of a city. This small car can get pretty expensive in order to do that with a lot of comforts. Because of this change in the definition of performance (expected function) among the population of users, the old generation of utilitarian cars of the car maker FIAT is no longer mapping onto the expected functions of the Italian socio-economic context. This is why, the car maker FIAT is now trying to move the production of "FIAT cinquecento" into a different associative context (e.g. moving to East-Europe). In that socio-economic context the original semantic meaning of the car, associated to that model – the validity of the original niche (**Fig. 8.9** - generalist models, having a car versus no car) - is still valid. Because of this we can expect that within this typology of associative context (made up of buyers looking for their first car), new versions of this model and new models of utilitarian cars will be generated, following to the expected adaptive "lazy-8" metaphor shown in **Fig. 8.7**.

The case of extinction of the FIAT Cinquecento model in Italy provides an example in which a large scale change in the socio-economic context made the semantic definition of essence for a given model of car (e.g. FIAT Cinquecento) no longer valid. Without a valid essence supporting the formal definition of types the process of evolution of new types (versions of the model) stopped. This has nothing to do with the usefulness of blue prints for fabricating an equivalence class of cars belonging to the same model. In this phenomenon of extinction, the quality of the information contained in individual blue-prints about the making of individual cars was quite irrelevant. Rather, it is the process of post-industrialization of the Italian economy, that translated into the definition of new essences for cars and therefore in the need of looking for a new generation of car models.

As noted earlier, the phenomenon of "emergence" of new essences can be expected only on the top of the holarchy. Only on the tope, it is possible to establish new relevant attributes to the definition of identities in the interaction of 5 contiguous levels. This implies learning about how to better interact with the environment. On the contrary, on the bottom of the holarchy, the standard relation "type"/"expected associative context" which is at the basis to validity of the mapping between "characteristics of the given organized structure"/"usefulness of the tasks-functions" **is given and must remain given**. A cell of our bones which gets old and which is replaced by a new born cell, must be organized according to the same template (type), reflecting the same essence over and over and over. The stability of the identity of lower level structural holons is a must for the possibility of expressing new function on the top of the holarchy. The structural stability of lower level components must be assumed as given in dissipative holarchies. As noted in Part1, when we apply the triadic reading, the requirement - on the lower level – of the stability of lower level structural components is the analogous of the requirement about the admissibility of the environment on the higher level.

For this reason, the last interface of the holarchy with its environment (the frontier of the holarchy on the triadic reading n/n+1/n+2) is the only place where the holarchy is able to generated new meaning about new forms of interaction with the context. This is where new essences are introduced into the information space (see the discussion about Post-Normal Science in **Fig. 4.3**).

8.2 Using the concepts of essence, type and equivalence class when making the distinction between identity and individuality

TECHNICAL SECTION

8.2.1 *The unimportance of the DNA in definition of essences in biological systems: The blunder of Genetic Engineering*

To introduce this discussion let's start with an example dealing with the evolution of non-biological essences. The two sets of identities given in **Fig. 8.10** show two trajectories of evolution referring to two "essences": (a) that of a famous "species" of cartoons "Mickey Mouse"; and (b) that of a famous "species" of cars the "Volkswagen Beetle". When searching on internet using a research engine after entering as key-words: "evolution" and "Mickey Mouse", one can find together with hundreds of sites that consider the evolution of Mickey Mouse as a fact, also a couple of sites presenting teaching material in which the "Mickey Mouse syndrome" is proposed as a systemic error made by humans when attributing anthropomorphic characteristics (the ability to evolve in time) to unanimated objects. The basic argument of this reductionist analysis is that "Mickey Mouse" is a dead object that cannot evolve since it/he does not have a DNA. This reasoning is simple. Since, the mechanism providing mutation to biological systems (assumed to be at the basis of the evolution of living systems) is associated with the existence of DNA, adaptive dissipative systems which do not have DNA cannot evolve in time. Therefore, if someone perceive a process of gradual changes in the identity of systems that do not have DNA in time as evolution, we are in presence of a pathological phenomenon of transfer of anthropomorphic concepts to unanimated things.

In relation to this position, we happen to believe that, on the contrary, **it is such a substantive association of DNA to both life and evolution which represents a pathological consequence of reductionism**. Moreover, this overstatement of the role of DNA in determining both life and evolution is an important misunderstanding which is heavily affecting the efficacy of discussions about sustainability. This is why, we believe that a general discussion about the mechanism driving the evolution of holons in terms of essence, types and equivalence class, can be very useful at this regard.

The two concepts of "type" and "individual" are particularly useful to conceptualize in semantic terms the nature of the process defining identities through impredicative loops. In fact, the concept of a "type" refers to that of a useful template used for the realization of an "essence" defined in the semantic realm. That is, a type is the representation of a set of qualities associated to a label used to refer to an equivalence class generated by the realization of a set of organized structure sharing a common template (e.g. a Volkswagen Beetle). The concept of "individual" refers to a special "realization" of a given type within a specific context (at a given point in space and time). Because of the particular path dependent process (stochastic events accumulated in the history of each individual realization), this concept entails that we will always find "special characteristics" for each individual realizations (e.g. my Volkswagen Beetle), even if they belong to a specified equivalence class.

The associated epistemological paradoxes illustrated in previous chapters entail that each specific realization of a given type (e.g. the fabrication of an organized structures) will be different from other realizations obtained adopting the same blue print (e.g. we will never find two cars of the same model and brand which are exactly identical). In the same way, we will never find two homozygote twins that are exactly identical. However, in spite of this unavoidable existence of differences between individuals, it is possible to recognize and assign each of the realizations of a VW Beetle to the same type, which refers to the shared characteristics of the equivalence class to which the individual is supposed to belong. This means assuming the validity of the hypothesis that each specimen of Volkswagen Beetle is reflecting a common set of properties shared by all individual realizations. This assumption is based on the fact that all these realizations share (= are mapping onto) the same blue print.

The validation of these assumptions leads us back to the existence of an impredicative loop (a chicken-egg paradox) implied by this circular definition. We have to know the characteristics of the type to decide whether or not a particular individual realization belongs to an equivalence class, but we can know about the characteristics of the type only through direct interactions with a set of individual realizations (which we must already recognize as legitimate members of that class).

It is possible to get out of this impasse, because of the parallel existence of non-equivalent perceptions and representations of the reality on different levels (and descriptive domains). The robustness of a set of identities generated by an impredicative loop is based on the congruence (triangulation of information) between two non-equivalent sources of information about a given holon. These non-equivalent sources of information have to be generated by two non-equivalent external referents that exchange information about it. In the VW Beetle case, the two typologies of information are: (1) the information used by the engineers when making an individual car following a given blue print (validated by the top management of the company): (2) the ability of consumers in recognizing the type of a Volkswagen Beetle from certain characteristics - the stored image of the model in their memory – validated by social evaluation of such a model of car). This is what makes possible for consumers to perceive individual realizations of such a model, when meeting it in the traffic. The pattern recognition (= identification of a particular realization as a legitimate member of a given equivalence class) at the level of the consumer not necessarily is obtained in the same way by different observers. For example a blind person can recognize the model of this car by listening to the noise of the engine, whereas someone else will look at the design. Finally, children can recognize cars of the last model of VW Beetle from their particular colors, some of which are unique among the cars running in these days.

No matter how individuals observers/potential buyers obtain their pattern recognition, humans will keep using this label "Volkswagen Beetle" (= a mapping of an integrated set of qualities associated to a name) as long as it will be useful to compress the demand of computational capability to process information about their interaction with the reality. If the label "Volkswagen Beetle" is a valid one, then the user will be able to apply to any individual member of the equivalence class (even if meeting it for the first time) the knowledge they have in relation to the type (e.g. where to find the switch of the lights, or how to operate the gear box). That is, the knowledge about the type makes possible to predict a given set of characteristics which are expected for each particular member of the class Volkswagen Beetle. This obviously requires that the mechanism of realization of the members of this equivalence class is capable of guaranteeing the predictability of their characteristics (according to a given common blue print). That the car maker guarantee a high level of reliability in the matching of expected standards from each car of a given model. From this example, we can say that the information stored in the blue print used for making car is the equivalent of the information stored in the DNA for the making of biological organisms.

We know that within the socio-economic domain it is the economic mechanism that is in charge of keeping a correspondence between: (a) the activities of engineers (those in charge to preserve the coherence of the characteristics of the equivalence class) which guarantee the validity of the "identity" of the type Volkswagen Beetle; and (b) the mechanisms of recognition adopted by consumers (those that buy this model of car for its perceived better performance according to their personal expectations). This second activity guarantees the stability of the terms of reference (expected associative context) of the engineers working in the Volkswagen corporation producing additional cars of this class.

This is a crucial point, since even when we find a Volkswagen Beetle with a missing wheel, we are still be able to consider it as a member of that equivalence class. Knowing the identity of the type, it becomes possible to infer the existence of a discrepancy between the identity of the realization (what we perceive in our direct interaction in the reality) and the identity of the type (what we expect according to the information in the blue print). This can be considered as the sign of stochastic perturbations occurred during the process of realization (or during the consequent life of the realization). That is, even if a given specimen of Volkswagen Beetle does not fit totally with our expectations (e.g. since it brings the sign of a recent crash), this will not affect our perception and representation of the type of its equivalence class. Whenever we have an identity for the type of an equivalence class which has been validated in our daily life, we will consider as "deviant features of particular realizations" or "noise" any information about special unexpected features found in individuals. We will judge such an information as irrelevant for discussing of the characteristics of types. This is why we tend to consider the characteristics of a type as out of time (we can recall the metaphor of Plato about this).

On the other hand, if we will find a consistent number of three-wheel realizations of Volkswagen Beetle and these "deviant realizations" will result relevant for our life (e.g. all the three-wheel Volkswagen Beetle are used by police), we will have to update quickly our repertoire of "useful typologies". That is, we will have to learn to make a distinction between three-wheel Volkswagen Beetle (labeled as "Beetle-police cars") versus four-wheel Volkswagen Beetle (labeled as "normal Beetle cars"). The number of wheels will be then included as a signal (a crucial attribute) to be used for quick pattern recognition. In this story we have an example of learning about the existence of: (a) a new "type" (species?) of car ("Beetle-police cars") living in the jungle that we call urban traffic; and (b) a new mechanism for pattern recognition (a new epistemic category – three-wheel versus four-wheel) which has to be included by the observers in their repertoire of attributes associated to the detection of identities.

So far we used a few biological related terms (species and jungle) in order to explore the similarity and differences between the role of blue print in the evolution of cars and of DNA in the evolution of biological species. Can the distinction between "realization" and "essence" can be used to better understand the difference between "phenotype" and "genotype" as suggested by Rosen (2000)? The analogy between these concepts seem to be in a way already there, but it requires some additional comments.

Phenotype (the realization of a type associated to an essence) - A phenotype can certainly be defined (at the organism level) as **the realization of a particular organized structure referring to a given essence obtained at a given point in space.** When defined is this way, the concept of phenotypes can be related to the ability of expressing agency through a member of an equivalence class. Exactly because of this, the special individuality of agents operating on a smaller descriptive domain – e.g. the phenotype of an individual organism of a given species - is totally irrelevant in terms of information to be learned either by biological systems and by scientists about the role plaid by the species - to which the organism belong - in a given ecosystem. The organism is operating at a hierarchical level too low to be relevant in terms of changes to types, let alone in terms of changes of essences. It is only when we consider the aggregate effect of all realizations (the various realizations of the phenotype), which are all mapping into the same "semantic identity" (the genetic information stored in the gene pool at the species level), that we reach an effect of aggregate agencies which has a scale large enough to be relevant for the definition of essences. That is, only when considering the aggregate effects of all the phenotypes realized in different points in space and time by a species (the result of the realization of different identities mapping all onto the same pool of genes organized according to the species), that we have the possibility of having an exchange of information - over the same scale - between "essence" and "realizations". Obviously, this implies adopting a definition of phenotype which refers to a space-time much larger than that of the individual organisms (= the set of populations operating in different associative contexts). This perception of phenotype is non-formalizable according to the structural organization of individual organisms. In fact, the set of all the populations of dogs cannot be expressed in relation to the identity of an individual organism belonging to that species (e.g. should we start using a Coker Spaniel? or a Fox terrier?). As noted earlier the set of all the phenotypes expressed in relation to the essence of a species can be expected to be determined by a component of stochastic events (noise) that usually is averaged out on a large scale (e.g. gene flow). In alternative, the set of all the phenotypes expressed by a given species can be seen as carrying useful information about the need of adjusting the definition of essences (e.g. in determining the direction of speciation). Which one is the right interpretation? This cannot be known when looking at the information space associated to that individual species. This could be answered only when considering all the information spaces associated to the different species with which the first species is interacting. But this would imply considering simultaneously all the interactions at different scales, in different contexts (in different points in space and time). This is why we used before the expression semantic identity of a species, which cannot be formalized.

Finally, if we accept along this reasoning that the definition of phenotype could also be applied to a hierarchical level higher than that of the individual organism (to arrive to a scale of operation associated to an impredicative loop which is required for providing a feed-back on the identity of a species), we can no longer accept the central dogma of molecular biology requiring that the "realization of an essence" can not imply any feed-back on the "definition of essence" in the first place. The large scale activity of all phenotypes (e.g. the ensemble of all individuals belonging to all populations of tigers) actually **do feed-back** first of all on the definition of the essence (the semantic identity) of the other species with which tigers are interacting. However, by doing that they are obviously affecting the "identity" of their own environment (the expected associative context of their own type). The concept of essence, for adaptive dissipative systems implies, in fact, that the environment of a given species is determined by the set of behaviors expressed by the other species interacting with it. This means that a change in the determination of the essence of other species, will induce a loop through which also the identity of the essence of the species tiger will have to be updated. The reader can recall here the example of the consequence of the huge production of FIAT500 and other cheap utilitarian cars, in Italy in the 60s that led to a different definition of the role that a car have in the life of Italian car buyers in the year 2000 (see the comments to figure **Fig. 8.9**).

Genotype (the role plaid by the characteristics of the template shared by a class of realizations) – as soon as one looks at the distinction between genotype and phenotype in relation to essences and realizations of equivalence classes of organized structures one is struck by a noteworthy observation. In evolved life forms (e.g. mammals) the material support used for the encoding information used for fabricating realizations (= the sequence of DNA bases read during the process of ontogenesis) **does not physically coincide** with the material support transmitted to the off-spring (= the sequence of DNA bases used for encoding information used within the genic pool for transmitting and storing the identity associated to the type)!

That is the DNA which is actually read within an organism (the string of chemical bases used as blue print for the realization of a particular individual) represents just one out of many formal identities that maps onto the same semantic identity. In fact, due to the crossing-over within the two sequences of basis, the final string passed to the off-springs is not an exact copy of any of the two strings that were used to fabricate the parents. Put in another way, even when dealing the DNA of an individual organism – with the identity of genotype - we assist to a loss of a 1 to 1 mapping between **the information used for the fabrication of realizations** (used for the location specific processes of ontogenesis) and the information used to **store and transmit information about essence to the pool of the species** (used for the larger scale processes of handling mutual information). The dual nature of holons (a formal part related to structural organization at the local scale and a semantic part related to the expression of larger relational functions) is, therefore, reflected even at the molecular level when coming to the encoding of information in the DNA. The DNA string actually read for ontogenesis represents a formal identity which is physically and formally different from the DNA string passed to the rest of the species. Only in semantic term the genotype is the same.

As a second observation we can note that the information of the DNA transmitted to off-springs (the DNA never read in the fabrication of the individual realization) contains not only information about future realization of individuals of the same species (let's say a cat – organisms belonging to the species *felis catus*), but also an indirect information about the characteristics of the "essence" of other species with which the individual realizations will interacted. Put in another way, relevant characteristics of members of other equivalence classes (characteristics of expected features of other species) are included in the form of the expected associative context in which organisms belonging to the species *felis catus* will interact. This second type of information can include, for a cat, indirect or direct information about expected features and behavior of the phenotype of mice, viruses, lizards, trees, poisonous plants, etc. Therefore, in a way, the ability of an individual realization of *felis catus* to survive and reproduce in a given associative context (in a given point in space and time) represents a check for that species about the validity of two types of information, which is about:

(1) the capability of fabricating realizations of individual organisms – other cats – which must result able to occupy the niche = the viability of the ontogenesis in relation to the existence of favourable boundary conditions (how good is this information at making cats in an expected associative context);

(2) the validity of the essence of "cat-ness" = that is, the aggregate indirect information about relevant characteristics of other species with which the various phenotypes of the *felis catus* will interact when operating within the expected associative context. This indirect information is embodied in the special characteristics of the organization of cats at different levels – e.g. it can refer to a better defense against possible microbial attacks, better efficacy when looking for specific preys, a better defense against larger level predators. This implies that the usefulness of the template used to make individual cats can be associated to a validity check on how the characteristics of the essence of the *felis catus* are compatible with the characteristics of the essence of the other species with which the cat interact and that represent its associative context. That is, the validity of the essence of "cat-ness" is related to how good is the indirect information about the usefulness of various tasks that the organized structure is supposed to perform, in relation to the expected niche occupied by cats.

In a way, individual realizations of cats which are able to survive and reproduce are just experiments (or better probes) that the species send around to confirm the validity of the relative information about **these two tasks**:

(1) ability of realizing – bring into existence – organized structures that can be considered members of the equivalence class *felis catus* (within an admissible environment). Here the goal is not about discussing how to improve the identity of the essence. On the contrary, the identity of the essence must be given, in order to be able to solve the problem of how to make realizations of it.

(2) ability to reflect in a valid essence of *felis catus* the constraints imposed on the species by crucial and relevant aspects of the essence of other interacting species. That is, how admissible is the environment in relation to what is expected according to the type (assumed to operate in a given associative context) associated to the template used in the process of fabrication.

Because of this, when an individual realization dies or thrives (at a given **level** n) it simply sends a message to the rest of the species (at the **level** $n+1$) about the validity of the information it was carrying in relation to: (a) blue print and procedures of realization of the organized structure (triadic reading **level** $n-2/n-1/n$) – the fitness of structural stability; and (b) usefulness of the information used to represent the essences of other species operating in the same environment, in the repertoire of models and detectors (triadic reading **level** $n/n+1/n+2$) – the fitness of relational functions.

Finally, we can get back to the discussion of the evolution of Mickey Mouse and the role that DNA plays in determining evolution. The analysis of biological systems presented so far can be perfectly applied to non-biological species, that is to species that do not store information about templates on strings of DNA (or RNA). First of all, what biological and non-biological holarchies have in common is that they are evolving in time in terms of essences and not in terms of individual realizations. Organisms just express agency, reproduce and dye. Realizations of specific types are just tools used to check whether or not the semantic definition of essence is still valid. Exactly as done by biological species, the people working at Volkswagen can be seen as doing an experiment based on the sending, every year, a bunch of cars produced using a given a blue print (i.e. VW Beetle) into a given socio-economic system. The experiment is aimed at knowing, whether or not the agents characterizing the context (= potential buyers) are still willing to use this model (if the picture of an admissible environment embodied in the blue-print is still valid). If they are still willing to use this model of car, then they will pay for it. Then, if the consumers still pay for it, the validity of the type (which is associated to the characteristics of the given blue print) is checked. In biological systems, that have to do everything by themselves (without an external design), the species gets back a semantic copy of the given blue print, in sign of validation, everytime the individual organism carrying it was able to reproduce. These two mechanisms are similar and provide the same result. The only difference is that in one case the blue print is written in computer disks (or paper) – for the making of VW Beetle – in the other is written using DNA basis – for the making of biological beetles. However, they represent two parallel validity checks determining whether or not a given essence used to define types and for the making of equivalence classes is still valid.

We can go back, now, to the evolution of the two essences shown in **Fig. 8.10.** The possibility of generating equivalence classes of realizations of these two "species" is generated by the web of activities performed within the "socio-economic-system" in which they are expressed. This is why these two species did change in time and evolved. Over the considered time period, the same essence was expressed using different identities. Mickey Mouse can be seen as a sort of virus, which remains alive (is replicated by someone else) because of the energy dissipation paid for by those reading it. The readers make possible to pay those that invest energy in drawing, printing, distributing and selling copies of it. Whereas the VW Beetle can be seen as a real organism which is dissipating on its own (it is eating gasoline). In this analogy, the VW Beetle can be seen as a domesticated species (e.g. milk cow), which depends on care and inputs from humans in exchange for a reliable supply of services. The only difference with cows is that the VW Beetle is not able to self-replicate. It should be noted, however, that this is a feature that is looked for in latest development of high tech genetic engineering (with varieties that cannot reproduce or when considering the terminator gene)! This means that until the process generating the "essence" of these two species holds [= the reciprocal entailment of expected behaviours of interacting agents - epistemological processes - makes possible the stabilization of the process of fabrication - ontological processes], then it is possible to have smooth changes in the characteristics of the identity (in the templates used to define the type) used to realize the essence at different points in time. The set of characteristics shared by the members of the equivalence classes will change smoothly. The slight but continuous accumulation of small changes will be reflected in changes in the relative blue-print associated to these species the representation of the template.

Remaining in the example of the evolution of species of cars, we can consider other examples of "trajectories" of evolution of species of cars. Two examples are illustrated in **Fig. 8.11.** On the right side, we have the evolution of different species (models) defined in the market niche (essence) "very cheap utilitarian cars of small size". This niche was filled at the beginning in Italy by the major Italian car maker with the model "FIAT Topolino" (from 1936). This species-model got soon extinct and then FIAT launched in 1957 one of its most successful models of car ever: the FIAT 500. The FIAT 500 was characterized by a very limited supply of power, very severe driving conditions, it was noisy, but still it was able to fulfill the task of supplying a car to Italian households during the transition toward industrialization. It was the car that made the transition from scooters to cars. Different versions of this basic model were generated during the years, trying to keep the demand high. However, the systemic weakness generated by the small size of its engine drove the model to an extinction in 1975. The new species-model – the FIAT 126 – was built around a bigger engine and new basic technical solutions. The trajectory across these 3 species-models [(1) FIAT Topolino --> (2) FIAT 500 --> (3) FIAT 126] – has already been discussed in **Fig. 8.7.** According to the metaphor proposed by Holling, these models of cars were following a "natural" pattern of evolution. The various models introduced were able to evolve through an expected sequence. The existence of this predictable sequence of stages for the type is the sign of an evolution in time of the relation type <=> associative context.

This means that the characteristics of the members of the equivalence class (species-models, that is typology of the car) were not only mapping onto a blue print (the information used by those making the cars in the factory), but also they were kept congruent with expectations about such a car expressed by the interaction of agents in the socio-economic context. That is, the typology of a car associated to a given model was congruent with the mosaic of mutual information stored by those interacting with the realizations of this car in the society. That is, Italy in those years was full of: (a) car buyers pleased with the performance of this given model, (b) mechanics able to repair them, (c) small micro-factories making spare parts at a lower price of that of the official maker; (d) bankers willing to finance the purchasing of this model; (e) insurance companies willing to insure this model; (f) young women thrilled by the idea of dating an owner of such a car; etc. etc..

Put in another way, the realizations of FIAT 500 had an admissible environment (a niche in which operating) that was determined by the coherence between the information and the expected behaviours of all those agents interacting with individual realizations of this model of car. The model-type was mapping onto a valid associative context. Completely different is the case of the model of car depicted in **Fig. 8.11** on the left of the axis indicating years. The model ARNA was generated by a joint venture of the Italian car maker Alfa-Romeo and the Japanese car maker NISSAN. However, the ARNA was only a "pseudo-species" of car. This model was one of the biggest disasters of the history of these two car makers. This model was not reflecting the existence of an essence in the real world. The "expected niche" imagined when projecting this model was simply not there. In this case, we have an example of: (1) a useful blue print, which was perfectly fit for making cars; (2) the existence of an equivalence class of individual realizations (based on a template), which were all sharing predictable characteristics (representing a potential type). The problem was that this set of characteristics never managed to generate a convergence of interest (they were never considered as relevant) by the various agents operating within the socio-economic-environment. The mutation induced through design (the generation of a new valid blue print), according to the prediction of the existence of a "virtual niche" for such a model, was validated by one of the external referent (the possibility of making functioning cars) at the local scale. However, such a process was not validate by the second external referent referring to the validity of the assumption about the existence of a benign associative context. Put in another way, the information about how to fabricate a class of organized structures sharing the same set of characteristics was valid in syntactic terms (ARNA were made and they were running fine). However, the type was not compatible in semantic terms with the information used by the other agents interacting with the members of this equivalence class. Those determining the existence of a niche (admissibility of the environment) for the class of realizations of "ARNAs".

The main point of this example is that we can learn a lot about the characteristics of the Italian society in the 60s by studying the characteristics of the car model - FIAT 500. Being a real species, the essence of FIAT 500 carries information about its socio-economic context. Whereas, we cannot say anything about the Italian society in the 80s when looking at the characteristics of the car model ARNA. The shape and the characteristics of the template used to make thi car reflect only the personal opinions of the people that were in charge for the development of this model.

This long discussion about the evolution of car models had the goal of making the following important point. When looking at the mechanism generating essences, we can conclude that **in no way the information stored in the blueprint (or in the DNA),** which is useful to fabricate individual realizations of members of an equivalence class**, has anything to do either with the definition of an essence or to the process of evolution of individualities, through trajectories of types within the room provided by a valid essences.**

The essence and the set of identities taken by the two species which are illustrated in **Fig. 8.10** [= "Mickey Mouse" and "VW Beetle"], as well as the three species of car models illustrated in **Fig. 8.9** and **Fig. 8.11** are determined **by the mutual information carried by adaptive systems interacting with each other on the basis of models they have of each other.** The difference between biological systems and human artifacts is that in the latter case, it is the designer that use models of the potential buyers to predict the future fitness of goods and services.

8.2.2 How to obtain an image of an "essence" within the frame of network analysis

In order to see an image of an essence within the frame of network analysis it is important to acknowledge the existence of a few hidden assumptions, which are required to represent biological systems in terms of dissipative networks. Two old papers of Robert Rosen can be used to focus on these crucial, but neglected assumptions: (1) Rosen, R. 1958 "A Relational Theory of Biological Systems" *Bulletin of Mathematical Biophysics* Vol. 20: 245-260. (2) Rosen, R. 1958 "The representation of biological systems from the standpoint of the theory of categories" *Bulletin of Mathematical Biophysics* Vol. 20: 317-341. In the second paper Rosen introduces his first ideas about category theory, which have been developed later on (Rosen, 1991). The text of these two papers is quite obscure, but yet it provides a few crucial points that are relevant for our goal.

In these two papers Rosen focuses on the characteristics that biological systems must have in order to be able to stabilize their own identity through a process of metabolism. First of all, Rosen starts his discussion by acknowledging that any decision about how to draw a graph representing interacting elements of a biological system (how to decide about boundaries) must be necessarily semantically driven. That is, this is a decision that cannot be formalized once and for all (in terms of a substantive protocol). In his own words he says that a decomposition of a system into its components has to be obtained by "some means". Then the dual nature of holons enters into play:

"*Let us observe that the problem of determining the structure of a given system resolves itself naturally in two more or less distinct parts.*

In the first place, we can regard the system as a collection of simpler, fundamental sub-objects (which we shall term ***components****), each of which also behaves in such a manner as to produce a defined set of output materials from a given set of input materials. These components are to be related to one another in the obvious manner; the output materials of a given component may serve as input materials to other components of the system. There will generally be other relations obtaining between the components of a given system; a complete enumeration of there relations will then determine the behavior of the system and will constitute a solution to what we may term the* ***coarse structure problem*** *of the theory of systems. Much of the information required for a solution of the coarse structure problem for a given system will be contained in the so-called* ***block diagram****, or flow chart, for the system*" Rosen, (1958a) – pag. 246.

This reflects the triadic reading **level *n-1* / level *n* / level *n+1*.**

"*For the purposes of the block diagram, we see that each component is regarded as a structureless element (i.e., a "black box"). Once a coarse structure has been obtained (i.e., once we have decomposed our original system into a suitable set of components), we may begin to inquire about the actual physical realizations of these components; this aspect of the theory of systems may be termed the* ***fine structure problem****. Speaking very roughly then, the coarse and fine structure of systems bear to each other the same relation as do macroscopic and microscopic states of a thermodynamic systems, as do physiology and anatomy, or, in Rashevsky's terminology (Rashevsky, 1954) as do relational and metrical aspects of biology*". Rosen, (1958a) – pag. 246 and 247.

This reflects the triadic reading **level *n* / level *n-1* / level *n-2*.**

Then, if we want to represent biological systems in terms of interacting elements on a network, what is the list of characteristics which make "special" this class of adaptive dissipative systems?

1. The identity of a graph – **level *n*** - made up of lower level elements – **level *n-1*** - requires 4 pieces of information (the reader can recall here the discussion about): (i) what is the form of energy used for the metabolism of the whole (= what flows of matter are associated with energy conversions operating at the interface between the black box and the environment). This defines an "expected identity" for energy carriers ("admissible input" in Rosen terminology); (ii) what is the output/input ratio of specific transformations associated to each element of the network (at the **level *n- 1*** as shown in **Fig. 8.12**); (iii) what is the throughput ratio - the rate of energy dissipation of the converter and the pace of the input and

output - (at the **level** ***n- 1*** as shown in **Fig. 8.12**). (iv) what is the relative position assigned to the element within the network with arrows indicating relations among components in the graph (defined at the **level** ***n*** as in **Fig. 8.12**).

2. All dissipative systems described at different levels (the whole system defined at the **level** ***n***, individual elements defined at the **level** ***n-1***, and sub-components making up the structure of components at the **level** ***n-2***) are assumed to operate (if they remain alive) in an "expected associative context" compatible with their identity. That is their very identity of "metabolizing systems" entails the existence of favourable boundary conditions associated to the specific process of dissipation required by their metabolism. That is, the validity of the association of a type with an expected associative context is **"guaranteed"** by the activity of the black box, for those components which are not interacting directly with the environment. The elements included in the indirect compartment have an associative context which is therefore associated to the surviving of the black box. Whereas the assumption of favourable boundary conditions **must be assumed valid "by default"** for those components exchanging matter flows directly with the environment (those supported by "environmental inputs" and those generating "environmental outputs"). This different set of assumptions is at the basis of the distinction made among the components defined at the **level** ***n-1*** in two typologies: **(1) those dealing with direct interactions with the environment** (component A, F and E in **Fig. 8.12**); **(2) those not interacting directly with the environment** operating within the boundary of the black box (internal components such as B, C, and D in **Fig. 8.12**). The identity and the characteristics of these components **is still affecting and affected by the environment, but in an indirect way**. That is, these compartments affect the environment by affecting the characteristics of the components of the first group. This distinction has been already discussed in **Fig. 7.8a**.

3. In order to be able to establish a stable relation among the various identities defined at different levels and scales, each element must be able to guarantee first of all the stability of its own characteristics. This implies the ability of: (a) reproducing itself using a template; (b) expressing a set of behaviors useful to preserve both organized structure and functionality on a short time scale (e.g. repairing itself, avoiding dangerous situations, controlling the inflow of required inputs). According to the specific characteristics of a particular element of the graph, we have to expect that each element not only must have a specified organized structure which share a common set of characteristics (it belongs to an equivalence class) but also that it is has an information system able to store and process two distinct types of information: **(1) BP – a *Blue Print* required to make additional copies/realizationsof its own organized structure.** This is required for preserving the identity, the reproduced component must result members of the same equivalence class (to fulfill the task of reproduction); **(2) AM – a set of *Anticipatory Models* required to express a set of behaviours useful to stabilize the process of metabolism of the given dissipative structure in the short run within the expected associative context.** These two functions expressed at the **level** ***n-1*** and are guaranteed by lower level mechanisms at the **level** ***n-2*** – an overview of this view is given in **Fig. 8.13**.

4. After admitting that lower level elements are able to preserve the given set of identities (the validity of points #1, #2, and #3) both at **level** ***n-2*** and **level** ***n-1***, then the particular *configuration of the network* (or *graph structure* or - as suggested by Rosen -*flow chart* or *block diagram*) at the **level** ***n*** assigns a "functional identity" to each of the internal components. This fact, is represented in **Fig. 8.14** by the expression "essence of B", which is indicated by the empty spot left when removing the component B from the graph (the same graph given in **Fig. 8.12**). Put in another way, after defining the identities over two different levels (**level** ***n-2*** and **level** ***n-1***) - as specified in the point #1 - of all the other elements (A, D, and E) linked to a given element (B) on a given graph – defined both at the **level** ***n-1*** and at the **level** ***n*** - we can describe the image of an "empty niche" left there. The set of expected characteristics determining this

empty niche are obtained using a mosaic effect of entailments across scale of the type discussed in Chapter 6 and Chapter 7.

The crucial point of this discussion is that **the information used to provide such a characterization of this network element is totally independent from the information required to make physical realizations (individual members of the equivalence class) occupying that position in the graph.** This means that because of the identity of the other elements and the given position in the graph the realizations of the typology of elements "expected" in the position B must be able to express a common set of characteristics. These characteristics associated to legitimate members of the equivalence class associated to the virtual element B are "expected" by the network according to the mutual information carried out by the various identities of the other elements of the holarchic dissipative network (the whole system as defined at the **level *n***, and the other components, defined at the **level *n-1*** and at the **level *n-2***). In this case, a given formalization of this dissipative network would make possible to define an image of the essence of the particular virtual element B. Such a image, clearly, is just one of the possible images of that essence that will reflect the choices made by the analysts about how to represent the dissipative network in formal terms in the first place.

Different is the case of those elements (e.g. in **Fig. 8.12** elements A, F and E) that are directly interacting with the environment. In fact, the identity of these components is not only determined by the mutual information carried about them by other elements of the network, but also by the characteristics of what Rosen calls as "environmental inputs" and "environmental outputs". In this way, the reciprocal definition of identities is expanded to include, even if in partial terms, also the characteristics of the environment. The concept of metabolism, in fact, implies imposing a few assumptions – actually a sort of "weak identity" – also on the environment. The environment of a dissipative system must be admissible by definition. This means that at the **level *n-2***, the definition of identity for energy carriers (= admissible input for those components "eating" or "depending on" environmental inputs), must be compatible with the processes occurring in the environment at the **level *n+2*** (those processes which we do not know, but that must be there to stabilize the supply of input and the sink of wastes). The total input required by the system as a whole (at the **level *n***), therefore coincides with the input required by the external components (at the **level *n-1***) and it must be compatible with the processes producing such an input in the environment at the **level *n+2***, so to have an adequate supply of input at the **level *n+1*** (an admissible set of boundary conditions). Also in this case a definition of an integrated set of identities for wholes and parts of the network translates into a requirement of compatibility in relation to the reciprocal conditioning of different processes determining admissible conditions on different scales and descriptive domains. We are back to impredicative loop analysis discussed in Chapter 7.

5. All the dissipative elements within socio-economic systems and ecosystems (= components of the graph, the whole network, and sub-components of components) have a common (= the same) "reference state" for their process of dissipation/self-organization. **They all discharge heat** as the final by-product of their metabolic process. Meaning that the various epistemic categories used to characterize their identities can be linked because in this case it is possible to establish a link between mapping of matter and energy flows. Recall here the various examples of impredicative loop analysis discussed in Chapter 7. The possibility of obtaining a reducible mapping between an extensive variable#1 and #2 is based on the possibility to establish an energetic equivalence between an energetic assessment and a mapping of a matter flow (tons of evapotranspirated water, kg of food, tons of oil equivalent). This is where the two mappings related to the representation of interaction: (a) black-box internal parts; and (b) black-box environment can be reduced to each other, even if accepting a certain degree of arbitrariness in this operation. Put in another way, in the virtually infinite ladder of space-time scales that can be used to look for "potential energy forms" useful for perceiving and representing the reality, when dealing with the metabolism of terrestrial ecosystems and human societies we can afford to focus only on a given space-time window. That is,

when looking at biological systems or socio-economic systems we can ignore atomic and subatomic energy forms and also the energy flows associated to pulsars or black holes. Put in another terms, the metabolism of ecological processes and the metabolism of societal systems can be represented using nested elements having very strong identities. Therefore, we can perceive and represent their metabolism using only a finite set of relevant energy forms, transformations and matter and energy flows. When additional categories become relevant (e.g. pollution by heavy metals) the analysis get immediately more difficult.

This makes easier to select a finite representation/description of the metabolism of societal systems or ecosystems. Such a representation can be based on a given finite and manageable set of components, energy forms, energy transformations and flows. Obviously, any representation will necessarily cover only a sub-set of all the possible components, energy forms, transformations and flows that could be used to perceive and represent terrestrial ecosystems or human societies. Actually, when non-equivalent observers (e.g. the interacting life forms within a terrestrial ecosystems) use different detectors operating on different scales to observe the same ecosystem in relation to different goals, they are generating a quite large set of non-reducible valid narratives. Again, deciding which energy forms have to be included in a given analysis (when defining the identity of a network and their components) does not imply that those energy forms not included are not relevant in absolute terms.

8.2.3 The difference between self-organization (emergence of essences and new relevant attributes) and design (increase in fitness within a given essence = set of attributes/associative context)

Networks of nested dissipative elements are very important for the discussion of this chapter, since they can be associated to a peculiar set of characteristics which are typical of life. To introduce another relevant basic concepts – centripetality - we quote here the work of one of the major experts in this field, Robert Ulanowicz.

"***Selective pressure that the overall autocatalytic form exerts upon its components.*** *... Unlike Newtonian forces, which always act in equal and opposite directions, the selection pressure associated with autocatalysis in inherently asymmetric. ... They tend to ratchet all participants toward* ***ever greater levels of performance*** *... The same argument applies to every members of the loop, so that the overall effect is one of* ***centripetality****, to use a term coined by Sir Isaac Newton: the autocatalytic assemblage behaves as a focus upon which converge increasing amounts of exergy and material that the system draws unto itself*". (Ulanowicz, 1997 pag. 47).

A short description of the concept of centripetality, based on the text of his book, follows.

By its very nature autocatalysis is prone to induce competition and not merely among different properties of components, its very material and mechanical constituents are themselves prone to replacement by the active agency of the larger system. For example, suppose that A, B, C and D are sequential elements comprising an autocatalytic loop as in **Fig. 8.15** and that some new element E appears by happenstance, which is more sensitive to catalysis by D. This means that it provides greater enhancement to the activity of B than does A. Then E will grow to overshadow A's role in the loop, or will displace it altogether. In like manner one can argue that C could be replace by some other component F (as in the lower level graph on the right). Then D can be replaced by another component G and the component B can be replaced in the same way by H. The final configuration of the sequential elements of the autocatalytic loop could become at that point E,H,F,G, which contains none of the original elements. [= this is our summary of the text found on pag. 47].

"It is important to notice in this case that the characteristics time (duration) of the larger autocatalytic form is longer that that of its constituents. The persistence of active forms beyond present makeup is hardly an unusual phenomenon – one sees it in the survival of corporate bodies beyond the tenure of individual executives or workers, or in plays like those of Shakespeare, the endure beyond the lifetime of individual actors." (ibid. pag. 48).

This refers to lower level elements turn-over in the role defined at a higher level.

If we try to apply the set of concepts developed so far to this representation of the process of evolution of an autocatalytic loop, we can say that what described by Ulanowicz with the name of centripetality refers to an "improvement in the design of an autocatalytic loop". That is, we have a **level *n*** at which we are describing the network generating the autocatalytic loop. This network has a given role (set of tasks to fulfil) in relation to its interaction with the environment (defined at the interface ***n/n+1***). The ability to fulfil the required tasks translates into the ability to guarantee the stability of expected boundary conditions for the elements which are operating inside the network - at the **level *n-1*** – seen as a black box. Within this specification of roles across levels, we can define for lower level components a formalization of "efficiency". As specified by Ulanowicz, an "improvement" in relation to a given 'context specific' setting [= (a) identities of the various elements at the **level *n-1***; (b) graph structure at the **level *n***; and (c) characteristics of the associative context (validity of the assumption of an admissible environment)] will feed-back to the starting component as a reinforcement of this new behavior (over the whole cycle – at the **level *n***). This is why more "efficient" components can replace obsolete ones in relation to the given set of relations and roles of the set of identities defined on the two levels ***n/n+1*** (black box/admissible environment). However, this has more to do with a natural implementation of the original design rather than with a real phenomenon of emergence. The substitution of an element A with an element E that does better in the niche of A is related to what in biology is called the survival of the "fittest" when talking of natural selection. But the definition of fittest is already related to the definition of an essence for components operating within a specified associative context (determined by the identity of the larger whole characterized at the level n). This has nothing to do with emergence.

Emergence has to do with the generation of new essences – new bridges across levels both in ontological and epistemological terms. This implies considering – as discussed in Chapter 6 and Chapter 7– a integrated set of facts referring and defined on two continuous triading readings, that is **levels *n-2/ n-1/ n*** and **levels *n/ n+1/ n+2***. The integration of these facts requires translating the definition of types across 5 levels in a way that implies a self-entailment of ontological and epistemological processes determining the feasibility of the resulting set of essences. That is, it requires the simultaneous compatibility on different scales of: (1) the ontological process of realization of individuals within equivalence classes defined at different levels; (2) the epistemological process based on the information about experienced and expected facts, which is stored in the various systems of control regulating the predictability of patterns of dissipation at different levels.

The concepts of type, essence and realizations of a given equivalence class can be used to make an important point, which has been proposed to us by Tim Allen (personal communication). It is useful to make a distinction between two drivers in the process of evolution. The former of these two drivers can be associated to the concept of "design", whereas the latter to the concept of "self-organization".

* we deal with "design" when we have the specification of a given role (a set of tasks to be fulfilled) and then different types of organized structures are changed in time in order provide an improvement in relation to the established definition of that performance (this is the example of the centripetality illustrated in **Fig. 8.15**).

* we deal with "self-organization" when an old set of organized structures (lower-lower level structural elements – ***n-2*** – organized in a structural pattern defined by the identity of lower level types – ***n-1***) interact in a way that generates a new behaviour at the **level *n***. This new behaviour makes possible the stabilization of a new set of functions on the interface black box/context – on the interface between levels ***n+1/n+2***. At this point we have an existing set of organized structures (on the lower triadic reading) which manages to express a new set of functions that makes sense in relation to processes detected on the higher triadic reading. A new set of categories is required to classify and represent this new set of functions/qualities.

At this regard, when discussing of evolution and the role that mutations (changes in the template used to make classes of organized structures) can play in determining emergence Popper says: "*The main* *thing in my form of the theory is that mutations can succeed only if they fall within an already established behavioural pattern. That is to say, what comes before the mutation is a behavioural change, and the mutation comes afterwards*". Popper, 1993 pag. 69). An "established behavioural pattern", according to what said in Chapter 6 and Chapter 7, implies a congruence of mutual information (reciprocally validated) on different levels by non-equivalent external referents. This term can be considered to be analogous to a "valid essence". Therefore we can translate the statement of Popper in our terms as: "what comes before the mutation (a change in the template used to generate a class of organized structures) is the existence of a virtual new essence (a change in the self-entailing process of definition of valid essences), and then the mutation comes afterwards". This statement can be directly related to the discussion of the successful or aborted speciation of new models of cars described in the previous section – **Fig. 8.11.**

We can try to wrap up now this discussion using the concepts introduced so far:

* organization following design = new organized structures which result more useful according to the given problem structuring for increasing the perceived fitness (efficiency) of the system = making better types within a given essence.

* self-organization = emergence = the making of new essences = this results into the need of introducing new attributes (variables) and new relational functions for the modeller.

8.2.4 Conclusions: So what? How to deal with the representation of becoming systems?

The challenge of describing the evolution of something that becomes something else while remaining the same cannot be faced by using formalisms developed within the reductionist paradigm (models and formal definitions given once and for all). What can we do in face to this predicament is try to understand as much as possible the implications of our arbitrary choices of what should be considered as relevant (the types or the individualities) when representing this process.

We believe that concepts derived from Complex Systems thinking, such as: essences, identity, types and individual realizations of members of an equivalence class, can result very useful for a better understanding of the epistemological implications of our choices in the step of representation. In particular, we can say that the unavoidable fuzzy characterization of holons and holarchies has to go through establishing a correspondence between an ontological and epistemological duality typical of adaptive dissipative systems. This duality is reflected in the following series of coupled terms:

A --> Essence	Type	Niche	Role	Relational Function;
B --> Realization	Individual	Popul. of a Species	Incumbent	Organized structure.

A valid essence reflects the ability to keep coherence/congruence throughout a process of autopoiesis within a holarchy between an epistemological side (row of definitions A) and an ontological side (row of definitions B). The two definitions obviously do not coincide in terms of descriptive domains. Therefore, they are related to each other in semantic terms but they are non-equivalent and non-reducible in formal terms to each other. This is why a semantic check, based on a triangulation of non-equivalent external referents, is always required when dealing with the representation of complex systems. An example of this resonating process is given in **Fig. 8.16.** This figure leads us back to the discussion of the Peircean triad given in Chapter 4. The parallel check done by two non-equivalent external referents in relation to two related, but not reducible, mechanisms of representations implies that such a process cannot be formalized. As already stated, **it is impossible to obtain "the right" representation of complex system, but only families of possible representations, which can be more or less useful depending on who will use such a representation.**

When facing this predicament, it is wise to look for procedures that includes also a discussion of the usefulness of a given representation in relation to a given situation and problem. In this context, impredicative loop analysis is useful, since it forces the analyst to adopt an integrated chain of choices that have to make sense in relation to a list of quality checks that are related to both: (a) internal congruence of the scientific representation on different descriptive domains; (b) relevance of the choices of characteristics included in the definition of identities adopted in the models.

The adoption of two non-equivalent external referents in parallel (local and large scale validation of a given identity in two non-equivalent ways) – **Fig. 8.16** - has also been suggested by Tarsky (1944) as the only way out of the epistemological impasse implied by complexity. The famous line he uses to express this concept is: **"Snow is white" is true if and only if *snow is white*.** The expression "snow is white" in quotation marks refers to **a formal representation of the reality** obtained within an object language (a formalized external referents), whereas the expression *snow is white* in italics refers to a validity check about the usefulness of the label ("snow is white") which is obtained through a non-equivalent external referents (what he calls a meta-language).

Living systems routinely validate the integrated sets of multiple identities they use to make models of them-selves for interacting with each other, throughout the establishment of "impredicative loops" (chicken-eggs self-entailment between ontological processes and epistemological processes). They are making models of them-selves all the time and use these models to generate integrated sets of predictable behaviours. The existence of these loops is perfectly explicable in scientific terms and very normal in the reality. Actually this mechanism of self-organization is much more general and likely to be found in nature than that of human design used by engineers for the making of machines. However, the process of self-organization of life seems to have a serious defect in the eyes of hard scientists. Such a process is not formalizable according to conventional differential equations and cannot be optimized in substantive way. As result of this unpleasant characteristics, the existence of chicken-eggs processes and complex mechanisms impossible to formalize is simply denied by "rigorous" scientists, when coming to the generation of models.

8.3 The additional predicament of reflexivity: the challenge of keeping useful narratives within the observed/observer complex

8.3.1 The surfing of narratives on complex time

We can start this section by recalling the implications of the concept of complex time for those attempting to generate useful models of the process of becoming of dissipative systems. As observed in section 8.1 there are three time differential that have two be considered:

(a) dt - the time differential of the dynamics within the model (this is the time differential chosen within the observer/observed complex to represent events on a given descriptive domain).

(b) dτ - the time differential at which models should evolve within a given problem structuring (this is the time horizon at which the validity of the model expires). This refers to the speed of change of the characteristics of the observed (e.g. is no longer behaving as before) and the observer (e.g. its ability of observing has changed).

(c) dθ - the time differential at which the relevant features of the selected problem structuring change in relation to the characteristics of the observer/observed complex. This can imply changes in the original set of goals of the modeller (because of a change in power relation among stakeholders), or the acknowledgment of inadequacy of previous problem structuring (because of the emergence of new relevant issues).

The definition and the determination of these three time differentials is logically independent from the chain of choices made during the process of modelling.

The third time scale is the one on which it is more probable to have bifurcations. That is, disagreements about what should be considered as the right set of relevant system qualities to be used to study a given problem. This translates into: (a) potential troubles on the descriptive side, and (b) expected troubles on the normative side. The **formal identity of models** (the identity of the system of differential equations used to describe movements in the state space according to the simple time defined by dt) should change over the time differential $d\tau$. Whereas the **semantic identity of useful metaphors** (selection of a finite set of relevant relations among system qualities) should change over the time differential $d\theta$.

At this regard we can recall as example the standard failure of econometric analyses based on the ceteris paribus assumption. Whenever econometric models failed to be predictive, econometricians found a ready, yet self-defeating, excuse: "history has changed the parameters" (Georgescu-Roegen, 1976). Georgescu-Roegen, however, notes in this regard: if "history is so cunning, why persist in predicting it?" Rather than relying only on formal models based on a quasi-steady state framing of the economic process (ceteris paribus hypothesis), it would be better to focus on understanding the basic mechanisms which are driving the evolution of the economic process (Georgescu-Roegen, 1976). As noted in Chapter 7, however, this is not easy, since it implies the need of using analyses referring to different hierarchical levels and therefore in parallel non-equivalent descriptive domains.

The concept of complex time which is associated to changes occurring in the "observer-observed" complex introduces an additional problem for the analysts of sustainability. In fact, when dealing with the behaviour of this complex there is an additional and dangerous source of **non-linearity**. This non-linearity is not referring to the mechanisms of causality perceived in the natural system under investigation. Rather this source of non-linearity can be found on the semantic side. The semantic side is related to the process through which the observer assign external referents to mathematical objects to provide them with meaning. Non-linearity here refer to sudden changes in the interests of the observer (the reader can recall here the example of the two logically independent definitions of the size for London and Reykjavik discussed in Section 3.1). When the "observer" is a social system (we are dealing with the "weltanschauung" in which the scientific activity is performed), non-linearity can be generated by a sudden change in societal power relations or by a sudden discovery of a new typology of problems which entail a paradigm shift in scientific analysis.

A sudden change in the set of goals and organized perceptions in a society can induce a collapse in its sustainability, because it makes obsolete and inoperative the actual system of control. This can happen even when boundary conditions and biophysical processes remain the same. Let's recall here the example of the fall of Soviet empire, which was primed by a lower level local collapse in the system of control operating at one of the gates of the Berlin wall. Such a local failure quickly spread throughout the various systems of control up into the holarchic structure. In fact, nothing changed in terms of technological performance, availability of natural resources for the Soviet economy in the following weeks and months. Still, the entire Soviet empire went through a process of implosion due to a quick loss of validity of reciprocal information stored in its hierarchical system of controls. The socio-economic structure of Soviet Union lost at an increasing speed the ability to keep alive the process of resonance between perception/representation/realization, required to validate the set of "essences" required to guarantee the stability of types and equivalence classes of realizations – **Fig. 8.16.** As result of this fact, the Soviet system lost the ability to keep coherence in the behaviours of the realizations (members of the equivalence classes) associated to the various types across levels (from large state organizations to individual citizens). At the end farmers stopped to be farmers, policemen stopped to be policemen.

The same can happen to modellers facing a sudden change in the definition of what is relevant in the problem structuring adopted in the definition of a particular dynamical system. A systemic loss of meaning can induce a sudden collapse in the validity of the model across levels. We can call this as "the emperor has no clothes" effect.

8.3.2 The moving in time of narrative

The various examples given in the set of figures seen so far enable us to make two important points about the relevance of changes which can take place on the side of the observer. This is a dimension characterized by the time differential $d\theta$. As discussed previously, this third dimension refers to the pace at which the observer is changing in time. This relevant rate of change can refer to both: (a) capability of observing (perceiving and representing); and (b) the interests which are associated to the act of observing.

Let's start with an example of the first type of change in the observer. Let's imagine that we are watching an old tape showing a final of the US Open of tennis on our TV set. Looking at a tape on a TV set is like looking at the dynamic simulated by a mathematical model in a computer. There is a simple time determined by the representation given by the tape. Like in a mathematical model, there is a system (e.g. in this case two interacting players, that behave according to a specified set of rules) which is represented as operating in a given associative context. The potential behaviour is determined a priori. As soon as a tennis match is recorded on a tape (as soon as a dynamic is formalized into a simple type) it becomes fully predictable (we can rewind the tape and then tell to someone else exactly what will happen next). We can go backward in time and travel even in the future (moving from the action recorded in the first set to the action recorded in the third set). This is possible because this is a finite representation of a real process, done in relation to a single descriptive domain. We are not dealing with a real event which is constrained by a set of parallel processes occurring on different scales and which can be observed in parallel on different levels. What we see on the screen of the TV now, depends on the choices made by the directors and the technology available when the tape was recorded. We cannot look under the shoes of a player if this has not be done by the director then. Let's imagine, for example, that we have a tape which is in black and white. The limits imposed by a black and white representation will remain a constraint also when we run the tape on a modern colour TV set.

The same problem (impossibility of perceiving enough relevant information from a formal representation of a modelled system) can occur in science. There are no pictures of Neanderthals (but only reconstructions of their faces), because at that time humans could not use cameras for perceiving and representing each other face. However, it should be noted that moving from a tape in black and white (e.g. differential equations) to a tape in colour (e.g. using genetic algorithms to represent complex behaviours) simply make richer our ability to perceive and represent the reality. It does not change the fact that the tape (either in black and white or in colour) will remain just a representation of a dynamic which occurs in simple time (it does not evolve). Even if we look at a colour tape of the final of the US open between John MacEnroe and Bjorn Borg (in 1980) we can immediately perceive that the tape is old.

That is, we can perceive a significant movement in relation to the time differential $d\tau$. In fact, we know that these two tennis players are no longer active in the tour. If we do not know this information, we can still observe that nobody in professional tennis uses anymore wooden tennis rackets (used by them in the final). If we do not know this information, we can observe that the clothes and the hair-style of those playing and those watching the match in this tape are different from what can be seen in the streets today.

The consideration of all these clear signs of a movement of the narrative in time - in relation to $d\tau$ - tends unavoidably to indicate also a potential change in relation to the second type of change in the observer. Probably, if the observer of this tape watched the same match live in 1980, she/he was also dressed like the people in the stadium. A change in the way an observer is dressed or is arranging her/his hairs is in general a sign of a more important changes.

To deal with the effects of the second type of changes occurring in an observer, we can use again the two figures **Fig. 8.1** and Fig. **8.3**. We have here a practical example of the implications that a change in the interests of the observer can have on the representation of becoming systems. In particular, in relation to **Fig. 8.1**, we can now inform the reader that Sandra is the actual wife of the first author of this chapter, whereas Marinella – the young woman represented in **Fig. 8.3** - is the person that was the companion of the first author 20 years ago. The bifurcation between two distinct complexes "observer/ observed" [= Mario/Sandra in **Fig. 8.1** versus Mario/Marinella in **Fig. 8.3**] can be seen as the explanation that caused the selection of two different representations of the process of ageing in the two figures over two distinct individualities. The possibility of a sudden switch in how to perceive the same pattern is illustrated in **Fig. 8.17**. Personal changes in the observer [in this example Mario considered at two different points in time – in the year 2000, when looking toward left, and in 1980 when looking toward right] have important implications on the process of representation (how ageing is perceived and represented: what is shown in **Fig. 8.1** and **Fig. 8.3**). In this example, the possibility of obtaining a different set of perceptions/ representations not only depends on who is asked to make such Figure (Mario versus Kozo), but also on when this request is done (in the year 2000 or 1980).

It should be noted also, that the new information given now to the reader can change also the explanations of what is represented in **Fig. 8.1** and **Fig. 8.3**. At this point, after receiving this new information, the reader can infer that Sandra and Marinella are the relevant individualities (the real external referents assigning sense to the description), that determined the choice of the set of representations used to illustrate the various types associated to ageing. In spite of the fact, that Bertha and Gina were the individualities used to give the name to the two lines of 4 types, they were not the individualities relevant for the choice made by the observer. Characteristics of individualities "per se" can be irrelevant if perceived at the wrong moment in time. For example, a young male meeting Marilyn Monroe when she was 2-year old would not have considered her as an exceptionally attracting woman. The reader already has learned about the process of ageing illustrated in **Fig. 8.1** and **Fig. 8.3** well before looking at these figures. But to do that she or he used her or his own set of relevant individualities.

8.3.3 In a moment of fast transition moving narratives in space can imply moving them in time

There is another important aspect of complex time that should be considered. When we discuss of the existence of three time differentials which are relevant for the process of representation of the reality, we refer only to the three time differentials, which can be associated to a particular choice of a triadic reading of the reality. The meaning of a triadic reading that can be translated into the definition of a given narrative. Obviously, there are always several other potentially relevant time differentials beside these three. For example, **Fig. 8.18** shows that when studying the process of ageing in primates and at the same time the process of evolution of primates, we should introduce yet another time differential, much larger of the previous three, that we can call **dT**.

If we do that, we have to put in a different perspective what is shown in **Fig. 8.1** and **Fig. 8.3**. Millions of years ago an observer of a species of apes would have observed the ageing of apes using a set of very coarse epistemic categories about which apes could share meaning (in the first box of **Fig. 8.18**). A caveman observer would have observed the ageing of cavemen using a set of epistemic categories about which cavemen could share meaning (in the second box of **Fig. 8.18**). Exactly like a modern human being observes the ageing of other human beings using a set of epistemic categories about which humans can share meaning (as in the last box of **Fig. 8.18**). The problem is that a modern observer cannot get the meaning of the set of categories (signs? markers? labels?), which were used by non-equivalent observers in the past (either apes or cavemen). We don't know why and how their information space was useful for guiding their action. That is, we do not know what type of external referents their information space was referring to. A too large time lag implies the risk of loosing the coherence within the observer/observed complex and therefore loosing track of useful narratives.

Useful narratives have a definite life span, after a while they simply loose sense, disappearing together with the complex observer/observed that generated them. This is why, humans cannot put up with the concept of eternity. Our perception of time is related to the existence of narratives (coherent representations of perceptions of events). By definition, the simple time used in representation must be finite, since simple time just reflects the epistemological choices associated to a given narrative: (a) the perception/representation of a duration, in relation to (b) another perception/representation of duration used as reference.

Therefore, whenever the complex observer/observed is forced change at a pace which is too fast for the Peircean semiotic triad (**Fig. 4.2**) to validate knowledge, there is a serious risk of destroying the coherence of useful narratives. In other words we can say that when the process used to define the set of essences associated to an operational adaptive holarchy (**Fig. 8.16**) has not enough time to go through the necessary steps of validation, such a holarchy is under stress and it is at risk of loosing its internal coherence (individuality). This is the situation of human societies facing the predicament of Post-Normal Science. This point is directly related to a serious threat to the sustainability of socio-economic systems undergoing a fast period of transition.

This threat is particularly serious for developing countries, which are trying to catch up with the existing gap between their actual achievements and what already has been achieved by more developed countries. An example of this problem is illustrated in **Fig. 8.19**. Let's imagine that different countries (or different socio-economic systems) are moving across a common trajectory of development as illustrated in **Fig. 8.19** along the diagonal line moving up toward right. The various stages of this trajectory are indicated in the figure by numbers. As discussed in the next chapter (chapter 9), when representing socio-economic systems as dissipative systems which stabilize their own identity through impredicative loops of energy forms, it is actually possible to individuate the existence of a common trajectory, which can be represented using predictable changes in some of the characteristics of societal metabolism.

Without getting into a technical description of such a phenomenon now we can say that when considering a socio-economic system as the focal level of analysis (**level *n***), the possible changes in the characteristics of its metabolism are constrained by: (a) internal constraints (the availability of enough accumulated capital, technology, infrastructure, know how); (b) external constraints (favourable boundary conditions related to the access to an adequate amount of natural resources and environmental services associated to a given level of metabolism). Obviously, if a country with a very low level of GDP - let's say Laos – wants to change dramatically the characteristics of its metabolism to become more similar to a country with a very high level of GDP - let's say the USA - there are a lot of internal and external constraints that have to be removed. On the side of internal constraints, it will take time to build infrastructures, to provide huge injection of capital and technology, to make a new generation of highly educated workers able to operate computerized technologies. On the side of the external constraints, it will take time to become able to stabilize the required inflow of limiting natural resources (e.g. fossil energy and other strategic materials such as steal or metalloids needed for the making of micro-processors). This implies that the timing of evolution of the metabolism of the society as a whole at the **level *n*** – the speed at which the socio-economic system can go through the different known stages of development – is affected by both types of constraint (internal and external), with the Liebig's law determining the final pace of evolution. The most limiting of these constraints – either internal or external – will determine the overall speed of change.

On the other hand, individual households, which are operating at the **level *n-1*** have a different perception/definition of internal and external constraints. The external constraints for a household is given by the universe of accessible opportunities given by its local associative context (the socio-economic interface within which it is operating). The internal constraints for a household is given by the definition of cultural identity of its members, which affects the definition of the set of activities which can be done and cannot be done, together with the overall perception and evaluation of "costs" and "benefits" derived from the interaction with the context.

Before the era of globalization, households (viewed as holons) were sharing with their context (the larger level holon within which they were operating) the pace of evolution. Their pace of change as observers ($d\theta$) was in a way synchronized with the pace of evolution of the context (defining the need of updating their know-how ($d\tau$). The big problem induced by globalization is associated to the free circulation of: (a) information (diffusion of mass-media everywhere); (b) goods (huge spread of trade); and

(c) people (huge migratory flows). At this point, the definition of "sustainability" at the household level is no longer univocally determined by what is going on in its direct context. The potential pace of change of a holon-household is no longer determined by the most limiting factor between internal and external constraints affecting the pace of evolution of the holon-community in which is embedded. Globalization transformed the definition of "external constraints" into an independent variable. In fact, in a globalized world individual households can chose (to a certain extent) their associative context. In this way, they can jump across typologies of observers, In this way, it is possible to move narratives across evolutionary time (like if a Neanderthal man could decide to perceive and represent the world using the same categories adopted by CNN). As soon as household of developing countries decide to do so, they can decide to boost the pace of change of their own identity as much as they can. This is a standard solution, whenever these "new generation of observers" find themselves not happy with what they get from their current associative context. As soon as, this new typology of observer/household decides that it pays to change, they can no longer see as admissible the old context in which they used to operate (e.g. young people refusing to remain in rural areas to farm). In this case, we are in presence of an irreversible change in the identity of the observer that literally can no longer see, at a given point in space and time, the same reality seen by the elderly of the same village. The jump into a different typology of observer (= an observe which is using a different set of epistemic categories to perceive and represent the costs and the benefits of rural life and of the related economic activities) requires also a dramatic change in the context within which such an observer can operate. In order to do that, first of all, these new observers must adjust (to a certain extent) their cultural identity in order to become compatible with a different definition of context (= a different set of identities and essences).

This is were serious trouble starts. Very often in many developing countries, among young people, the new knowledge about how to perceive and represent the reality is learned from television. That is, according to what is done in socio-economic systems operating, elsewhere, at a different stage of development. In this way, this generation of new observers tend to imitate mechanisms of perception and representation not particularly useful to operate in the local associative context of their houshold.

Reflexivity of humans implies that lower level holons (e.g. households), even if belonging to a given focal level holon (e.g. belonging to a given socio-economic system) can decide to shift to another associative context by changing their identity as types. They can do that, by taking advantage of the set of opportunities guaranteed by the different characteristics found in different socio-economic systems. Because of this, as soon as they no longer accept the typology of household they happen to belong to, they tend to stop those activities required to interact with the original associative context. Often this implies the need of emigrate, which can become an obliged choice after the stop. This simply means that remaining in the old associative context becomes too costly in relation to the new identity assumed by the observer. This is what happened in the Soviet Union at the moment of the collapse, and this is what is happening in many rural areas of developing countries. We can recall here the example of the Chinese lady shown in **Fig. 5.1**, that after watching in television the possibility of operating in a different associative context, was giving an assessment of the performance of her agro-ecosystem dramatically different from that given by Western scientists.

For this reason, it is crucial to be able to package the scientific information gathered in an integrated assessment of agroecosystems in a way that makes possible to address explicitly the relevant attributes considered by lower level agents (the households), when deciding whether or not it pays to sustain the socio-economic context in which they are operating. It is impossible to sustain an agroecosystems in which farmers have lost their feeling of belonging to their particular identity as socio-economic system (the set of essences and types associated to the impredicative loop that stabilizes their metabolism). A sound integrated analysis has to characterize the sustainability (feasibility) of agroecosystems in relation to the non-equivalent perceptions of performance of different agents operating at different hierarchical levels (this is illustrated in Chapter 11).

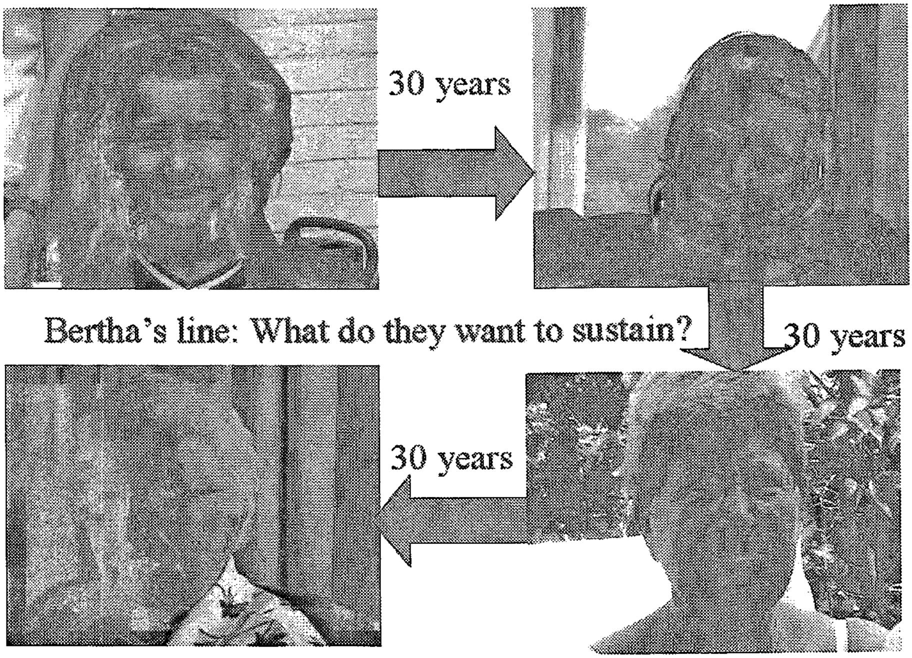


Fig. 8.1 Sustainability of what? Sustainability for how long?

Photos by Mario Giampietro

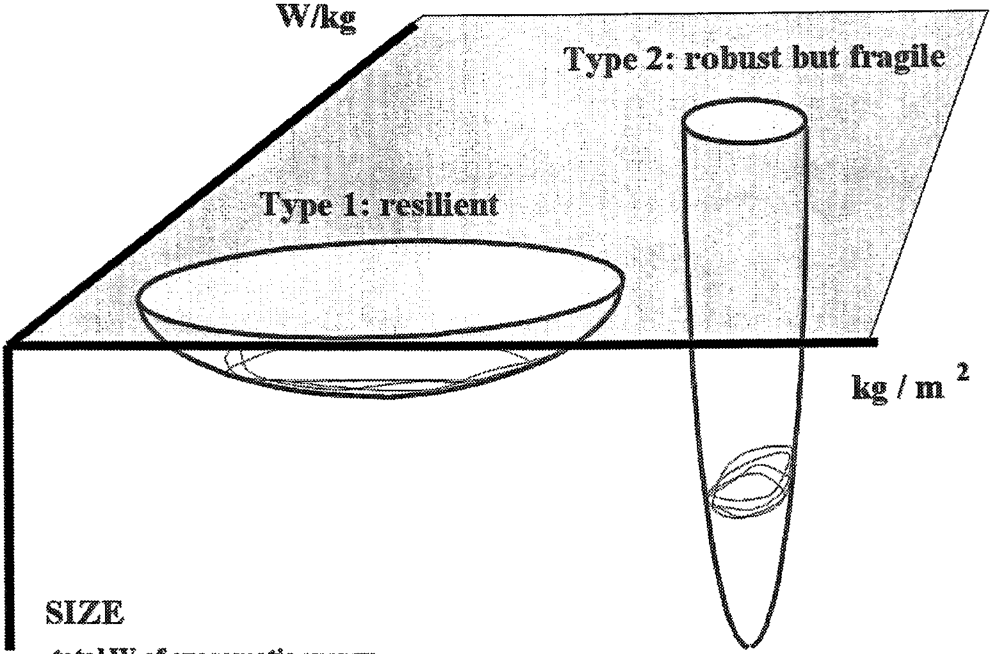
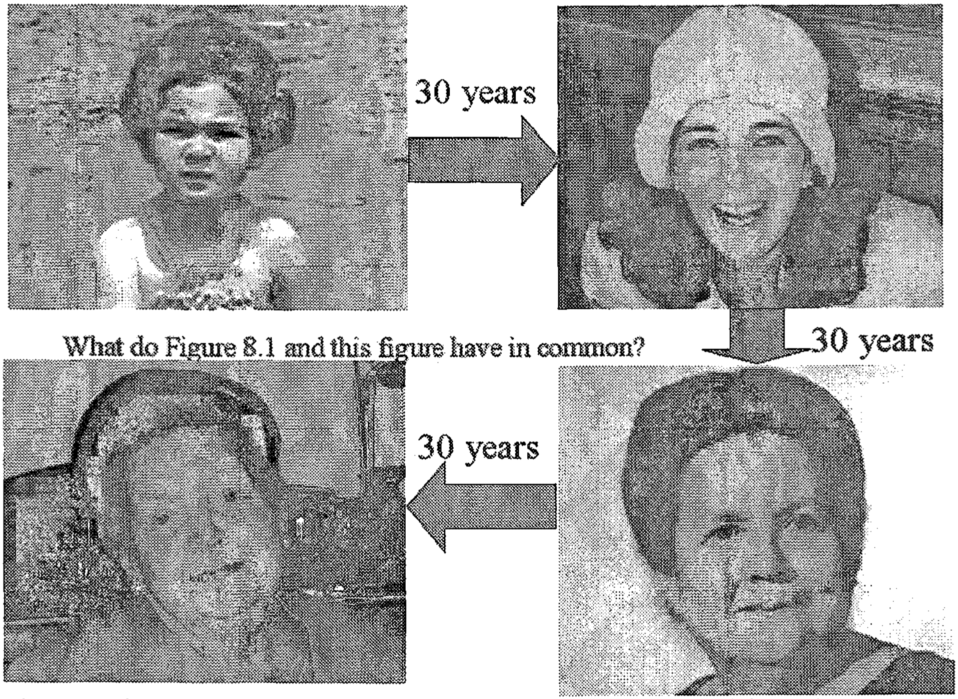


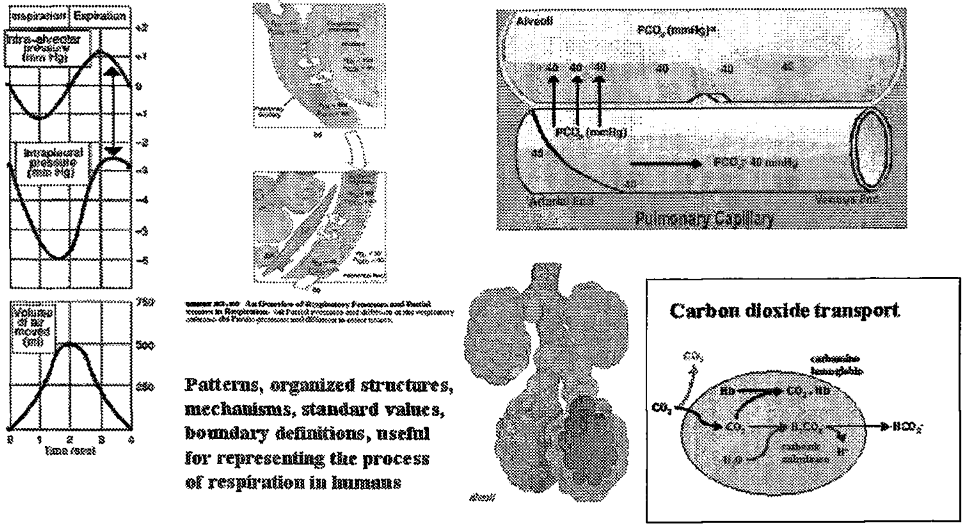
Fig. 8.2 Shapes of basins of attraction



What do Figure 8.1 and this figure have in common?

Fig. 8.3 Gina's line represented as an analogous of Bertha's line (Fig. 8.1)

Photos by Marinella Veneziani



Patterns, organized structures, mechanisms, standard values, boundary definitions, useful for representing the process of respiration in humans

Graphic material from the BIO 301 Human Physiology syllabus (Gary Ritchison, eastern Kentucky University) - http://www.biology.eku.edu/RITCHISO/301notes6.htm

Fig. 8.4 Respiration cycles perceived and represented at different hierarchical levels of analysis

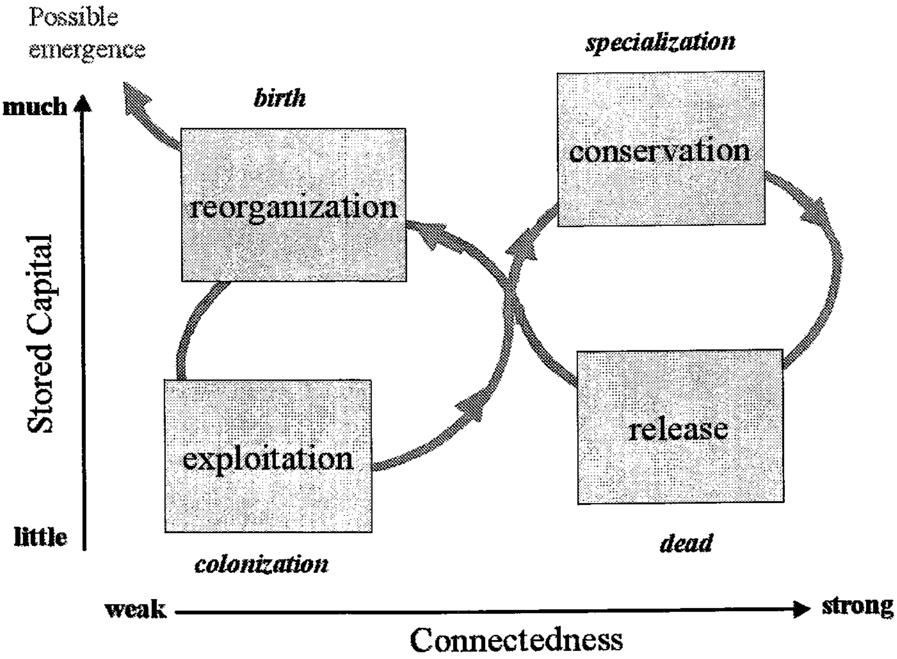


Figure 8.5 - Holling's Metaphor about Adaptive cycles (after Holling 1995)

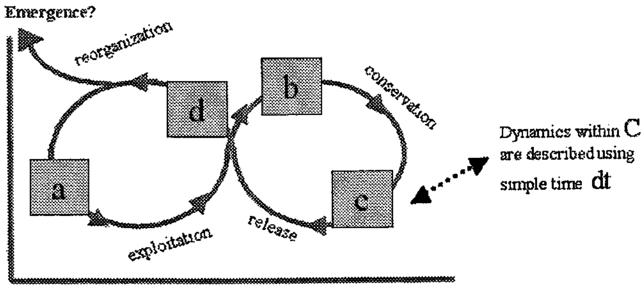
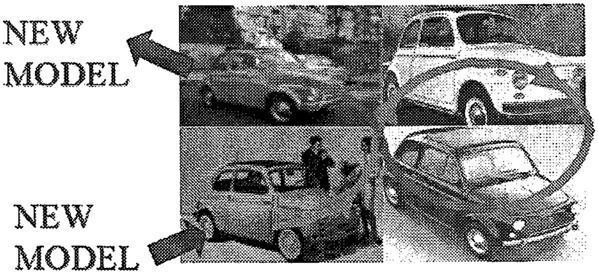


Fig. 8.6 The metaphor of Lazy-8 applied to cars



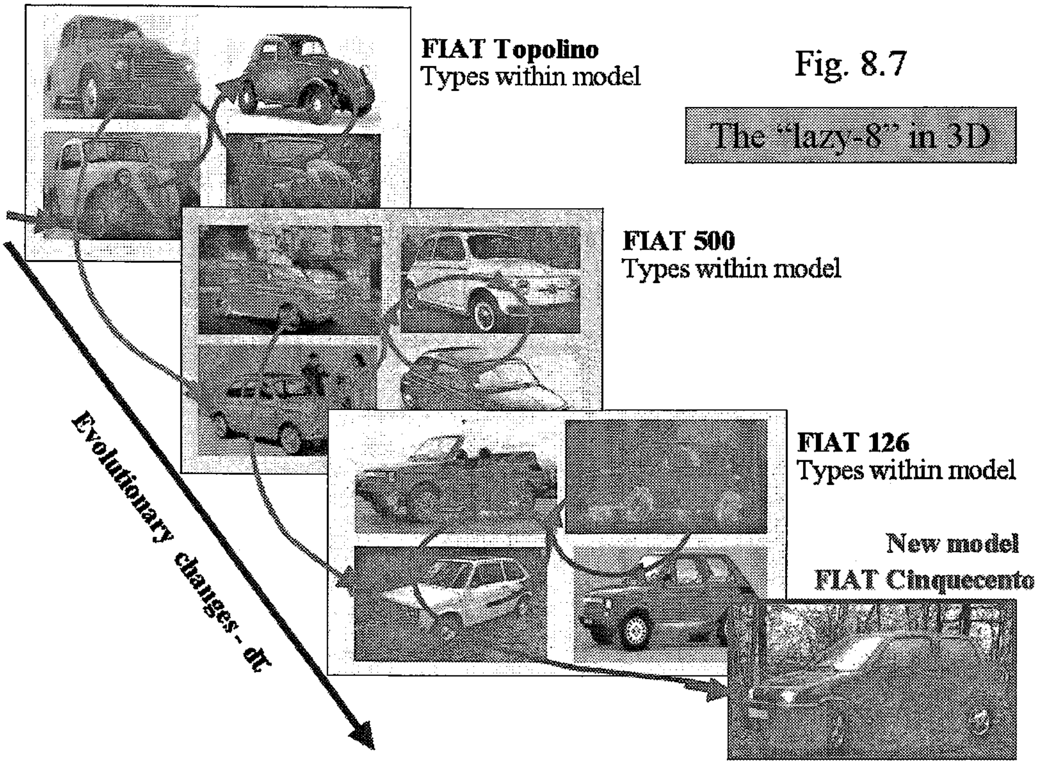


Fig. 8.7

The “lazy-8” in 3D

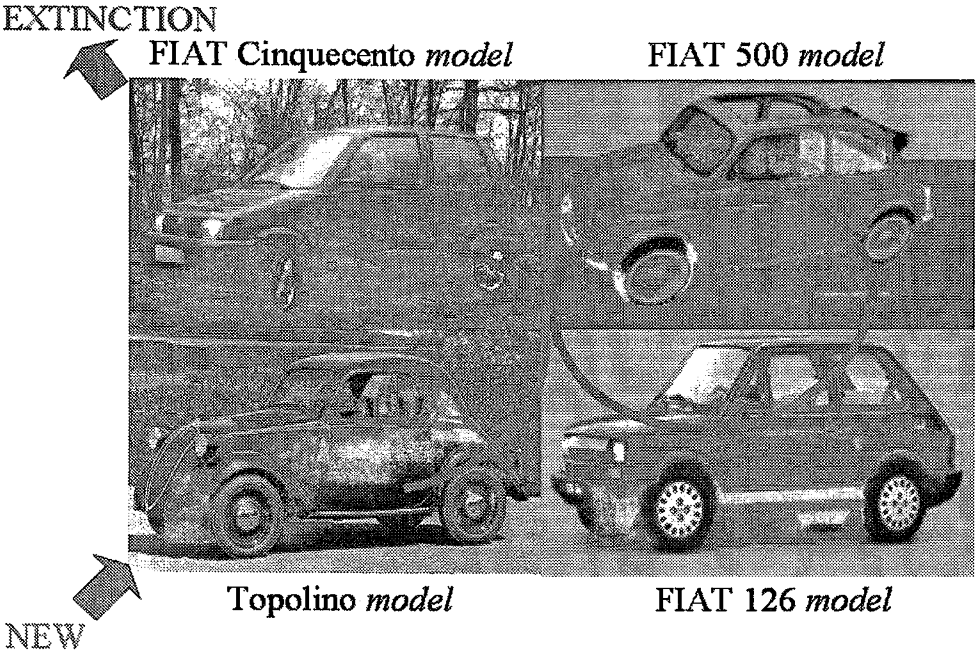


Fig. 8.8 Evolution of models within the same “essence”

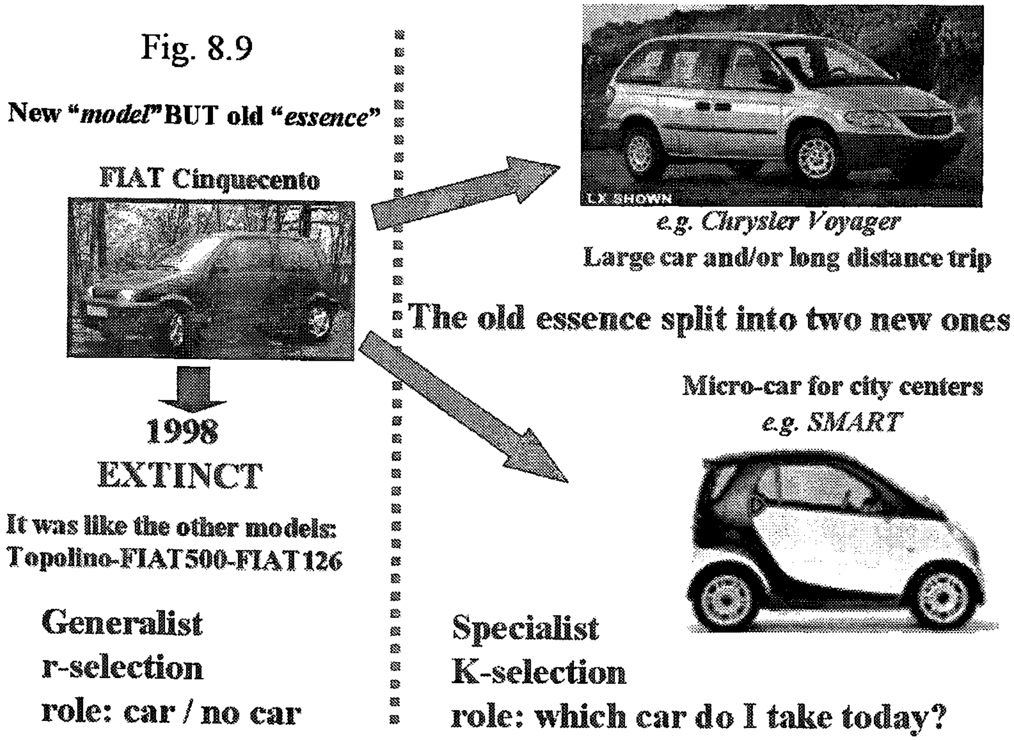


Fig. 8.9

New "*model*" BUT old "*essence*"

FIAT Cinquecento

1998

EXTINCT

It was like the other models:
Topolino-FIAT500-FIAT126

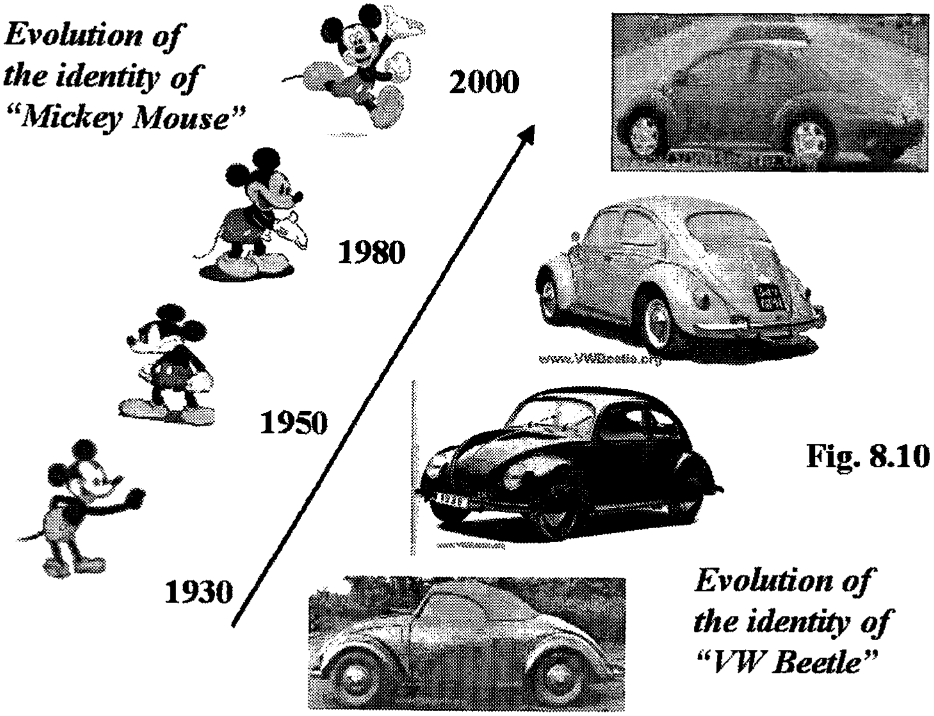
Generalist
r-selection
role: car / no car

The old essence split into two new ones

e.g. Chrysler Voyager
Large car and/or long distance trip

Micro-car for city centers
e.g. SMART

Specialist
K-selection
role: which car do I take today?



Evolution of the identity of "Mickey Mouse"

Fig. 8.10

Evolution of the identity of "VW Beetle"

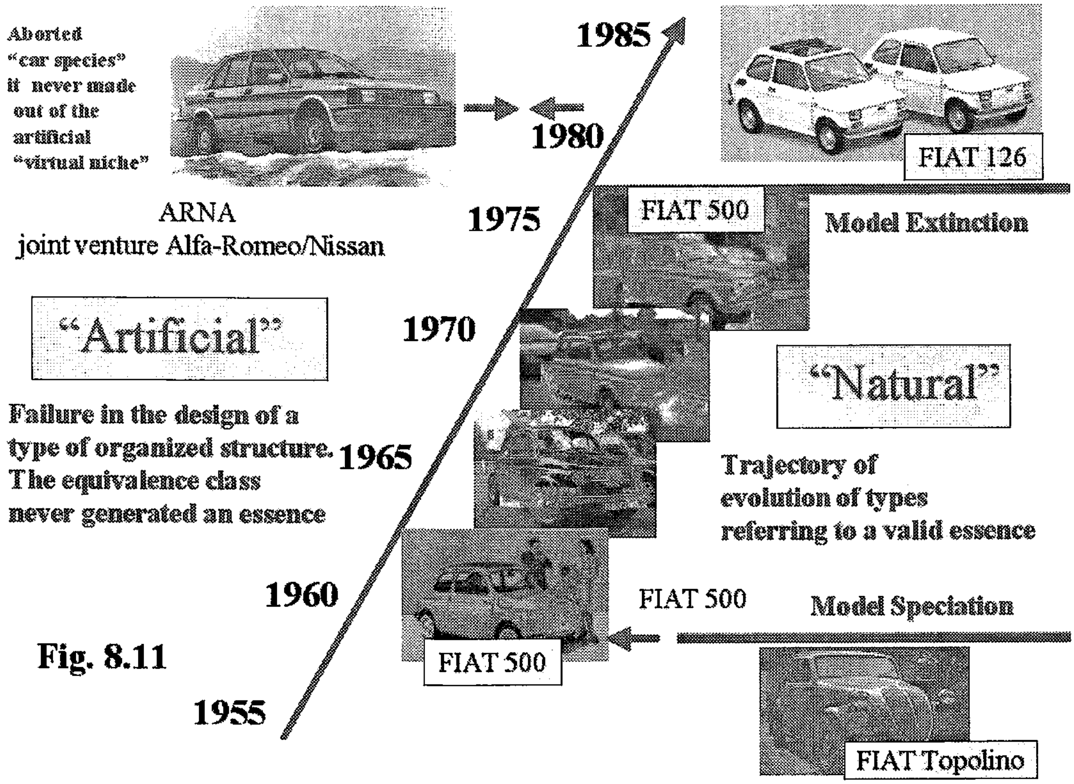


Fig. 8.11

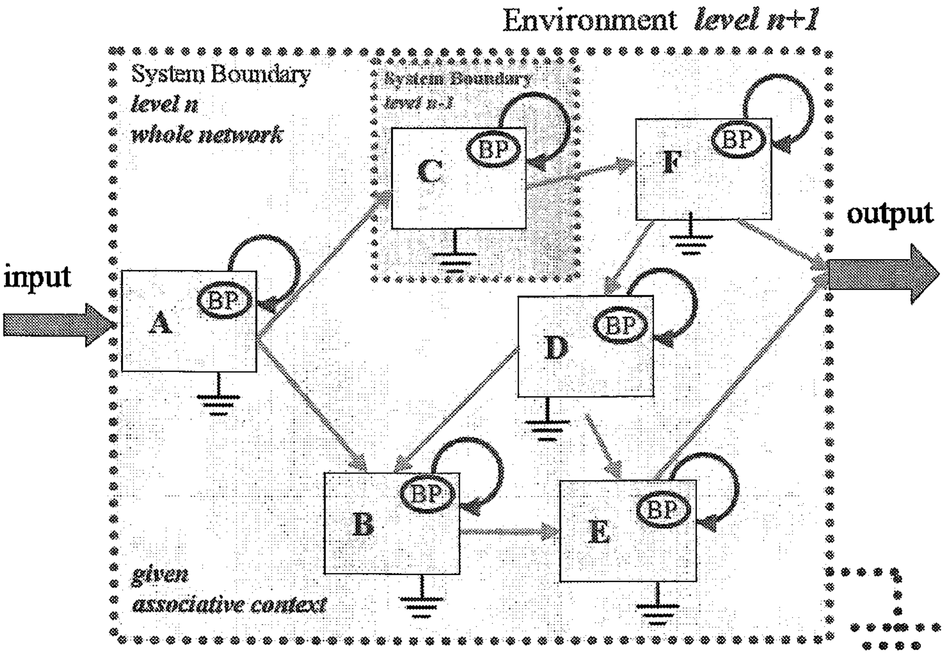


Fig. 8.12 Rosen's view on the representation of biological network

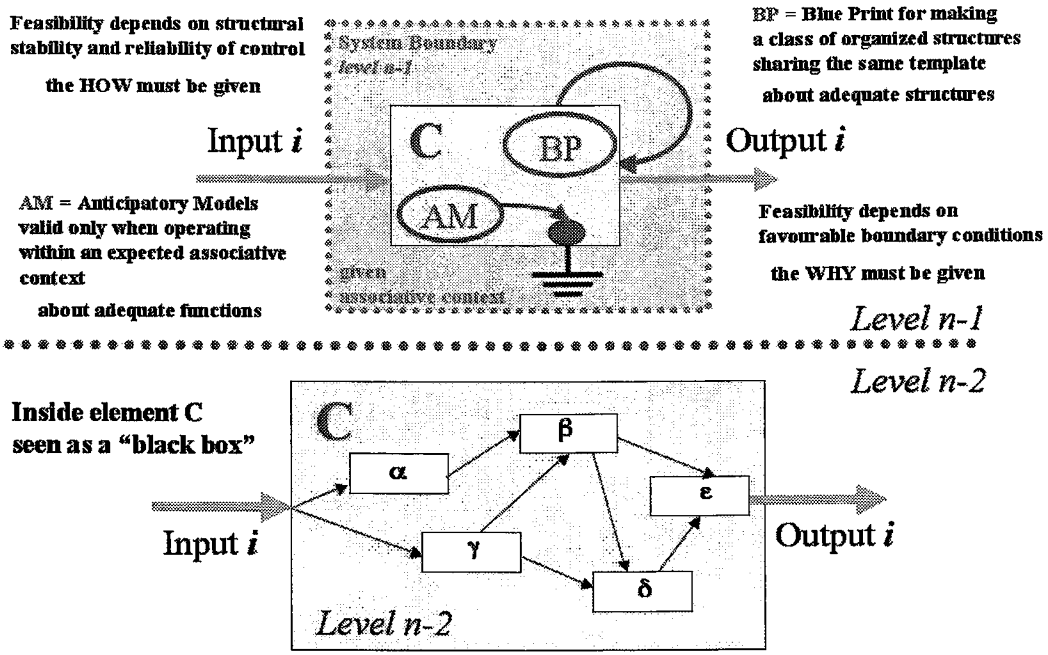


Fig. 8.13 Different view of the identities of elements of biological networks when shifting the triading reading to lower levels

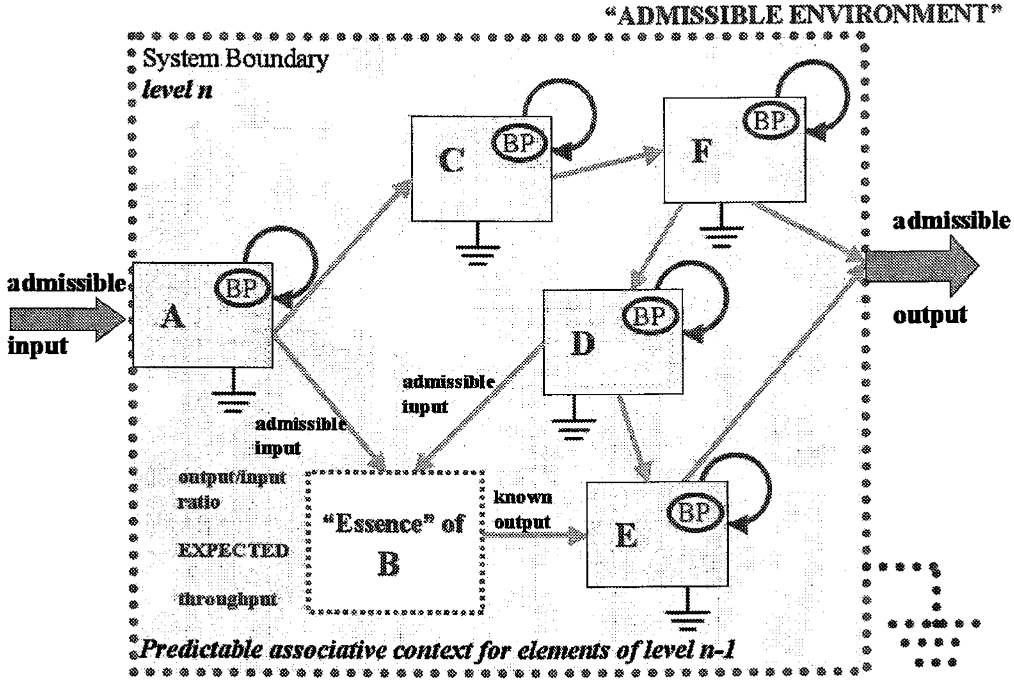


Fig. 8.14 Definition of an image of an "essence" using a mosaic effect across scales

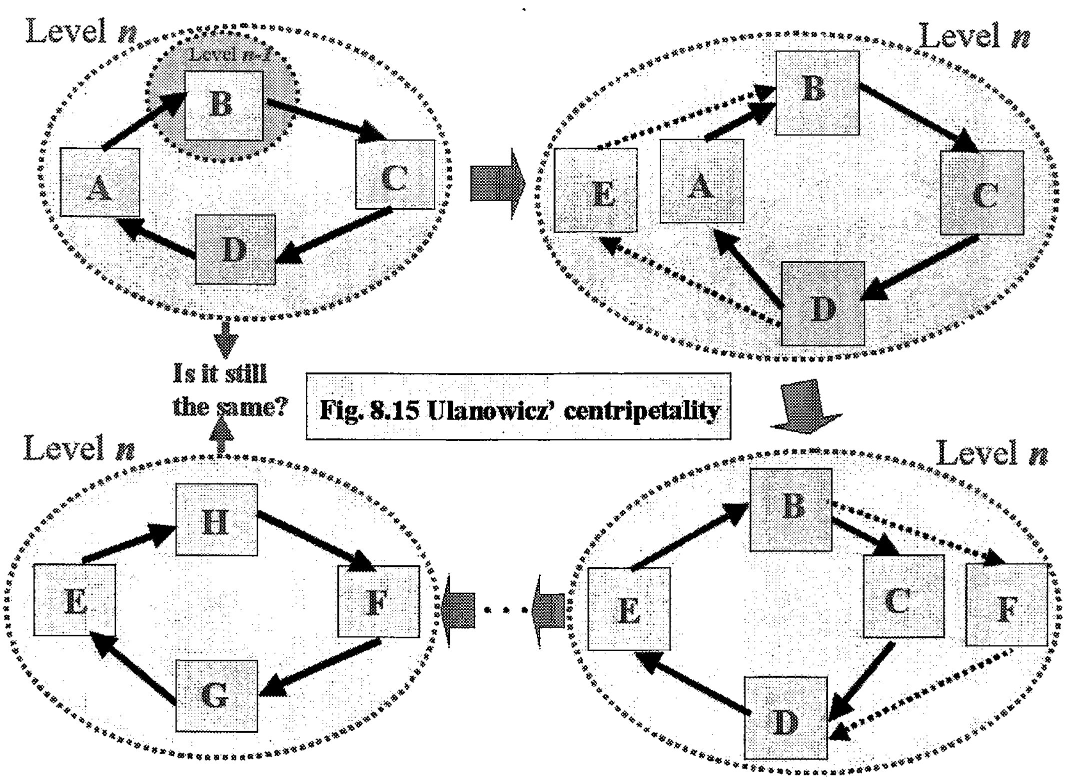


Fig. 8.15 Ulanowicz' centripetality

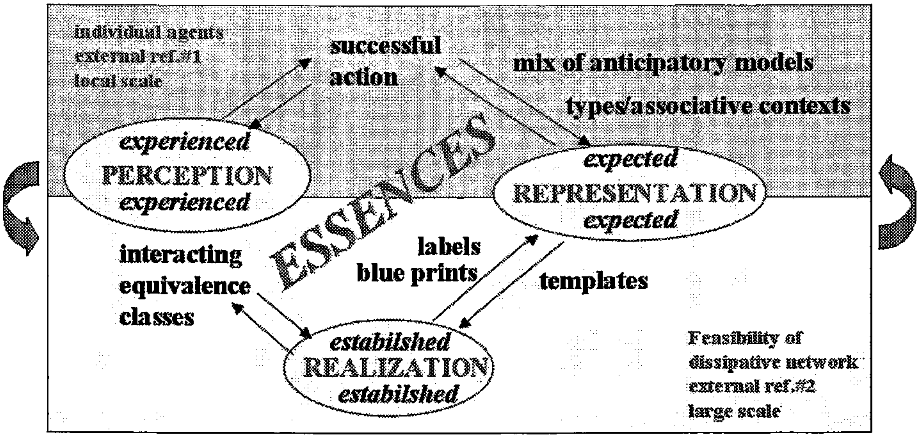


Fig. 8.16 The generation of essences through a process of parallel validation at different scales (two non-equivalent external referents)

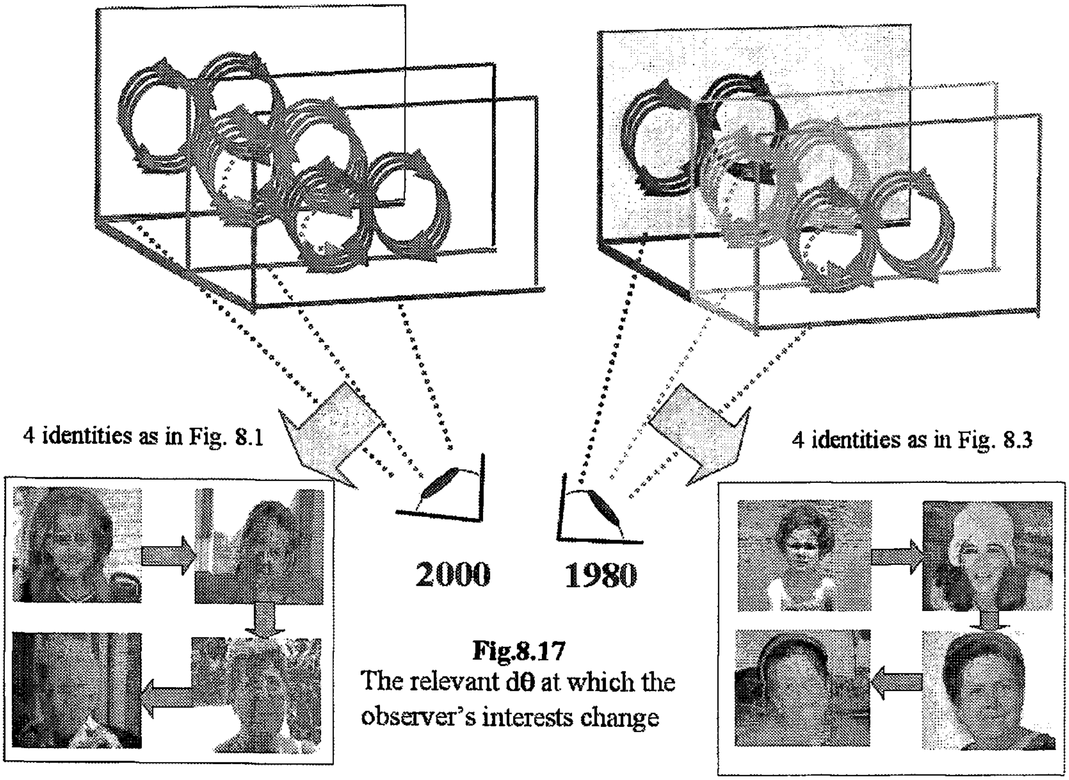


Fig.8.17
The relevant dθ at which the observer's interests change

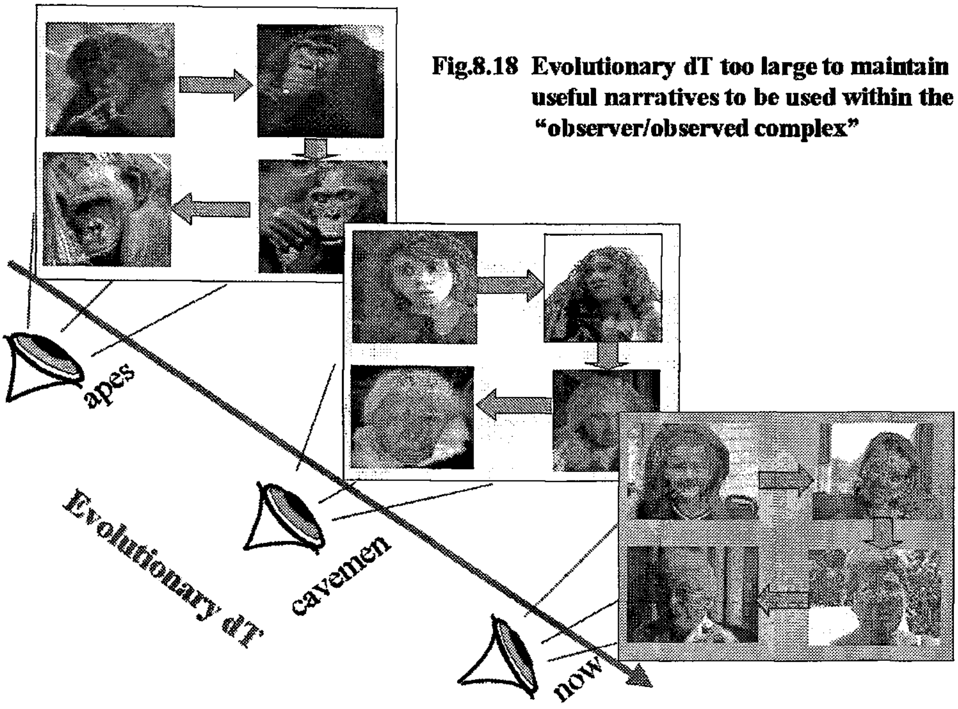
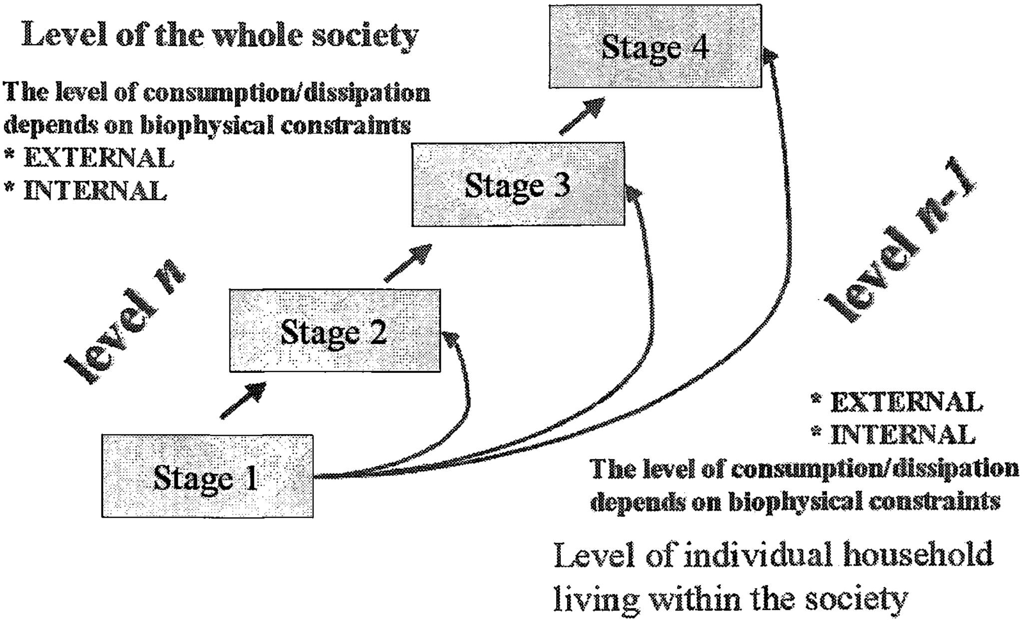


Fig.8.18 Evolutionary dT too large to maintain useful narratives to be used within the "observer/observed complex"

Fig. 8.19 Different perspectives about a trajectory of development



PART 3

Looking for a meta-tool kit useful for Multi-Scale Integrated Analysis of Agro-ecosystems

Introduction to Part 3

What is the beef which has been served in the first two parts of this book?
After this long excursion through different issues and innovative concepts which has led us through very old philosophical debates and innovative scientific developments it is time to get back to the original goal of this book. Why and how the material presented and discussed so far (for 8 chapters!) in this book is relevant for those willing to study the sustainability of agroecosystems? Part 3 provides examples of applications aimed at convincing the reader that the content of Part1 and Part2 are relevant indeed to an analysis of the sustainability of agroecosystems. Before getting into such a presentation, however, it could be useful to have a quick wrap up of the main points made so far.

1. Science deals not with the reality but with representation of an agreed-upon perception of the reality. Any formalization provided by hard science starts from a given narrative about the reality. That is, any formalization requires a set of pre-analytical choices about what should be considered relevant and on what time horizon. These pre-analytical choices are value loaded and entail an unavoidable level of arbitrariness in the consequent representation. Substantive models of the sustainability of real systems do not exist.

2. To make things more difficult science dealing with sustainability must address the process of becoming of both the observed system and the observer. This implies dealing with an unavoidable load of uncertainty and genuine ignorance, which is associated to the existence of legitimate non-equivalent perspectives found among interacting agents.

3. The process of generation of useful knowledge is, therefore, a continuous process of "creative destruction". In his book – The Science of Culture – White starts the first chapter entitled "**science is sciencing**" by saying: "*Science in not merely a collection of facts and formulas. It is pre-eminently a way of dealing with experience. The word may be appropriately used as a verb: one sciences, i.e. deals with experience according to certain assumptions and with certain techniques*" (1949; pag. 3). Especially when dealing with science used for governance it is easy to appreciate a sort of Yin Yang tension in the process used by humans for dealing with their experience. The description of this tension made by White says it all. There are two basic ways for dealing with the need of updating our knowledge: **one is science the other is art.** "*The purpose of science and art is one: to render experience intelligible i.e. to assist man to adjust himself to his environment in order that he may live. But although working toward the same goal, science and art approach it from opposite directions. Science deals with particulars in terms of universals: Uncle Tom disappears in the mass of Negro slaves. Art deals with universals in terms of particulars: the whole gamut of Negro slavery confronts us in the person of Uncle Tom. Art and science thus grasp a common experience of reality, by opposite but inseparable poles*". (White, ibid).

We have at this point developed a new vocabulary to express this concept. In order to handle the growing mass of data associated to experience humans must (A) compress the requirement of computational capability needed to handle more sophisticate models and larger data sets. To do that they need science which uses types to describe equivalence classes of natural entities. (B) expand the information space used to make sense about the reality. This can only be done by adding new types and new categories about which it is possible to obtain a shared understanding. This is where art enters into play. Art is needed to find out the existence of new relevant aspects of the reality, about which it is important to dedicate a new entry in our language or a new narrative about the meaning of reality. This leads to the idea that when dealing with science for governance, science cannot be taken from the shelf, as a repertoire of useful data and protocols. On the contrary, it is important to imagine "science for governance" as a set of procedures that can be used to do "**sciencing**".

4. There are already several attempts to develop procedures aimed at implementing the concept of "**sciencing**". In Chapter 5 an example was given in relation to the Soft System Methodology proposed by Checkland. However, several other similar efforts in this direction can be found in literature. The basic rationale is always the same. When dealing with a given perception of the existence of a problem, one has to start, necessarily, with a narrative. However, such a narrative should not be used directly, as such, to get into a scientific characterization. Rather it is important to explore as many alternative narratives as possible to expand the possible useful perspectives, detectors, indicators, models to be used, later on, in the scientific problem structuring. Obviously, in the final choice of a given scientific problem structuring the number of narratives, indicators and models used has to be compressed again. In a finite time scientists can handle only a finite and limited information space. But exactly because of this, it is important to work on a semantic check of the validity of the narratives chosen as basis for the analytical part.

5. If one agrees on the statements made in the previous 4 points, one is forced to conclude that when dealing with science for governance there are two distinct tasks, which require a different type of expertise and a different approach. These two tasks, which imply facing a formidable epistemological challenge, should not be confused - as it is done, unfortunately, by reductionist scientists. **Task #1** is related to the ability to provide a useful and sound input on the descriptive side. This implies the ability of tailoring the development of models, the selection of indicators, the gathering of data according to the specificity of the situation. **Task#2** is related to the ability to handle the unavoidable existence of legitimate but contrasting values, fears, aspirations. This unavoidable existence of conflicts in terms of values will be reflected on the impossibility to determine in a substantive way: (a) what should be considered the best problem structuring; (b) what should be considered the best set of alternatives to be evaluated; (c) what should be considered the best set of scenarios; (d) what should be considered the best alternative among those considered; (e) what is the best way for handling the unavoidable presence of uncertainty and ignorance in the problem structuring used in the process of decision making. Using the vocabulary adopted in Chapter 5 we can say that:
* Task#1 scientists should be able to provide a flexible input consisting of a Multi-Scale Integrated Analysis (generating a coherent but heterogeneous information space able to represent changes and dynamics at different hierarchical levels and in relation to different forms of scientific disciplinary knowledge).
* Task#2 has to be based on a process. That is, the issue of incommensurability and incomparability can only be handled in terms of Societal Multi-Criteria Evaluation. This concept implies forgetting about the approach proposed by reductionism. Different indicators should not aggregated into one single aggregate function (e.g. as done in Cost-Benefit Analysis). In this way one loses track of the behaviour of individual indicators, meaning that their policy usefulness is very limited. The assumption of complete compensability should not be adopted, i.e. the possibility that a good score on one indicator can always compensate a very bad score on another indicator (money cannot compensate the loss of everything else). Any process of analysis and decision making has to be as much transparent as possible to the general public.

From this perspective, we can define a reductionist approach as an approach based on the use of just one measurable indicator (e.g. a monetary output or a biophysical indicator of efficiency), one dimension (e.g. economic or biophysical definition of tasks), one scale of analysis (e.g. the farm or the country), one objective (e.g. the maximisation of economic efficiency, the minimization of nitrogen leakage in the water table) and one time horizon (e.g. one year). Reductionist analyses imply also a hidden claim about their ability to handle uncertainties and ignorance when they claim that a particular option (e.g. technique of production) is "better" than another one.

This is the reason why in multi-criteria evaluation it is claimed that what is really important is the "decision process" and not the final solution.

6. The set of innovative concepts presented in Part 2 can be used to organize a Multi-Scale Integrated Analysis of agroecosystems. These tools are required to organize conventional scientific analyses in a way that make explicit and transparent the chain of pre-analytical choices made by the analyst. Actually, these decisions become an explicit object of discussion, since they are listed as required input to Impredicative Loop Analysis.

In conclusion, what is presented in Part 3 is not an analytical approach aimed at finding the best course of action or indicating to the rest of society the right way to go to improve the sustainability of our agroecosystems. The text of Part 3 is just a series of examples of how the insight derived from Complex Systems Theory can be used to organize scientific information to generate informed discussions about sustainability. To do that the proposed approach generates useful information spaces made up of non-equivalent descriptive domains (integrated packages of non-reducible models) that can be tailored on the specific characteristics of relevant agents. The ultimate goal is that of structuring available data sets and models according to a selected set of narratives which have been defined as relevant for a given situation.

What is the beef which is served in Part 3?

If we do a quick overview of the literature dealing with sustainable agriculture we will find a huge number of papers dealing with assessments and/or comparisons of either different farming techniques or different farming systems operating in different areas of the world. The vast majority of these papers is affected by a clear paradox:

(A) analyses of farming systems and/or assessments of the sustainability of agricultural techniques generally start with an introduction that makes an explicit or implicit reference to the following quite obvious two statements: (i) what can be produced and what is produced in a farming system depends on the set of boundary conditions in which the farming system is operating (= the characteristics of both the ecological and the socio-economic interface of the farm). After conditioning "what to produce" these characteristics influence also "how to produce it" (= the choice of techniques of production and the choice of related technologies). (ii) any assessment of the agricultural process obtained by considering only a particular perspective of farming (e.g. agronomic performance, economic return, social and cultural effects, ecological impact) necessarily misses other important information referring to other perspectives of the same process. To be meaningful any evaluation of agricultural techniques should consider a plurality of perspectives through a holistic description of farming processes.

So far so good, the main message about the need of integrated analysis for complex systems seems to be clear to the majority of authors, at least when reading the introductory paragraphs. However, such a wisdom tends to disappear in the rest of the paper. That is:

(B) before entering into a discussion of case studies, comparisons of techniques of production, or more in general in analyses of sustainability of farming systems authors omit to provide **in an explicit form *all* three pieces of information listed below:**

(i) characterization of boundary conditions the farming system is dealing with; that is:

* according to the set of constraints coming from the socio-economic side, how fast must be the throughput in the farming system? (e.g. minimum level of productivity per hour of labor which is acceptable for farmers and minimum level of productivity per hectare forced by demographic pressure - where applicable);

* according to the set of constraints coming from the ecological side - type of ecosystem exploited and intensity of withdrawal on primary productivity - what is the current level of environmental loading and what do we know about the eco-compatibility of such a throughput ? (= what is the room left for intensification ?);

(ii) characterization of the basic strategy affecting farmer's choice; that is:

* what is the optimizing strategy under which farmers are making decisions?
e.g. are they minimizing risk (farming system must be resilient since it is on its own in case of troubles), or rather are they maximizing return (the farming system is protected against risks – e.g. crop failure - by the rest of the society to which it belongs – as in developed countries) – e.g. there are location specific strategies affecting their choices?;
* are farmers sustaining the development of the rest of society (are farmers net tax payers) ? or rather are they subsidized by the rest of society (are farmers supported by subsidies)?
(iii) a critical appraisal about the limits of validity of the particular type of analysis performed on the farming system; that is: out of the many possible perspectives under which farming activities can be represented and assessed, any choice of a particular window of observation and a particular set of attributes to define the performance of farming (i.e. the one that was adopted in the study) implies the missing of other important views of the process. What consequences does it carry for the validity of the conclusions? For example, checking the agronomic performance and/or the ecological compatibility of different techniques does not say anything about the sustainability of these techniques. To discuss sustainability we need also a parallel check on economic viability and on the compatibility of these techniques with cultural identity and aspirations of farmers that are supposed to adopt them. How much it is possible to generalize the validity of the conclusions of this paper that are related to a location specific analysis?

The three chapters of Part 3 have the goal to show that it is possible to develop a tool kit for multi-scale integrated analysis of agroecosystems which makes possible to:
(1) link the economic and biophysical reading of farming in relation to structural changes occurring in larger socio-economic system to which the farming system beling during the process of development. This makes possible to use an integrated set of indicators of development, able to represent the effects of changes on different hierarchical levels (fromt he country level to the level of the household) – **Chapter 9**;
(2) establish a bridge, which can be used to explain how changes occurring in the socio-economic side are reflected in changes in the level of environmental impact associated to agriculture. The biophysical reading of these changes at the farm level, makes possible to explain the existing trends of increased environmental impact of agriculture to existing trends of technical progress of agriculture – **Chapter 10.**
(3) represent agroecosystems in terms of holarchic systems. This makes possible to study the reciprocal influence of the decisions of agents operating at different levels in the holarchy. In this case, indicators related to economic, social and ecological impact can be integrated across levels to indicators of environmental impact based on changes in land use – **Chapter 11.**

Chapter 9

Multi-Scale Integrated Analysis agro-ecosystems: bridging disciplinary gaps and hierarchical levels

This chapter has the goal to illustrate examples of Multi-Scale Integrated Analysis of societal metabolism which are relevant for the analysis of the sustainability of agroecosystems. In particular, Section 1 illustrates the application of Impredicative Loop Analysis at the level of the whole country using in parallel different typologies of variables. In this way, one can visualize the existence of a set of reciprocal constraints affecting the dynamic equilibrium of societal metabolism. That is, feasible solutions for the dynamic budget represented using a 4-angle figure can only be obtained by coordinated changes of the characteristics of parts in relation to the characteristics of the whole, and changes in the characteristics of the whole in relation to the characteristics of the parts. Section 2 provides the results of an empirical validation based on a data set covering more than 100 countries (including more than 90% of world population) of this idea. In particular, such an analysis shows that an integrated set of indicators derived from ILA makes possible to: (a) establish a bridge between an economic and biophysical reading of technical progress; (b) represent the effect of development in parallel on different hierarchical levels and scales. Section 3 deals with the link between changes occurring at the level of the whole country (society) and changes in the definition of "feasibility" for the agricultural sector. That is, socio-economic entities in charge for agricultural production must be compatible with their socio-economic context. This implies the existence of a set of biophysical constraints on the intensity of the flow of produced output. Finally, Section 4 deals with trend analysis of technical changes in agriculture. Changes in the socio-economic structure of a society translated into a pressure for boosting the intensity of agricultural output both in relation to land (Demographic Pressure = increase in the output per hectare of land in production) and in relation to labor (Bio-Economic Pressure = increase in the output per hour of labor in agriculture). Indices assessing these two types of pressures can be used as benchmark to frame an analysis of agroecosystems.

9.1 Applying ILA to the study of the feasibility of societal metabolism at different levels and in relation to different dimensions of sustainability

9.1.1 The application of the basic rationale of ILA to societal metabolism

The general rationale of Impredicative Loop Analysis, illustrated in Chapter 7, is applied here to the analysis of societal metabolism. The level considered as the **level *n*** is the level of the whole society (country). This requires:

(1) a characterization of total requirement at the **level *n*** – this is a **consumed flow assessed in relation to the whole.** This is done by using an **Intensive Variable#3 mapping the level of dissipation (consumption of Extensive Variable#2) per unit of size of the whole (measured in terms of Extensive Variable#1).**

(2) a characterization of internal supply at the **level n-1** – this is a **produced flow assessed in relation to a part** of the whole. This is done by using an **Intensive Variable#3 mapping the flow of supply (measured using Extensive Variable#2) per unit of size of the part (measured in terms of Extensive Variable#1).**

(3) an analysis of **the congruence over the loop of the reciprocal definition of identities** of: (a) whole; (b) parts; (c) sub-parts and inputs and outputs of parts; and (d) the weak identity assigned to the environment (reflecting its admissibility).

The applications discussed below are based on the use of:
* **two "Extensive Variable#1"** used to assess the size of the system, providing a common matrix representing its hierarchical structure. These two EV#1 are: (i) "human activity" and (ii) "land area";
* **three "Extensive Variable#2"** used to assess the intensity of a flow, which can be associated to a certain level of production/consumption. These three EV#2 are: (i) "exosomatic energy dissipated"; (ii) "added value" related to market transactions; (iii) "food". The definition of the size of parts (lower level compartments), in terms of EV#1, has to be done in a way that guarantees the closure of the assessments of the size of the whole across levels. The same applies to the distinction between: (a) the direct compartment generating the internal supply; versus (b) rest of society.

Step 1 – Discussing of typologies

Two possible choices considered here for Extensive Variable#1 are useful to address two main dimensions of sustainability. (1) Human time – when used as Extensive Variable#1 – is useful for checking the compatibility of a given solution within the socio-economic dimension. Whereas, (2) Land area – when used as Extensive Variable#1 – is useful for checking the ecological dimension of compatibility.

The first thing to do, is therefore an analysis of possible types that can be used to establish a ILA according to the general scheme presented in **Fig. 9.1**.

When applying the scheme of **Fig. 9.1** to the analysis of the dynamic equilibrium of societal metabolism of a whole society using human activity as Extensive Variable#1, we are in a case which has been discussed in two occasions so far. There are different sets of types on different quadrants. The profile of distribution of individuals over the set of types will determine the value taken by the angle. For example, starting with the upper-left angle we find that, the level of physiological overhead on Disposable Human Activity can be expressed as generated by a set of types and a profile of distribution over it. This has been discussed in **Fig. 6.9** (profile of distribution of individuals over age classes) and **Fig. 6.10** (profile of distribution of kg of body mass over age classes). The effect of changes (either in the set of types – e.g. longer life span – or in the profile of distribution over the types), which can affect the "physiological overhead" has been discussed in relation to **Fig. 7.2** and **Fig. 7.3** (when illustrating a simplified analysis of the dynamic budget of the societal metabolism – using food as Extensive Variable#2 – for a hypothetical society of 100 people on a remote island).

After subtracting from Total Human Activity the physiological overhead we obtain the amount of Disposable Human Activity for the society – left side of **Fig. 9.2**. This amount of Disposable Human Activity is then invested in a set of possible activities. The various categories of human activities can be divided between "work" (the types marked in light blue) and "leisure" (the types marked in red and green). Making this distinction implies always a certain degree of arbitrariness. This is why it is important to have: (i) the constraint of closure across levels; (ii) the possibility of making in parallel various ILAs based on a different selection of Extensive Variable#2. This is particularly important for the decision about the definition of the direct compartment, the compartment providing the internal supply, which is characterized in the lower-right quadrant. For example, we can decide to include the Service Sector among those lower-level parts making up the indirect compartment when studying the dynamic budget of exosomatic energy. That is, when making a 4-angle figure with "exosomatic energy" as E.V.#2, we can assume that the service sector does not produce either a direct supply of exosomatic energy or machines for using exosomatic energy. Whereas when making a 4-angle figure with "added value" as E.V.#2, we have to include the service sector in the direct compartment. In fact, when considering the dynamic budget of added value, the service sector is among those sectors producing added value.

Obviously, the choice of the set of typologies used to obtain closure on Disposable Human Activity is necessarily open. At this regard we can recall the crucial role of the category "other" to obtain closure – **Fig. 6.1**. In this example, the difference between DHA and the sum of the various investments on working activities can be considered in this system of accounting as Leisure. With this choice we can end-up by including into leisure investments of human activity in typologies of work not included in the list of typologies.

The scheme of **Fig. 9.1** can also be applied to an analysis of the dynamic budget of societal metabolism, which uses land area as Extensive Variable#1. In this case, we start with a level of Total Available Land defined as the area associated to the entity considered as the whole socio-economic system (e.g. the border for a country or the area needed to stabilize a given flow). Also in this case, this scheme can be used to have a preliminary discussion of the standard typologies to be used for the analysis of land use. In general a first list of land typologies is found when looking at data (e.g. desert, too hilly, permanent ice, swamps, arable land, forest). Not necessarily, the categories found in published data are useful for a particular ILA. As soon as, the analysts manages to obtain a set of useful typologies for the analysis, then, the profile of distribution of individuals hectares (unit used to assess the size according to Extensive Variable#1) over the set will define the level of biophysical overhead (Reduction I) determining the Colonized Appropriated Land (CAL) – see **Fig. 9.3**. To indicate the process of permanent alteration of the identity of terrestrial ecosystems due to human interference on biological and ecological mechanisms of control, the group of IFF of Vienna (Institute of Interdisciplinary Studies of Austrian University – see for example, Fischer-Kowalski and Haberl, 1993; Haberl and Schandl, 1999) suggests the term of "colonization". By adopting their suggestion we use the acronym CAL (Colonized Appropriated Land).

At this point, we need a set of possible typologies of land use covering the entire Colonized Appropriate Land to classify investments of human activity within this compartment. This is illustrated on the left of **Fig. 9.3**. This is a very generic example and depending on the type of problem considered it requires an additional splitting of these coarse typologies into a more refined classification.

Step 2 Defining the critical elements of the dynamic budget

Depending on the E.V.#2, which is chosen for the Impredicative Loop Analysis and the specificity of the questions posed, it is necessary at this point to interpret the metaphorical message associated to **Fig. 9.2** and **Fig. 9.3**. This requires that the analyst discuss how to formalize this rationale in relation to a specific situation, in terms of numerical assessments based on available data set.

* *Example#1 - Human Activity as E.V.#1 and Food as E.V.#2*

Let's start with the example of an Impredicative Loop Analysis referred to Human Activity (as Extensive Variable#1) and food (as Extensive Variable#2). This is a case that has already been discussed in the example of the 100 people on the remote island.

(1) assessing total requirement at the level of the whole - level *n*.

This is an assessments of total "consumption" associated to the metabolism of a given human system. In the case of food this flow can be written - at the **level *n*-** as:

$$\text{POPULATION x Consumption p.c.} = \text{Total Food Requirement (E.V.\#2)} \qquad (1)$$

In relation (1) Total Food Requirement is expressed as a combination of the extensive variable#1 (size of the system – mapped here in terms of population) and the intensive variable#3 (consumption per capita, which means a given level of dissipation per unit of size). Relation (1) can be easily transformed into:

$$\text{THA x } FMR_{AS} = \text{Total Food Requirement (E.V.\#2)} \qquad (2)$$

when considering that [THA = population x 8760 = total amount of hours of human activity per year], and that ***consumption per capita*** represents an assessment of a given flow (e.g. MJ of food or kg of food per year), that can be transformed into $\mathbf{FMR_{AS}}$ (Food Metabolic Rate assessed as Average of Society) by dividing the relative value of consumption per capita (flowing in a year) by 8760. This provides the amount of flow of food consumed per hour of human activity. With this change we can write

$$\mathbf{FMR_{AS}} = (\text{Consumption p.c.}/8760) = \text{I.V.\#3}_n \qquad (3)$$

(2) Assessing internal supply - level *n-1*

This is an assessments of the internal supply of input provided to the black box because of the activities performed within the direct compartment [HA_{AG}]. This internal supply requires the conversion of energy inputs into useful energy able to fulfill the tasks. When mapping the effect of agricultural activities against human activity - at the **level *n-1*** – we can write:

$$(HA_{AG} \times BPL_{AG}) = \text{Internal Food Supply (E.V.\#2)} \qquad (4)$$

The total supply, assessed at the **Level *n-1***, is expressed as a combination of the extensive variable#1 (size of the lower level compartment – HA_{AG} = Human Activity invested in the Agricultural Sector – the one labeled as "**direct**" in the upper part of **Fig. 7.8**) and the intensive variable#3 (BPL_{AG} - Bio-Physical Productivity of Labor in Agriculture - which assesses the return of human activity invested in the set of tasks performed in the compartment called as "**direct**"). BPL_{AG} measures the input of food taken from the land and delivered to the black box per unit of human activity invested in the **direct** compartment. This is the lower level compartment in charge with the direct interaction with the context to get an adequate supply of input (see upper part of **Fig. 7.8**).

$$\mathbf{BPL_{AG}} = \text{Biophysical Productivity of Labor in Agriculture (I.V.\#3)}_{n-1} \qquad (5)$$

(3) checking the congruence of the required and the supplied flow

At this point by combining relation (4) to relation (2) we can look for the congruence among the two flows:

$$THA \times FMR_{AS} = HA_{AG} \times BPL_{AG} \qquad (6)$$

As noted before, not necessarily these two flows must coincide either on the short term (periods of accumulation and depletion of stocks) and in the long term (a society can be dependent on import for its metabolism or can be a regular exporter of food commodities).

Additional information can be added to the congruence check expressed by relation (6). For example, the reader can recall the discussion given in Chapter 6 about the characterization of endosomatic flow in Spain across different levels (**Fig. 6.8**). The characterization of the total food requirement can be expanded including information referring to different hierarchical levels by substituting the term FMR_{AS} with three terms – in parenthesis - as done in the following relation:

$$THA \times (ABM \times MF \times QDM\&PHL) = HA_{AG} \times BPL_{AG} \qquad (7)$$

In relation (7) the total requirement of endosomatic energy, assessed at the **level *n***, is expressed as a combination of an extensive variable#1 (size of the system – mapped here in terms of Total Human Activity, linked directly to the variable population) and three variables: (i) ABM – Average Body Mass, (ii) Metabolic Flow – endosomatic metabolic rate per kg of human mass and unit of time; (iii) QDM&PHL – a factor accounting for Quality of Diet Multiplier and Post-Harvest Losses. QDM&PHL accounts for the difference between the energy harvested in the form of produced food at the food system level (recall here the assessment of embodied kg of grains versus the kg of grain consumed directly at the household level in **Fig. 3.1**) and the endosomatic energy flowing within the population. QDM&PHL depends on: (i) QDM - the degree of double conversion of crops into animal product (associated to the quality of the diet and the modality of production of animal products), plus other utilization of crops into the food system (seeds, industrial preparations associated to losses); and (ii) PHL - direct losses due to pests, decay and damages in the step of processing, handling, storage and distribution in the food system.

The congruence check suggested by relation (7) is still related to: (a) a requirement associated to the identity of the whole; and (b) an internal supply associated to the identity of the direct compartment. However, the more elaborated characterization of the total food requirement makes possible to consider a larger set of identities in the forced relation.

Before getting into other examples of Impredicative Loop Analysis it is useful to go through a few considerations that can be already be made after this first.

* ***The lessons learned from this example***

When looking for a closure in the representation of the black box (**level *n***) on the lower level (**level *n-1***), we have to contrast, in the lower-right quadrant the **direct** compartment versus the "**rest of society**". The size of the "rest of society" in this case is determined by:

(a) REDUCTION I – expressed in terms of EV#1 – associated to either physiological overhead (for human activity) or biophysical overhead (for land use) PLUS

(b) REDUCTION II – expressed in terms of EV#1 – associated to the fraction of investment of DHA or CAL which is going to the indirect compartment. For example, in the system of accounting adopted in relation (7) – **Fig. 9.2** - the "rest of society" includes all the investments of human activity not included in the compartment "agriculture".

It should be noted that the investments of human activity in the **indirect compartment** (see **Fig. 7.8**) can be considered as irrelevant in relation to the assessment of the specific mechanisms guaranteeing the supply of flows consumed by society – referring to a reading of this event at the **level *n-1***. However, when looking at events - at the **level *n*** - the size of HA_{RoS} [in the case of relation (7) this would be all Human Activity non invested in agricultural work] becomes very relevant for two reasons. First, because it participates in determining the total requirement of input at the level of the whole system. Second, because the indirect compartment includes different typologies of activities associated to different consumption levels. For example, even when considering activities belonging to leisure, the sub-category "sleeping" implies a much lower level of consumption than the sub-category "running marathons". The higher is the fraction of human activity invested in "energy intensive" activities in the indirect compartment, the higher will be its share of total consumption. As a consequence of this, the higher will be the necessity for the fraction of human activity invested in the direct compartment to be productive.

To clarify this point, let's consider the profile of investments of Human Activity of a developed society – such as the USA – which is illustrated in **Fig. 9.4**. Starting from a THA = 100%, we have a REDUCTION 1 of 71% associated to the physiological overhead. Then Leisure absorbs another 19% of THA. This implies that only 1 hour of Human Activity out of ten is actually invested into typologies of work included in the class Paid Work. The internal competition among lower level sub-compartments of Paid Work implies that another 6% of THA goes in the sector Service and Government. Leaving only 4% to the productive sectors of the economy dealing with the stabilization of the endosomatic (food for people) and exosomatic (fossil energy for machines) metabolism. The vast majority of the work in the productive sectors goes to manufacturing and other activities related to energy and mining, leaving a very tiny fraction of work allocated in agriculture, which keeps shrinking in time. In 1994 (the year to which the profile of investments of human activity given in **Fig. 9.4** refers to) the fraction of work force in agriculture was 2%. This means 2% of the 10% of Paid Work. At this point we can see that

REDUCTION 2 implies moving from the 29% of THA of Disposable Human Activity, available after REDUCTION 1, to a 0.2% of THA invested in the "direct compartment" agriculture. Put in another way, after defining "agriculture" as the direct compartment in charge for producing the internal supply of food, we obtain that the size of the compartment "**rest of society**" is:

Rest of society = RED. 1 (71.0% THA) + RED. 2 (28.8% THA) = 99.8% THA (8)

The relation in size between the direct compartment (HA_{AG}) and the "rest of society" (which can be represented as THA - HA_{AG}], implies a constraint on the relative densities of the two flows [total requirement and internal supply] represented at different levels (***n*** and ***n-1***) to obtain congruence. By recalling the definitions of I.V.#3 at different hierarchical levels given by: relation (3) [$\mathbf{FMR}_{As}$ = (I.V.#3) ***n***] and relation (5): [$\mathbf{BPL}_{AG}$ = (I.V.#3)***n-1***], and by using the relation of congruence (6), we can write:

$$THA/HA_{AG} = \mathbf{BPL}_{AG}/\mathbf{FMR}_{AS} = 500 = 1/0.002 \qquad (9)$$

That is, the higher the difference between the size of the "rest of society" and the size of the "direct compartment" (according to Extensive Variable#1), the larger must be the ratio among the two intensities of the flows (I.V.#3) assessed at the **level *n-1*** and at the **level *n*.** The assessment expressed in terms of Intensive Variable#3 obviously reflects the choice of an Extensive Variable#2 (in this case food).

Reaching an agreement about the definition of what should be considered as working a non-working and about the correct assessment of the size of the resulting compartments (e.g. the profile of investments given in **Fig. 9.4**) within a real society is everything but simple. The reader can recall here the example of the 100 people on the desert island discussed in Chapter 7. Any definition of labels for characterizing a typology of human activity is arbitrary. When dealing with the representation of human activity in relation to the metabolism of a country, a community, a household, nobody can provide a substantive characterization of what should be considered as "working" (direct contribution to the stabilization of the input metabolized by society, which is taken from the context in the short term) and what should be considered as "non-working". Any formalization of these concepts will depend on the time scale and on the selection of variables (epistemic categories) used to perceive and represent the mechanisms stabilizing the metabolism of the society in the first place. The working of a housewife preparing meals can be accounted as invested in the non-working compartment (when characterizing the compartments using the categories – "household sector" versus "paid work sector") or can be accounted as invested in the working compartment (when characterizing the compartments using the categories – "leisure" versus "working and chores"). In the same way, the service sector can be viewed as a sector producing added value in an economic accounting (as a part of the ***direct*** compartment in terms of production of added value), whereas it can be viewed as a net consumer of energy and goods in a biophysical accounting (as a part of the ***indirect*** compartment in terms of production of useful energy and material goods). This unavoidable arbitrariness, however, is no longer a problem, as soon as one accept to use non-equivalent representations in parallel, and as long as one addresses the technical aspects required to keep coherence in the non-equivalent sets of definitions (see Giampietro and Mayumi, 2000).

The various relations of congruence discussed so far are examples of impredicative loops, in which the definition of what are the activities included in the label "working in the direct compartment" will also define: (a) the assessment of the I.V.#3 (the output of work in the direct compartment); as well as (b) the definition of what has to be included under the label "rest of society". As soon as a particular system of accounting about how to assess food requirement and supply is agreed upon, then, the relation among the identities expressed by the loop will become self-referential. That is, as long as the observer stick to the definitions and the assumptions used when developing the specific system of accounting, impredicative loops can be used for looking at external referents that can provide mosaic effects to the integrated assessment.

*** Example#2 - Human Activity as E.V.#1 and Added Value as E.V.#2**
In this case, the congruence check over the dynamic budget is related to a characterization of the total requirement (on the left side of the relation) and to an internal supply (on the right side of the relation):

$$THA \times GDP/hour = HA_{PW} \times ELP_{PW} = [THA \times (SOHA+1)] \times ELP_{PW} \qquad (10)$$

The total requirement of added value, assessed at the **level *n***, is expressed as a combination of an extensive variable#1 (size of the system – mapped here in terms of Total Human Activity, linked directly to the variable population) and to a well known intensive variable#2 – the GDP per capita, expressed in $ per hour. In this case, the GDP (or GNP depending on the selected procedure of accounting) is defined in terms of the sum of the expenditures of the various sectors. The only trivial transformation required by this system of accounting to make this variable compatible with the other non-equivalent readings is to divide the value of GDP per capita per year, by the hours of a year

The internal supply of added value, assessed at the **level *n-1***, is expressed as a combination of an extensive variable#1 (size of the lower level compartment – $HA_{PaidWork}$), which considers all human activity invested in generation of added value which is paid for (productive and service sectors including government) and an intensive variable#3- ELP_{PW} - Economic Labor Productivity of Paid Work.

An overview of the reciprocal entailment among the terms included in relation (10) can be obtained using a 4-angle figure - as shown in **Fig. 9.5**. It should be noted again, that ELP_{PW} has nothing to do with an economic assessment of how much added value is produced by the production factor "labor". In fact, the assessment of ELP_{PW} refers to the combined effect of labor, capital, know-how, and the availability and the quality of natural resources used by a particular economy, or sector, or sub-sector, or typology of activity, or a particular firm/farm.

$$ELP_{PW} = \frac{\text{Added value generated by an element } j \text{ over a given period of time}}{\text{hours of human work in the element } j \text{ over the same period of time.}} \qquad (11)$$

That is, we are dealing in this application only with a mechanism of accounting which has the goal of guaranteeing the congruence of non-equivalent systems of mapping providing an integrated analysis of the performance of a socio-economic system. Put in another way, ELP_{PW} is not used to study which particular combination of capital, labor, know-how and natural resources is generating a given flow of added value, in order to improve or optimize the mix. Rather, the only use of the assessment of ELP_{PW} is that of looking for the existence of constraints of congruence with non-equivalent, but related, assessments of flows, which can be obtained when looking at the same system, but on different hierarchical levels or using a different definitions of identity for the elements.

To this ILA we can apply the same condition of congruence about the ratio between the intensities of the two flows of total requirement and internal supply seen in relation (9):

$$THA/HA_{PW} = \mathbf{GDP_{hour}/ELP_{PW}} = 10 \qquad (12)$$

In a developed society, such as the USA, the overhead over the investment of the resource human activity in the sector Paid Work is 10/1. This value reflects the combined effect of demographic structure and socio-economic rules (high level of education, early retirement and light work loads for the economically active population). This translates into a requirement of a very high Economic Labor Productivity (the Average Flow of Added Value produced in the economic sectors per hour of labor), which must be ten times higher than the average level of consumption of added value per hour in the society.

*** Example#3 - Human Activity as E.V.#1 and Exosomatic Energy as E.V.#2***
At this point the reader can easily guess the basic mechanism of accounting for checking the congruence of the dynamic budget of exosomatic energy. Also in this case the total requirement is characterized on the left and the internal supply on the right:

$$THA \times EMR_{AS} = HA_{PS} \times BPL_{PS} \qquad (13)$$

The total requirement of exosomatic energy, assessed at the **level *n***, is expressed as a combination of an extensive variable#1 (size of the system – mapped here in terms of Total Human Activity, linked directly to the variable population) and an intensive variable#3 - EMR_{AS} – which is the amount of primary energy consumed per unit of human activity as Average by the Society. In this case, we are accounting the total exosomatic throughput (TET) expressed using a quality factor for energy (e.g. converted into GJ or Tons of Oil Equivalent) reflecting an appropriate procedure of accounting for the sum of the exosomatic energy expenditures of the various sectors. EMR_{AS} is the equivalent to what is usually defined in literature as Energy consumption per capita and it is usually expressed in GJ of Oil Equivalent per year. In analogy with what done with GDP p.c. also this assessment given in GJ per year is "converted" into an assessment per hour (e.g. MJ/hour). This is required to make possible the bridging of assessments at the level of individual sectors (**level *n-1***) and the whole system (**level *n***).

In fact, the total supply of exosomatic energy, assessed at the **level *n-1***, is expressed as a combination of an extensive variable#1 (size of the lower level compartment – $HA_{ProductiveSector}$), that is, by considering the hours of human activity invested in those activities associated to the stabilization of the autocatalytic loop of exosomatic energy (Giampietro and Mayumi, 2000), and an intensive variable#3 – BLP_{PS} - Biophysical Labor Productivity of the Productive Sector – assessed as the ratio between the flow of exosomatic energy consumed by society (TET) and the requirement of working hours in this sector [$BLP_{PS} = TET/HA_{PS}$].

Due to the complete analogy with the two 4-angle figure illustrated so far (**Fig. 9.2**, **Fig. 9.5**) we can skip the representation of this congruence check using that scheme. It is time to move to a more elaborated analysis. In fact, the congruence check described in relation (13) can also be written as:

$$THA \times EMR_{AS} = HA_{PS} \times EMR_{PS} \times TET/ET_{PS} \qquad (14)$$

In this relation BLP_{PS} has been replaced by $EMR_{PS} \times TET/ET_{PS}$. In this way, the use of an Intensive Variable#3 (EMR_{PS}) referring to the **level *n-1*** has been substituted by two terms, which imply the bridging of identities (establishing bridges among the values taken by variables) across different hierarchical levels.

In fact, the amount of exosomatic energy spent in the productive sector [called ET_{PS} in Chapter 6] can be written using the relation $ET_{PS} = HA_{PS} \times EMR_{PS}$. Whereas, the ratio TET/ ET_{PS} has to respect the constraint $TET - ET_{PS} = ET_{RoS}$. That is, the difference between TET and the energy required to operate the sector PS – which is ET_{PS} - has to be enough to cover the required investments in the Rest of Society – which is ET_{RoS}. Therefore, the feasibility in relation to this constraint implies considering (depends on) a lot of additional parameters [e.g.(a) the mix of tasks performed in the Productive Sectors; (b) the mix of energy converters adopted in the productive sectors; (c) the mix of energy forms dealt with in the energy sector; (d) the mix of tasks performed in the various compartments of the society - end uses; (e) the mix of technologies adopted in the various compartments of the society- end uses (with different degrees of efficiency)].

Therefore, the application of relation (14) requires a much more elaborated example of ILA. This is discussed in detail in the next two sections. Section 9.1.2 illustrates the possibility of establishing, in this way, bridges across an economic and a biophysical reading of the dynamic budget. Section 9.1.3 then illustrates the possibility of generating mosaic effects across levels.

9.1.2 Establishing horizontal bridges across biophysical and economic reading

An overview of the relation between the terms used in relation (14) is given in **Fig. 9.6**. The reader can recognize immediately that this representation of the dynamic budget of exosomatic energy is different from the scheme used so far in **Fig. 9.2** and **Fig 9.5**. When applying the rationale implied by relation (14) we obtain a 4-angle loop figure which has been already illustrated in Chapter 7 - **Fig. 7.5**. As promised then, we can go, now, into a detailed discussion about the selection of the set of parameters used over the loop.

Let's start with the total requirement of exosomatic energy – EV#2 - (TET = Total Exosomatic Throughput) which is expressed by using the three numerical assessments found on the quadrant North-East (upper-right) [TET = THA x EMR_{AS}], where THA is EV#1 and EMR_{AS} is an IV#3 assessed at the **level *n***. On the left side, the total size of the system (expressed in terms of EV#1) is reduced to the size of one of its lower level element considered as the direct compartment (in this case, HA_{PS} is the investment of Human Activity in the compartment PS). This implies a first difference with the 4-angle figures seen so far in this chapter. The quadrant North-West (upper left quadrant) is used for representing the overall reduction (Reduction I plus Reduction II) related to the classification: "rest of the society" <==> "direct compartment". In this example, the definition of direct compartment of PS (productive sector) includes all the sectors stabilizing the autocatalytic loop of exosomatic energy. Such a reduction can be indicated as [SOHA+1 = THA/HA_{PS}]. In this expression SOHA stands for Societal Overhead on Human Activity, SOHA = HA_{HH} /HA_{PS}, with the closure requirement THA = HA_{HH} + HA_{PS}. The product "SOHA+1 x THA", therefore, represents the size taken by the compartment **rest of society** which "affects"/"is affected by" the size of the **direct compartment** PS. For a representation based on real number the reader can refer to **Fig. 7.5**.

At this point, after having collapsed the two reductions in a single quadrant, there is an extra-quadrant to be used. We can take advantage of this opportunity by using this extra quadrant (the lower-right) to compare the size of the whole – assessed using Extensive Variable#2 at the **level *n*** (TET) - to the size of the "direct compartment" – assessed using Extensive Variable#2 at the **level *n-1*** (ET_{PS}). This relation is represented in the quadrant South-East (lower right quadrant) under the label [SOET+1 = TET/ET_{PS}]. This label has been chosen since the parameter "Societal Overhead on Exosomatic Throughput" is the equivalent of SOHA in relation to EV#2. That is, the shape of this angle will reflect/determine the relative size (expressed this time in EV#2) of both the "direct compartment" PS and the "rest of society".

The two profiles of investments for the two variables (EV#2 – expressed in fractions of TET; and EV#1 – expressed in fractions of THA) over the set of lower level compartments is not the same. This is what generate differences in the value taken by IV#3 on different compartments and on different levels.

As observed in the example of the parallel assessment of the metabolism of the human body and of its parts – Chapter 7 - it is actually possible to associate to the identity of a particular lower level element (e.g. the brain or the liver) to a specific rate of metabolism per kg, which is related to the very identity of its lower-lower level elements. In metabolic systems, the given identity associated to the structural organization of lower level elements represents a non-equivalent external referents, which can be used to study the feasibility of the congruence in the representation of energy flows across levels. That is, we can associate to typologies of lower level elements (e.g. urban households living in compact building or high-input agricultural sector of a developed country) an expected level of intensity of flows. Put in another way, it is possible to obtain experimental measurement scheme for both: (a) the whole society at the level **level *n*** (North-East upper-right quadrant) –associated to an external referent; and (b) for specific sectors at the level **level *n-1*** (South-West lower-left quadrant) – whose identity can be associated to the existence of a non-equivalent set of external referents.

Looking at the other quadrants in **Fig. 9.6** we can observe that:

* **North- West upper-left quadrant** - the reduction from THA to HA_{PS} – this angle is related to the parameter (SOHA), which can be associated to another set of external referents such as demographic

variables, social rules, institutional settings – as discussed in Chapter 6.

* **South- East lower-right quadrant** - the ratio TET/ET_{PS} – this angle is determined by technological efficiency and quality of natural resources used to guarantee the supply of required input. This has to do with determining what fraction of the total energy consumption goes in the household and in the service sectors (final consumption of exosomatic energy) and what fraction has to be invested just in the making of machines and in the extraction of energy carriers and material flows.

As soon as we represent the dynamic budget of exosomatic energy as in **Fig. 9.6**, we discover that a very similar analysis can be obtained, for the same society, using flows of added value as Extensive Variable#2, rather than flows of exosomatic energy. An example of this parallel analysis is given in **Fig. 9.7**. Technicalities linked to the calculation of these two 4-angle figures are not relevant here (for a detailed discussion of this analogy and the mechanisms of accounting see Giampietro and Mayumi, 2000 and Giampietro et al, 2001). What is important in the comparison of **Fig. 9.6** and **Fig. 9.7** is: (1) the striking similarity in the characterization of the dynamic budget; (2) the fact that both types of extensive variable#2 (added value and fossil energy) are mapped against the same hierarchical structure in a matrix mapping the size of elements across levels provided by Extensive Variable#1.

This means that IF:

(a) there is a relation – at the level *n* – between the values taken by the two IV#3 variables, that is: (i) EMR_{AS} (the exosomatic metabolic rate associated to the activity of producing and consuming goods and services in that society); and (ii) GDP/hour (the added value metabolic rate – so to speak – which is associated to the activity of producing and consuming goods and services in that society); AND

(b) there is a relation – at the level *n-1* - between the values taken by the two IV#3 variables, that is: (i) EMR_{PS} (the exosomatic metabolic rate associated to a hour of human work in this sector as compared to EMR_{AS}) – which is associated to the level of technical investments – exosomatic devices controlled by workers during their work - which is also associated to their biophysical labor productivity; and (ii) ELP_{PW} (the amount of added value generated per hour of labor by workers in this sector as compared to GDP/ hour). This is, in general, associated to the level of economic investment per worker.

THEN, we can expect that:

(c) changes in SOHA – the overhead of fixed investment of Human Activity required to have a hour of Disposable Human Activity (defined in different ways according to the different identities assigned to the direct compartment associated to the choice of EV#2); and

(d) changes in SOET (Societal Overhead on Exosomatic Throughput) - the overhead of fixed investment of Exosomatic Energy required to have a MJ of Exosomatic Energy in final consumption) **and SOAV** (Societal Overhead on Added Value - the overhead of fixed investment of added value required to have a $ in final consumption).

will be coordinated.

It is not time to discuss the validity of the assumptions (a) and (b) now. Section 9.2 is fully dedicated to the validation of this approach with an empirical data set. The important point to be driven home from the comparison of **Fig. 9.6** and **Fig. 9.7**, is that when framing the analysis in this way, it is possible to establish a bridge among two different ways of looking at the dynamic budget associated to societal metabolism. One is based on biophysical variables, which can be compared with themselves across levels, and the other is based on economic variables that can also be compared with themselves across levels.

Concluding this section we can say that **by using a representation of the metabolism of human systems based on the concept of impredicative loop analysis and using a set of parameters able to induce a mosaic effect across levels, it is possible to establish a relation between the representation of structural changes obtained when using economic variables and the representation of structural changes obtained when using biophysical variables.** These two representations of structural changes using two non-equivalent descriptive domains can be linked because they are both mapped against the same nested structure of compartments used when adopting Human Activity as common Extensive Variable#1. This implies that we can expect that when going through structural re-adjustment of the whole in relation to its parts, even when adopting two non-equivalent descriptive domains to represent requirement and internal supply of flows (the economic one and the biophysical one) we should be able to find some common feature.

9.1.3 Establishing vertical bridges, looking for mosaic effects across scales
TECHNICAL SECTION

There is another way to justify the name impredicative loop analysis for describing the typology of 4-angle figures presented in **Fig. 7.5**, **Fig. 9.6** and **Fig. 9.7**, Such a name is also justified by the fact that these figures represent the very same ratio among two variables "TET/HA_{PS}", which is characterized simultaneously in 2 different ways. Let's discuss this fact, using again the example given in **Fig. 9.6**:

1. the ratio TET/HA_{PS} can be viewed and defined as "**BEP – Bio-Economic Pressure**" when looking at it **from the requirement side** [by considering the value taken by variables related to identities defined at the **level *n*** and **level *n-1***]. In relation to **Fig. 9.6** we can write:

$$BEP = a/b = EMR_{AS} \times (SOHA + 1) = TET / HA_{PS} \qquad = \Sigma\, x_i\, (EMR_i) \times (\Sigma\, HA_i)/HA_{PS} \tag{15}$$

The term [$EMR_{AS} \times (SOHA + 1)$] can be viewed as the pace of dissipation of the whole (**level *n***) per unit of human activity invested in the direct compartment (**level *n-1***). Because of this, it can be expressed using the Intensive Variable#3. This assessment can be expressed using two focal level characteristics [$EMR_{AS} \times (SOHA + 1) = TET / HA_{PS}$]. In alternative, this ratio can be expressed using information gathered at the **level *n-1***. After determining a set of identities for ***i*** components on the **level *n-1*** that guarantee closure (e.g. let's imagine that we chose $i = 3$; Productive Sector; Services and Government; and Household Sector). Then we can write $THA = HA_{PS} + HA_{SG} + HA_{HH}$. Then we need information about the size and level of dissipation of each of these three lower level elements. That is, we need the assessment of: (a) the profile of investments of human activity HA_{PS}, HA_{SG}, HA_{HH} and (b) level of dissipation of exosomatic energy per hour in these three compartments EMR_{PS}, EMR_{SS}, EMR_{HH}, (or in alternative, the size of investments in exosomatic energy ET_{PS}, ET_{SS}, ET_{HH}) in these three sectors. At this point it is possible to express both: EMR_{AS} [$= \Sigma\, x_i\, (EMR_i)$] and (SOHA+1) [$= \Sigma\, HA_i/HA_{PS}$] using only lower level assessments – see Chapter 6.

That is, the parameter BEP can be associated to a family of relations establishing a bridge between non-equivalent representations of event referring to **level *n*** and **level *n-1***.

The name Bio-Economic Pressure, which increases with the level of development of a society, wants to indicate **the need for developed countries of controlling a huge amount of energy in the productive sectors while reducing as much as possible the relative work requirement.** Such a name was suggested by Franck-Dominique Vivien to refer to Georgescu-Roegen's ideas (1971): Increasing the intensity of the economic process to increase the "enjoyment of life" induces - as biophysical side-effect - an increase in the intensity of the throughputs of matter and energy in the productive sectors of the economy.

2. the ratio TET/HA_{PS} can be viewed and defined as "**SEH - Strength of the Exosomatic Hypercycle**" when looking at it **from the supply side** [by considering the value taken by variables related to identities defined on the two interfaces **level *n-2/n-1*** and **level *n/n+1*** when representing the performance of the direct sector in guaranteeing the supply of the required input].

$$SEH = a/b = EMR_{PS} \times (SOET + 1) = TET / HA_{PS} \tag{16}$$

The last term on the right (TET / HA_{PS}) can be viewed as the characterization, in terms of intensive variables only [again the same unit as Intensive Variable#3], of the supply of energy delivered to the black box – MJ of TET - (**level *n*** assessment) per unit of investment of human activity in the lower level component PS – hour of HA_{PS} - (**level *n-1*** assessment: Productive Sector). This characterization is based on variables referring to identities defined on the **level *n*** and the **level *n-1***, and therefore compatible with what done when determining BEP. However, we can express the term on the left side [EMR_{PS} x (SOET +1)] in relation to other variables, which are reflecting characteristics defined and measurable only on different hierarchical levels. That is the capability of the direct sector of generating enough supply of energy input for the whole is dependent on two conditions:
(i) those working in the Productive Sectors must be able to control enough power (= the level of EMR_{PS} per unit of human activity invested there) to fulfill the set of tasks required to guarantee an adequate supply. This condition is related to the value taken by the angle South-West (lower-left) of **Fig. 9.6.** The value of EMR_{PS} can be related to lower level characteristics, the level of capitalization of the various sub-sectors making up the PS sector: [$EMR_{PS} = \sum x_i (EMR_i)$]. This analysis can be done, by using the same approach discussed in Chapter 6 (dividing sector PS in lower level compartments in terms of investments of HA and guaranteeing closure to the hierarchical structure used to aggregate lower level elements into higher level element). The definition of a profile of values of EMR_i (reflecting the tasks to be performed in the various sub-sectors) will determine how much capital is required per worker in the various compartments defining the PS sector. The definition of ET_i, EMR_i, and HA_i will make possible to establish a relation between the characteristics of identities defined on **level *n-2*** to those defined on **level *n-1*.**
(ii) the amount of power to be invested in fulfilling the set of tasks will depend on the return in the process of exploitation of natural resources (SOET +1). This condition is related to the angle South-East (lower-right) of **Fig. 9.6**. That is, the lower the return on the investment to fulfill the tasks performed in the direct compartment, the higher will be the requirement of investment (expressed either in terms of ET_{PS} or HA_{PS}) in the direct compartment.

Given a high level of required ET_{PS} it is possible to reduce the requirement of HA_{PS} – requirement of hours of working - by increasing the value of EMR_{PS} – requirement of technical capital per worker and exosomatic energy spent per working hour. Put in another way, the constraints faced by the direct compartment to stabilize the flow of required input to the black-box can be related to the two economic concepts of: (i) level of capitalization (amount of exosomatic devices per worker), measured by the EMR of a given sector; (ii) level of circulating capital, measured by the ET of a given sector; and that of (iii) performance of technology [(SOET + 1) = TET/ ET_{PS}]. This ratio, in fact measures how much of the total energy used by society (TET) is consumed in the internal loop required for the metabolism of technical devices = by the Productive Sectors for their own operation (ET_{PS}). The higher the fraction of TET used by technology, the lower is the relative performance.

The name **SEH - Strength of the Exosomatic Hypercycle** wants to focus on the fact that this ratio measures the return (the amount of spare input made available to the rest of the society) obtained by investment of human activity in the sector labeled "direct" in the upper part of **Fig. 7.8.** The ability to keep this ratio high is crucial in defining how much human time can be invested in activities not directly related with the stabilization of the flow of matter and energy required for the metabolism. Put in another way, SEH determines the fraction of TET and THA that can be invested in final consumption (in adaptability, by exploring new activities and new behaviours).

At this point we can get back to **Fig. 9.6** to note that relation (16) is determining the ratio between the two segments ***a*** and ***b*** going through the two lower angles of the 4-angle figure. In doing so, it can be seen as the reciprocal of relation (15), which links the two segments ***a*** and ***b*** going through the two upper angles. This means that, in this 4-angle figure, we are dealing with two non-equivalent representations of the same ratio "TET / HA_{PS}" which are based on the reciprocal entailment of the identity of the elements of the loop. Such a ratio is characterized one time in terms of total requirement using the terms included in relation (15) and the other time in terms of internal supply using the terms included in relation (16).

This impredicative loop requires two sets of external referents able to validate the representation of the same relation in two different ways. In relation (15) the value of BEP can be calculated using data related to identities defined on only two hierarchical levels - the interface **level *n-1*/level *n*.** Whereas, when dealing with the value of SEH – according to relation (16) - assessments of technical characteristics are related to both: (a) the interface **level *n-2*/level *n-1*** (the conversion of an input into a specified flow of applied power to perform the set of tasks assigned to the direct compartment); and (b) the return of a set of tasks defined on the interface **level *n*/level *n+1*.** The reader can recall here the Technical Appendix of Chapter 7. Moreover, the stability in time of this return (the stability of the supply of input gathered from the context to feed the black box) – the stability of the quality of natural resources – is based on a hypothesis of ***admissibility*** for the context of the black-box on **level *n+2*** (a hypothesis of future stability of boundary conditions), which is not granted. This is the hidden assumption implied by a representation of steady-state of dissipative systems, which entails defining a weak identity for the environment, as discussed in Chapter 7.

Any attempt to bring into congruence this 4 angle figure in terms of a forced congruence between the two parameters BEP <==> SEH implies the challenge of bringing into coherence assessments referring to 5 different hierarchical levels. As noted earlier, when discussing of holons and holarchies, it is impossible to do such an operation in formal terms (in "the correct way"). That is, we must expect that we will find different ways to formalize an impredicative loop (depending on the definitions and assumptions used for characterizing extensive and intensive variables over the 4-angle figure which will lead to a set of congruent assessments over the loop). The reader can recall the discussion of this problem about the example of the society of 100 people on the desert island given in Chapter 7 – **Fig. 7.4.**

This implies, that a model based on the application of the approach presented in **Fig. 9.6** will not represent "the right" representation of the mechanism determining the stability of the metabolism of a given society. Rather it will be just one of the possible representations of one of the mechanisms that can be used to explain the stability of the investigated metabolism. Recall again the example of the 100 people on the island discussed in **Fig. 7.5.** A very high return of food per hour of labor would not have guaranteed the long term sustainability of such a human system, if all 100 people on the island were men. The analysis of the minimum number of fertile women as potential constraint on the stability of a given societal metabolism would require the adoption of a totally different narrative.

The ability of impredicative loops to establish bridges among levels is based on the bridges across levels provided by Intensive Variable#3. As noted in Chapter 6, we can go through levels using a redundant definition of compartments across different hierarchical levels. For example starting with relation (15), by substituting:

$$EMR_{AS} = \sum x_i \, EMR_i \qquad = (MF \times ABM) \times Exo/Endo \qquad (17)$$

$$(SOHA + 1) = THA/HA_{PS} \qquad (18)$$

We can write:

$$BEP = (MF \times ABM) \times Exo/Endo \times (THA \,/\, HA_{PS}) \qquad (19)$$

Relation (19) establishes a reciprocal constraint on the set of values which can be taken by the three parameters on the right given a value of BEP. This is very important, since these three parameters happen to describe the characteristics of socio-economic systems on different hierarchical levels and in relation to different descriptive domains. Examples of this parallel reading have been given in Chapter 6 (e.g.

Fig. 6.8 and **Fig. 6.9**). In this case, the three parameters listed in the right side of relation (19) are good indicators, describing changes in the metabolism of human societies on different hierarchical levels and in relation to different descriptive domains - for more details see Pastore et al. (2000). In particular:

(1) ***MF x ABM*** = assesses the endosomatic metabolic rate (per capita per hour) of the population. This is an indicator of the average endosomatic flow per person (a value referring to an average assessed looking at the level of the whole society level). This value refers to a descriptive domain related to physiological processes within the human body.
* Metabolic Flow is the endosomatic metabolic rate per kg of body mass of a given population – expressed in MJ/hour/kg – determined by: (1) the distribution of individuals over age classes; and (2) the life style of individuals belonging to each age class.
* Average Body Mass is the average kg of body mass per capita of the population, determined by: (1) the distribution of individuals over age classes; and (2) the body size of the particular population at each age class.

The higher the value of ***'MF x ABM'*** the better are physiological conditions of humans living in the society. According to the data base presented in Pastore et al. (2000) the parameter 'MF x ABM' has a minimum value: 0.33 MJ/hour (short life expectancy at birth, small average body mass in very poor countries); and a maximum value: 0.43 MJ/hour (long life expectancy at birth, large average body mass), which is a plateau reached in developed countries.

(2) ***Exo/Endo*** = Exosomatic/Endosomatic energy ratio is the ratio between the exosomatic metabolism (MJ/hour) and endosomatic metabolism (MJ/hour). This is an indicator of development valid at the socio-economic hierarchical level (reflecting short-term efficiency – Giampietro, 1997a). This ratio can be easily calculated by using available data on consumption of commercial energy of a country (assessing the exosomatic flow) and the assessment of endosomatic flow (food energy flow). 'Exo/Endo energy ratio' has a minimum value around 5 (when exosomatic energy is basically in the form of traditional biomass, such as fuels and animal power). The maximum value is around 100 (when exosomatic energy is basically in the form of machine power and electricity obtained by relying on fossil energy stocks). Exo/Endo is a good indicator of economic activity, it is strongly correlated to the GNP p.c. (see section 9.2 for data). The higher the exo/endo, the more goods and services are produced and consumed per capita.

(3) ***THA/HA***$_{PS}$ = SOHA+1 = this is an indicator valid at the socio-economic hierarchical level (reflecting long-term adaptability – Giampietro, 1997a). The fraction of the total Human Activity available in the society / Working Time allocated in productive sectors of the economy. The ratio 'THA/HA$_{PS}$' has a minimum value of 10 (crowded subsistence socioeconomic systems in which agriculture absorbs a large fraction of work force). The maximum value is 45, in post-industrial societies with a large fraction of elderly and a large fraction of work force absorbed by services. This indicator reflects social implications of development (longer education, larger fraction of non-working elderly in the population, more leisure time for workers coupled to an increased demand for paid work in services and government sector).

Concluding this section we can say that **by using a representation of the metabolism of human systems based on the concept of impredicative loop analysis it is possible to take advantage of the existence of mosaic effects to establish a relation between the representations of changes obtained using an integrated set of variables which refer to non-equivalent descriptive domains.** That is, changes detected at one level using variables defined in a given descriptive domain (e.g. life expectancy, average body mass) can be linked, to changes detected at a different hierarchical level, using variables defined on a descriptive domain which is non-equivalent and non reducible to the first one (e.g. exosomatic energy consumption, GDP per capita, number of doctors per capita).

9.2 Validation of this approach. Does it work? Yes, it does.

9.2.1 The data base used for validation

A validation of the analytical framework of multiple-scale integrated assessment of societal metabolism has been presented in Pastore et al. 2000. Data and figures presented in this section are taken from that source.

The analysis started with a database of 187 world countries, from which 55 countries with less then 2.000.000 inhabitants were excluded because of their too small size (this excluded 0.6% of total world population). For 25 of the remaining 132 countries (some countries formerly included in ex USSR, ex Yugoslavia, ex Czechoslovakia, plus South Africa, Libya, Algeria, Cambodia - which comprise 9% of the total world population) data are not available. Thus, the database includes 107 countries, comprising more than 90% of world population. The database has been created using official data of UN, FAO and World Bank statistics (specified in Pastore et al. 2000). BEP has been calculated according to relation (19) as follows:

(1) the term "ABM x MF"

- ABM has been calculated by pondering the average weights (by age and sex classes) and the structure of population as reported by James & Schofield (1990) for all FAO countries. Data on the total population of 1992 as reported by the World Tables published for the World Bank (1995b).
- MF has been computed separately for each sex and age class following the indication given by James and Schofield (1990) and merged into national averages.

(2) the term Exo x Endo

- The annual flow of exosomatic energy was evaluated according United Nations statistics (1995) for commercial and traditional biomass consumption (expressed in Tons of Coal Equivalent) in 1992, by using a conversion factor of 29.3076 terajoules per thousand metric tons of coal. However a minimum value of 5/1 has been adopted for countries with a resulting value of exo/endo <5. This is due to the fact that official statistics are mainly reflecting the use of commercial energy and therefore tend to underestimate, for rural communities, the contribution of animal power, biomass for cooking and building shelters (see Giampietro et al. 1993)
- The annual flow of endosomatic energy has been computed using population size of 1992 as reported by the World Tables published for the World Bank (1995b), multiplied by the value of "ABM x MF".

(3) the term THA/HA_{PS}

- the fraction of economically active population and the distribution of labor force in different sectors of economy both derive from United Nations statistics (1995) and refer to the latest available data in the period 1990-93.
- In this analysis productive sectors of economy include: agriculture, hunting, forestry and fishing; mining, quarrying; manufacturing; electricity, gas, water; construction and a fraction of transport. Transport (non residential) was in fact divided between productive sectors and service sector, proportionally, for each country, according to the working time spent in the primary sectors and the working time spent in service sectors (which include trade, restaurants, hotels; financing, insurance, real estate, business; community, social and personal services).
- work-load was estimated at a flat value of 1,800 hours/year when including vacations, absences and strikes (after Giampietro and Mayumi, 2000a).

The conventional indicators of material standard of living and development used in the analysis are 24. Such a selection of indicators is basically reflecting the selection found in World Tables. The 24 indicators can be divided in three groups:

(i) 8 indicators of nutritional status and physiological well being:
(# 1) life expectancy; (# 2) energy intake as food; (# 3) fat intake; (# 4) protein intake; (# 5) average BMI adult; (# 6) prevalence of children malnutrition (Wt/Ht< 2 z-score of the US National Center for Health Statistics reference growth curve); (# 7) infant mortality; (# 8) % low birth weight.

(ii) 7 indicators of economic and technological development:
(# 9) GNP per capita; (# 10) %GDP from agriculture; (# 11) ELPpW – Average Added Value per hour of paid work = GDP/(HA_{SG}+ HA_{PS}) [note this indicator has the label COL_{AV} in the figures]; (# 12) % of labor force in agriculture; (# 13) % of labor force in services; (# 14) Energy consumption per capita; (# 15) % of GDP expended for food.

(iii) 9 indicators of social development :
(# 16) television/1000 people; (# 17) cars/1000 people; (# 18) Newspaper/1000 people; (# 19) Phones/100 people; (# 20) Population/physician ratio; (# 21) Population/hospital bed ratio; (# 22) Pupil/teacher ratio; (# 23) Illiteracy rate; (# 24) Access to safe water (% of population).

All data on these 24 indicators come from FAO (FAO Yearbook 1995); United Nations (1995) and World Bank (1995a) and each one of them refers to the latest available year between 1991 and 1993. Data on prevalence of malnutrition in children come from ACC/SCN (1993).

9.2.2 The representation of development according to economic variables can be linked to structural changes in societal metabolism represented using biophysical variables

The correlation of BEP with the chosen set of indicators of development

The analysis of Pastore et al, 2000 indicates that BEP is strongly correlated with:
(i) all classic economic indicators of development see the gray column of **Tab. 9.1** - average value of r = 0.88 (ranging from 0.77 to 0.92) and **Fig. 9.8 upper part** for a graphic representation.
(ii) all nutritional status and physiological well being indicators see the gray column of **Tab. 9.1** - average value of r = 0.78 (ranging from 0.65 to 0.87) and **Fig 9.8 lower part** for a graphic representation.
(iii) all health indicators (**Fig. 9.9 upper part**) and social development indicators (**Fig. 9.9 lower part**) – average value of r = 0.76, (ranging from 0.44 to 0.89). See the gray column of **Tab. 9.2.**

9.2.3 Changes associated to economic development can be represented using an integrated set of indicators on different levels and descriptive domains

Assessing changes related to development on more hierarchical levels

The ability of seeing changes coupled with development on more hierarchical levels has been verified by studying the correlation of each one of the three terms composing BEP with conventional indicators of development in the field of: (i) nutritional status and physiological well-being (by using only "ABM x MF"); (ii) economic development at the level of society (by using only "exo/endo"); (iii) socio-economic level (by using only the ratio "THA/HA_{PS}").

Since we are no longer dealing with a parameter such BEP that is the product of three factors, the graphs illustrating the correlation with each of these individual parameters are no longer based on a logarithmic scale. This makes more evident the existence of "threshold values" for the various parameters determining the characteristics of the energy budget (BEP and SEH), when considered in an evolutionary trajectory – see for example **Fig. 9.10.** Above a given value (the same for the entire sample of correlation with the 24 indicators) all countries seem to converge toward an attractor value.

(i) physiological /nutrition - individual hierarchical level

"ABM x MF" showed to be a good indicator for assessing changes coupled to the process of development at the physiological level. Actually the example of correlation with 6 indicators provided in **Fig. 9.11 upper part**, shows quite clearly that is possible to individuate a threshold value of "ABM x MF" around 9 MJ/day (0.4 MJ/hour) above which socio-economic systems tend to converge on similar values.

(ii) economic development - societal hierarchical level (steady-state view)
"Exo/Endo" is an excellent indicator to assess changes coupled to the process of development at societal level (**Fig. 9.10 upper and lower part**). Beside the obvious correlation with energy consumption and GNP (not reported in these graphs, since it is a perfect diagonal with a light dispersion due to the noise typical of the data), Exo/Endo shows an extraordinary ability to detect sharp structural changes of socioeconomic system which can be related to the process called demographic transition (Giampietro, 1998). The graphs reported in **Fig. 9.10** clearly show a threshold value of Exo/Endo (about 25/1). This indicate a change in the path of expansion of the activity of self-organization (measured by TET). After this threshold point, socioeconomic systems stop expanding by increasing in human mass. Further increases in size of economic activity (TET) are obtained by increasing the Exo/Endo energy ratio (the EMR per unit of HA). Such a change, in turn, is affecting the value taken by THA/HA_{PS} ratio (which keeps growing). This has important consequence in evolutionary terms. In fact, this can be seen as an increase in the fraction of exosomatic energy and human activity which are invested in long-term adaptability (allocated in social roles not strictly encoded - such as leisure time; and in job positions in the services sector) instead of in short-term efficiency (Giampietro, 1997a; Giampietro et al. 1997).

(iii) socio-economic level - societal hierarchical level (evolutionary view)
THA/HA_{PS} also correlates with traditional indicators of economic development (**Fig. 9.11 lower part**). However, such a correlation is less strong than the one found with Exo/Endo (**Tab. 9.1** and **9.2**). The power of resolution of THA/HA_{PS} increases when it is compared to indicators of social development. Also in this case, we can see a threshold value (at about 30/1), that could be interpreted as an indication for a switch to a new form of metastable equilibrium of the dynamic energy budget (for more see Giampietro, 1998). The increase in THA/HA_{PS} are possible only when SEH and BEP both increases in a coordinated way (Giampietro et al. 1997). However, there is an inertia toward changes in socioeconomic parameters (especially those under direct cultural control, when dealing with profile of allocation of human activity) determining a lag time in adjustments of THA/HA_{PS}. This inertia is generated by the existing social and cultural identity, which is related to the history of the socioeconomic system. This could explain the lower correlation of THA/HA_{PS} with traditional indicators when compared with the correlation factors of the other parameters of BEP: "Exo/Endo" and "ABM x MF". The possible role of cultural identity in slowing down the changes induced by development can also seen looking at the graph "BEP vs illiteracy" on **Fig. 9.11 lower part**. Such a relation is much more loose that the ones found in the graphs referring to economic indicators. For example, in many Islamic countries the illiteracy rate of women is higher than the value expected in countries having the same level of GDP/THA.

9.3 Applications to the analysis of the role of agricultural systems

9.3.1 The particular identity of the metabolism of a socio-economic system implies minimum thresholds on the pace of throughputs in the various components

Conventional analyses of the agricultural sector are based on the generic (unspecified) assumption that this sector is in charge for the generation of the supply of two types of flows:
(1) a flow of food; (2) a flow of added value.

However, as soon as we consider different entities related to agriculture at different hierarchical levels (e.g. farmers, rural villages, agricultural sectors) we discover that in relation to these two flows, different entities can belong to one of the following three categories:

* **in relation to food production**: (a) net producer of food surplus for the rest of society; (b) self-sufficient in terms of food production/consumption (pure subsistence); or *in the worst case scenario* (c) covering only a fraction of the internal requirement of food.

* **in relation to added value production**: (a) generating surplus of added value for the rest of society; or (b) managing to remain economically viable by breaking-even in economic terms; or *in the worst case scenario* (c) covering only a fraction of their consumption of added value.

As noted in the introduction to Part 3, an integrated analysis of the performance of an agro-ecosystem has to be structured in a completely different way, depending on which one of these three options [either (a) or (b) or (c)] applies to the particular farming system and agro-ecosystem under analysis. Therefore, before getting into a discussion on how to formalize an integrated analysis of a given agroecosystem, it is crucial for the analyst to individuate critical goals and constraints has to be addressed in the relative problem structuring. This requires individuating the particular role that the agricultural holon (viewed as a lower level element operating at the **level *n-1***) is playing within the the larger agricultural holon (viewed as the context at the **level *n***, to which the first holon belongs).

In order to do that, one can explore the hierarchical relation that the two elements (e.g. the agricultural sector and the whole society) have in relation to their ability to generate and consume both flows: food and added value. There are cases in which the agricultural sector is a net producer of both food and added value for the rest of the society (e.g. in some countries at low demographic density, such as Argentina). In this case, the agricultural sector belongs to the "direct" sector when mapping both types of flows. It has to be considered as "direct" since it generates a positive return on the investment in relation to both food energy and added value. There are other cases in which the agricultural sector is a net producer of food, but a consumer of added value (e.g. in some crowded developed countries in Europe). In this case, the agricultural sector is the "direct" sector when mapping flows of food (it generates positive return on the investment of human activity) and a net consumer of added value (it generates a return on the economic investment which is lower than the national average). Finally, there are cases in which poor subsistence farming systems tend to collapse becoming a humanitarian problem (they become net consumers of both a flow of food and added value).

This discussion can be generalized by saying that, when studying the stability of the metabolism of a system organized in nested elements, the contribution (and the role) of a particular element (e.g. in this case the agricultural sector) is determined by the relative value of average densities of flows in the whole and in the parts. Any assessment of these densities, however, is not "absolute" or "substantive", rather it reflects the choices made by the analyst on how to account for quantities included in the flow (again the reader can recall the example of the 4 different assessments of the consumption of cereal per capita within the USA – **Fig. 3.1**). The applicability of the numerical indication will therefore depend on the agreement of the users of this information in relation to the choice of the narrative used to formalize the analysis.

In this section, we apply the methodological approach presented so far to compare the density of flows within the agricultural sector – viewed as **level *n-1*** – and the density of the same flows characterized at the level of the whole society – viewed as **level *n*.**

In Chapter 11, the same rationale is applied to the study of lower level interfaces (to do benchmarking within the holarchy). There, the performance of an agroecosystem, perceived and represented at the community level – viewed as **level *m-1*** – is framed in relation to the perception and representation of the performance of the same agroecosystem viewed at the larger level (e.g. the province) to which it belongs – viewed as **level *m*.** Within the same frame, it is possible to bridge the representation of the typology of individual households – viewed as **level *m-2*** – in relation to the representation of the performance of a community – viewed as **level *m-1*** – to which the selected type of households belongs.

This process of comparison across levels requires looking at different definitions of constraints on the throughputs (I.V.#3), which are characterized using variables relevant for the analysis (e.g. kg of food per hour and per ha, $ of added value per hour and per ha, MJ of exosomatic energy per hour and per ha). Next section looks at the existence of constraints related to the biophysical productivity (density of food produced) against human activity (per hour of work in the agricultural sector) and against land in production (per ha of land in production). In the same way, one can look at the existence of constraints related to the economic productivity (density of added value produced) against human activity (per hour of work in the agricultural sector) and against land in production (per ha of land in production).

9.3.2 Determination of minimum thresholds for congruence over the loop

Minimum throughput of food per hour of labor in the agricultural sector

The congruence check to agricultural element can be done by applying relation (7) we can write a Food Metabolic Requirement (FMR) at the level of the food system:

$$FMR_{FS} = THA \times (ABM \times MF \times QDM\&PHL) = HA_{AG} \times BPL_{AG} \qquad (7)$$

Just to give an examples of application of relation (7) based on a very simple system of mapping, we can represent the requirement of endosomatic energy per capita (left side of the relation) using an assessment based on kg of grains-equivalent per capita per year. A more elaborated analysis of energy consumption in relation to the quality of the diet and the double conversions within the food system is given in the last section of Chapter 10.

Assuming an average level of consumption of 250 kg of grain-equivalent per person, and a society of 1 million people, we get a final requirement of a flow of 250 million kg of grains per year. Depending on the quality of the diet and the characteristics of the food system we can apply to this initial flow of endosomatic energy a coefficient QDM&PHL of 3/1 for developed countries, and a coefficient QDM&PHL of 1.5/1 for poor developing countries.

This will provide the following assessment of the flow of grain required in production (for a society of 1 million of people):

FMR_{FS} = 750 million kg – for a society with a food system typical of developed countries;
FMR_{FS} = 375 million kg – for a society with a food system typical of developing countries.

Lets check the congruence threshold on the pace of the relative throughput in production.
This check can be obtained by using relation (9):

$$THA/HA_{AG} = \mathbf{BPL_{AG}/FMR_{FS}} = 500 = 1/0.002 \text{ (for the USA)} \qquad (9)$$

These values are obtained by applying to our hypothetical society of 1 million people the values found for the profile of allocation of human activity shown in Fig. 9.4.
* Using extensive variable#2: THA (*8.76 billion*); HA_{AG} (*17.5 million*)
* Using fractions of reduction of THA: [1/(SOHA+1)] (*0.1*); [HA_{AG}/HA_{W}] (*0.02*)

The agricultural sector of this hypothetical society to be self-sufficient should operate above a minimum threshold of labor productivity (assuming that the whole agricultural sector is totally dedicated to grain production) of 40 kg of grains per hour of labor. The assessment of this threshold can be obtained using extensive variables, by dividing the total requirement FMR_{FS} (= 750 million kg) by the available supply of working hours HA_{AG} (17.5 million hours). In alternative, the assessment of this threshold can be obtained using intensive variables. According to relation (9) we can assess $\mathbf{BPL_{AG}}$ as the product of

$\mathbf{FMR}_{FS}$ x 500. Starting with a value of $\mathbf{FMR}_{FS}$ which is 750 kg of grain per year (250 x 3 for a developed country). This assessment has to be divided by 8760 (to get the assessment of kg of food per hour) and then multiplied by 500 according to the congruence constraint. Both methods, obviously, provide the same answer 40 kg of grain per hour of labor as a minimum threshold of labor productivity for being self-sufficient.

This threshold, however, is never relevant in developed countries. In fact, in the agricultural sector of a developed society, grain production is just one of the tasks to be performed in agriculture. Actually, it is exactly because of the ability of reaching levels of biophysical labor productivity much higher than this minimal threshold (in the order of hundreds of kg of grains per hour of labor), that it is possible for the agricultural sector of developed countries to produce a lot of animal products (based on a double conversion of cereals) and a diversified abundant supply of fresh vegetables.

It should be noted, however, that a Biophysical Labor Productivity of 40 kg of grains per hour is completely out of the range of technical coefficients found in subsistence farming systems.

**** Minimum throughput of food per ha of land in the agricultural sector.***

Let's look now for the constraint on the throughput of endosomatic energy flows based on the adoption of land area as Extensive Variable#1. This time, the threshold can be calculated in relation to availability of land to be invested in production. Using the 4 angle figure given in **Fig. 9.3** we can see that TAL (Total Available Land) is first reduced to Colonized Available Land (CAL), which is further reduced to Land in Production (LIP). At this point, we can use an analogous of relation (9) to assess the minimum thresholds of land.

We can look for an expression based on intensive variables, using the concepts of:

* **BOAL = Biophysical Overhead on Available Land**, which is the analogous of SOHA. This represents the ratio NAL/CAL (natural available land over colonized available land). By adopting the same system of accounting, we can write (BOAL+1) = TAL/CAL.

* $\mathbf{YLP}_{AG}$ **= Yield of Land in Production in the agricultural sector**. This is the yield (or the average of aggregated yields) perceived within the element considered in the analysis. It can be the direct yield (e.g. kg of rice per ha assessed in a defined field), or an average value for a farming system (e.g. kg of total output per ha assessed in a defined year), or the aggregate output of crop energy for a food system of a given country. Obviously, depending on the choices made by the analyst it is crucial to remain consistent in the system of accounting (selection of variables and measuring schemes) across hierarchical levels.

The finding of a threshold value on YLP_{AG} based on relation (9) is a trivial task. The rationale of this analysis has been already illustrated in the various examples seen so far. Starting with the total requirement of food - e.g. the FMR_{FS} = 750 million kg per year calculated for the hypothetical developed society of 1 million people. Then, given the overall ratio TAL/LIP, it is possible to calculate the minimum threshold YLP_{AG}. Depending of the goal of the analysis we can decide to keep disaggregating the lower level element LIP by considering a mix of different techniques of production within LIP. Depending on additional categorizations we can split the area allocated to agricultural production LIP into "agricultural production for subsistence" and "agricultural production for cash". Within the area in production for subsistence we can then divide cereals from vegetables and so on.

It is always important to define the set of categories used to define the identities on **level *m-1*** in a way that provides closure on **level *m***. It is at this point that the category "other uses" enters into play. A discussion of this mechanism of accounting based on aggregation through levels has been given in **Fig. 6.1** and **Fig. 6.2**.

Also in this case, it should be noted that the minimum threshold found when dividing FMR_{FS} by LIP is a minimum threshold of throughput density that would be required to keep the system self-sufficient. As noted earlier, such an information (a minimum throughput to be self-sufficient) can be useful or not.

We are living in a market economy in which trade plays a crucial role in allocating investments of labor and capital. If a given social element is not self-sufficient - like a city - it can always import food from elsewhere.

Two quick points can be made to rebut this objection: (1) when talking of agriculture the degree of self-sufficiency of food systems remains in any case a relevant criterion of performance. A criterion which is logically independent from economic considerations. (2) an element can be buy food from its context only when it generates enough surplus of added value to be able to do so. Very often, in poor rural areas of developing countries the three issues: (i) minimization of risk and self-sufficiency in food production; (ii) lack of purchasing power to guarantee food security, whenever the biophysical constraints prevent the system to access an adequate flow of food; (iii) insufficient generation of added value to increase the income of the family in terms of net disposable cash for non-food expenditures; are deeply mixed.

As noted earlier it is important to be able to characterize first of all, what is the situation of the particular farming system considered (e.g. net producer/consumer of food; net producer/consumer of added value, a household with characteristics above or below the average values found in the country).

When discussing of minimum threshold of labor productivity we found that the food systems tend to avoid to operate with values of throughput too close to such a threshold. In fact, this would imply a very dangerous situation (possibility of collapses in case of perturbations). In this case, a food system which is not able to generate enough endosomatic energy input is forced to produce a very limited variety of crop outputs. When in trouble with the balancing of the dynamic budget, only those tasks (crops) that provide a maximum in throughput and return are amplified in the profile of investments over the set of potential tasks. This implies that other tasks (crops) with lower throughputs are neglected when selecting the final profile of investments of land and human work.

Unfortunately, as it will discussed later on in chapter 11, this predicament (= food systems operating very close to viability thresholds) is affecting more and more agro-ecosystems of both developing and developed countries. In developing countries the problem is generated by the increasing severity of biophysical constraints. That is many subsistence societies can no longer achieve the biophysical viability of the autocatalytic loop "food --> human activity --> food". This is pushing the food systems of these societies toward a monotonous diet geared around a cereal (or a starchy root where possible). This key crop – whose production is amplified to boost efficiency - is the crop that, according to boundary conditions, provides a maximum throughput both per hour and per hectare. Put in another way, the existence of a strong external constraint affecting the feasibility of the metabolism of the social system is indicated by a very skewed distribution – at the lower level - of the profile of investments of both human activity and land in production over the set of potential tasks (in this case over the set of cultivated crops). This has been suggested to be a general feature in the organizational pattern of human societies – (Bailey, 1990). In order to boost the efficiency of the system, investments of either labor, suitable land, and technology tend to be concentrated only on the (or those) crop(s) providing the highest throughput both per hour of labor and/or per hectare of land in production.

A similar skewed distribution of investments over possible productive tasks in agriculture is found in the food system of developed countries. In this case, however, it is a constraint on economic viability which generates the set of relevant constraints. The food system of rich countries tends to focus only on crops, which are easy to mechanize (e.g. cereals) to boost labor productivity and/or on animal products. Animal products have two major advantages compared with conventional crops: (1) they make possible to reduce the space requirement of the production system through feed imports (= externalization of the requirement of space to other systems – this avoid the constraint of space on the generation of flow of added value); and (2) they make possible to better use the large investment of capital they require. In fact, contrary to what happens in crop production, the expensive equipments required for animal production are used every day all over the year.

In conclusion, farmers in developed countries are forced, by the economic constraint on their viability, to focus only on those productions that maximize the flow of added value per hour of labor and that maximize the economic return of economic investments.

Minimum throughput of flows of added value per hour of labor in the agricultural sector. We can apply the same approach used so far, to detect a minimum thresholds of flow density related to added value viewed as E.V.#2. However, before getting into the discussion of how to assess a minimum threshold on the throughput of added value in different socio-economic entities (the economy of a country, an economic sector or sub-sector, a firm, a farm or a household) one has to answer first of all the obvious question: in which sense can we speak of a flow of added value? To answer this question I do not intend to get into a technical discussion of foundations of economic theory, but just mention a few points about the method generally used to assess the Gross Domestic Product of an economy (the mechanism of accounting for national income).

First of all, the analysts has to define a space-time domain (the system – an aggregate of interacting actors within a boundary defined in a given area and space). This already leads to a distinction between GDP (domestic product – the accounting is referring to geographical location of the flows of added value) or GNP (national product – the accounting is referring to the nationality of those getting revenues).

The assessment of GDP is based on the required congruence of three non-equivalent systems of accounting of the same "system quality" defined and assessed three times in non-equivalent ways. For the sake of simplicity I do not include the effect of imports and exports, in the description of the three methods given below:

(1) GDP as the sum of the assessments of added value produced by the various sectors. That is the assessment of GDP –Average Society is:

$$\mathrm{GDP}_{AS} = \sum x_i\, \mathrm{GDP}_i \qquad (20)$$

The value added generated in sectorial GDPs (GDP_i) are calculate as "final value of goods and services produced by the sector minus cost". How to formalize such an assessment in specific situations, obviously, is an open question. But this problem is found with each one of the assessments discussed in here. Relation (20) implies the ability of expressing the characteristics of **level *n*** (the whole) as a function of assessments referring to characteristics of elements defined at **level *n-1***. After selecting a particular protocol for accounting, we will find out that **not all the sectors of the economy produce added value at the same rate** or produce added value at all (e.g. the household sector).

(2) The flow of added value (GDP average for a society) can be assessed as the sum of the assessments referring to the revenues received by the various production factors of the economy.

$$\mathrm{GDP}_{AS} = \mathrm{WFW} \times \mathrm{HA}_{PW} + \sum(\mathrm{PF}_i \times \mathrm{RPF}_i) + \mathrm{GS} \times \mathrm{TFS} \qquad (21)$$

GDP_{AS} is determined by three terms:
(i) wages [WFW (= Wages For Work) x HA_{PW} (= Working time)];
(ii) profits (including rents) for those owning capital and other production factors beside labor [PF_i (= production factors) x RPF_i (= return of production factors);
(iii) taxes for the government and other administrative entities, which can be expressed as [GS (= Governmental Services) x TFS (= Taxes For Services)];

Relation (21) can be used to explain once again that ELP (economic labor productivity) expressed as the ratio $\mathrm{GDP}/\mathrm{HA}_{PW}$ has nothing to do either with the wages received by the worker or the economic return of labor as a factor of production. In fact, from relation (21) it is clear that other elements enter in play in the determination of GDP beside HA_{PW}.

(3) The flow of added value (GDP average for a society) can be assessed as the sum of the assessments referring to the expenditures of two different compartments: (1) Private sector; and (2) Public sector. We can write:

$$GDP_{AS} = [(CGS \times PGS) + (IGS \times CIGS)]_{PRIVATE} + [(CGS \times PGS) + (IGS \times CIGS)]_{PUBLIC} \quad (22)$$

The expenditures of the two sectors Private and Public can be assessed using the following formula [CGS (= Consumption of Good & Services) x PGS (= Price of Good & Services)] and [(IGS = Investment in Good and Services) x CIGS (= Cost of the investment in Good & Services)]. This represent the profile of investments within the black-box of the available input of added value.

Practical aspects of the definitions of the various acronyms used in relations (20), (21) and (22) are beside the point here. The relevant point is, rather, that the formalization of each one of these three assessments is everything but simple (even when asking the professional consultancy of expert economists). The problem, which has been already discussed over and over about impredicative loop analysis is that the various acronyms written in the various relations can be formalized in different ways depending on a lot of arbitrary choices of the analyst. For example this can start with very basic questions:
* What is value added? (should we account good produced but not yet sold, how to account for potential changes in the values of stocks of goods already available due to potential future changes in price?)
* How to calculate revenues (how to deal with the variation of the value of fixed capital, which could move suddenly up or down? Depreciation is not only related to physical obsolescence but also to functional obsolescence, which is much more difficult to deal with. A computer perfectly working can suddenly lose its value, because of the introduction on the market of a new model);
* How to distinguish between consumption and investment when having to chose between different systems of accounting (an expensive wine to impress a potential business partner should be accounted for as a business investment? What about a private purchase of a car? A car in modern times is for leisure or it is a necessary investment for getting a decent job?).

Not even mentioning the problem of deciding how to deal with the simultaneous discounting of different forms of capital on different time horizons.

It should be obvious at this point that the mechanism used to define what should be considered an assessment of GDP is very similar to what has been proposed in the previous chapter for the biophysical accounting of societal metabolism (TET assessed in relation to BEP and SEH, which in turn are assessed in relation to the characteristics of lower level elements). A lot of semantic definitions of system qualities, which are impossible to formalize, are brought in congruence by using mosaic effects and impredicative loop analysis (defining the "same thing" in non-equivalent ways, looking for different external referents determining assessments on non-reducible descriptive domains). Only in this way, it becomes possible to arrive at a coherent representation of these concepts through convergence on an arbitrary number, that – on the other hand - must match the reciprocal constraints imposed by the set of definitions selected by the analyst.

Another important observation associated to this mechanism of accounting is related to the fact that assessments of GDP are related to the integrated process of "producing" and "consuming" flows of added value across compartments over the whole system. The overall assessment has to be congruent through the set of assessments performed at the **level *n-1*** and the whole **level *n*.** This means that if we define:

$$ELP_{AS} = GDP_{AS}/HA_{PW} \quad (23)$$

We obtain an average value of generation of added value per hour of human activity invested in working for the "direct" compartment (the average economic labor productivity for a given economy in which the direct compartment assessed in terms of investment of human activity is defined as Paid Work). The value of ELP_{AS} can be assumed to be a sort of "cost opportunity" of labor in that society. It should be recalled, in fact, that at the hierarchical **level *n*** of the whole society – "working time" **is already a cost for the society, due to the Societal Overhead on Human Activity**! In fact, ELP_{AS} represents the amount of $ of GDP generated at the hierarchical level of the whole society – **level *n*** - in a defined year, per hour of work supply delivered in the "direct" compartment (Paid Work) at **level *n-1***.

When dealing with economic mechanisms of regulation, things are in reality more complex since debts can be used to buffer difference between requirement and supply of added value at a particular moment in time. However, let's remain here in a basic theoretical analysis. We can write, at **level *n-1***, relation (23) j-times, applied to j economic sectors (with $1 < i < j$):

$$ELP_i = GDP_i/HA_i \qquad (24)$$

Combining relations (23) and (24) we obtain:

$$GDP_{AS} = HA_{PW} \times ELP_{AS} = \qquad \Sigma\ (HA_i \times ELP_i) \qquad (25)$$

When a particular economic sector (or activity) ***w*** has an average return of added value per unit of labor lower than the one achieved at societal level ($ELP_w < ELP_{AS}$), then the hours of work supply allocated to that particular sector (activity) becomes a sort of economic cost for the society. In fact, in presence of working time allocated in sectors with an ELP_i lower than the average of the society, in order to maintain the same societal average ELP_{AS}, it is necessary to allocate work in other economic sectors with a ELP_i higher ($ELP_h > ELP_{AS}$). In particular, the surplus of added value generated in these sectors (e.g. let's assume that all the other sectors are included in K) has to be equivalent to the deficit generated by the hours of work allocated in sector ***w***:

$$\text{Cost opportunity of work in } w = HA_w \times (ELP_{AS} - ELP_w) \qquad (26)$$

Equation (26) establishes a new form of constraint on the amount of working time that can be allocated to activities that have an average return of added value lower than the average return at societal level ARL_{AS}. A society can afford to allocate hours of labor to these economic sectors (or activities) – while remaining at its original level of ELP_{AS} - only if the remaining hours of work supply allocated to other economic sectors (or activities) are able to generate enough surplus to pay for them. Recalling relation (26) this means:

$$HA_w \times (ELP_{AS} - ELP_w) \iff HA_k \times (ELP_k - ELP_{AS}) \qquad (27)$$

In any particular case, the higher the difference ($ELP_{AS} - ELP_w$) the higher will be the pressure at the level of society to reduce the investments of working time allocated at societal level on activity ***w***.

If we apply this rationale to the role that agriculture plays within a given country we can write, relation (27) as:

$$GDP_{AS} = HA_{PW} \times ELP_{AS} = (HA_{AG} \times ELP_{AG}) + (HA_{OS} \times ELP_{OS}) \qquad (28)$$

where the subscripts mean:
AS Average Society; ***PW*** Paid Work; ***AG*** in agriculture; ***OS*** (other sectors).
**** Minimum throughput $ per ha of land in the agricultural sector.***

The ability to generate a given amount of added value per hectare can be used to detect the existence of constraints on the aggregate value of added value, that can be associated to a given mix of land uses over a given land area. Depending on the yield (YLP_{AG}) expressed in biophysical variables (e.g. kg of crops produced per year and per hectare) we can associate to the various typologies of crop production a relative flow of added value. Such a flow will reflect the relative difference between revenues (determined by the price of the produced crop) and the costs (determined by the expenditures associated to the production – e.g. cost due to the remuneration of production factors). Again, the procedure to obtain such an assessment is difficult to generalize. When looking at different farming systems around the world, one can find a lot of weird definitions for "costs" and "revenues" to be considered when looking for this assessment. In any case, no matter how we decide to formalize this assessment, it will always possible to find a constraint related to the availability of productive land, which affect the supply of added value. Such a constraint can be expressed as:

$$GDP_{AG} = LIP \times YLP_{AG} \times AVP_{AG} \qquad (29)$$

Where:
LIP (Land in Production) and YLP_{AG} (Yield on the land in production) have been already introduced, and AVP_{AG} represents the amount of added value associated to the agricultural production assessed in biophysical terms. A more elaborated discussion of the implications of this relation is provided in Chapter 11, when this constraint is explored in relation to the choices available to the farmer. Given a limited amount of land to be used in production (LIP), it is possible to increase the value of the yield (YLP_{AG}) by increasing the use of technical inputs. However, this implies sooner or later to reach a plateau in the average production of added value associated to this higher biophysical productivity (because of a higher fraction of production costs). This is a predicament which is well known and studied in agricultural economics. However, when analyzing this mechanism within an approach of integrated analysis, it is possible to complement the reading of this trade-off with a parallel analysis of other incommensurable trade-offs (e.g. minimization of risk for subsistence, material standard of living associated to the choice of production techniques, ecological impact of selected techniques).

9.4 Demographic pressure and Bio-economic Pressure

9.4.1 Introducing these two basic concepts

** Demographic pressure*

The concept of demographic pressure is traditionally related to the ratio: "population size"/"area occupied by the society". Such a parameter is an important factor affecting the choice of techniques of agricultural production (e.g. Boserup, 1981). Beside scientific analyses, common sense suggests that a high demographic pressure in a society tends to select farming techniques with a high yield of food per unit of area.

In relation to the intensity of such a pressure we can calculate the following two parameters:

- AP_{DP} (= Agricultural Productivity due to Demographic Pressure) as the level of productivity of land (yield of food energy per hectare) which would be required to get self-sufficiency (to match the aggregate food demand) given: (i) current population; and (ii) current availability of land. Such an indicator is obtained by considering the food system under analysis as closed. Then the **aggregate demand of food** (which depends on population, current characteristics of the diet, post-harvest losses) **is divided by** the **amount of land used for generating food supply** (which depends on population size, endowment of land, characteristics of the available land, existence of alternative land uses implied by socioeconomic organization).

- AP_{ha} (= Actual Agricultural Productivity of Land) as the level of productivity of land (yield of food energy per hectare) actually achieved by a country. Such an indicator is obtained by dividing the assessment of **aggregate internal production of food** (which depends on mix of cultivation and yields of different crops) by the assessment of **land used in food production.**

The goal of self-sufficiency would imply reducing the difference between these two parameters [$AP_{DP} - AP_{ha} \Rightarrow 0$]. Even though this solution is very seldom reached by societal systems (at all levels: entire food systems, provinces, individual villages or households). In any case, an increase in demographic pressure tends to select a mix of productions and production techniques that increase the output per hectare of land in cultivation. The alternative is the expansion of food production on marginal land, by reducing the ratio TAL/LIP. This can imply the reduction of the fraction of area of terrestrial ecosystems not colonized by humans and alternative land uses to LIP.

Indicators of the level of demographic pressure on agriculture - To characterize this pressure we can use the three Extensive variable#2 (exosomatic energy, added value and food) used to characterize societal metabolism in relation to land area. In this case, assessment of local supply or requirement of added value ($/ha) or food (kg/ha) calculated at different levels (e.g. whole country, individual economic sector, sub-sectors, and individual firms/farms). These indicators can be used to characterize the performance of agroecosystems in relation to other socio-economic characteristics. An assessment of the exosomatic energy applied per ha in agricultural production, can be used to characterize the performance in relation to ecological impact.

**** Bio-economic pressure***

In parallel with the demographic pressure, we can define a bio-economic pressure as determined by the ratio "Total Human Activity in a society" (THA) divided by the hours of Human Activity invested in "work in agriculture" (HA_{AG}). Since food demand is proportional to Total Human Activity, whereas internal food supply is proportional to the amount of work in agriculture, the value of the fraction THT/HA_{AG} will affect the productivity of a hour of labor in the agricultural sector (Giampietro et al. 1997). That is, in analogy with what seen about Demographic Pressure, we can expect that a high socio-economic pressure tends to select farming techniques generating a large quantity of food produced per unit of labor delivered in the agricultural sector.

To calculate an indicator assessing the intensity of such a pressure let's first calculate the following two parameters:

- AP_{BEP} (= Agricultural Productivity due to Bio-economic pressure) the level of productivity of labor (yield of food energy per hour) which would be required to get self-sufficiency at societal level (to match the aggregate food demand). Such an indicator is obtained by considering the food system under analysis as closed, by dividing: (i) aggregate demand of food (which depends on population, current characteristics of the diet, post-harvest losses); by (ii) "labor available within the country for generating food supply" (which depends on population size, fraction of population which is in the working age, unemployment, work load for the working population, fraction of work force absorbed by non-agricultural sectors). AP_{BEP} at the level of the whole country is the equivalent of BPL_{AG} described in relation (6) and relation (9).

An economy such the one of the US that allocates only 2% of its workers to agriculture has a level of AP_{BEP} of at least 270 MJ of food energy per hour. Such an AP_{BEP} is well out of the range of productivity of farmers in all developing countries (e.g. lower than 4 MJ/h in China) and is not even reached by farmers in the EU (lower than 100 MJ/h - **Tab. 9.3**).

- AP_{hour} (= Agricultural Productivity per hour of labor) the level of productivity of labor (throughput of food energy per hour of work supply in the agricultural sector) actually achieved by a country. Such an indicator is obtained by dividing: (i) the aggregate internal production of food (which depends on mix of cultivation and yields of different crops); by the (ii) amount of working time allocated in food production.

The goal of self-sufficiency would imply reducing the difference between these two parameters $[AP_{BEP} - AP_{hour} => 0]$. Even though this solution is very seldom reached by societal systems (at different levels: entire food systems, provinces, individual villages or households). More in general economic considerations are determinant in driving changes in techniques of production in agriculture. In particular, it is the difference between the economic labor productivity in agriculture compared to the economic labor productivity averaged over the various economic compartments that tends to select a mix of productions and production techniques that increase the output per hour of labor in agriculture. However, to boost economic labor productivity it is often necessary to subsidize human labor with huge injections of fossil energy in the form of technical inputs.

Indicators of the level of bio-economic pressure on agriculture - To characterize this pressure we can use the three Extensive variable#2 (exosomatic energy, added value and food) used to characterize societal metabolism in relation to Human Activity. In this case, assessments of local supply or requirement of added value ($/hour) or food (kg/hour) can be calculated at different levels (e.g. whole country, individual economic sector, sub-sectors, and individual firms/farms). These indicators can be used to characterize the performance of agroecosystems in relation to other socio-economic characteristics. An assessment of the exosomatic energy associated to a hour of labor in agricultural production, can be used to characterize the level of capitalization of this sector.

9.4.2 The effect of the quality of the diet, trade and market

Several practical problems make it difficult to formalize (in terms of substantive numerical assessments) these basic concepts. For example: (i) a different "quality" of the diet due to a different mix of food products will determine different space and labor demand for the same amount of MJ of food; (ii) the same applies for a different profile of post-harvest losses for different mixes of products; (iii) the definition of working time in the food system are quite variable. In general terms, when considering a food system, producing food is only the first step of a long chain of activities. A lot of post-harvest tasks are also required for storing, transporting, processing, and preparing meals. Moreover, activities related to food security are difficult to quantify in terms of work demand and are often performed, at least in part, by children or elderly not included in the working force; (iv) the calculation of the area required for food production is also quite tricky (e.g. in the case of shifting cultivation, when an integrate use of the landscape implies that agricultural production is integrated by other activities of hunting and gathering food from wild ecosystems).

All these difficulties have been already discussed when introducing the concept of impredicative loop analysis. Definitions can be variable but after agreeing on one particular definition (accepting the consequent approximations) we can write down individual - "definition specific"- equations of balance. For example, we can decide to check the existence of biophysical constraints only in relation to a particular food input about which it is easier to gather data (e.g. check only on the supply of the main staple-food produced in the subsistence farming system). In alternative, we can decide to focus only on a particular step in the food system (e.g. considering only agricultural production at the field level). An additional help is represented by the fact, that when looking for benchmarking in the representation of the performance of an agroecosystem, when comparing the severity of socio-economic constraints affecting farmers in developed countries with those affecting pure subsistence farming systems differences are huge. Therefore, whatever approximation we use to calculate constraints on the intensity of throughputs, we will still obtain significant results to be used to characterize different systems of production. For example, for cereal production, the level of productivity of labor in subsistence societies is in the order of one or a few kg/hour, whereas in developed countries is in the order of hundreds of kg/hour.

Another objection to the idea of using assessments of "minimum threshold" for the value of the throughput is related to the role of market and trade. That is, when a society is based on trade and market the amount of food made available to society per hour of labor is no longer determined by the amount of food produced within the society. In fact, market and trade can change dramatically the requirement of congruence over the 4-angle picture. In a modern country, rather than biophysical quantities of food commodities produced within the society, it is the amount of added value generated per hour of labor which, through the international price of commodities, defines the availability of food for internal consumption (assuming the existence of an adequate supply on the international market). Put in another way, the possibility of importing food could reduce the relevance of the constraint of congruence over the dynamic budget imposed by food security.

However, when looking at data describing the performance of actual agricultural sectors, we find the opposite. Because of the effect of economic variables, the bio-economic pressure becomes more relevant in pushing up the actual levels of productivity of labor in different countries. The bio-economic pressure, in fact, act on two hierarchical levels in parallel:

(i) at the hierarchical level of the whole society - by reducing the amount of work allocated in those economic sectors which have a productivity of added value lower than ELP_{AS}. In fact, in this way, the society can increase its economic performance;

(ii) at lower hierarchical levels (according to the perspective of a region, village or farmer living within such a society) - by the effort of individual lower level elements (rural regions, rural villages, farmers) to achieve an income similar to the average income enjoyed at the level of society by other regions, villages and citizens. Agricultural entities (holons) are forced to keep up with the economic development of their context in order to maintain a standard of living comparable to that enjoyed by the rest of society.

9.4.3 How useful are these two concepts when looking at data ?

Data of this section are taken from Giampietro, 1997b and Conforti and Giampietro (1997), they refer to the year 1990/1991 over a sample of 60 countries (see **Tab. 9.3**). The sample of 60 countries is representative of different combinations of demographic pressure, economic development, and geographic location. The sample includes: Algeria, Argentina, Australia, Bangladesh, Brazil, Burkina Faso, Burundi, Cambodia, Cameroon, Canada, Central African Republic, Chad, China, Colombia, Congo, Costa Rica, Ecuador, Egypt, El Salvador, Ethiopia, EU (average for the 12 countries making up the European Union in 1991), Finland, Gambia, Guatemala, Honduras, India, Indonesia, Iran, Jamaica, Japan, Jordan, Kenya, South Korea, Madagascar, Malawi, Mali, Mauritania, Mexico, Morocco, Mozambique, New Zealand, Nicaragua, Niger, Nigeria, Pakistan, Paraguay, Philippines, Senegal, Sri Lanka, Sweden, Switzerland, Tanzania, Thailand, Tunisia, Turkey, U.S.A., Uganda, Uruguay, Venezuela, Zimbabwe.

A. Technological development, GDP versus fraction of GDP from the agricultural sector, and employment in agriculture

The analysis of this data set indicates 3 main points, which are well known within the field of traditional economic analyses:

(i) when, in a country, the fraction of labor force in agriculture is high, the GDP per capita is low. That is, agricultural labor alone, without a significant support of technological inputs provided by a strong manufacturing sector, generates a flow of added value per hour of labor which is much lower than the one generated in developed countries. This point is well illustrated by **Fig. 9.12**, showing that all the countries with a GDP per capita higher than 10,000 US$/year have less than 7% of the working force in agriculture .

(ii) in developed countries (where GDP p.c. > 10,000 US$/year):
==> % of labor force in agriculture ≥ % of GDP from agriculture < 10 %
The higher the GDP p.c. the lower the % of labor force in agriculture and GDP. This point is illustrated by **Fig. 9.12**, that shows a general trend over the entire sample of 60 countries (covering the entire range of GNP p.c.).

(iii) in poor developing countries (where GDP p.c. < 1,000 US$/year):
==> % of labor force in agriculture > 20 % > % of GDP from agriculture
This point is illustrated by **Fig. 9.13**, that presents in detail the situation of developing countries (it encloses only the countries of the sample with a GDP p.c. below 5,000 US$/year). In this situation, developing countries would increase their GDP per capita if they were able to allocate a larger fraction of their work supply to non-agricultural activities;

These three points can be resumed into two general trends associated to technical and economic development of a country:
1. a continuous decrease of the fraction of labor force in agriculture to arrive at level below 5% (when the GNP p.c. is over 15,000 US$); and
2. a tendency to reduce % of labor force and % GNP from agriculture toward single digit percentage value.

B. The effect of Demographic and Bio-Economic Pressure

Within modern societies trade plays a significant role in stabilizing the equilibrium between food demand and food supply. Therefore, as already discussed in the previous section, the two indicators AP_{DP} and AP_{BEP} (= the density of biophysical throughput per hour and per hectare needed in agriculture to achieve self-sufficiency) do not indicate mandatory threshold values for the stability of a given food system. Rather these are values toward which the system tends to operate. When $AP_{DP} > AP_{ha}$ and/or $AP_{BEP} > AP_{hour}$, society has to rely on import to offset existing differences between internal demand and internal supply of food (both on land basis and on agricultural labor basis). This solution has three basic negative implications: (i) dependency on foreign countries for food security; (ii) risk of economic shocks in the case of price fluctuations; (iii) economic burden to guarantee the needed flow of imports. The degree of economic development and the size in population of a country will determine the importance of these factors. Obviously, there are also cases in which farming systems are operating in countries that are net food exporters [using previous indicators when $AP_{DP} < AP_{ha}$ and/or $AP_{BEP} < AP_{hour}$].

Data reported in **Fig. 9.14** and **Fig. 9.15** refer to a significant sample of world countries (the same considered in **Fig. 9.12** and **Fig. 9.13**). From this comparison it is possible to see the existence of a direct link between: (1) characteristics of a socio-economic system - determining the values of AP_{DP} and AP_{BEP}; and (2) characteristics of techniques of agricultural production adopted in a defined society - determining the values of AP_{ha} and AP_{hr}. In particular:

- the higher the value of AP_{DP} in a country the more probable it becomes to find also a higher AP_{ha} (= throughput of food energy produced by the agricultural sector per hectare) - **Fig. 9.14**. That is current technological performance in terms of yield per hectare is affected by existing demographic pressure.

- the higher the value of AP_{BEP} in a country, the more probable it becomes to find a higher AP_{hour} (= throughput of food energy produced by the agricultural sector per hour of work delivered) - **Fig. 9.15.** That is current technological performance in terms of productivity of labor is affected by existing socio-economic pressure.

For the poorest countries of the sample, where the openness of the food system is minor and the aversion to risk higher, the constraint given by the goal of self-sufficiency in both land and labor terms is obviously stricter (that is AP_{ha} --> AP_{DP} and AP_{hour} --> AP_{SEP}).
Whereas, developed countries can heavily rely on fossil energy to boost internal supply of agricultural products both per ha and per hour. Where an adequate amount of arable land per farmer is available, injection of machinery can boost the value of AP_{hour} well above the value of AP_{BEP} (e.g. USA, Canada, Australia).

However, it should be observed that the two levels of productivity (per hectare of arable land and per hour of labor) are not independent. As Hayami and Ruttan (1985) show, we can write the productivity of labor as a function of yield per hectare:

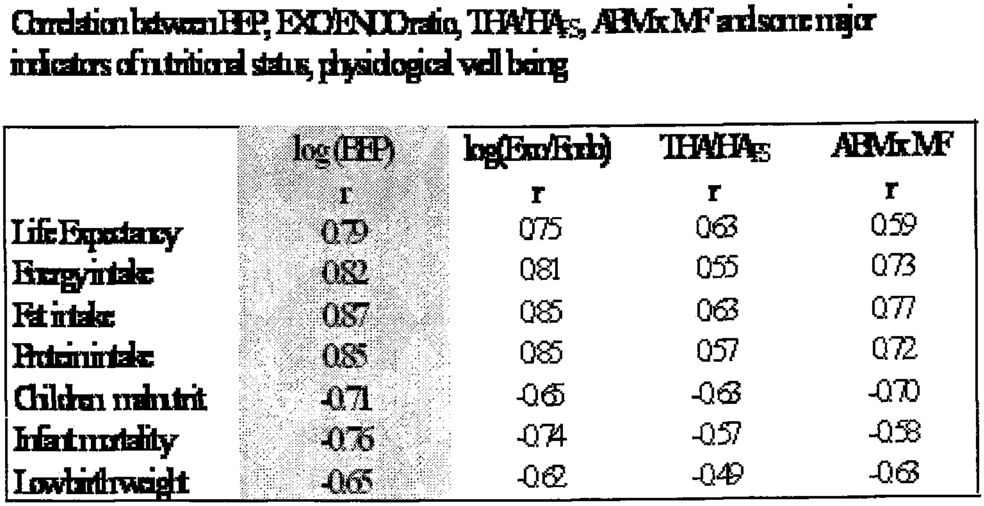
$$BPL_{AG} = \text{output (kg)/hour} = \text{“output (kg)/ha”} \times \text{“ha managed/hour”} \qquad (30)$$

Therefore, it is not possible to achieve a very high level of kg/hour (average referring to the whole year) when producing at a very low level of kg/ha (e.g. 1 ton per hectare). Two main problems would occur in this case: (i) land required to achieve targeted labor productivity could exceed the endowment of hectares available per farmer; (ii) too much technical investment would be required to harvest an increasing area with a limited amount of labor. The same applies to the case in which it is the second term (hectares available to be managed), which becomes limiting. For example, when the value of AP_{BEP} is in the order of hundreds of kg of grain per hour and the arable land per farmer is in the order of 1 ha (e.g. Japan) there is no feasible technical solution to match such a challenge. At that point, a limiting constraint on land entails two consequences: (1) crowded and developed countries have to depend on import for their food security (if the selected diet entails a high value for QDM&PHL); and (2) their farmers have to depend on subsidies to get an income similar to the average income typical of other economic sectors.

This brings us to the third indicator of pressure ELP_{AS}. The amount of added value related to a particular agricultural production, which depends on revenues (on yield and outputs' price) and the structure of costs at the farm level (depending on inputs' cost). All these factors are heavily influenced by international agreements, governmental policies and regulations. At a particular moment in time, given the set of current boundary conditions (prices on the international market, cost of inputs, existing laws, rules and policies affecting the market) a given farmer is affected by a pressure to achieve a certain economic return, determined by the characteristics of the society to which he/she belongs. In turn a set of biophysical constraints are also affecting a particular farmer operating at a defined point in time and space (shortage of land or water, climatic conditions). Given all this information, to break-even a farmer should be able to produce a determined crop pattern at determined levels of throughput per hour of labor and per hectare.

Translating economic variables into biophysical variables and vice versa (establishing a relation between BPL and ELP) is especially useful when comparing farming systems that are operating under widely different levels of demographic and bio-economic pressure. In this way, by an integrated use of these numerical indicators, we can characterize the influence of different socio-economic contexts on technical and economic performance of farming. For example, Japanese farmers are operating under a high bio-economic pressure (THT/WS_{AG} = 0.005 - **Tab. 9.3**) and under a very high demographic pressure (about 0.04 ha of arable land per capita - **Tab. 9.3**). In terms of added value Japan was characterized by an ELP_{AS} of about 37 US$/hour in 1991 – (**Tab. 9.3**). According to the range of technical coefficients achievable in agriculture the task for Japanese farmers can become a "mission impossible" [= very small endowment of land (less than 1 ha per farmer - **Tab. 9.3**) and the need of reaching levels of labor productivity of hundreds of kg of rice per hour]. The characteristics of their socio-economic context place them at a disadvantage when competing, both: (i) with farmers operating under a much lower bio-economic pressure - e.g. Chinese rice producers with a negligible opportunity cost of labor (= a ELP_{AS} of about 0.5 US$/hour in 1991 - **Tab. 9.3**). Chinese farmer can afford to produce rice at a level of productivity of labor in the order of tens kg per hour and be still economically viable; and (ii) with farmers operating under a much lower demographic pressure - e.g. US farmers can boost their labor productivity by using an endowment of arable land which is more than 30 ha per farmer (**Tab. 9.3**).

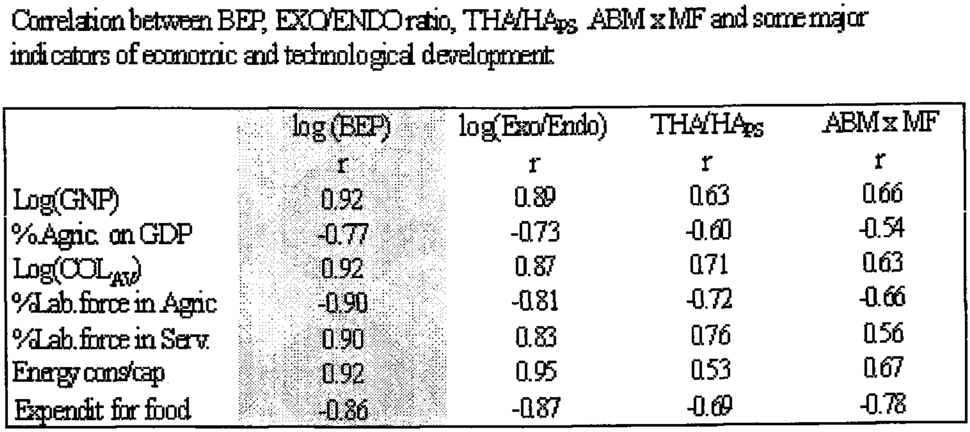
The integrated use of these indicators makes it possible to link economic analyses to the effect of demographic changes. According to actual trends we can expect that a general economic development of the various countries of our planet will determine a continuous increase in both demographic and bio-economic pressure in the next decades. What consequences can we expect for the environment from this trend? This is the subject of the next chapter.



Correlation between BEP, EXO/ENDO ratio, THA/HA_{PS}, ABM x MF and some major indicators of nutritional status, physiological well being

	log(BEP)	log(Exo/Endo)	THA/HA_{PS}	ABM x MF
	r	r	r	r
Life Expectancy	0.79	0.75	0.63	0.59
Energy intake	0.82	0.81	0.55	0.73
Fat intake	0.87	0.85	0.63	0.77
Protein intake	0.85	0.85	0.57	0.72
Children malnutrit	-0.71	-0.65	-0.63	-0.70
Infant mortality	-0.76	-0.74	-0.57	-0.58
Low birth weight	-0.65	-0.62	-0.49	-0.63

Table 9.1 Correlation of the proposed set of integrated indicators with conventional indicators of development
(Pastore et al. 2000)



Correlation between BEP, EXO/ENDO ratio, THA/HA_{PS}, ABM x MF and some major indicators of economic and technological development

	log(BEP)	log(Exo/Endo)	THA/HA_{PS}	ABM x MF
	r	r	r	r
Log(GNP)	0.92	0.89	0.63	0.66
%Agric. on GDP	-0.77	-0.73	-0.60	-0.54
$Log(COL_{AV})$	0.92	0.87	0.71	0.63
%Lab.force in Agric	-0.90	-0.81	-0.72	-0.66
%Lab.force in Serv.	0.90	0.83	0.76	0.56
Energy cons/cap	0.92	0.95	0.53	0.67
Expendit for food	-0.86	-0.87	-0.69	-0.78

Table 9.2 Correlation of the proposed set of integrated indicators with conventional indicators of development

Correlation between BEP, EXO/ENDO ratio, THA/HA$_{PS}$, ABM x MF and some major indicators of social development:

(Pastore et al. 2000)

	log (BEP)	log(Exo/Endo)	THA/HA$_{PS}$	ABM x MF
	r	r	r	r
Televis./ inhab.	0.89	0.89	0.62	0.72
Cars / inhab.	0.88	0.91	0.59	0.72
Newspap / inhab	0.77	0.80	0.47	0.60
Phones / inhab.	0.87	0.88	0.61	0.71
log(pop./physician)	-0.81	-0.76	-0.60	-0.67
log(pop./hosp.bed)	-0.77	-0.78	-0.51	-0.70
Pupil/teacher	-0.77	-0.76	-0.51	-0.62
Illiteracy rate	-0.61	-.058	-0.42	-0.44
Prim. school enroll.	0.44	0.39	0.38	0.36
Acces to safe water	0.78	0.77	0.53	0.59

Table 9.3 Parameters defining demographic and bio-economic pressure in a sample of 60 countries (year 1991) – (Giampietro, 1997a)

Country	GNP p.c. US$	%lab in ag.	% GNP from ag.	ELP *AS*	$\frac{\text{THA}}{\text{HA}_W}$	$\frac{\text{HA}_{AG}}{\text{THA}}$	$\frac{\text{ha}}{\text{cap.}}$	$\frac{\text{ha}}{\text{farm}}$
Algeria	1991	24.0	14.0	4.3	21.3	0.011	0.14	2.55
Argentina	3966	10.0	8.1	11.9	14.5	0.007	0.38	10.50
Australia	17068	5.0	3.3	22.0	11.0	0.004	1.35	57.53
Bangladesh	205	69.0	36.8	0.4	16.3	0.041	0.04	0.19
Brazil	2920	24.0	10.0	4.6	13.8	0.016	0.16	1.85
Burkina Faso	290	84.0	44.0	0.4	11.4	0.073	0.19	0.44
Burundi	218	91.0	55.0	0.2	10.3	0.088	0.10	0.21
Cambodia	202	70.0	48.9	0.3	13.1	0.053	0.13	0.45
Cameroon	858	61.0	23.0	1.3	13.9	0.042	0.25	1.10
Canada	20740	3.0	3.0	24.8	10.9	0.003	0.85	53.30
Cent. Afr. Rep.	407	63.0	41.0	0.5	11.2	0.053	0.31	1.09
Chad	212	75.0	43.0	0.4	14.8	0.048	0.28	1.12
China	364	67.0	28.4	0.5	8.6	0.076	0.04	0.10
Colombia	1254	27.0	16.1	2.7	16.6	0.015	0.06	0.68
Congo	1060	60.0	13.2	1.6	15.1	0.039	0.03	0.14
Costa Rica	1841	24.0	15.8	3.8	15.4	0.014	0.05	0.57
Ecuador	1010	30.0	13.4	2.2	15.9	0.018	0.08	0.81
Egypt	611	41.0	18.0	1.4	18.5	0.021	0.02	0.19
El Salvador	1084	37.0	11.2	1.8	12.0	0.029	0.05	0.46
Ethiopia	123	75.0	47.0	0.1	11.4	0.062	0.13	0.42
EU	17393	6.3	3.0	24.9	11.9	0.005	0.10	3.90
Finlandia	24089	8.0	6.0	0.6	15.6	0.004	0.25	6.27
Gambia	367	81.0	28.5	2.2	17.9	0.051	0.10	0.28
Guatemala	944	51.0	25.7	0.6	10.0	0.028	0.08	0.51
Honduras	587	55.0	20.0	1.1	15.6	0.034	0.16	0.91
India	330	66.0	31.0	0.5	13.6	0.048	0.10	0.38
Indonesia	592	48.0	21.4	1.1	12.7	0.036	0.04	0.23
Iran	2274	28.0	21.0	4.8	19.8	0.013	0.14	1.87
Jamaica	1446	27.0	5.0	1.5	9.4	0.027	0.03	0.24
Japan	26824	6.0	2.5	36.6	10.2	0.005	0.02	0.52
Jordan	935	6.0	7.0	2.6	18.9	0.003	0.04	3.21
Kenya	350	77.0	27.0	0.4	11.8	0.064	0.04	0.13
Korea (South)	6227	25.0	9.0	10.1	11.6	0.019	0.02	0.21
Madagascar	207	77.0	33.0	0.3	13.4	0.056	0.11	0.32
Malawi	200	75.0	35.0	0.3	14.4	0.050	0.08	0.28
Mali	251	81.0	42.1	0.5	16.4	0.048	0.11	0.44
Mauritania	500	64.0	22.0	0.9	15.0	0.042	0.05	0.24
Mexico	2971	30.0	8.0	5.8	14.0	0.020	0.14	1.31
Morocco	1033	37.0	16.8	1.9	15.7	0.022	0.18	1.57
Mozambique	84	82.0	64.0	0.1	8.7	0.092	0.10	0.24

Table 9.3 Parameters defining demographic and bio-economic pressure in a sample of 60 countries (year 1991) - **continued**

Country	GNP p.c. US$	%lab in ag.	% GNP from ag.	ELP *AS*	THA / HA_W	HA_{AG} / THA	ha / cap.	ha / farm
New Zealand	12301	9.0	8.4	16.0	11.1	0.008	0.06	1.44
Nicaragua	283	37.0	31.1	0.6	15.7	0.022	0.15	1.39
Niger	303	87.0	34.8	0.3	11.3	0.076	0.23	0.52
Nigeria	305	65.0	37.0	0.4	12.0	0.053	0.14	0.55
Pakistan	383	50.0	26.0	0.8	17.3	0.028	0.09	0.58
Paraguay	1266	46.0	27.8	2.7	15.9	0.029	0.25	1.56
Philippines	728	47.0	22.1	1.3	13.9	0.033	0.04	0.25
Senegal	736	78.0	20.3	1.0	12.1	0.064	0.16	0.47
Sri Lanka	495	52.0	27.0	1.0	13.9	0.037	0.03	0.14
Sweden	25254	4.0	3.0	29.1	10.3	0.003	0.16	8.51
Switzerland	33850	4.0	3.6	46.6	11.4	0.003	0.03	1.45
Tanzania	95	81.0	61.0	0.1	10.5	0.075	0.05	0.14
Thailandia	1697	64.0	12.7	2.3	9.7	0.064	0.16	0.45
Tunisia	1504	24.0	18.0	3.1	15.9	0.013	0.18	2.24
Turkey	1793	48.0	18.0	4.2	12.3	0.037	0.22	1.07
U.S.A.	22356	2.0	2.0	0.2	10.5	0.020	0.37	32.85
Uganda	163	81.0	51.0	30.2	10.7	0.075	0.14	0.39
Uruguay	2883	14.0	11.3	4.4	13.0	0.010	0.20	3.90
Venezuela	2728	11.0	5.4	4.7	14.5	0.007	0.08	2.15
Zimbabwe	641	68.0	20.0	0.8	13.0	0.051	0.13	0.50

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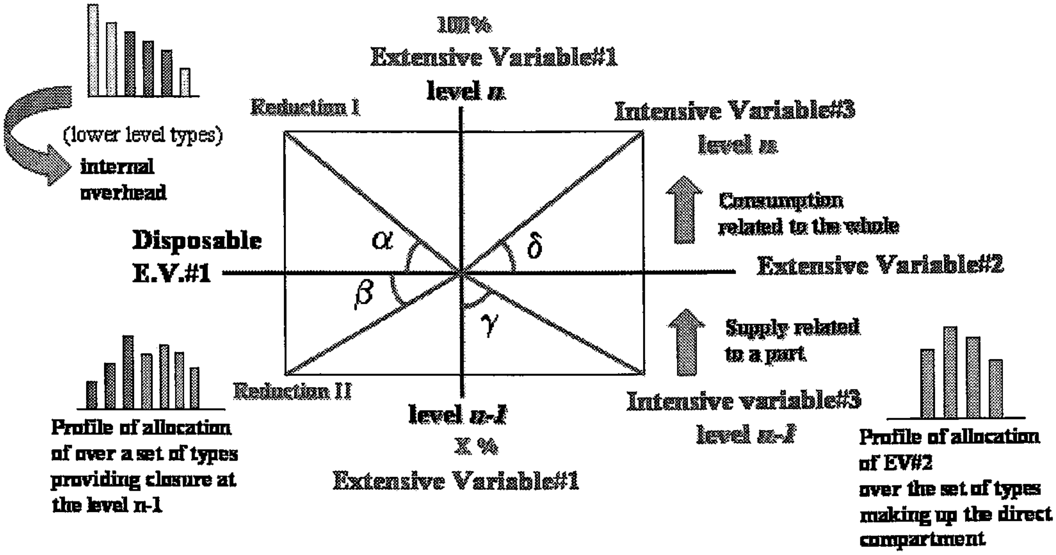
1. GNP per capita expressed in US dollars - 1991 - from WRI, 1994;
2. percentage of labor force in agriculture - from WRI, 1994;
3. percentage of GDP in agriculture - from WRI, 1994
4. ELP_{AS} - US dollar/hour -- Economic Labor Productivity Average for the Society- (it is obtained by dividing GDP by the amount of hours worked in that year - HA_W; HA_W = economically active population x 2,000 hours
5. THA/ HA_W - ratio Total Human Activity/ Human Activity allocated to working (where THA = population x 8,760; and HA_W as above) - data from WRI, 1994;

6 HA_{AG} /THA - ratio HA in agriculture/total human activity (where HA_{AG} = HA_W x % of labor force in agriculture);

7 hectares of arable land per capita - from WRI, 1994;

8 hectares of arable land per farmer - total arable land divided by HA_{AG} /2000

Fig. 9.1 ILA: general relation among types in societal metabolism



* Extensive Variable#1 ==> (i) Human Activity; (ii) Land Area
* Extensive variable#2 ==> (a) Exosomatic Energy; (b) Added Value; (c) Food

Fig. 9.2 Chosing how to define and aggregate typologies over the ILA
E.V.#1: Human Activity

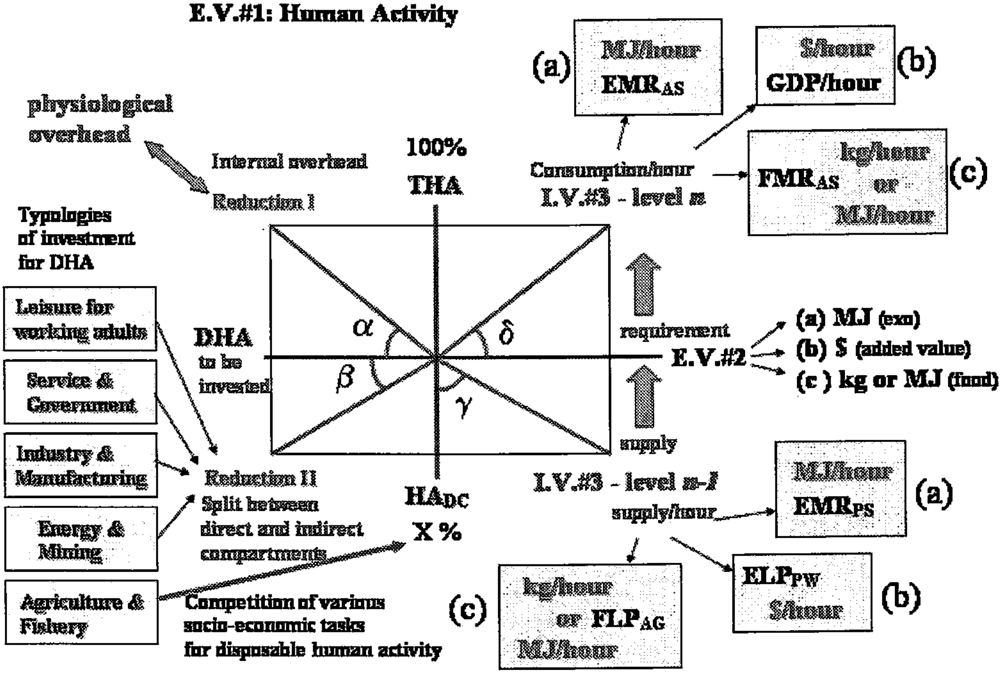
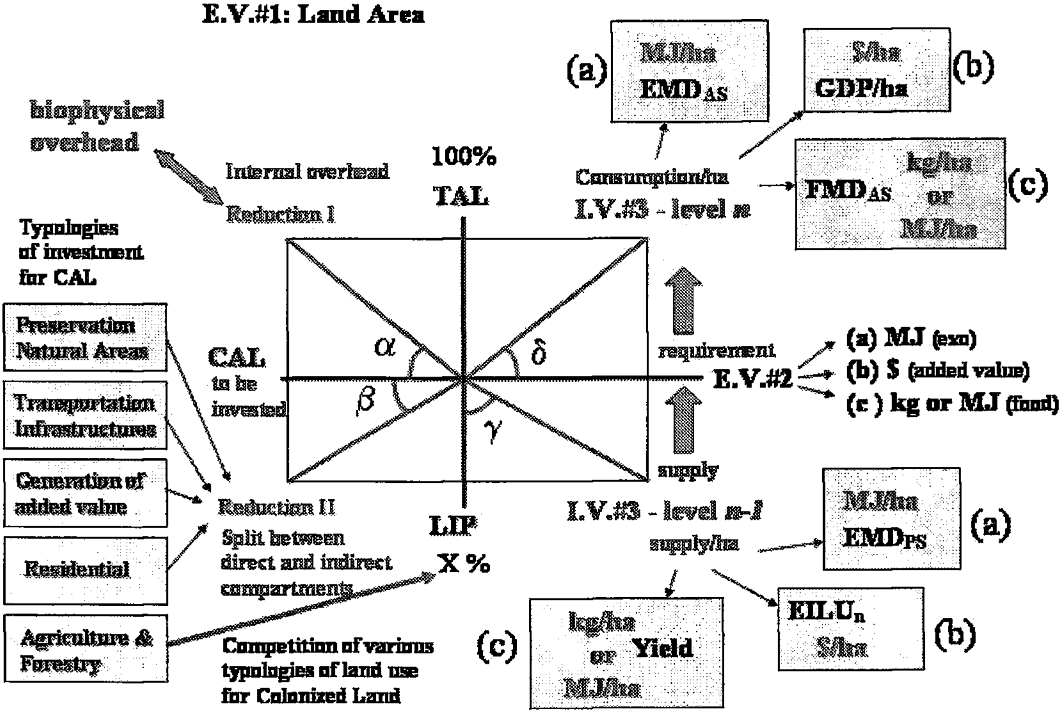
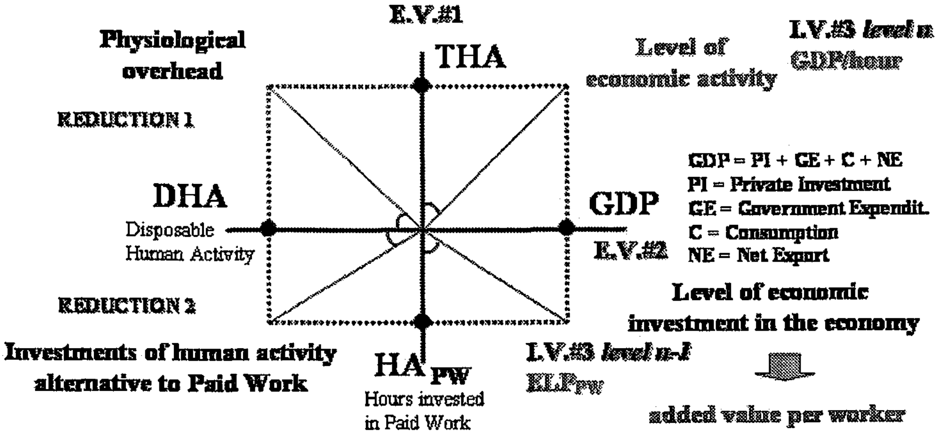


Fig. 9.3 Chosing how to define and aggregate typologies over the ILA
E.V.#1: Land Area





(Giampietro et al. 2001)

Fig. 9.5 Example #2
ILA with:
EV#1 Human Activity and
EV#2 Added Value

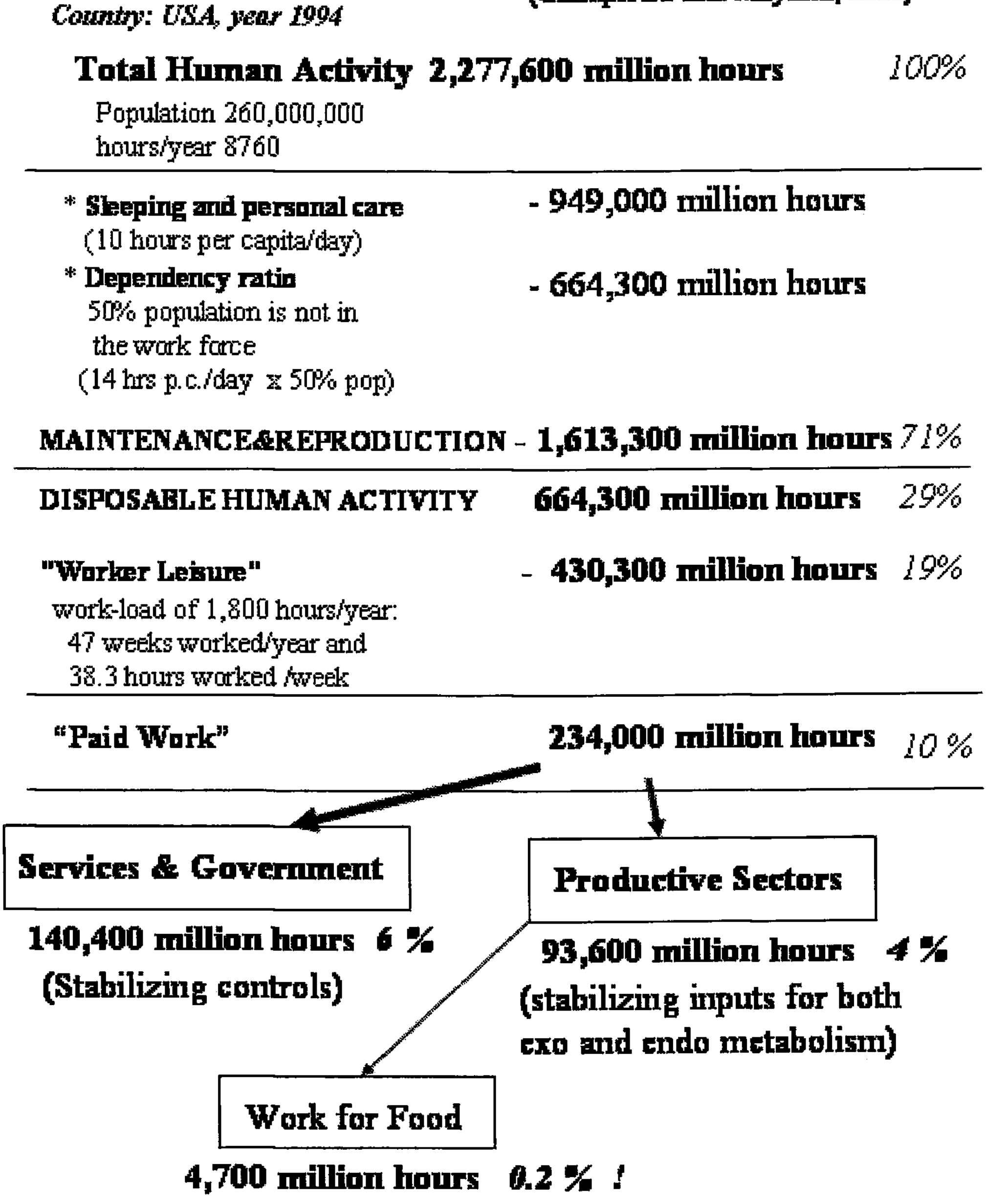
Equations of congruence linking different parameters

$$\frac{\text{GDP p.c.} \times (\text{SOHA} + 1)_{\$}}{8760} = HA_{PW} \times ELP_{PW}$$

$(\text{SOHA} + 1)_{\$} = THA / HA_{PW}$

Fig. 9.4 Profile "consumption <==> end uses" of investments of human activity in a developed country (U.S.A)

(Giampietro and Mayumi, 2000)



Country: USA, year 1994

Total Human Activity 2,277,600 million hours *100%*

Population 260,000,000
hours/year 8760

---

* **Sleeping and personal care** (10 hours per capita/day) **- 949,000 million hours**

* **Dependency ratio** 50% population is not in the work force (14 hrs p.c./day x 50% pop) **- 664,300 million hours**

MAINTENANCE&REPRODUCTION - 1,613,300 million hours *71%*

DISPOSABLE HUMAN ACTIVITY 664,300 million hours *29%*

"Worker Leisure" work-load of 1,800 hours/year: 47 weeks worked/year and 38.3 hours worked /week **- 430,300 million hours** *19%*

"Paid Work" 234,000 million hours *10 %*

Services & Government

140,400 million hours 6 %
(Stabilizing controls)

Productive Sectors

93,600 million hours 4 %
(stabilizing inputs for both exo and endo metabolism)

Work for Food

4,700 million hours 0.2 % !

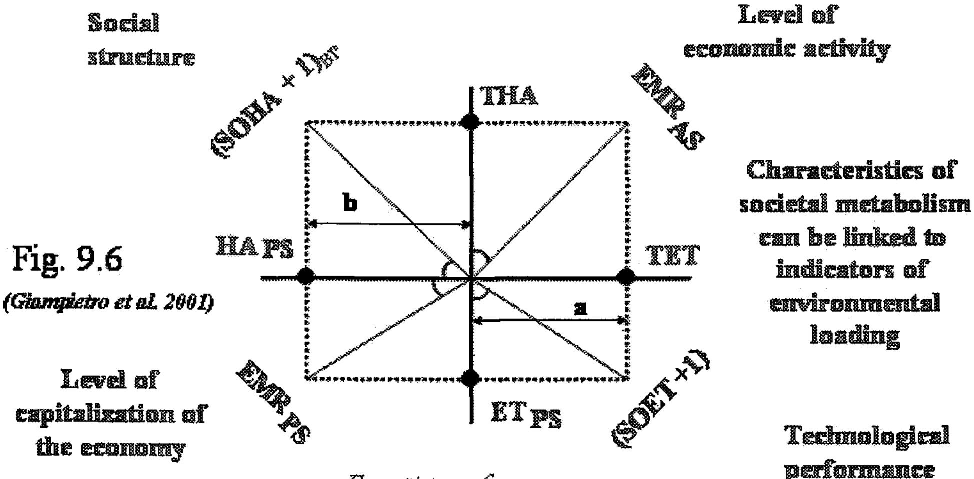


Fig. 9.6

(Giampietro et al. 2001)

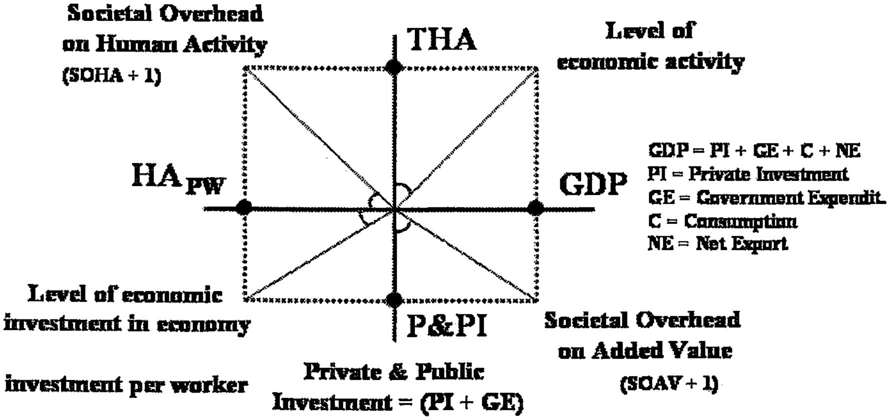
Equations of congruence

$(SOHA + 1)_{BP} = THA / HA_{PS}$ $EMR_{AS} = TET / THA$

$EMR_{PS} = ET_{PS} / HA_{PS}$ $(SOET + 1) = TET / ET_{PS}$

$BEP = a/b = EMR_{AS} \times (SOHA + 1) = TET / HA_{PS}$

$SEH = a/b = EMR_{PS} \times (SOET + 1) = TET / HA_{PS}$



Equations of congruence linking different parameters

$$\frac{GNP\ p.c. \times (SOHA + 1)_k}{8760} = LEIE \times (SOAV + 1)$$

Fig. 9.7

(Giampietro et al. 2001)

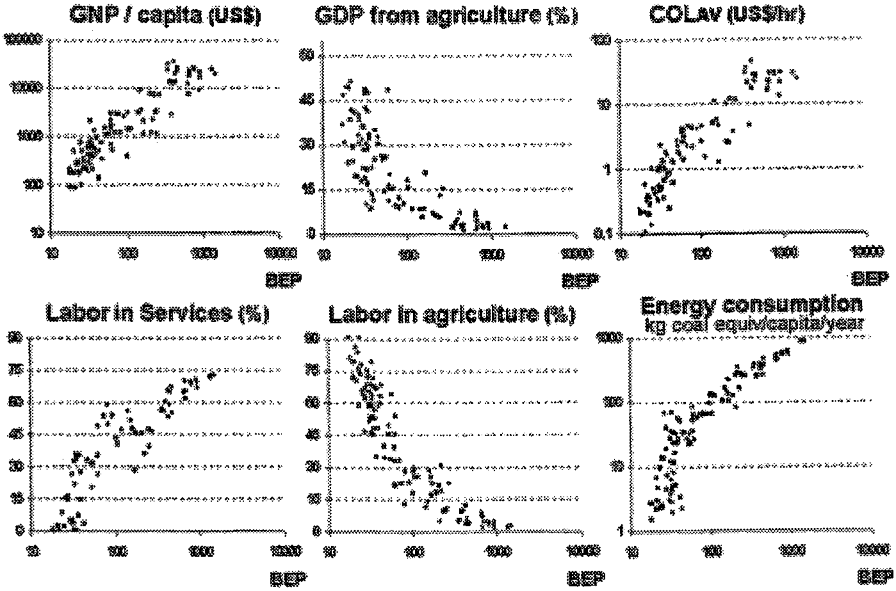
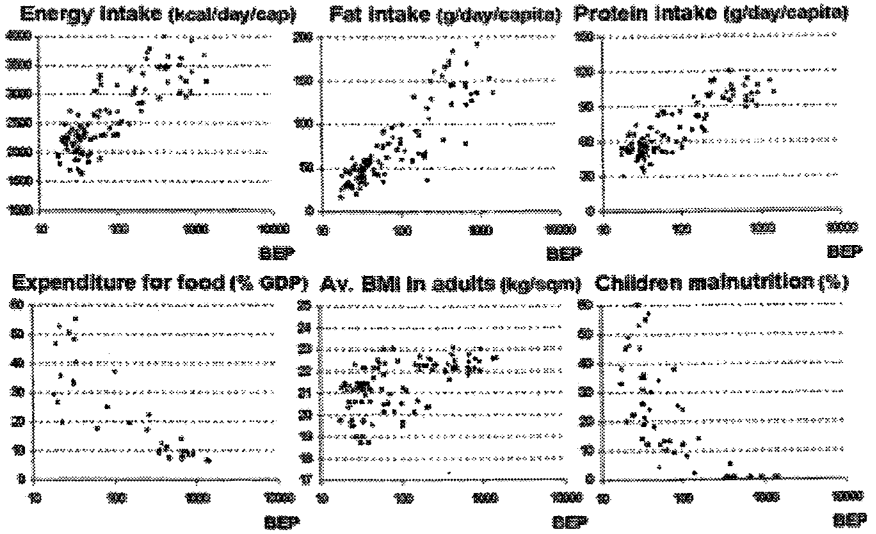


Fig. 9.8 Conventional indicators of development versus BEP
(Pastore et al. 2000)



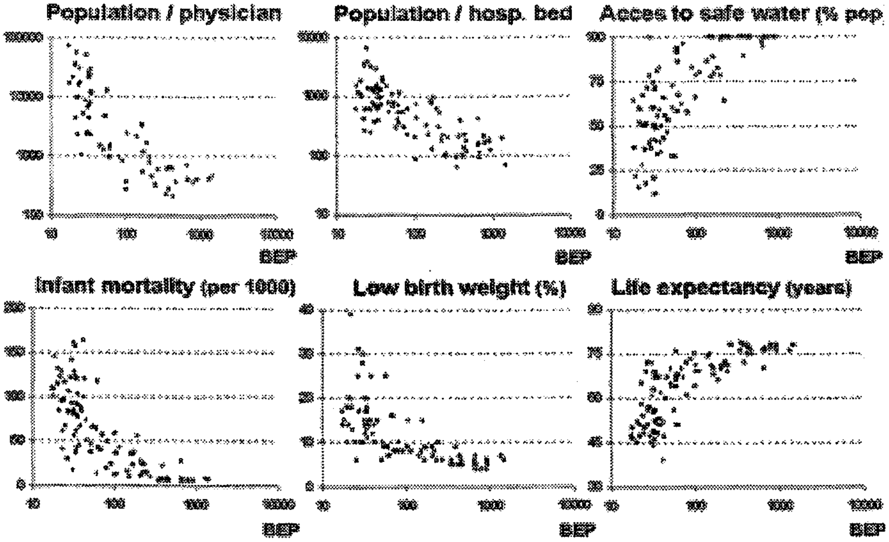
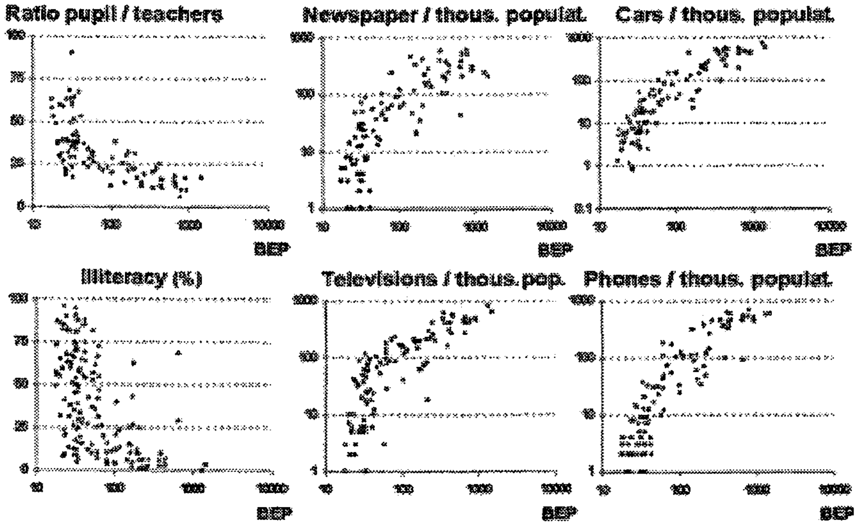


Fig. 9.9 Conventional indicators of development versus BEP
(Pastore et al. 2000)



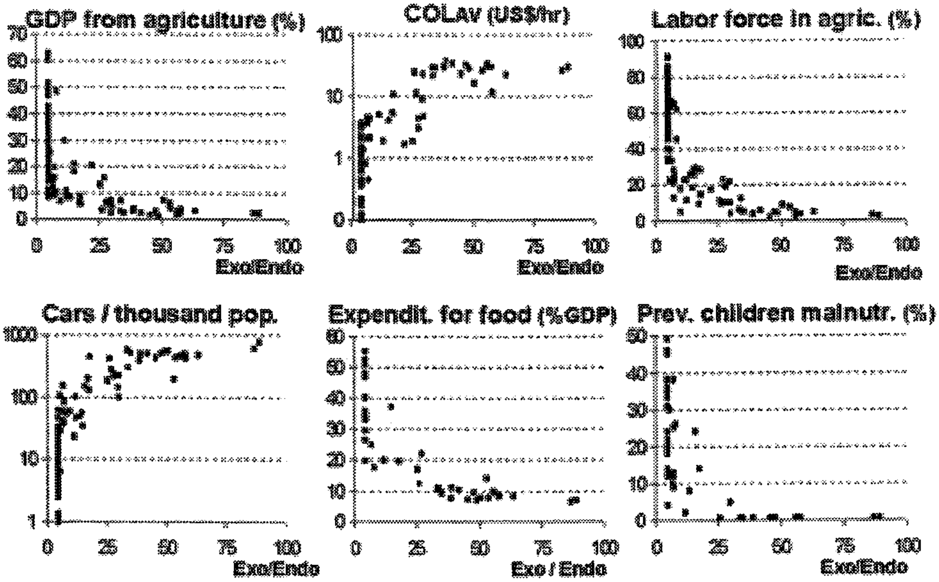
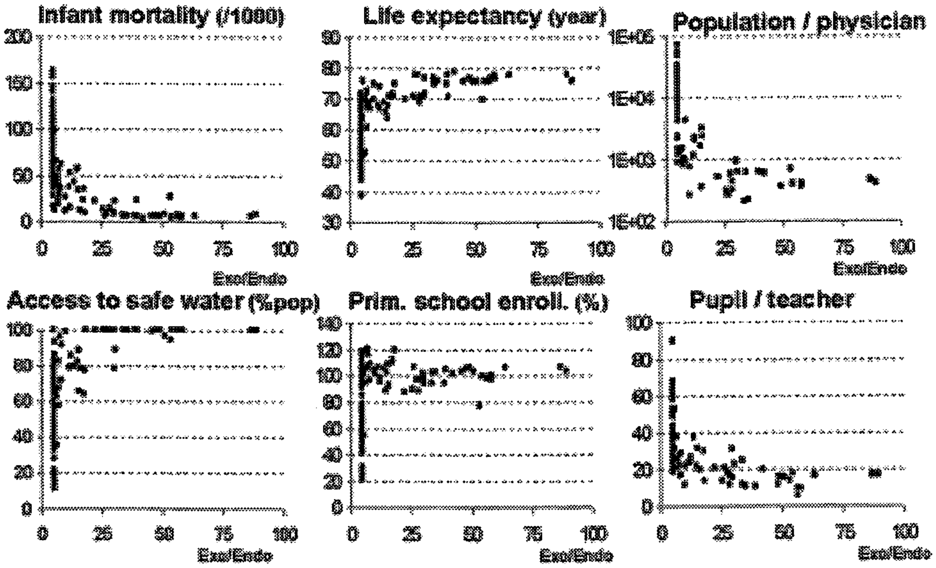


Fig. 9.10 Conventional indicators of development versus Exo/Endo
(Pastore et al. 2000)



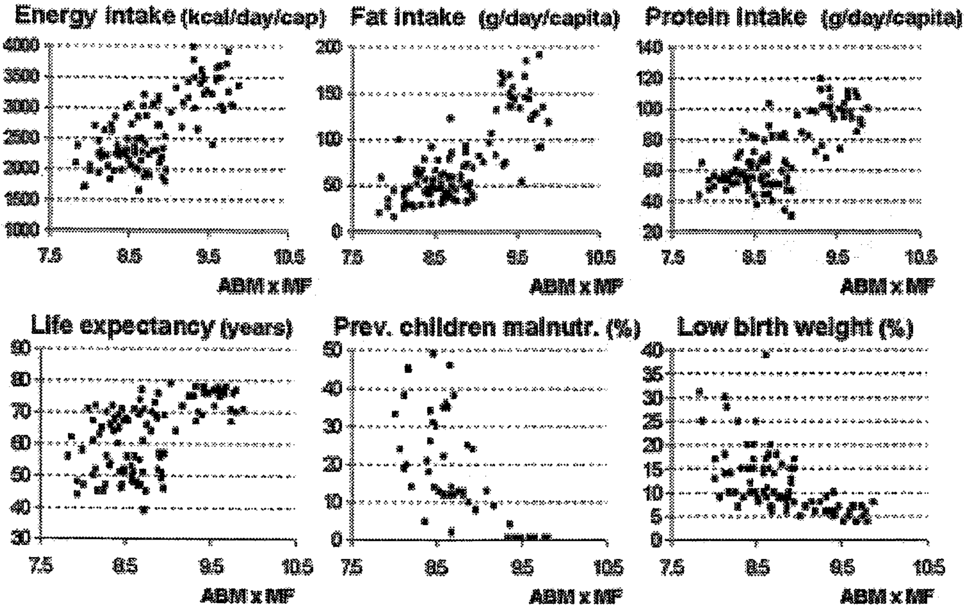


Fig. 9.11 Conventional indicators versus "ABM x MF" and THA/HA$_{PS}$ *(Pastore et al. 2000)*

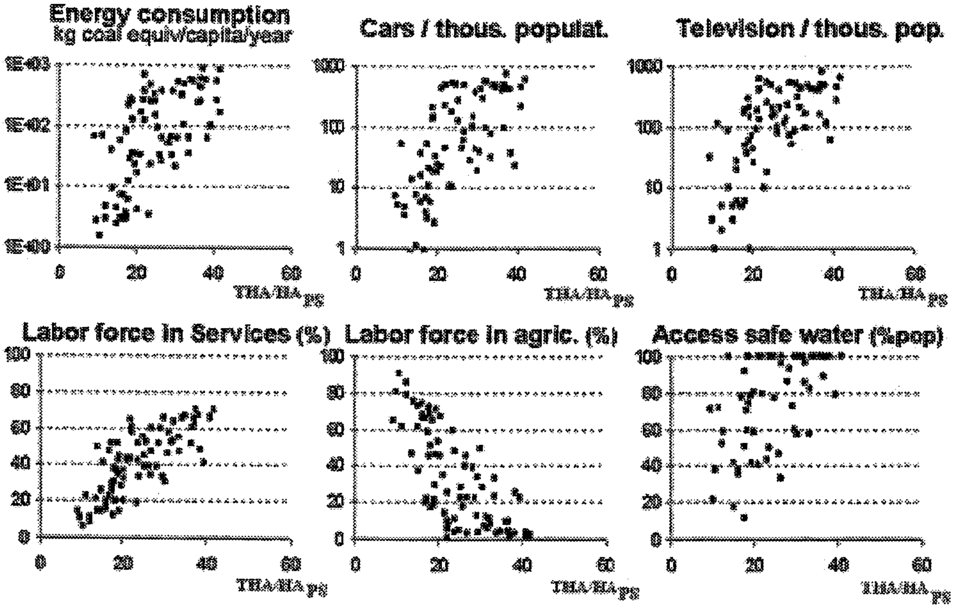


Fig. 9.12 If the work force is just producing its own food the society will never become rich . . .
(Giampietro, 1997b)

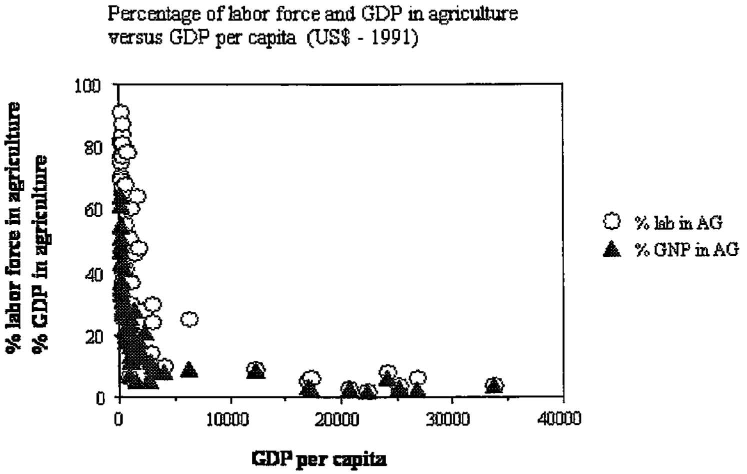
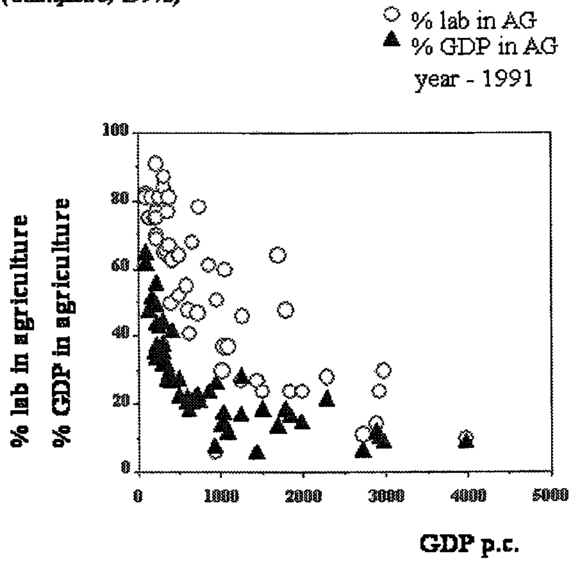


Fig. 9.13 In developing countries investments of human activity in agriculture contribute less to GDP than investments in other sectors
(Giampietro, 1997b)



(countries of the sample with a GDP p.c. < 5,000 US$)

Fig. 9.14 **Demographic pressure: the higher the population density the higher the productivity of agricultural land** *(Giampietro, 1997b)*

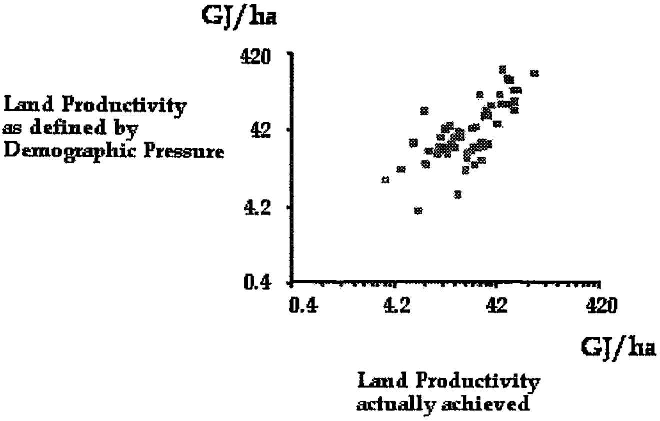
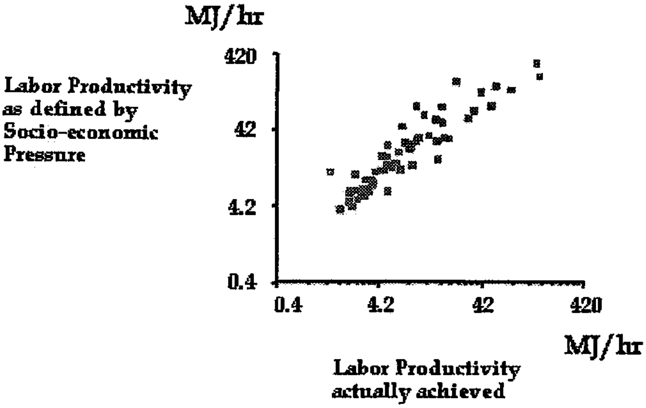


Fig. 9.15 **Bio-Economic pressure: the higher the societal overhead on human activity in agriculture, the higher must be the productivity of labor** *(Giampietro, 1997b)*



Chapter 10

Multi-Scale Integrated Analysis of agro-ecosystems: "technological changes" and ecological compatibility

According to the analysis presented in the previous chapter a general increase of both the demographic and bio-economic pressure on our planet is the main driver of intensification of agricultural production at the farming system level. In turn a dramatic intensification of agricultural production can be associated to a stronger interference on the natural mechanisms of regulation of terrestrial ecosystems. That is, to a reduced ecological compatibility of the relative techniques of agricultural production. In order to deal with this problem it is important, first of all, to understand the mechanisms through which changes in the socio-economic structure are translated into a larger interference on terrestrial ecosystems. This is the topic of this Chapter. Section 1 studies the interface socio-economic context/farming system. At the farm level, in fact, the selection of production techniques is affected by the typology of boundary conditions faced by the farm. In particular, this section focuses on the different mix of technical inputs adopted when operating in different typologies of socio-economic context. Section 2 deals with the nature of the interference on terrestrial ecosystems associated to agricultural production. A few concepts introduced in Part2 are used to discuss the possible development of indicators. The interference generated by agriculture can be studied by looking at the intensity of the throughput of appropriated biomass per unit of land area. Changing the metabolic rate of a holarchic system (such as a terrestrial ecosystem) requires: (i) a readjustment of the relative size of its interacting parts; (ii) a redefinition of the relation among interacting parts; and (iii) changing the degree of internal congruence between produced and consumed flows associated to its metabolism. When the external interference is too large, we can expect a total collapse of the original system of controls used to guarantee the original identity of the ecosystem. Finally, Section 3 looks at the big picture presenting an analysis, at the world level, of food production. This analysis explicitly addresses the effect of the double conversion associated to animal products (plants produced to feed animals). After examining technical coefficients, and the use of technical inputs related to existing patterns of consumption in developed and developing countries, the analysis discusses the implications for the future in terms of expected requirement of land and labor for agricultural production.

10.1 Studying the interface socio-economic systems/farming systems: the relation between throughput intensities

10.1.1 Introduction

After agreeing that technological choices in agriculture are affected by (1) characteristics of the socio-economic system to which the farming system belongs; (2) characteristics of the ecosystem managed for agricultural production; and (3) farmers' feelings and aspirations, it is important to develop models of integrated analysis that can be used to establish bridges among these 3 different perspectives. This requires defining in non-equivalent ways the performance of an agro-ecosystem in relation to: (1) socio-economic processes; (2) ecological processes; (3) livelihood of households making up a given farming system.

The link between economic growth and the increases in the intensity of the throughput "per hour of labor" and "per hectare" at the societal level (due to increasing bio-economic and demographic pressure) has been explored in Chapter 9. That is, that Chapter addresses the link related to the first point of the previous list. This chapter explores the implications of the trend of intensification of agricultural production in relation to ecological compatibility. That is, it addresses the link implied by the second point of the list. An integrated analysis reflecting the perspective of farmers seen as agents in relation to the handling of these contrasting pressures at the farming system level - the link implied by the third point of the list - is proposed in Chapter 11.

The need of preserving the integrity of ecological systems – the ecological dimension of sustainability – in effect can be seen as an alternative pressure coming from the outside of human systems, which is contrasting the joint effect of demographic and bio-economic pressure – a pressure for growth coming from the inside. That is, whereas human aspirations for a better quality of life and freedom of reproduction push for increasing the intensity of the throughputs within the agricultural sector. A more holistic view of the process of co-evolution of humans with their natural context provides an opposite view pushing for keeping as low as possible the intensity of throughput of flows controlled by humans within agro-ecosystems. As noted in Part 1 the sustainability predicament is generated by the fact that these two contrasting pressures are operating at different hierarchical levels, on different scales, and this makes difficult to interlock the relative mechanisms of control.

At the level of individual farms, at the level of villages, at the level of rural areas, at the level of whole countries and at the supranational level different rules, habits, allocating processes, laws, cultural values are operating for enforcing the two views. However, an overall tuning of this complex system of contrasting goals is everything but easy. Especially when considering that humankind is living in a fast period of transition, which implies the existence of huge gradients among socio-economic systems (very rich and very poor) operating on different points of the evolutionary trajectory.

This implies that human agents at different levels, at the moment of technological choices, must decide about the acceptability of compromises (at the local, medium, large scale) in relation to the contrasting implications of these two pressures. This chapter obviously does not claim to be able to solve this Yin Yang predicament. Rather the goal is to shows that it is possible to use the pace of the agricultural throughput to establish a bridge between the perception and representation of benefits and constraints coming from societal context (when using the throughput per hour of labor) and the perception and representation of benefits and constraints referring to the ecological context (when using the throughput per hectare) of a farm.

In order to make informed choices it is important to have a good understanding of the mechanisms linking the two types of pressures: (i) the internal asking for a higher level of dissipation and therefore for an expansion into the context; and (ii) the external reminding that a larger level of dissipations entails higher stress on boundary conditions and therefore a shorter life expectancy for the existing identity of the socio-economic system generating the ecological stress. The debate over sustainability, in reality, means discussing the implications of human choices when looking for compromise solutions between these two pressures.

The analysis described in Section 9.4 (**Fig. 9.12, Fig. 9.13, Fig. 9.14, Fig. 9.15**) indicates the existence of a clear link between the values taken by:

(i) relevant characteristics of the food system **defined at the hierarchical level of society** (using the two I.V.#3: AP_{DP} and AP_{BEP}), which can be characterized by a set of variables such as GNP and density of produced flow, that cab be related to other relevant system qualities such as: age structure, life span of citizens, profile of labor distribution over economic sectors, work load (as discussed in Chapter 9). These variables refer to the societal system seen as a whole, without any reference to the farming system level; and

(ii) relevant characteristics of the food system **defined at the hierarchical level of farming system** (using the two I.V.#3: AP_{ha} and AP_{hour}), which are determined by a set of biophysical constraints such as technical coefficients, technical inputs, climatic conditions, and location specific socio-economic constraints such as local prices and costs, local laws. These characteristics, for example, refer to the horizon seen by farmers when making their living. The variables used to represent these system qualities are well known to agronomist, agricultural economists, agro-ecologists (technical coefficients, economic parameters characterizing the economic performance of the farm, local indicators of environmental stress).

This link among two different hierarchical levels: "society as a whole" - **level *n*** - and "individual farming system"- **level *n-1*** - can be visualized by using a plane describing the agricultural throughput according to two IV#3: (1) agricultural throughput "per ha" [when using Human Activity as EV#2] and (2) agricultural throughput "per hour" [when using Land Area as EV#2]. In this way, technical performance of farming system can be described in parallel on two levels **Fig. 10.1**:

* on the **level *n*** "society as a whole" by considering values of AP_{DP} and AP_{BEP} [which are two types of IV#3$_{n}$] assessed by using societal characteristics. These values must be compatible with the constraints coming from the socio-economic structure associated to the particular typology of societal metabolism; and

* on the **level *n-1*** "individual farming system", by considering values of AP_{ha} and AP_{hour} [which are two types of IV#3$_{n-1}$]. These values must result feasible according to local economic and biophysical constraints and available technology.

In this way, the characteristics of an agricultural throughput can be seen as determined by: (1) the set of constraints coming from the context (societal level); and (2) by the set of constraints operating at the farming system level.

On the upper plan of **Fig. 10.1** (with the axis x and y respectively represented by values of AP_{DP} and AP_{BEP}) it is possible to define areas of feasibility for agricultural throughputs according to socio-economic characteristics. As noted earlier, developed countries require agricultural throughputs above 5,000 kg of grain per hectare and above 250 kg of grain per hour of labor, when talking of cereal cultivation. On the lower plan (with the axis x and y respectively represented by values of AP_{ha} --> kg_{ha} and AP_{hour} --> kg_{hour}) it is possible to define areas of feasibility for agricultural throughputs according to farm-level constraints and characteristics of techniques of production. For example, subsistence societies that do not have access to technical inputs cannot achieve land and labor productivity higher than 1,000 kg of grain per hectare and 10 kg of grain per hour (clearly, these values are general indications not always applicable to special cases – e.g. delta of rivers). As noted earlier, we can expect that farming systems belonging to a particular socio-economic system tend to adopt techniques of production described by a combination of values of AP_{ha} and AP_{hour} that keeps them as much as possible close to the area determined by socio-economic constraints.

In conclusion when describing technological development in agriculture on a plane AP_{DP} - AP_{BEP} we can expect that:

- farming systems operating within different socio-economic contexts (in societies described by different combinations of AP_{DP} - AP_{BEP}) tend to operate in range of land and labor productivity (AP_{ha} - AP_{hour}) close to the values defined by socioeconomic constraints. As noted in Chapter 9, whenever a biophysical constraint on land imposes an $AP_{hour} << AP_{BEP}$ (in developed countries) imports (market and trade) must be available to cover the difference. Getting into an economic reading, in a situation in which $ELP_{AG} << ELP_{PW}$ farmers require protection from international competition and direct subsidies, in order to keep a level of income similar to that achieved by workers making a living in other economic sectors. This requires the availability of financial resources (surplus of added value), at the country level, which can be allocated to subsidize the agricultural sector;
- changes in demographic and socio-economic pressure (AP_{DP} - AP_{BEP}) will be reflected, sooner or later, in changes of technical coefficients of farming techniques (AP_{ha} - AP_{hour}). As soon as economic growth (parallel increase in GNP per capita and population size) translates into a parallel increase of demographic and socioeconomic pressure, technical progress is coupled to changes in socioeconomic characteristics that require techniques of agricultural production characterized by high values of AP_{hour}. The same link between economic development and increases in labor productivity in agriculture is found when adopting a more conventional economic reading of technological development of agriculture (Hayami and Ruttan; 1985).

According to this integrated analysis we should be able to represent general trends in the evolution of food production techniques for different types of socioeconomic systems on the two-dimensional plane (made using I.V.#3): productivity of land (kg/ha) and productivity of labor (kg/hour) as illustrated in **Fig. 10.2**. For the sake of simplicity the plain describes productivity of land and labor mapped in terms of kg of grain. Four main types of socioeconomic systems, having different combinations of demographic and bio-economic pressure, are represented there:

(1) Socioeconomic systems with low demographic and low bio-economic pressure. This situation is characterized by more than 0.5 ha of arable land per capita (this value depends on available productive land and population size) and less than 1,000 US$ per year of GNP per capita (depending on economic performance). This type of socioeconomic system includes several African countries, such as Burundi.

(2) Socioeconomic systems with low demographic and high bio-economic pressure. This situation is characterized by more than 0.5 ha of productive land per capita and more than 10,000 US$ per year of GNP per capita. This type of socio-economic system includes countries such as U.S.A., Canada, and Australia.

(3) Socioeconomic systems with high demographic and low bio-economic pressure. This situation is characterized by less than 0.2 ha of arable land per capita and less than 1,000 US$ per year of GNP per capita. This type of socio-economic system includes countries such as China and Egypt.

(4) Socioeconomic systems with high demographic and high bio-economic pressure. This situation is characterized by less than 0.2 ha of arable land per capita and more than 10,000 US$ per year of GNP per capita. This type of socio-economic system includes countries such as several countries of European Union and Japan.

According to existing trends in population growth and economic development for these four different types of socioeconomic systems, we may expect the following movements in the plane (see **Fig. 10.2**):

(1) Societies with low demographic and bio-economic pressure (e.g., some African countries): The population is growing faster than the GNP per capita, which means that AP_{DP} will grow faster than AP_{BEP}. Hence, they will move toward a situation typical of China.

(2) Societies with low demographic and high bio-economic pressure (e.g., Canada, U.S.A.): Economic development is expected to be maintained (GNP per capita will remain high) and population growth will be relatively slow but steady (medium/low internal fertility but high immigration rate). On the plane, this means a slow movement toward higher values of AP_{DP}.

(3) Societies with high demographic and low bio-economic pressure (e.g., China) look for a quick economic growth (increasing GNP per capita) and they are expected to maintain if not expand their already huge population size. At a national level, an increasing GNP per capita will result in an accelerated absorption of the labor force currently engaged in agriculture (e.g. 60% in China at present) by other sectors (primary and service sectors) of the economy. This will inevitably require a dramatic increase in agricultural labor productivity (AP_{hour}) to maintain food security. Hence, a movement toward the West European conditions of agricultural production is to be expected.

(4) Societies with high demographic and bio-economic pressure (e.g. The Netherlands, Japan): These societies have no alternative but to try to maintain a high material standard of living and keep population growth to a minimum. This means a more or less stable and high level of AP_{BEP} and a very slowly increasing value of AP_{DP} (mainly due to a strong pressure of immigrants). For these societies, trying to reduce the environmental impact of their food production becomes a major factor.

Note that food import from the international market, a must for countries where biophysical or economic constraint determine a value of $AP_{DP} > AP_{ha}$ and/or $AP_{BEP} > AP_{hour}$, is based on the existence of surpluses produced by countries where the relation between these parameters is inverse. Countries producing big surpluses in relation to both types of pressures are scarce. In 1994, the U.S.A., Canada, Australia, and Argentina combined produced over 80% of the net export of cereals on the world market (WRI, 1994). But, at their present rate of population growth (including immigration) and because of an increasing concern for the environment (policies for set-aside and development of low-input agriculture) this surplus may be eroded in the near future. For instance, the U.S.A. is expected to double its population in 60 years (USBC, 1994). However, the situation is aggravated when including in this analysis the legitimate criteria of respect of ecological integrity. This criterion is already leading to a push for a less-intensive agriculture all over the developed world (slow-down, at the farming level, of the rate of increase in AP_{ha}). This combined effect could play against the production of food surpluses in those countries that could do so. In conclusion, at the world level, demographic and bio-economic pressures are certainly expected to increase, forcing the countries most affected by those two pressures to rely on imports for their food security.

It is often overlooked that at the world level, there is no option to import food from elsewhere. When increases in demographic and bio-economic pressure are not matched by an adequate increase in productivity of land and labor in agriculture, food imports of the rich will be based on starvation of the poor. This simple observation points at the unavoidable question of the severity of biophysical constraints affecting the future of food security for humankind. How do these trends fit the sustainability of food production at the global level?

The rest of this section focuses on the changes in techniques of production (in particular in the pattern of use of technical inputs) which can be associated to changes in demographic and bio-economic pressure as perceived and represented from the lower level [changes in techniques of production at the farm level]. Whereas, Section 10.2 deals with the relation between changes in techniques of production associated to changes in demographic and bio-economic pressure as perceived and represented from the higher level – the aggregate effect that these changes have on the integrity of terrestrial ecosystems. This is where the ecological dimension of sustainability becomes crystal clear. Agricultural production, in fact, depends on the stability of boundary conditions for the productivity of agro-ecosystems. Finally, Section 10.3 explores the relation between qualitative changes in the diet – the implications of increasing the fraction of animal products and fresh vegetables and fruits (changes in the factor QDM – Quality of Diet Multiplier) - and changes in the profile of use of technical inputs in perspective and at the world level. Increasing the amount of animal products in the diet requires a double conversion of food energy (energy input to crop and crops to animals). In the same way, increasing the amount of fresh vegetables in the diet requires a mix of crop production associated to a much higher investment of human labor per unit of food energy produced and a reduced supply of food energy per hectare. Both changes (typical of the diet of developed countries) represents an additional boost to the problems associated to higher demographic and bio-economic pressure.

10.1.2 Technical progress in agriculture and changes in the use of technical inputs

The classic analysis of Hayami and Ruttan, (1985) indicates that two forces are driving technological development of agriculture:

(1) the need of continuously increasing the productivity of labor of farmers. This is related to the need of: (a) increasing income and standard of living of farmers; and (b) making available, at the societal level, during the process of industrialization, more labor for the development of other economic sectors.

(2) the need of continuously increasing the productivity of agricultural land. This is related to the growing of population size, which requires guaranteeing an adequate coverage of internal food supply using a shrinking amount of agricultural land per capita.

It is important to understand the mechanism through which bio-economic and demographic pressure push for a higher use of technical inputs in agriculture. In fact, the effect of these forces is not the same in developed and developing countries. In developed countries, the increasing use of fossil energy had mainly the goal of boosting labor productivity in agriculture to enable the process of industrialization.

This made possible a massive move of the work force into industrial sectors, increasing at the same time the income of farmers. For example, in West Europe the percentage of the active population employed in agriculture fell from 75% before the industrial revolution (around the year 1750) to less than 5 % today. In the U.S. this figure fell from 80% around the year 1800 to only 2% today. As observed in **Fig. 9.12**, none of the countries considered in that study with a GNP per capita higher than 10,000 US$/year has a % of work force in agriculture above the 5% mark. In the same way, none of the countries with more than 65% of the work force in agriculture has a GNP per capita higher than 1,000 US$/year of GNP. The supply of human activity allocated in work (HA_{PS}) is barely capable of producing the food consumed by society there is no room left for the development of other activities of production and consumption of goods and services not related to food security.

In developing countries, the growing use of fossil energy has been, up to now, mainly related to the need of preventing starvation (just producing the required food) rather than to increase the standard of living of farmers and others. Concluding his analysis of the link between population growth and the supply of nitrogen fertilizers Smil (1991, p. 593) makes beautifully this point: "*The image is counterintuitive but true: survival of peasants in the rice fields of Hunan or Guadong -with their timeless clod-breaking hoes, docile buffaloes, and rice-cutting sickles - is now much more dependent on fossil fuels and modern chemical syntheses than the physical well-being of American city dwellers sustained by Iowa and Nebraska farmers cultivating sprawling grain fields with giant tractors. These farmers inject ammonia into soil to maximize operating profits and to grow enough feed for extraordinarily meaty diets; but half of all peasants in Southern China are alive because of the urea cast or ladled onto tiny fields - and very few of their children could be born and survive without spreading more of it in the years and decades ahead.*"

The profile of use of technical inputs can be traced more or less directly to these two different goals. Machinery and fuels are basically used to boost labor productivity, whereas fertilizers and irrigation are more directly related to the need of boosting land productivity.

The data presented in this section are taken from a study of Giampietro et al. 1999. Twenty countries were included in the sample to represent different combinations of socioeconomic development (as measured by GNP) and availability of arable land (population density). Developed countries with low population density are represented by the United States, Canada, and Australia. Developed countries with high population density include France (net food exporter), the Netherlands, Italy, Germany, the United Kingdom (UK) and Japan (net food importers). Countries with an intermediate GNP include Argentina (with abundant arable land), Mexico, and Costa Rica. Countries with a low GNP and little arable land per capita include P.R. China, Bangladesh, India, and Egypt. Other countries with low GNP include Uganda, Zimbabwe (net food exporters), Burundi, and Ghana. The data on input use refer to the years 1989-1990. Technical details can be found in that paper.

The relation between the use of irrigation and the amount of available arable land per capita over this sample of world countries is shown in **Fig. 10.3**. The upper graph clearly indicates that the different intensities in the use of this input reflect differences in demographic pressure (the curve is smooth in the upper graph – **Fig. 10.3a**) more than difference in economic development. If we use the same data of irrigation use versus an indicator of bio-economic pressure (e.g. GNP p.c.), we find that crowded countries, either developed or developing tend to use more irrigation than less crowded countries, with very little relevance of gradients of GNP – **Fig. 10.3b**.

It is remarkable that exactly the same pattern is found when considering the use of synthetic fertilization over the same sample of countries – **Fig. 10.4**. The upper and lower graphs of **Fig. 10.4** are the analogous of those presented in **Fig. 10.3** for irrigation. The only difference is that they are obtained with data referring to nitrogen fertilizer. The similarity between the two set of figures (**Fig. 10.4a** and **Fig. 10.3a** versus **Fig.10.4b** and **Fig. 103b**) is self-explanatory. Demographic pressure seems to be the main driver of the use of nitrogen and irrigation.

Completely different is the picture for another class of technical inputs: machinery (tractors and harvesters in the FAO database used in the study of Giampietro et al. 1999). The two graphs in **Fig.**

10.5 indicate that machinery for the moment is basically an option of developed countries (**Fig. 10.5b**). Within developed countries, huge investments in machinery can be associated to large availability of land in production. This is perfectly consistent with what discussed in Chapter 9. In order to reach a huge productivity of labor, at a given level of yields, it is necessary to increase the amount of hectares managed per worker. This requires both, plenty of land in production and an adequate amount of exosomatic devices (technical capital) to boost human ability to manage large amount of cropped land per worker. This rationale is confirmed by the set of data represented in the graph of **Fig. 10.6a**. Over the sample considered in the analysis of Giampietro et al, 1999, the highest level of labor productivity are found in the agricultures which have available the largest endowment of land in production per worker.

Finally it should be noticed that there is a difference between agricultural land per capita (land in production divided population) and agricultural land per farmer (land in production divided workers in agriculture). In fact, a reduction of the work force in agriculture (e.g. by reducing the fraction of the work force in agriculture from 80% to 2%) can increase the amount of land per farmer at a given level of demographic pressure. However, this reduction of the work force in agriculture can only have a limited effect in expanding the land in production per farmer. Economically active population is only half of the total population and when the accounting is done in hours of human activity, rather than in people, we find out that the effect on AP_{BEP} is even more limited, since $HA_{Working}$ is only 10% of THA. When looking at the existing levels of demographic pressure and the existing gradients between developed and developing countries – **Fig. 10.6b** – it is easy to guess that such a reduction, associated to the process of industrialization, will not even be able to make up for the increase in the requirement of primary crop production associated to the higher quality of the diet (higher Quality of Diet Mix and Post-Harvest Losses), which industrialization tends to carry with it (more on this in section 10.4).

The biophysical cost of an increasing demographic and bio-economic pressure: the output/input energy ratio of agricultural production.

The output/input energy ratio of agricultural production is an indicator that gained an extreme popularity - after the oil crisis in the early 70s - to assess the energy efficiency of food production. Assessments of this ratio are obtained by comparing the amount of endosomatic energy contained in the produced agricultural output to the amount of exosomatic energy embodied in agricultural inputs used in the process of production. Being based on accounting of energy flows such an assessment is generally controversial (see technical section in Chapter 7). The two most famous problems are: (1) truncation problem on the definitions of an energetic equivalent for each one of the inputs - Hall et al. 1986. (as noted in Chapter 7 this has to do with the hierarchical nature of nested dissipative systems); (2) the summing of apples and oranges – in particular the most controversial assessment of energy input is that related to human labor (especially the summing done by some analysts of endosomatic and exosomatic energy); Fluck, 1992. As noted in Chapter 7 this has to do with the unavoidable arbitrariness of energy assessments that rather than linear analysis would require the adoption of impredicative loop analysis. Methodological details are, however, not relevant here.

This ratio is generally assessed by considering: (i) **the output** in terms of an assessment of an amount of endosomatic energy which is supplied to the society (e.g. the energy content of crop output); and (ii) **the input** in terms of an assessment of an amount of exosomatic energy consumed in production. In order to obtain this assessment it is necessary to agree on a standardized procedure (e.g. on how to calculate the amount of fossil energy embodied in the various inputs adopted in production).

IF the analysis focuses only on the embodied requirement of fossil energy in the assessment of the input, THEN, the resulting ratio [= the amount of fossil energy consumed per unit of agricultural output] can be used as an indicator of "biophysical cost" of food. In fact, it measures the amount of exosomatic energy (one of the possible EV#2 - fossil energy – which can be used for the analysis of the dynamic budget of societal metabolism) that society has to extract, process, distribute and convert into useful power to produce an unit of food energy.

Thus, by using this ratio we can study the relation between: (i) biophysical cost of food production; (ii) level of socio-economic development (when using as an indicator either the fraction of working force in agriculture; GNP p.c.; or AP_{BEP}); and (iii) level of demographic pressure (by using as the indicator a measure of agricultural resource per capita, such as arable land). An overview of the relation between these factors - represented on a 2 x 2 matrix - is provided in **Fig. 10.7**. All these indicators are obtained by applying the analysis of the dynamic budget of societal metabolism using a different combination of Extensive Variables#1 (human activity and land area) and Extensive Variables#2 (exosomatic energy, added value, and food).

Where the combination of the two pressures is high/high we have societies that have the lowest values of output/input energy ratios in agriculture - for a more detailed analysis see Conforti and Giampietro (1997). Therefore these societies face the highest "biophysical cost" of one unit of food produced. On the other hand, **Fig. 10.7** shows the importance of performing an integrated assessment of agricultural performance based on non-equivalent indicators reflecting different dimensions. In fact, by a simple observation at the values presented in the 2x2 matrix makes easy to realize that the output/input energy ratio of agricultural production should not be considered as a good "optimizing" parameter. Very high values of output/input are found in those agricultural systems in which the throughput is very low. This situation is generally associated with very poor farmers and a low level of societal development. The goal of keeping the "biophysical cost" of food low – assessed in terms of a fossil energy price - is in conflict with the goal of keeping the material standard of living high.

10.2 The effect of the internal "bio-economic pressure" of society on terrestrial ecosystems

10.2.1 Agriculture and the alteration of terrestrial ecosystems

Three simple observations make evident the crucial link between food security and the alteration of terrestrial ecosystems worldwide: (1) more than 99% of food consumed by humans comes from terrestrial ecosystems, and this percentage is increasing! (FAO food statistics). (2) more than 90% of this food is produced by using only 15 plant and 8 animal species, while estimates of the existing number of species on the Earth are in the millions (Pimentel et al. 1995). (3) world-wide, land in production per capita is about 0.24 ha (FAO food statistics), and is expected to continue to shrink because of population growth. In addition, arable land is being lost. During the past 40 years nearly one-third of the world's cropland (1.5×10^9 ha) has been abandoned because of soil erosion and other types of degradation (Pimentel et al. 1995). Most of the added land (about 60%) that replaces this loss has come from marginal land made available mainly by deforestation (Pimentel et al. 1995). High productivity per hectare on marginal lands requires large amounts of fossil energy-based inputs. This occurs at the very same time that the economic growth of many developing countries is dramatically increasing the demand of oil for alternative uses (e.g. construction of industrial infrastructures, manufacturing and household consumption).

Agriculture can be defined as a human activity that exploits natural processes and natural resources in order to obtain food and other products considered useful by society (e.g., fibers and stimulants). The verb "exploits" suggests that we deal with an alteration of natural patterns, which is disturbance. Indeed, within a defined area, humans alter the natural distribution of both animal and plant populations in order to selectively increase (or reduce) the density of certain flows of biomass that they consider more (or less) useful for the socioeconomic system.

When framing things in this way it become possible to establish a link between two types of costs and benefits which refer to two logically-independent (non-equivalent) processes of self-organization, which we can perceive and represent as two impredicative loops (referring to the definition within nested hierarchies of identities and essences). On the side of human systems we can look for impredicative loops based on endosomatic and exosomatic energy in which the definition of identities of socio-economic entities is related to biophysical, social and economic variables (examples have been given in **Fig. 7.7**). In this way the throughput in agriculture can be related to the characteristics of human holons on different hierarchical levels as illustrated in **Fig.10.1**. This makes possible, for example, to guess – when using a graph such as the one described in **Fig.10.2** – that a given technique of production characterized by the point 1 on the plane can be adopted in Africa but not adopted in the USA, whereas a technique of production characterized by the point 3 can be adopted in Europe but not in China. It is interesting to observe that by adopting this analysis we can find out that not necessarily an "intermediate technology" - as for example a technique characterized by point 2 – is a wise solution to look for. Such an intermediate solution can result un-suitable for any of the agroecosystems considered. That is, the parallel definition of compatibility at two levels can imply that something that is technically feasible is not compatible in socio-economic terms, whereas something looked for in socio-economic terms cannot be realized for technical or ecological reasons.

If we characterize the effect of 3 different techniques of production – the same three solution indicated in **Fig. 10.2** using three different points - in relation to their impact on terrestrial ecosystems, we have to add new epistemic categories to our information space. That is, we have to add a new dimension to our representation of performance. Just to provide a trivial example this requires adding a third axes to the plane, in which the third axes is used as an indicator of environmental impact. This is done in **Fig. 10.8** in which a vertical axes called environmental loading has been added to the representation of **Fig. 10.2**. By adding an additional attribute used to characterize the performance of the system we can obtain a richer biophysical characterization of technical solutions. That is, we can check: (a) the socio-economic compatibility, using the plane labor and land productivity; and (b) the ecological compatibility, looking at the level of environmental loading associated to the technique of production. In the example of ***Fig. 10.8*** two proxies/variables [(i) ***kg of synthetic nitrogen fertilizer per ha*** and (ii) ***total amount of fossil energy embodied in technical inputs per ha***] are proposed on the vertical axes as possible indicators of environmental loading. After having established a mapping referring to the degree of environmental loading it is possible to assess the situation against a given Critical threshold of Environmental Loading that is assumed to be the level at which damages to the structure of ecological systems becomes serious (we can call such a threshold value as CEL).

The distance between the current level of EL and the critical threshold (the value of the difference $|EL_i - CEL|$ assuming that $EL_i < CEL$) can be used as an indicator of stress.

Even in this very simplified mechanism of integrated representation of the performance of agriculture it is possible to detect the existence of two non-equivalent optimizing dimensions. The best solution in relation to a socio-economic reading (solution 3 when considering only the information given in **Fig. 10.2**), not only is the worse when considering the degree of environmental impact, but could result non-sustainable (not feasible) according to the constraint imposed by the ecological dimension ($EL_3 > CEL$). That is, according to the identity of the particular ecosystem considered (determining the value of CEL) the given technical solution defined by the point 3, as an optimal solution in relation to socio-economic considerations, should be considered as not ecologically compatible, when considering the process of self-organization of terrestrial ecosystems.

The indicator used in **Fig. 10.8** - the amount of fossil energy associated to the management of agro-ecosystem per ha - is a very versatile indicator. In fact, it not only tells us the degree of dependency of food security on the depletion of stocks of fossil energy, but also it indicates how much useful energy has been invested by humans in altering the natural impredicative loop of energy forms associated to the identity of terrestrial ecosystems. Such interference is obtained by injecting into this loop a new set of energy forms, which are not included in the original set of ecological essences and equivalence classes of organized structures.

We can represent the use of fossil energy to perform such an alteration using a 2x2 matrix – **Fig. 10.9**

– which is very similar to that given in **Fig. 10. 7**. Also in this case, we can observe that the different intensity of use of fossil-energy (to power the application of technical inputs) is heavily affected by the characteristics of the socio-economic context. The only difference between the two matrices is that, rather than the ratio output/input, the variable used to characterize typologies of societal context is the total throughput of fossil energy which is required to alter the natural identity of the terrestrial ecosystem within the agricultural sector. The cluster of types of countries obtained in the matrix of **Fig. 10.9** is the same of that found in the matrix of **Fig. 10.7**. This could have been expected when considering the message of the maximum power principle – (technical appendix of Chapter 7: the output/input ratio of a conversion is inversely correlated to the pace of the throughput). Again, this observation can be used to warn those considering "efficiency" as an optimizing factor in sustainable agriculture. Increasing the efficiency of a given process, in general, entails: (a) a lower throughput; and (b) less flexibility in terms of regulation of flows.

As noted in the theoretical discussion in Chapter 7, when dealing with metabolic systems that base the preservation of their identity on the stabilization of a given flow it is impossible to discuss of the effect of a change in a output/input ratio or more in general of the effect of a change in efficiency of a particular transformation, if we do not specify first of all, the relation between the particular identity of the system and the admissible range of values for its specific throughput. Increasing the output/input by decreasing the throughput is not always a wise choice. This trade-off requires a careful consideration of what is gained with the higher output/input and what is lost with the lower pace of throughput. This is particularly evident when discussing of flows occurring within the food system.

10.2.2 The food system cycle: combining the two interfaces of agriculture

The overlapping within the agricultural sector of flows of energy and matter that refer to the set of multiple identities found in both terrestrial ecosystems and human societies can be studied by tracking our representation of inputs and outputs through the four main steps of the food system cycle (Giampietro et al., 1994). This approach is illustrated in **Fig. 10.10**. The four step considered in that representation are:

(1) Producing Food; where food is defined as forms of energy and matter compatible with human metabolism.

(2) Making the food accessible to consumers; where accessible food is defined as meals (mix of nutrient carriers) ready to be consumed according to defined consumption patterns of typologies of households.

(3) Consuming food and generating wastes; where wastes are defined as forms of energy and matter no longer compatible with human needs.

(4) Recycling wastes to agricultural inputs; where agricultural inputs are defined as forms of energy and matter compatible with the productive process of the agro-ecosystem.

The scheme in **Fig. 10.10** shows that it is misleading to assess inputs and outputs or to define conversion efficiency by considering only a single step of the cycle. All steps are interconnected and hence the definition of a flow as an input, an available resource, an accessible resource, or waste is arbitrary. First of all, the definition of the role of a flow depends on the point of view from which the system is analyzed. For example, the introduction of trees in a given agro-ecosystem can lead to increased evapotranspiration. This may be negative in terms of less accessible water in the soil, but positive in terms of more available water in the form of rain clouds. Second, the definition of the role of a flow depends on the compatibility of the throughput density with the processes regulating the particular step in question. For example, night soil of a small Chinese village is a valuable input for agriculture (recall here **Fig. 5.1**), but the sewage of a big city is a major pollution problem. Same flow but different density in relation to the capability of processing it of a potential user. Whether or not the speed of a throughput at any particular step is compatible with the system as a whole depends on the internal organization of the system. Feeding a person 30,000 kcal of food per day, about 10 times the normal amount, would represent "too much of a good thing", meaning that person would not remain alive for a long period of time. Why then do many believe it to be possible to increase the productivity of agro-ecosystems by several times without generating any negative side-effects on agro-ecosystem health?

Technical progress sooner or later implies a switch from:
* **low-input agriculture** which is based on nutrient *cycling* within the agroecosystem (**Fig. 10.11a**). In this case, the relative size of the various equivalence classes of organisms (populations) which are associated to the various types/components of the network (ecological essences – see the discussion about **Fig. 8.14**) is related to their role in guaranteeing nutrient cycling; to
* **high-input agriculture** in which the throughput density of harvested biomass is directly controlled and maintained at elevated levels through reliance on external inputs that provide *linear* flows of both nutrients and energy (**Fig. 10.11b**).

In low-input agriculture the harvested flow of biomass reflects the range of values associated to a natural turn-over of populations making up a given community. That is, the relative size of populations of organized structures mapping in the same type – species – has to make sense in relation to the job done by that species within the network – the essence associated to the role of the species. In this situation the activity of agricultural production interferes only to a limited extent with the ecological system of controls regulating matter and energy flows in the ecosystem. This form of agriculture requires that several distinct species are used in the process of production (e.g. shifting gardening, multi-cropping with fallows) so as to maintain the internal cycling of natural inputs as a pillar of the agricultural production process. For humans (the socioeconomic system) this implies a poor control over the flow of produced biomass in the agro-ecosystem because of the low productivity per hectare when assessing the yield of a particular crop at the time. Especially serious is the problem associated with low input agriculture, when facing a dramatic increase in demographic pressure. This type of farming cannot operate properly when the socio-economic context would require levels of throughput per hectare too high (e.g. 5,000 kg/ha/year of grain). On the positive side, with low input agriculture the direct and indirect biophysical costs of production are very low. Few technical inputs are required per unit of output produced and, when population pressure is not too high, the environmental impact of this form of agricultural production can remain modest.

The contrary is true for high-input agriculture. In this case, the harvested flow of biomass is well out of the range of values that is compatible with regulation processes typical of natural ecosystems (when considering the natural expected yields of an individual species at the time). Harvesting 8 tons of grains every year (bringing away the nutrients from the agro-ecosystem), would not be possible without putting back the missing nutrients in the form of human made fertilizer. In high-input agriculture, human management is based on an eradication of the natural structure of controls in the ecosystem. In fact, when several tons of grain have to be produced per hectare and hundreds of kilograms of grain per hour of agricultural labor, natural rates of nutrient cycling and a natural structure of biological communities are unacceptable. In high-input agriculture, not even the genetic material used for agricultural production is related to the original terrestrial ecosystem in which production takes place. Seeds are produced by transnational corporations and sold to the farmer. In this way, humans keep the flow of produced biomass tightly under control. Humans can adjust yields to match increasing demographic and socioeconomic pressure (e.g., green revolution). However, this control is paid for with a high energetic cost of food production. When adopting this solution, humans must continuously: (a) provide artificial regulation in the agro-ecosystem in the form of inputs; and (b) defend the valuable harvest against undesired, competitive species. Therefore, the environmental impact of high-input food production is necessarily large and involves a dramatic reduction of biodiversity in the altered area. That is, the destruction of the entire set of mechanisms that regulated ecosystem functioning before alteration (e.g. predator-prey dynamics, and positive and negative feed-backs in the web of water and nutrients cycling). In addition, high input agriculture has several negative side-effects such as on-site and off-site pesticide and fertilizer pollution, soil erosion, and salinization.

In conclusion, we can expect that under heavy demographic and socioeconomic pressure agriculture will experience a drive toward a dramatic simplification of natural ecosystems in the form of linearization of matter flows and use of monocultures. How serious is this problem in terms of long term ecological sustainability? Can we individuate reliable critical thresholds of environmental loading that can be used in decision making? Even if we find out that a certain level of human interference over the impredicative loop determining the identity of a terrestrial ecosystem can be associated to an irreversible loss of its individuality, can we use this indication in normative terms? For example, can we use in optimizing models that the environmental stress associated to an environmental loading equal to 80% of the value of Critical Environmental Loading is the double of the environmental stress associated to an environmental loading equal to 40% of the critical threshold? If we try to get into this quantitative reasoning, how important are the issues of uncertainty, ignorance, non-linearity and hysteretic cycles?

10.2.3 Dealing with the informalizable concept of integrity of terrestrial ecosystems

In Chapter 8 the integrity of ecosystems was associated to their ability to preserve the validity of a set of interacting ecological essences. In that analysis the concept of essence was not associated to a material entity, but rather to a system property defined as the ability to preserve in parallel the reciprocal validity of: (i) non-equivalent mechanisms of mapping representing a type (a template of organized structure) which is supposed to perform a set of functions in an expected associative context; and (ii) the actual realization of equivalence classes of organized structures (determined by the typology of the template used in their making). This validity check is associated to the feasibility of both the process of fabrication and the metabolism associated to agency of these organized structures which are operating as interacting non-equivalent observers at different levels and across scales.

The main concepts presented both in Chapter 7 and in Chapter 8 point at the possibility of associating a particular throughput (used to characterize a specific form of metabolism) of learning holarchies to a set of identities used to characterize the nested hierarchical structure of their elements. In particular, the reader can recall here both **Fig. 8.13** and Fig. **8.14** referring to the possible use of network analysis to generate images of essences and to study relations among identities. This rationale has been utilized in the right side of **Fig. 10.11a** to represent the characterization of a given community in relation to an expected throughput of nutrients. A given level of dissipation of solar energy, required to stabilize the cycling of nutrients at a given rate, can be associated to the existence of a given set of essences (a valid definition of identities of ecological elements and their relation over a network), which are, in fact, realized and acting in an actual area.

The concept of a profile of distribution of an extensive variable over a set of possible types providing closure to express characteristics of parts in relation to characteristics of the whole can be used to have a different look at the mechanism regulating both: (i) the rate of input/output of energy carriers in ecological networks; and (ii) change in relative size of the various components of the network. In particular, it is possible to apply the concepts of age classes and profile of distribution of body mass over age classes (used to study changes in the socio-economic structures - see **Fig. 6.10**), to the analysis of changes in turnover time of biomass over populations (considered as elements of a network).

In his discussion of the mechanism governing population growth, Lotka (1956, p. 129) downplays the importance of fertility and mortality rates in defining the dynamics of growth of a particular species: "*birth rate does not play so unqualifiedly a dominant role in determining the rate of growth of a species as might appear on cursory reflection . . . . Incautiously construed it might be taken to imply that growth of an aggregate of living organisms takes place by births of new individuals into the aggregate. This, of course, is not the case. The new material enters the aggregate in another way, namely in the form of food consumed by the existing organisms. Births and the preliminaries of procreation do not in themselves add anything to the aggregate, but* *are merely of directing or catalyzing influences, initiating growth, and guiding material into so many avenues of entrance (mouths) of the aggregate,* ***provided that the requisite food supplies are presented*** " [emphasis is mine]. The same point is made by Lascaux (1921, p. 33, my translation): "*both for humans and other biological species, the density is proportional to the flow of needed resources that the species has available.*"

Placing this argument within the frame of hierarchy theory, we can say that fertility and mortality are relevant parameters to explain population growth only when human society is analyzed at the hierarchical level of individual human beings (Giampietro, 1998). When different hierarchical levels of analysis are adopted, for example when studying the mechanisms regulating the demographic transition, a different level of analysis is required. A study of the relation of changes of the size of parts and wholes (e.g. ILA) can be much more useful to individuate key issues. For instance, when human society is described as a "black box" (society as a whole) interacting with its environment, we clearly see that its survival is related to the strength of the dynamic budget associated to its "societal metabolism". Hence, such a system can expand in size (increase its population at a certain level of consumption per capita or expand the level of consumption per capita at a fixed size of population or a combined increase of consumption per capita and population size) only if able to amplify its current pattern of interaction with the environment on a larger scale (Giampietro, 1998). Exactly, the same reasoning can be applied to the size of a population operating in a given ecosystem.

As observed by Lotka, within an ecosystem the total amount of biomass of a given population (the amount of biomass included in all the realizations of organisms belonging to the given species) increases because the population of organized structures is able to increase the rate at which energy carriers are brought into the species compared to the rate at which energy carriers (for other species) are taken out. When looking at things in this way – **Fig. 10.12** – that the total amount of food utilized by a given species to sustain the activity of the various realizations of organism, can be represented using: (i) the set of typologies of organisms (e.g. age classes or types found in the life cycle of a species); (ii) a profile of distribution of biomass over this set of types. Obviously, biomass tend naturally to move from one age class (or from one type to another) to the next during the years, whereas there is a set of natural mechanisms of regulation determining the input and the output from each age class or each type (e.g. natural causes of death and selective predation). For an example of a formalization of the analysis of the movement across population cohorts see Hannon ad Ruth, (1994), section 4.1.1.

Therefore, the size of a given population is in a situation of steady-state can be associated to a given profile of distribution of biomass over the different typologies associated to the set of possible types. As noted for socio-economic systems (e.g. **Fig. 6.9** and **Fig. 6.10**), changes in such a profile of distribution can be associated to transitional periods in which the size of the whole is either growing or shrinking.

When applying these concepts to agro-ecosystems we can say that the more the amount of agricultural biomass harvested from a defined population per unit of time and area (considering a single species at the time) differs in density from the natural flow of biomass per unit of time and area (size x turnover time) of a similar species in naturally occurring ecosystems, the larger can be expected the level of interference that humans are determining in the agro-ecosystem. Because of this larger alteration of the natural mechanisms of control, we can expect that the energetic (biophysical) cost of this agricultural production will result higher. Indeed, in order to maintain an 'artificially' high density of energy and matter flow only in a selected typology of a population of a certain species (= **amplification of an equivalence class associated to a type, well outside the value that the "ecological role" associated to the relative essence would imply**), humans must 'interfere' with the impredicative loop of energy forms determining the identity of terrestrial ecosystems.

In this way, humans end up by amplifying the genetic information of the selected populations (species) and by suppressing genetic information of competing populations (species). Whenever, this process is amplified on a large scale, this systemic interference carries out the possibility of destroying the web of mutual information determining the set of **essences** at the level of the web of interaction. As noted, this interference in the dissipative network (altering the profile of admissible inputs and outputs over the set of constituent elements) must be backed-up by a supply of an "alien" energy forms. In modern agriculture these alien energy forms are imposed by human activity, which is amplified by exosomatic power and an adequate amount of material inputs (external fertilizers and irrigation). Extremely high densities of agricultural throughput (per hectare and/or per hour) necessarily require production techniques that ignore the functional mechanism of natural ecosystems, that is the nutrient *cycles* powered by a linear flow of solar energy. Clearly, individual species, taken one at the time, cannot generate cycles in matter since they perform only a defined 'job' (occupy a certain niche associated to a given essence) in the ecosystem.

Following the scheme of ecosystem structure proposed by the brothers Odum, we can represent a natural ecosystem as a network of matter and energy flows in which nutrients are mainly recycled within the set of organized structures composing the system and solar energy is used to sustain this cycling (**Fig. 10.13a**). Within this characterization we can see that the amount of solar energy used for self-organization by the ecosystem is proportional to the size of its matter cycles. In turn, matter cycles must reflect in the distribution of flows and stocks the relative characteristics of nodes in the networks and the structure of the graph (**Fig. 8.14**). As noted in Chapter 7 in terrestrial ecosystems this has to do with availability and circulation of water which makes possible to generate an autocatalytic loop between: (i) solar energy dissipated for evapotranspiration of water required for gross primary productivity; and (ii) solar energy stored in living biomass in the form of chemical bonds through photosynthesis, which is required to prime the evapotraspiration.

The interference provided by agriculture on terrestrial ecosystems consists in boosting only those matter and energy flows in the network that humans consider beneficial and eliminating or reducing the flows that they consider detrimental to their purposes. Depending on the amount of harvested biomass such a process of alteration can have serious consequences for an ecosystem's structure (**Fig. 10.13b**). This has been discussed before when describing the effects of high input agriculture associated with linearization of nutrient flows (**Fig. 10.11**). When going for high input agriculture humans: (1) look for those crop species and varieties that better fit human-managed conditions (= this is the mechanism generating the reduction of cultivated species and the erosion of crop diversity within cultivated species); and (2) tend to adopt monocultures in order to synchronize the operations on the field (substitution of machine power for human power). This translates into a skewed distribution of the profile of individuals over age classes as described in Fig. 10.12.

10.2.4 Looking at human interference on terrestrial ecosystems using ILA

The autocatalytic loop of energy forms stabilizing the identity and activity of a terrestrial ecosystem has been described in the form of a 4-angle representation of an impredicative loop in **Fig. 7.6**. To discuss the implications of that figure more in detail, a non-equivalent representation of the relation among the parameters considered in that 4-angle figure is given in **Fig. 10.14**. This representation of the relation among the key parameters is based on the use of an economic narrative.

The ecosystem starts with a certain level of capital (SB - the amount of standing biomass of the terrestrial ecosystem), which is used to generate a flow of "added value" (Gross Primary Productivity – that is a given amount of chemical bonds, which are considered as energy carriers within the food web represented by the ecosystem). To do that it must take advantage of an external form of energy (solar energy associated to water flow, generating the profit keeping alive the process). A certain fraction of this GPP is not fully disposable since it is used by the compartment in charge for the photosynthesis (autotrophic respiration of primary producers). This means that the remaining flow of chemical bonds, which is available for the rest of the terrestrial ecosystem – NPP, Net Primary Productivity – can be used either for final consumption (by the heterotrophs) or by replacing and/or increasing the original capital (Standing Biomass). What is important in this narrative is the possibility of establishing a relation among certain system qualities. That is:

(1) to have a high level of GPP, an ecosystem must have a large value of SB. In the analogy, with the

economic narrative, this would imply that in order to generate a lot of added value, an economic system must have a lot of capital;
(2) to keep a high degree of biodiversity it is important to invest a reasonable fraction of NPP in the heterotrophic compartment. In the analogy with the economic narrative, this would imply that in order to have a large variety of activities in the system (i.e. biodiversity) it is important to boost the resources allocated in final consumption (e.g. post-industrialization of the economy). As noted by Zipf, an adequate supply of leisure time associated to an adequate diversity of behaviors of final consumers can become a limiting factor for the expansion of the economies after the process of industrialization (Zipf, 1941). In order to be able to produce more an economy must learn how to consume more.
(3) human withdrawal, in this representation, represents a reduction of the capital available to the system; and
(4) human interference with the natural profile of redistribution of available chemical bonds among the set of natural essences expected in the ecosystem implies an additional compression of final consumption. Heterotrophs, which are usually called within the agricultural vocabulary "pests", are within this analogy those in charge for final consumption in terrestrial ecosystems. Those that would be required to boost primary productivity according to Zipf, and that in reality are the big losers in the new profile of distribution of NPP imposed by humans in high-input agro-ecosystems.

There is an important implication that can be associated to the use of the concept of "capital" for describing the standing biomass of terrestrial ecosystems. When dealing with metabolic systems there is a qualitative aspect of biomass that cannot be considered only in terms of assessment of mass. That is, the size of a metabolic system is not only related to its mass in kg, but also to its overall level of dissipation of a given form of energy, which implies a coupling with its context. This is why an ILA represents a non-equivalent mechanism of mapping of size which is obtained by using in parallel two extensive variables (EV#1 and EV#2), able to represent such an interaction from within and from outside, in relation to different perception/representation of it. Getting back to the example of biomass of different compartments of different ecosystems, 1 kg of ecosystem biomass in the tundra has a very high level of dissipation (= the ratio of energy dissipated to maintain a kg of organized structure in its expected associative context). This high level of dissipation can be explained by its ability to survive in a difficult environment, that is to say, to maintain its ability of transforming solar energy into biological activity, despite severe boundary conditions (Giampietro et al. 1992). The same concept of "capital" can be applied to study the activity of terrestrial ecosystems in different areas of the biosphere. Not all hectares of terrestrial ecosystems are the same. Tropical areas are very active in the process of sustaining biosphere structure (a high level of utilization of solar energy per square meter as average, meaning more biophysical activity per unit of area and therefore more support for biogeochemical cycles). On the other hand, because of the low level of redundancy in the genetic information stored in tropical ecosystems (K-selection means a lot of essences – a spread distribution of the total capital over different types - which translates into many species with a low number of individuals per each species), these systems are very fragile when altered for human exploitation (Margalef, 1968).

Getting back to the representation of the impredicative loop of energy forms defining the identity of terrestrial ecosystems (**Fig. 7.6**) we can try to represent the catastrophic event associated to the process of linearization of nutrients due to high input agriculture and monocultures - **Fig. 10.15**. Two major violations of the constraints of congruence over the loop are generated by human interference and are related to the parameters and factors determining the two lower level angles:
(1) humans appropriate almost entirely the available amount of Net Primary Productivity. This does not leave enough capital in the ecosystem to guarantee again a high level of GPP in the next year.
(2) humans interfere with the natural profile of distribution of GPP among the various lower level elements of the ecosystem (e.g. a distortion of the shape of Eltonian pyramids).

Can we use this approach to represent different degrees of alteration

Giampietro et al. (1992) proposed a method of accounting based on biophysical indicators that can be used to describe the effect of changes induced by human alteration of terrestrial ecosystems. This system of representation is based on the use of thermodynamic variables such as: W/kg, kg/m^2 (and their combination W/m^2), which assumes that terrestrial ecosystems are represented as dissipative systems. That is, a combination of EV#2 and EV#1 variables. The rationale of this analysis is that human intervention implies sustaining an agro-ecosystems which is "improbable" according to the natural process of self-organization. Human intervention is therefore viewed as an interference preventing the most probable state of a dissipative system from a thermodynamic point of view. This makes possible to study the degree of alteration by measuring the increase in the level of energy dissipation per kg of standing biomass. "*The effect of human intervention can be better detected by the change in the level of energy dissipation of corn field biomass. After human intervention the biomass of a corn field in the USA dissipates 9.0 W/kg, compared with 0.5 W/kg dissipated by the wild ecosystem biomass that was replaced*" (Giampietro et al. 1992).

An example of this type of representation is given in **Fig. 10.16**. On the horizontal axis the variable used to represent the state of terrestrial ecosystem is the amount of Standing Biomass (expressed in kg of dry mass) averaged over the whole year. This requires the averaging of the amount of standing biomass assessed per week (or per month) over the 52 weeks (or the 12 months) making up a year. On the vertical axis, we have a variable which represent a proxy for the ratio GPP/SB (in this case the total flow of solar energy for water transpiration associated to GPP, per unit of biomass available), which is assessed in W/kg. The assessment of solar energy is obtained by calculating the PAWF (Plant Active Water Flow), which is the amount of energy required to evaporate the water used to lift nutrient from the roots to the leaves, which must be associated to the relative amount of GPP. This calculation is based on a fixed amount of water required to bring nutrients from the root to the place where photosynthesis occurs (more details on Giampietro at al. 1992). Technical aspects of the choice of the mechanism of mapping of PAWF, however, are not relevant here. What is important is that it is possible to establish a mechanism of accounting that establishes a bridge between the solar energy used for evapotranspiration of water, which can be directly linked to the amount of chemical bonds (GPP - the internal supply of energy input for the terrestrial ecosystem) and the amount of ecological capital (the amount of standing biomass) available to the terrestrial ecosystem per year.

Possible configurations for terrestrial ecosystems are represented in **Fig. 10.16** (data from Giampietro et al. 1992). According to external constraints (i.e. different boundary conditions – soil, slope and climatic characteristics) different types of ecosystems can reach different levels of activity, measured by this graph by the value reached by the parameter W/m^2 (a combination of the values taken by the two variables W/kg and kg/m^2). This should be considered a sort of level of technical development reached by the ecosystem. By adopting an analogy with what proposed for the analysis of socio-economic system we can define the equivalence: (a) exosomatic energy for human societies = solar energy spent in evapotranspiration by terrestrial ecosystems; and (b) endosomatic energy for human society = energy in the form of chemical bonds- GPP in terrestrial ecosystems. At this point, we can say that those terrestrial ecosystems which are able to dissipate a larger fraction of solar energy associated to GPP per square meter (thanks to the use of more water) are able to express more biological activity and store more information (define more identities and essences) than those ecosystems, which are operating at a lower level of dissipation.

An increase in the level of dissipation can be obtained either by stocking more biomass (more kg) at a lower level of dissipation per kg (at a lower W/kg) or viceversa. As noted earlier the parallel validity of the maximum power principle and the minimum entropy generation principle, pushes for the first hypothesis (a larger amount of structures at a lower level of dissipation). This is perfectly consistent with the discussions presented in Chapter 1 and Chapter 7 about the physical root of Jevons paradox. An improvement assessed when adopting an intensive variable (lower ratio W/kg) tends to be used by dissipative adaptive system to expand their capability to handle information in terms of an expansion of an extensive variable (kg of biomass stored in the same environment). Terrestrial ecosystems can increase their stability and the strength of their identity (at least in the medium term) by increasing the quantities of reciprocal interactions and mechanisms of control operating in a given ecosystem, while keeping the relative "negentropic cost" (W/kg) as low as possible.

Going back to **Fig. 10.16** the points of the plane indicated by green triangles represent the most probable states in which we can find the typologies of terrestrial ecosystems indicated by the various labels. The essences and relative identities of these systems have been determined by millions year of evolution and reflect the "biological/ecological knowledge" accumulated in impredicative loops of energy forms stabilized by the information encoded in elements participating in self-entailing processes of self-organization.

The point indicated by red circles represent improbable states for natural terrestrial ecosystems. However, as noted before, the improbable configuration of a corn field in which a single species (the monoculture crop) enjoys a stable dominance over other potential competitors is maintained because of the existence of an "alien" system of control, reacting to different signals. That is, it is the profit looked for by farmers, which makes possible to buy the biophysical inputs and the seed required to obtain another corn field in the next season. This system of control is completely unrelated to the need of closing matter cycles within the ecosystem. On the contrary, when adopting an economic strategy of optimization, the more linear are the flows, the higher is the pace of the throughput and therefore the more compatible is perceived the agricultural production with human needs. The "ecological improbability" of a corn field (in terms of profile of distribution of GPP over the potential set of types of biota) is indicated by the very high ratio GPP/SB, which in our thermodynamic reading is indicated by a very high level of energy dissipation (W/kg of solar energy used to evaporated water associated to photosynthesis – PAWF – per unit of standing biomass – average over the year). This requires also that the needed inputs must arrive at the right moment in time (e.g. fertilizers and irrigation has to arrive when they are needed – in the growing season – and not as average flows during the year).

It is interesting to observe, that by adopting the representation of the characteristics of the impredicative loop associated to the identity of terrestrial ecosystems it becomes possible to study the interference induced by humans using two variables rather than one – **Fig. 10.16.** On the vertical axis, we can detect a quantitative assessment related to the degree of alteration, that is how much human alteration is increasing the "negentopic cost" associated to the energy budget of the produced biomass. On the horizontal axis, we can detect the level of destruction of capital implied by the management of a given area generally associated to a given typology of ecosystem. That is, the management of a tropical forest implies the destruction of a huge quantity of biophysical capital, and therefore we can expect that this will have a huge impact on biodiversity (see also **Fig. 10.15**). As shown by **Fig. 10.16** a corn field dissipates much less energy and sustains much less standing biomass (on average over the year) than a tropical forest. This type of assessment is completely missed if we describe the performance of these two systems in terms of Net Primary Productivity (an indicator often proposed to describe the effects of human alteration of terrestrial ecosystems). In fact a monoculture such as corn or sugar cane can have very high level of NPP – similar to that found in forests. This can induce confusion when assessing their ecological impact. By adopting this two-variable mechanism of representation of the alteration of a terrestrial ecosystem for crop production, we can see that managing a temperate forest to produce corn is much better than managing a tropical forest. Corn produced by displacing a temperate forest provides a large supply of food for humans and destroy less natural capital than corn produced by displacing tropical forests.

A last consideration about the representation of human alteration given in **Fig. 10.15**. According to what represented in that figure, the total appropriation of the available NPP by humans implies a complete reshuffling of the profile of investment of the resource "chemical bonds" available to the ecosystem over the lower level component (either to boost final consumption or to increase the level of capitalization of the system – increasing SB). This, in **Fig. 10.15** at the level of β angle, translates into a major distortion of the natural profile of the Eltonian pyramid of the disturbed ecosystem. An analysis of this rationale, but this time applied to aquaculture, has been performed by Gomiero et al. (1997).

The main results are given in **Fig. 10.17**. Given the natural profile of distribution of energy flows in the Eltonian pyramid of a natural fresh water ecosystem (on the left of the figure) we can see that the two forms of aquaculture: (1) low input aquaculture in developing countries (e.g. China) – upper graph; and (2) high input aquaculture in developed countries (e.g. Italy) – lower graph, can be characterized as following two totally different strategies.

"*The Chinese system is based on polyculture, which means rearing several species of fish in the same water body. As different species have different ecological niches (they feed on different sources), a balanced polycultural system has the potential to reach a very high efficiency, in terms of the use and recovery of potential resources. Even if the pond is an artificial setting in which inputs are imported, the internal characteristics of the managed system still play a fundamental role in the regulation of matter and energy flows. In the Chinese polycultural system as many as eight or even nine fish species can be reared in the same pond in a balanced combination of size and number... Italian intensive monocultural systems rely on carnivorous fish species for 85% of their production*" (Gomiero et al., ibid. Pag. 173-174).

In practical terms, this means that Chinese farmers replace the role that top carnivores play in natural fresh water ecosystems. At the same time, they provide an adequate input able to keep the population associated to the types of lower level components of the Eltonian pyramids in the right relation between size and number (they preserve the meaning of the essences required to determine the interaction of the food web on lower levels). On the contrary the producers in developed countries keep the top carnivores in the managed ecosystems, and replace all the rest of the ecosystem. That is humans have to provide the expected associative context which is required to provide the stability of top carnivores. In other terms, to do that "high input" aquaculture has to guarantee a huge supply of feed and the capability of absorbing the relative huge flow of wastes. An idea of the difference in requirement of environmental services associated to these two different strategies can be obtained by looking at the embodied consumption of environmental services per kg of produced fish in these two systems.

The high tech aquaculture system has a very high level of throughput:
(1) I.V.#3 (hour) = 20/80 kg of fish per hour of labor; and
(2) I.V.#3 (ha) = 80,000 kg of fish per ha per year.
Whereas the Chinese system operates with a much lower throughput:
(1) I.V.#3 (hour) = about 1 kg of fish per hour of labor; and
(2) I.V.#3 (ha) = 2,400 kg of fish per ha per year.

Because of its high productivity the Italian system operates at a ratio of 30 kg of imported nitrogen in the feed per kg of nitrogen in the produced fish. It consumes 200,000 kg of fresh water per kg of produced fish, and is generating 30,000 kg of nitrogen pollution per ha of water body. The Chinese system operates with a much higher efficiency ratio (2.5 kg of nitrogen in the feed per kg of nitrogen in the produced fish) and a much lower environmental loading (only 7,000 kg of fresh water per kg of produced fish and a negligible load of pollution of nitrogen from the ponds) – Gomiero et el. 1997. Actually, weeds are often planted by Chinese farmers around crop fields to recover nitrogen run-off from cropped areas and then these weeds are fed to the herbivores fishes reared in the pond, with an overall effect of reducing the pollution from nitrogen in the agricultural landscape. We have here another example of the same activity – aquaculture – that can be used: (a) to reduce nitrogen pollution, while producing at the same time valuable output (animal protein) in rural China; (b) to produce added value, at the cost of a pollution of nitrogen and a taxation on other aquatic ecosystems (industrial pellets used for high input aquaculture are made up mainly of fish meal obtained from marine catch). Also in this case, an approach based on the definition of: (i) a set of types; and (ii) a profile of distribution of an EV#1 over the set, can be used to study changes induced from an external perturbation on a natural organization of a metabolic system organized over different hierarchical levels.

In conclusion, the examples discussed in this section seem to confirm the potentiality of impredicative loop analysis to study the representation of the interference that humans induce with agriculture on natural ecosystems. By framing the analysis in this way, it is possible to study and assess which energy forms are associated to ecological mechanisms of control (expressed by the set of identities typical of natural ecosystems), and which energy forms are associated to the mechanisms of control expressed by human society (technology and fossil energy in developed societies).

10.3 Animal products in the diet and the use of technical inputs

10.3.1 Introduction

Before concluding this chapter dealing with the consequences that the drivers of technological progress in agriculture can imply on the overall ecological compatibility of food production, it is important to have an idea of the effect of an additional key factor: the quality of the diet adopted by humans in a given food system. As mentioned several times before, the same amount of food calories consumed per capita at the household level can imply a dramatic difference in the requirement of food production, depending on the fraction of animal products in the diet. As a matter of fact, levels of consumption per capita of more than 600 kg of cereals per year can only be obtained because of animal production.

To address the implications of this point this section provides an overview of food production at the world level, accounting for both vegetal and animal products included in the diet of developed and developing countries. The analysis start by examining technical coefficients and the requirement of land, labor, and technical inputs related to existing patterns of consumption across different continents. Then the relative data set is used to discuss implications for future scenarios. The following analysis is taken from Giampietro, 2001 "Fossil energy in world agriculture". In: *Encyclopedia of Life Sciences.* Macmillan Reference Limited - http://www.els.net/

10.3.2 Technical coefficients - Material and methods used to generate the data base

As already discussed in Chapter 7, any assessment of energy use in agriculture is difficult and, in a way, arbitrary. Reading the literature of energy analysis we can find a variety of energy assessments, which almost reflects the variety of authors generating them. For example, very often, standard statistics of energy consumption assign to agriculture a negligible share of total consumption of a country (e.g. less than 3% of total energy consumed in developed countries). These assessments refer to the fraction of energy directly consumed in this sector (e.g. fuels, electricity). That is, they do not include the large amount of fossil energy spent in the making of fertilizers and machinery used in modern farming (this energy consumption is recorded as fossil energy spent in industrial sectors). In this study, indirect inputs to agricultural production are included in the total assessment. However, after deciding to do so, where to stop such an accounting? (e.g. should we include the fossil energy spent at the household level by rural population?). Again, the decision on what should be considered as "fossil energy spent in agriculture" remains necessarily dependent on the logic and goals of the analyst. There is not a unique "right" way to make this accounting.

For this reason, a large part of this section is dedicated to explain the assumptions and the data used to generate the assessments of fossil energy input in plant and animal production at the world level presented in the following Tables. In this way, those willing to use a different perspective for the analysis, or a different boundary definition for agricultural production, or a different set of energy conversion factors for the inputs considered, will still be able to use and compare the set of data presented here with others. In addition to that, any attempt to assess fossil energy use in developing and developed countries, both for crop and animal production, is unavoidably affected by additional practical problems, such as the reliability of the statistical data and the availability of appropriate conversion factors to be used in the calculations.

The assessments given in this study are based on:

(A) a common data-set (taken from FAO Agricultural Statistics, which is available on internet – data referring to 1997). This database covers different aspects of agricultural production: (1) means of production – e.g. various technological inputs used in production (excluding data on pesticide use), (2) food balance sheets – accounting of production, imports, exports and end uses of various products, as well as composition of diet and energetic value of each item, per each social system considered; (3) data on agricultural production, and (4) data on population and land use. Data on pesticides have been estimated starting from Pimentel (1997).

(B) a common set of energy conversion factors, which have been applied to these statistical data sets to provide a common reference value. These conversion factors tend to apply generalized values, but at the same time to reflect peculiar characteristics of various socio-economic contexts in which agricultural production occurs (reflecting the system of aggregation provided by FAO statistics).

Factors of production are given in Tab. 10.1 (from FAO data-set). Assessments of pesticide consumption have been re-arranged from Pimentel (1997) to fit FAO system of aggregation. Assessments of fossil energy used in primary production of crops, based on the inputs reported in Tab.10.1, are given in Tab.10.2. Fossil energy conversion factors are discussed below.

(1) **Machinery** – to assess energy equivalent of machinery from FAO statistics I adopted basic conversion factors suggested by Stout (1991), since they refer directly to FAO system of accounting. A standard weight of 15 Metric Tons (MT) per piece (both for Tractors and for Harvester and Thresher) for USA, Canada and Australia; a common value of 8 MT for pieces in Argentina and Europe; a common value of 6 MT for pieces in Africa and Asia. To the resulting machinery weight Stout suggests an energy equivalent of 143.2 GJ/Metric Ton of machinery. This value (which includes maintenance, spare parts and repairs) is quite high, but it has to be discounted for the life span of machinery. It is the selection of the discount time, which will define, in ultimate analysis, the energy equivalent of a metric ton of machinery. Looking at other assessments, made following a different logic, it is possible to find in literature values between 60 MJ/kg for H&T and 80 MJ/kg for tractors, but only for the making of the machinery. The range of 100 – 200 MJ/kg found in Leach analysis (Leach, 1976) includes also the depreciation and repair. Pimentel and Pimentel (1996) suggest an "overhead" of 25 – 30 % for maintenance and repairing to be added to the energy cost of making. In general a 10 year life-span discounting is applied to these assessments. The original value of 143.2 GJ/Metric Ton of machinery suggested by Stout can be imagined for a longer life-span than 10 years (the higher the cost of maintenance and spare parts the larger should be the life span). Depending on different types of machinery the range can be 12 – 15 year. Therefore, in this assessment a flat discount of 14 years has been applied to the tons of machinery, providing an energy equivalent of 10 GJ/MT/year.

(2) **Oil consumption per piece of machinery** – conversion factors from Stout (1991) – again these factors refer directly to data found in FAO statistics. The estimates of consumption of fuel per piece are the following: 5 MT/year for USA, Canada and Australia; 3.5 MT/year for Argentina and Europe; 3 MT/year for Africa and Asia. The energy equivalent suggested by Stout is quite low (42.2 GJ/MT of fuel – typical for gasoline, without considering the cost of making and handling it). A quite conservative value of 45 GJ/MT as average fossil energy cost of "fuel" has been adopted.

(3) **Fertilizers** – conversion factors from Hesel (1992) – within the Encyclopedia edited by Stout (1992) – These assessments include also the packaging, transportation and handling of the fertilizers to the shop. Values are:

- For Nitrogen, 78.06 MJ/kg – this is higher than the average value of 60 – 63 MJ/kg for production

(Smil, 1987; Pimentel and Pimentel, 1996) and lower than the value estimated for production of Nitrogen in inefficient plants powered by coal (e.g. in China), that can reach the 85 MJ/kg reported by Smil (1987).

- For Phosphorous, 17.39 MJ/kg – this is higher than the standard value of 12.5 MJ/kg reported for the process of production (Pimentel and Pimentel, 1996). But still in the range reported by various authors: 10 – 25 MJ/kg by Smil (1987), 12.5 – 26.0 MJ/kg by Pimentel and Pimentel (1996). The packaging and the handling can explain the movement toward the upper value in the range.
- For Potassium, 13,69 MJ/kg – also in this case the value is quite higher than the standard value of 6.7 MJ/kg reported for production. Ranges are 4 – 9 MJ/kg given by Smil (1987) and 6.5 – 10.5 MJ/kg given by Pimentel and Pimentel, (1996). Clearly, the energy related to the packaging and handling, in this case influences in a more evident form the increase in the overall cost per kg.

(4) **Irrigation** – conversion factors suggested by Stout (1991) are 8.37 GJ/ha/year for Argentina, Europe, Canada, USA, and Asia; and 9.62 GJ/ha/year for Africa and Australia. These values refer to full fossil energy based irrigation. However, when looking at FAO statistics on irrigation one can assume that only a 50% of it is machine irrigated. So that this conversion factor has been applied only to 50% of the area indicated as irrigated (but in Australia).

(5) **Pesticides** – a flat value of 420 MJ/kg has been used for both developed and developing countries. This includes packaging and handling (Hesel, 1992). Values in literature vary between 293 MJ/kg for low quality pesticides in developing countries to 400 MJ/kg in developed countries (without including packaging and handling).

(6) **other energy inputs** - at the agricultural level there are other technical inputs which are required for primary production. For example, infrastructures (commercial buildings, fences), electricity for on farm operations (e.g. drying crops), energy for heating, embodied energy in vehicles and fuels used for transportation. For this reason a flat 5% of the sum of previous energy inputs has been adopted in this analysis. This has been applied only to agricultural production in developed countries. It should be noted that this assessment of "other inputs" does not include infrastructures and machinery related to animal production, which are reported in Tab.10.5.

An overview of world agricultural production includes: (i) production of plant products - Tab. 10.3a. (ii) estimate of food energy intake from consumption of plant product -Tab. 10.3b. (iii) production of animal products - Tab. 10.3c. (iv) estimate of energy intake from consumption of animal products - Tab.10.3d (all data from FAO database). It should be noted that the effect of trade (imports and exports) is almost negligible, when using this level of aggregation. The only relevant item is a 10% of the total production of cereals, which is moving from developed to developing countries. The trade of animal products across these groups is not significant.

Data reported in Tab. 10.3 are from Food Balance Sheet (excluded forages that are estimated – more details in the notes to Tab.10.4). Values reported in Tab. 10.3b are total amounts, which are consumed at the level of the social system considered (either directly or indirectly as feed for animals, seeds, processed in the food industry or lost in the food system). Also in this case the data on forages are estimated. Values related to animal production do not include animal fat and offal.

Starting from these data, the assessment of how much fossil energy is invested in plant production and in animal production is not an easy task. In fact: (a) a certain fraction of food energy produced in the form of plant (e.g. 37 % of cereals at the world level) is used as feed for animal production. (b) a fraction of plant products (e.g. vegetable oil) implies the existence of by-products, which are then used as feed. This implies a problem of accounting – joint production dilemma (same fossil energy input used for producing both vegetable oils and feed). (c) a large fraction of animal feed comes from forages, and it is difficult to attribute fossil energy costs to forage production (in relation to different continents, developed and developing countries), when following the aggregation used in FAO statistics. (d) additional inputs of fossil energy, which are not included in the assessment reported in Tab. 10.2, are required for animal production (e.g. for making and heating buildings, technology and energy used for running feed-lots, producing milk and eggs, etc.).

Therefore, additional information is needed to assess global fossil energy investments in plant and animal production, both in developed and developing countries. This information is given in Tab. 10.4 and Tab. 10.5.

An overview of inputs used for feed in animal production is given in Table 10.4.

Values reported in Tab. 10.4a are mainly based on the assessment provided by Tamminga et al. (1999) the Wageningen Institute of Animal Sciences, Wageningen University (NL). This study has been used, since it provides an assessment of requirements both of concentrates and forage for animal products, divided per item and continent, following the organization of FAO statistics. Minor adjustments have been made to the original data, in relation to the consumption of concentrates (following the need of congruence between quantities of concentrates produced and consumed within developed and developing countries). The same check has been applied to estimates of forages for world, developed and developing countries, as well as per continent. Estimates of forages reported in Tab. 10.4 are consistent with: (i) assessments of consumption for various animal productions, and (ii) data on estimated yields from permanent pasture reported by FAO statistics.

An overview of fossil energy input in animal production is given in Tab.10.5.
Conversion factors adopted for the making of this table are:

For the making of concentrates:

- for cereals - 4.7 MJ/kg from Sainz (1998), this reflects an output/input in cereal production of 2.5/1 which is more or less common in developed and developing countries;
- for starchy roots – 1.8 MJ/kg in developed countries and 0.8 MJ/kg in developing countries (assuming output/input ratios: 1.5/1 and 5/1);
- for pulses – 8 MJ/kg in developed countries and 4.7 MJ/kg in developing countries (assuming output/input ratios: 1.8/1 and 3/1);
- a 10% overhead of fossil energy for making feed from the harvested crops, has been applied to the production of these crops, following the estimate of Sainz (1998).
- for oil-seed by-products – no fossil energy charge for their production is considered. In fact oil seed represent an important item in the diet of both developed and developing countries. A fossil energy cost of 1.2 MJ/kg has been calculated for processing the by-product into feed;
- for other feeds and industrial by-products – these include vegetables, fruits, residues from sugar and beer production - a value of 10 MJ/kg, following Sainz (1998).
- Forages – it is almost impossible to imagine a unique conversion factor for the production of forages in developed and developing countries on marginal land at different levels of productivity. Such an assessment is, therefore, necessarily approximated. A conversion factor of 1.7 MJ/kg has been used for forage production in developed countries (including the production and handling of harvested biomass), whereas a factor of 0.8 MJ/kg has been used for production of forages in developing countries (referring only to the production of biomass). However, a very conservative estimate of the amount of forage produced by using fossil energy input has been used for developing countries. At this regard, there is an item of Tab. 4b (140 million MT of by-products used to make concentrates in developing countries without use of fossil energy for their handling) which reflects the completely different logic in animal production between developed and developing countries. In developing countries a large amount of feeds is obtained by recycling by-products rather than by producing "ad hoc" crops or forages.

Overall assessment of fossil energy used in animal production

According to the conversion factors listed before, the average fossil energy cost of concentrates in 1997 can be estimated in: 3.86 MJ/kg at the world level, 4.76 MJ/kg for developed countries and 2.75 MJ/kg for developing countries. These values include: (i) the production of crops (cereals, starchy roots, pulses) [reported in Tab. 10.5b]; (ii) an extra 10% of the previous amount of energy for the preparation of feed from these crops [reported in Tab. 10.5b]; (iii) the processing of oil-seed by-products and the processing of other industrial by-products [reported in Tab. 10.5b]. The fossil energy used in running the infrastructures used for the production of animal products has been assessed following Sainz indications (1998) that the fossil energy embodied in the feeds is a fixed percentage of total production costs. He suggests the values of: 90% for beef, 88% for milk, 65% for pig, 50% for poultry, 58% for eggs. At this point, the item "Additional input" for buildings, technical devices and energy for running feed-lots, producing milks and eggs has been calculated starting from the assessment of energy in feed. That is, the figures in this column represent complementing percentages to 100% of total production, using the estimates of Sainz. The production of sheep meat was not considered as a relevant item for the assessment of fossil energy consumption.

Estimates of Fossil energy consumption in animal production are given per type of production - Tab. 10.5a – and per type of input - Tab. 10.5b.

An overall assessment of fossil energy used in both plant and animal production at the world level, in developed and developing countries (as resulting from the set of data reported in previous tables) is given in Table 10.6. They are calculated using data from Tab. 10.2, Tab. 10.5. Data on food energy supply (consumed in the diet) are from FAO Food Balance Sheet (averages of daily consumption times the relative population).

Various indicators related to fossil energy use in world agriculture, derived from the assessments presented in this study, are given in Tab. 10.7.

10.3.3 Looking ahead: what can we say about the future of agricultural production

Some of the indicators calculated so far are listed in Tab. 10.8 together with relevant characteristics of the various socio-economic aggregates considered in this study. An integrated analysis of these data can be useful for discussing of possible future trends of fossil energy use in agriculture.

First of all, an important point is that only for the step of agricultural production, humankind is using an amount of fossil energy, which is very close to the amount of food energy intake in the diet. That is, 0.83 MJ of fossil energy are spent in world agriculture for each MJ of food energy consumed at the household level. To make things worse, it should be noted that the direct consumption of fossil energy input in agricultural production (= the assessment given in Tab. 10.6) is just a fraction of the total amount of fossil energy spent in the food system. This is especially true in developed countries. **Additional sources of fossil energy consumption in the food system are**: (i) energy required to move around the various food items imported and exported in world agriculture, (ii) energy required by the food industry for processing and packaging of food products. To give an example, a 455g can of sweet corn, requires 2.2 times more fossil energy for the making of the can than for the production of the corn (Pimentel and Pimentel, 1996), (iii) energy required for distribution, handling and refrigeration of food items to and within the shops; (iv) energy required for preparing, cooking and consuming food at the household level. Just to give an idea, Pimentel and Pimentel (1996) estimate that in the USA, for home refrigeration, cooking and heating of food, dishwashing and so forth, there is a consumption of about 38 MJ/day person (more than the amount of fossil energy needed to produce the food consumed in the diet).

A second observation should be related to the large differences found when considering indices describing the energetic performance of agriculture in developed and developing countries. Even though "agriculture" is doing the same thing in these two systems (= producing food for the rest of society), the logic and the strategy for achieving such a goal are totally different. That is, assessments of indices referring to fossil energy consumption as "world averages" are totally useless for a discussion of trends and future scenarios. This different logic is shown by the differences in output/input energy ratio (in this study the output is "food energy in food products disappearing at the household level", whereas the input is "fossil energy spent in the production of the various food items consumed"). Developed countries spend twice as much as fossil energy in the step of agricultural production than the energy food they consume (an O/I ratio = 1/2), whereas developing countries get more energy food from the diet than the fossil energy they consume in agricultural production (an O/I ratio = 2.2/1). Particularly relevant is the difference in relation to the output/input ratios of animal production. Developed countries have a large investment for the production of animal product (4.3 MJ of fossil energy in production per MJ of food energy intake of animal products). On the contrary, developing countries get a very good output/input energy ratio for animal production (they are producing 1MJ of animal product per MJ of fossil energy invested in production). This ratio is even higher than the ratio achieved by developed countries in relation to plant food. Developed countries spend 1.2 MJ of fossil energy in production per MJ of food energy intake of vegetal products. This difference in fossil energy use in the production of animal products between developed and developing countries indicates that poor societies are mainly using "spare feeds" (e.g. by-products and forages obtained on marginal land), rather than investing valuable crops in animal production.

However, this lower investment in producing feed is reflected by the lower consumption of animal products in the diet (1.3 MJ/day in developing countries versus 3.6 MJ/day in developed countries). This reflects the general rule always valid when dealing with agricultural conversions, a better output/input for a given flow is linked to a lower throughput.

A third important observation can be related to the fact that the output/input energy ratios, **both in developed or developing countries, do not depend much on technical coefficients in agricultural production. The composition of the diet, especially the double conversion of crops (mainly cereals) into meat is, rather, the major determinant of such a ratio.** We can look at a different output/input energy ratio, by considering: (a) total output of plant production. Which in 1997 it was 34,700 million GJ, which includes all uses of cereals, starchy roots, pulse, oil from oil-seed crops, sugar, alcohol, vegetables and fruits. (b) fossil energy input in primary plant production (the 18,200 million GJ reported in Tab. 2). When considering this ratio both, developed and developing countries, have an output/input energy ratio in plant production larger than 1 (1.3/1 and 2.7/1 respectively). However, this huge supply of plant production is not all used for direct human consumption. Beside the making of feed for animals there are other important alternative uses of crops – especially cereals - in the food system. We can recall the example of the embodied consumption of cereals discussed in **Fig. 3.1.** In 1997, in the USA out of the 1,015 kg of cereals consumed per capita (using the chain of physiological conversions as the mechanism of mapping), more than 600 kg were used for feeding animal, more than 100 kg consumed in the form of bread, pasta, pizza or other simple products, with an additional 280 kg for making beer, seeds, in industrial processes, plus losses in processing and distribution. To give a comparison, in developing countries, only 260 kg per capita of cereals were consumed in the same year, only 50 kg of it went in feed, 10 kg in beer, and only minor quantities in other uses. The larger investment of plant products in alternative uses explains why the index of total plant food energy produced per capita is more than double in developed (28 MJ/day) than in developing (13 MJ/day) countries. Even though this difference disappears when considering the amount of food energy intake from vegetables directly consumed in the diet (10 MJ/day in developed and 9.8 MJ/day in developing). That is, consumers of developed countries consume more than the double of plant products consumed per capita in developing countries, but in an indirect way.

The larger use of fossil energy in developed countries is reflected both by the index of consumption per hectare (20 GJ/ha versus 11 GJ/ha in developing) and per hour of agricultural work (152 MJ/hour versus 4 MJ/hour in developing). When analyzing the pattern of food consumption in relation to: (1) available arable land and (2) available work force in agriculture, we obtain a first important observation. The arable land used for generate the same amount of food energy consumed in the diet is much higher in developed countries (0.1 ha/GJ/year) than in developing countries (0.04 ha/GJ/year). [NOTE, these values are the inverse of the values 10.1 GJ/ha and 24.2 GJ/ha reported in Tab. 10.7]. This larger availability/use of land can be related to the better quality of the diet of developed countries. In fact, in spite of the fact that the agriculture of developed countries is using more fossil energy per hectare of arable land (twice as much than developing countries), it is also using more than twice as much land in production per capita. Finally, looking at the ratio "energy of food consumed in the diet"/"hour of labor invested in agriculture" we find another large difference. Developed countries have a value (75 MJ/hour), which is almost 10 times larger than that of developing countries (8 MJ/hour).

To better understand the causes and the implications of these differences, we can analyze the different patterns of use of technical inputs (Table 10.8). The larger use of fossil energy in developed countries is mainly due to the larger use of machinery and fuel. In fact when assessing the fossil energy per worker, we obtain an "investment" of 273 GJ/year of fossil energy in the agriculture of developed countries versus an investment which is 45 times smaller in developing countries (6GJ/worker/year). When fossil energy based inputs are separated into two classes, then their different "roles" become more evident. When accounting only for fertilizers and irrigation, we can see that developing countries are already using more fossil energy per hectare than developed countries (7.4 GJ/year versus 4.9 GJ/year)! The situation is totally reversed when looking at machinery and fuel. These inputs are virtually absent in many poor crowded countries. The difference between developed and developing countries on this index (70 MJ/hour versus 0.8 MJ/hour) is of about 90 times!

Another general observation is that, all things considered, fossil energy consumption in agricultural production, even when assessed by including indirect amounts of fossil energy (production of fertilizers and machinery generally recorded in industrial sectors), are not particularly relevant in relation to the total fossil energy consumption of modern societies. The total assessment of 21,200 million GJ in 1997 is only a 6% of total fossil energy consumption at the world level (about 350 10^{18} Joules according to BP-Amoco World energy statistics, 1999). This percentage does not change much for developed (5% – over an estimated total of 245 10^{18} Joules), and developing countries (8% - over an estimated total of 105 10^{18} Joules).

Last but not least, it should be observed that the differences in indices reported in Tab.10.7 and Tab. 10.8, between developed and developing countries, are quite significant, even when considering possible adjustments in the set of conversion factors adopted to assess fossil energy consumption or different estimates for various inputs.

Getting into an analysis of possible scenarios, this set of data for sure generates concern. At the moment, fossil energy consumption in developing countries is mainly due to high demographic pressure (0.17 ha of land in production per capita, versus 0.49 ha in production p.c. in developed countries). Such a pressure can only get worse. Almost the totality of population growth expected in the next decades (we are talking of another 2 or 3 billions) will occur basically within developing countries. The other big force driving agricultural changes (the reduction of work force in agriculture and the improvement of farmer income) still did not enter in play in developing countries, or only very marginally.

Looking at developed countries, the "fancy" excess of animal products in the diet of the rich is reflected by a consumption of cereals per capita of 650 kg/year (see Tab. 10.3b). Probably, using a double conversion of cereals into animal products and beer is the only known solution for making humans consume so much. In this way, in fact, it is possible to maintain a high economic demand for cereals (the easiest crop to produce in a mechanized way). That is, in this way it is possible to keep high the income of farmers in developed countries. This has been especially important in Europe, where a relative shortage of land per farmer has pushed toward more and more animal products in the diet and cereals in the beer (the only accessible option for boosting the economic labor productivity of farmers). For example, in the Netherlands the consumption of cereals for beer (106 kg/year p.c.) is higher than the direct consumption of cereal products in the diet (75 kg/year p.c.).

As noted earlier, it is evident that the strategy of fossil energy use in developed countries has not been driven by the need of increasing land productivity. The strategy of technical changes in agriculture of developed countries has been aimed at: (1) improving the nutritional quality of the diet, rather than optimizing the energy supply of the diet. This implied a dramatic elimination of the dominant role of a cereal staple food, (e.g. by increasing the availability of fresh vegetables and fruits, the diversity of products available on the market, as well as increasing the fraction of animal proteins). The opposite is true for typical diets of developing countries; (2) reducing, as much as possible, the fraction of work force absorbed by food production, trying to preserve at the same time the economic viability of farmers.

Developed countries can still look for improvement in relation to the first goal (a better quality of diet), whereas we cannot expect more changes toward the second goal (further reduction of the number of farmers). Statistics reported in Tab. 10.8 are in a way misleading, since the system of accounting of FAO includes within the aggregated developed countries, the countries of the ex-Soviet Union and the countries of East Europe (where the fraction of work force in agriculture is still relatively high). In reality, the fraction of work force in agriculture in countries like USA, Canada or Australia is already at 2%, and in the European Union is already smaller than 5%. In addition to that, a growing fraction of farmers in developed countries is engaged in part-time-off-farm economic activities to sustain their income (are working less than the flat amount of 1,800 hours used in the calculations of this study). A further reduction of the number of farmers in the most developed countries would generate major social problems at the level of rural communities, which are already under stress because of a too low density of population and serious problems of aging.

A reduction of the percentage of farmers in the economically active population will be quite difficult also for developing countries, but for completely different reasons: (1) the amount of available land, both per capita and per worker is much smaller in developing countries than in developed countries, so that mechanization is almost impossible due to the very small plots; (2) a massive process of mechanization (to increase of 90 times the level of fossil energy investment per hour of work) would require huge economic resources. These resources are simply not there; (3) demographic growth keeps occurring in rural areas, generating many unemployed with little education. This makes impossible a "large scale" implementation of techniques aimed at a reduction of jobs in agriculture; (4) an acceleration of the movement of rural population into cities is impossible to achieve in the short/medium horizon. The speed of this move is already overwhelming the capability of building and handling functional cities in many developing countries. Looking at the existing number of farmers in developing countries (plus the billions of expected new arrivals) the possibility of achieving a quick reduction of it seems to be out of question. On the other hand, the "traditional solution" of farming, without support of machines, due to its intrinsic low productivity of labor, tends to spell poverty for the large number of farmers in developing countries. To make things worse, they will be, more and more, forced to produce on a shrinking area of arable land. That is, the more agricultural production will spread into marginal land, the higher will be the demand for agricultural inputs in production, the higher the risk of critical environmental impact, the lower the return for farmers.

10.3.4 The sustainability issue: what future biophysical constraints in agriculture ?

When dealing with the issue of sustainability, we can say that existing heavy reliance on fossil energy is not only bad when considering as a relevant criterion of performance the degree of dependency of food security on a non-renewable resource, but also (and especially) when considering as a relevant criterion of performance the environmental impact that "high input" agriculture implies. Getting into an analysis of environmental impact of fossil energy based inputs we can make a distinction between (Giampietro, 1997b):

1. **technical inputs aimed at producing more per hour of labor,** which imply:
- synchronization of farming activities in time and concentration of farming activities in space;
- homogeneity in the patterns of application of inputs and harvesting of outputs (to get economies of scale in the development and operation of new technologies).

This translates into heavy reliance on monocultures, a large dimension of crop fields (loss of "edge effect", good for preservation of biodiversity in agro-ecosystems), erosion of genetic diversity of crops (due to the use of commercial seeds linked to technological packages) and more in general to the spread of technology of extensive adaptation (not tailored on "location specific" characteristics of different agro-ecosystems).

2. **technical inputs aimed at producing more per hectare of land**, which imply:
- unnatural concentration of fertilizers and toxic substance in the soil, in the agro-ecosystem and more in general in the food and the environment;
- local alteration of the water cycle (e.g. salinization in crop-fields, and depletion of underground water reservoirs).

This translates into the depletion of natural resources that usually are considered as "renewable" (fertile soil and fresh water stored under ground) due to a rate of their exploitation much higher than the rate of their replenishment, and a dramatic reduction of biodiversity at the agro-ecosystem level (due to the effects of these alterations).

Can we forecast an inversion in the medium term of existing negative trends?
The data set presented in this study, especially data in Table 10.6, 10.7 and 10.8 do not give reasons for much optimism. Given the existing trends of population growth and the strong aspiration for a dramatic improvement in economic and general living conditions in the rural areas of developing countries, a reduction of fossil energy consumption in agriculture, in the next decades, seems to be a very unlikely event indeed. On the positive side, it is important to observe that the total consumption of fossil energy in agriculture is still a small fraction of the total energy consumption in the rest of the society. **In a way, the concern for the ecological impact of "high input" agriculture should be, for the moment, much more worrisome than the concern for the limitation of existing reserves of fossil energy.**

Boundary conditions and physical laws do impose biophysical constraints on what is feasible for human societies in spite of our wishes and aspirations. Therefore, it is important to have a sense of what are the most likely biophysical constraints faced by humankind in the future in terms of food security. In addition to shortages of arable land, soil erosion, and a lack of alternatives to high input agriculture to guarantee elevated productivity both per hour and per hectare, there are two other crucial constraints.

(1) Water shortages - Presently, 40% of the world's people live in regions that compete for short water supplies. Related to these growing shortages is the decline in per capita availability of freshwater for food production and other purposes in the arid regions of the world. There is very little that technology can do when human development clashes against limits in the water cycle. As noted earlier the amount of energy required to sustain the water cycle in the biosphere is almost 4000 times the entire amount of energy controlled by humankind worldwide. The idea that human technology will substitute for the services provided today by nature in this field is simply based on ignorance of biophysical realities.

(2) Biodiversity for the long-term stability of the biosphere - The dramatic reduction of species caused by the conversion of natural ecosystems into agro-ecosystems has been discussed earlier. Since we need biodiversity to stabilize the structure and functions of the biosphere we cannot transform all terrestrial ecosystems into agricultural fields and/or cement for housing and infrastructures. A large diversity of species is vital to agriculture and forestry, and plays an essential role in maintaining a quality environment and recycling the vital elements such as water, carbon, nitrogen, and phosphorus. This is another clear

example of a form of natural capital that cannot be replaced by human technology.

Other well known global problems can be added to this list: changes in the composition of the atmosphere (greenhouse effect, ozone layer depletion), the cumulative effects of pollution, the intensification of the occurrence of contagious diseases (e.g., AIDS, viruses moving to humans from livestocks kept at a too high concentration). I am mentioning them here not to get into the very well known argument between "cornucopians" and "neo-malthusians" but only to make the point that, in spite of current disagreements about the evaluation of the seriousness of these problems, we have to acknowledge the obvious fact that there are biophysical limits to the expansion of human activity. These limits can be avoided only by adequately reacting to feed-back signals coming from disturbed ecosystems. Whenever humans are not able to obtain reliable indications about the room left for expansion (or when they are not able to understand those signals) they should be reluctant to further expand their disturbance, when is not absolutely needed.

In order to end this discussion with a positive note, we can say that in the past two centuries humans have shown an almost magic ability to adapt to fast changes as soon as they "detect and acknowledge" the existence of a major reason for doing so. For sure, the challenge of sustainability of food security will represent soon one of these reasons. Therefore, we can expect that some major readjustments - the genuine emergence of new patterns - will occur in how humans produce and consume their food in the new millennium. Even though we cannot guess today what they will be, we can - the sooner the better - clarify as much as possible the terms of reference of the sustainability predicament.

Tab. 10. 1 Means of production in primary vegetal production in world agriculture (Giampietro, 2001)

	arable land Million ha	work supply Bill. hours	irrigation Million ha	H&T 1,000	Tractors 1,000	Nitrog.(N) Mill. MT	Phosp. (P) Mill. MT	Pota. (K) Mill. MT	Pesticides Mill. MT
World	1,379	2,385	268	4,193	26,335	85.1	32.9	23.3	2.7
Developed	632	85	66	3,372	19,879	31.5	12.5	12.3	1.5
Developing	747	2,300	201	820	6,455	53.6	20.4	11.0	1.2
Asia	499	1,886	187	1,917	7,079	43.9	12.6	2.5	0.9
Africa	175	352	12	39	557	2.2	0.9	0.5	0.1
Europa	294	56	25	1,222	11,198	20.7	6.3	12.0	0.8
N. America	222	6	22	794	5,511	12.9	4.9	5.2	0.6
L. America	134	80	18	159	1,587	4.5	3.2	3.1	0.2
Oceania	55	5	3	60	401	1	1.5	0.5	0.1

NOTE: work supply = labor force in agriculture (number of workers) x 1,800 hours/year (a flat work load)

Tab. 10.2 Fossil energy input in primary vegetal production in world agriculture (Giampietro, 2001)

	machinery millionGJ	fuel million GJ	Nitrog. (N) million GJ	Phosp. (P) million GJ	Pota. (K) million GJ	Irrigation million GJ	Pesticides million GJ	Oth. Input million GJ	Total million GJ
World	2,730	5,000	6,650	550	325	1,130	1,130	650	18,200
Developed	2,150	3,800	2,460	200	170	280	630	650	10,350
Developing	580	1,200	4,190	350	155	850	500	0	7,850
Asia	540	1,200	3,450	240	34	780	380	50	6,700
Africa	35	70	170	20	7	60	40	0	400
Europa	995	1,960	1,600	110	164	100	340	300	5,600
N. America	950	1,400	1,000	90	71	90	250	250	4,100
L. America	140	270	350	60	42	80	80	0	1,000
Oceania	70	100	80	30	7	20	40	50	400

Tab. 10.3a - Major items, primary vegetal production in world agriculture
(Giampietro, 2001)

	Cereals mill MT	Starch. Rt. mill MT	Pulse mill MT	Oil crops mill MT	Vegetables mill MT	Fruits mill MT	Forages mill MT
World	***2,030***	***631***	***55***	***447***	***532***	***502***	***5,000***
Developed	976	183	15	137	142	137	2,000
Developing	1,055	448	40	310	390	365	3,000

Tab. 10.3b - Total amounts consumed (kg p.c. per year) per item
(Giampietro, 2001)

	Cereals kg p.c.year	Starch. Rt. kg p.c.year	Pulse kg p.c.year	Oil crops kg p.c.year	Vegetables kg p.c.year	Fruits kg p.c.year	Forages kg p.c.year
World	***350 (46%)***	***109 (56%)***	***10 (66%)***	***77 (n.a.)***	***91 (99%)***	***86 (80%)***	***860 (0%)***
Developed	647 (21%)	153 (50%)	12 (25%)	102 (n.a.)	113 (89%)	127 (71%)	1,550(0%)
Developing	260 (65%)	97 (59%)	9 (78%)	70 (n.a.)	85 (91%)	74 (83%)	666 (0%)

NOTE 1: include crops used for feeding animals, making beer and processed by industry
NOTE 2: the percentages in parenthesis indicate the amount consumed directly as food

Table 3c - Animal production in world agriculture – major items
(Giampietro, 2001)

	Meat Mill. MT	Beef Mill. MT	Sheep Mill. MT	Pig Mill. MT	Poultry Mill. MT	Milk Mill. MT	Eggs Mill. MT
World	***212***	***56***	***11***	***81***	***60***	***545***	***53***
Developed	101	30	3	35.4	30	340	18
Developing	111	26	8	45.5	30	205	35

NOTE: these values include amount of products processed

Table 3d – Animal Products in the diet – major items

(Giampietro, 2001)

	Meat kg p.c.year	Beef kg p.c.year	Sheep kg p.c.year	Pig kg p.c.year	Poultry kg p.c.year	Milk kg p.c.year	Eggs kg p.c.year
World	***36***	***10***	***2***	***14***	***10***	***93***	***9***
Developed	76	23	2	27	22	246	14
Developing	25	6	2	10	7	50	8

NOTE: these values include amount of product processed (e.g. milk for cheese)

Tab. 10. 4a Types of Animal production and feed use in world agriculture
(Giampietro, 2001)

	<-Large ru	minant(bee	f & milk->	<--- Small	ruminant	(sheep) -->	<- Mono	gastric	(pigs) -->	<--Fowl	(includes	eggs) -->
	meat	Concentr.	Forage	meat	Concentr.	Forage	meat	Concentr.	Forage	meat	Concentr.	Forage
	Mill. MT	Mill. MT	Mill. MT	Mill. MT	Mill. MT	Mill. MT	Mill. MT	Mill. MT	Mill. MT	Mill. MT	Mill. MT	Mill. MT
World	56.0	340.0	3500.0	11.0	negl.	900.0	81.0	400.0	500.0	59.0	400.0	negl.
Developed	29.0	250.0	1500.0	2.8	negl.	230.0	36.5	180.0	225.0	29.5	200.0	negl.
Developing	27.0	90.0	2000.0	8.2	negl.	670.0	44.5	220.0	275.0	29.5	200.0	negl.
Asia	12.5	46.0	860.0	5.8	negl.	480.0	42.5	210.0	262.0	19.8	134.0	negl.
Africa	3.8	13.0	280.0	1.9	negl.	160.0	0.8	4.0	5.0	2.4	16.0	negl.
Europa	13.0	112.0	600.0	1.6	negl.	130.0	24.4	121.0	151.0	11.0	75.0	negl.
N. America	12.8	112.0	600.0	negl.	negl.	negl.	9.0	45.0	56.0	15.9	108.0	negl.
L. America	11.5	37.0	860.0	0.5	negl.	40.0	3.5	17.0	22.0	9.0	61.0	negl.
Oceania	2.5	20.0	300.0	1.1	negl.	90.0	0.4	2.0	2.0	0.6	4.0	negl.

Table 10. 4b – Animal Products, feed igredients and forages used in animal production
(Giampietro, 2001)

				<-----ingre	dients for	making	co ncentrate	s feeds	--------->		Forages	Forages
	TOTAL Meat Mill.MT	TOTAL Milk Mill.MT	TOTAL Eggs Mill.MT	Cereals (%) Mill.MT	Starchy root (%) Mill.MT	Pulses (%) - Mill.MT	oil-seed by-prod. Mill.MT	other ind. by-prod. Mill. MT	by-prod. no fossil Mill. MT	TOTAL Concentr Mill. MT	no fossil en. input Mill. MT	with fossil en. Input Mill. MT
World	212.0	545.0	52.4	(34) - 688	(21) - 134	(25) - 14	120	40	140	1140	2,600	2,300
Developed	101.0	340.0	17.7	(54) - 452	(23) - 46	(63) - 10	80	40	negl.	630	450	1,500
Developing	111.0	205.0	34.7	(20) - 235	(20) - 88	(10) - 4	40	negl.	140	510	2,350	600

NOTE 1: % of Cereals, Starchy roots and Pulse in parenthesis, refer to % of total production of these crops
NOTE 2: oil-seed and other ind. by-products refer to concentrates requiring fossil energy input for their processing
NOTE 3: other by-product no-fossil refers to high quality feed obtained from residues and by-products in developing countries

Table 10. 5a Fossil Energy input in anmimal production per type of production

(Giampietro, 2001)

	Concen. beef Mill. GJ	Forage beef Mill. GJ	Concen.. milk Mill. GJ	Forage milk Mill. GJ	Concen. pig Mill. GJ	Forage pig Mill. GJ	Concen. Poultry Mill. GJ	Concen. Eggs Mill. GJ	input Mill. GJ	TOTAL Foss. En. Mill. GJ
World	950	2,000	500	600	1,500	400	1,300	250	2,000	9,500
Developed	800	1700	400	400	900	300	800	100	1,550	7,100
Developing	150	300	100	200	600	100	500	150	450	2,400

Table 10. 5b Fossil energy input in animal production per type of input

(Giampietro, 2001)

	crop production million GJ	**forage** production million GJ	**extra feed** from crop million GJ	**extra feed** from by-pr million GJ	**oth. inputs** beef+milk million GJ	**oth. inputs** poult+eggs million GJ	**oth. inputs** pigs million GJ	**Total** anim prod million GJ
World	3,500	3,000	400	600	500	900	600	9,500
Developed	2,300	2,500	250	500	300	750	500	7,100
Developing	1,200	500	150	100	200	150	100	2,400

Tab 10. 6 – Overall analysis of food production at the world level

(Giampietro, 2001)

	Total input prim. prod million GJ	Fraction for feed million GJ	Total input plant prod. million GJ	Total input anim. Prod million GJ	Total input for food million GJ	Total food consumed million GJ	Plant food consumed million GJ	Anim food consumed million GJ	Plant food produced million GJ	Population millions
World	18,200	6,500	11,700	9,500	21,200	24,500	20,700	3,800	34,700	5,801
Developed	10,300	4,800	5,550	7,350	12,900	6,400	4,700	1,700	13,200	1,293
Developing	7,850	1,700	6,150	2,150	8,300	18,100	16,000	2,100	21,500	4,507

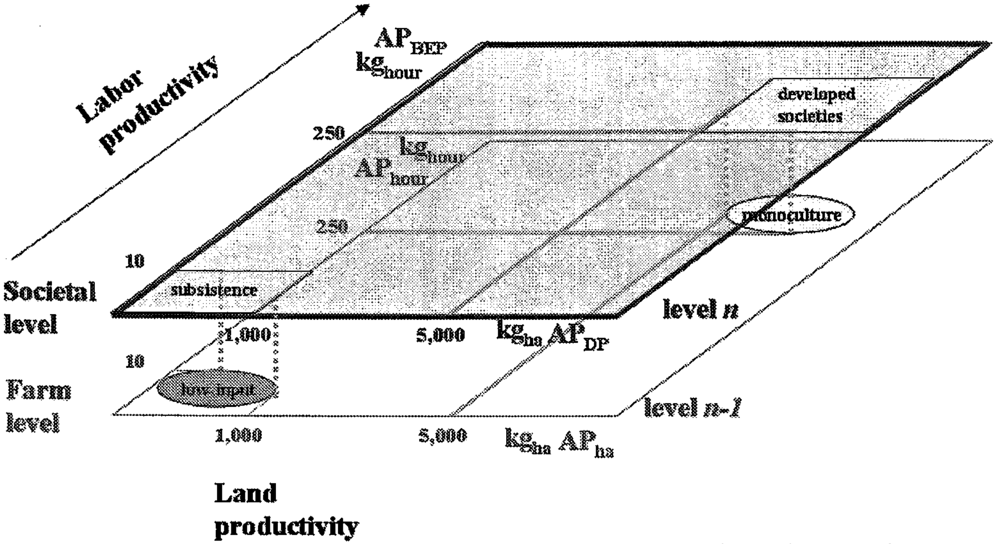
Table 10. 7 – Different indicators about fossil energy use in agriculture
(Giampietro, 2001)

	O/I ratio food cons foss.en.	O/I ratio plant cons foss. en.	O/I ratio anim.cons foss. en.	O/I ratio plant prod foss. en.	Tot food cons. p.c. MJ/day
World	1.2/1	1.8/1.0	1/2.5	1.9/1	11.6
Developed	1/2	1.0/1.2	1/4.3	1.3/1	13.6
Developing	2.2/1	2.6/1.0	1/1.0	2.7/1	11.1

	Anim food cons p.c. MJ/day	Tot plant prod p.c. MJ/day	Foss en. arab. land GJ / ha	Foss en. agr. work MJ / hour	Food-diet arab.land GJ / ha	Food-diet agr. work MJ / hour
World	1.8	16.4	15.4	9	17.7	10
Developed	3.6	28.0	20.4	152	10.1	75
Developing	1.3	13.0	11.1	4	24.2	8

Tab. 10. 8 Indicators for studying trends of fossil energy in world agriculture (Giampietro, 2001)

	arable land per capita ha	Ag.work.force as fraction TOTw.forc	arable land per worker ha	Fossil energy per worker GJ/year	Fert + irrig per ha GJ/year	Mach + fuel per hour MJ	Foss.en. AG as fraction TOT Foss. en
World	0.24	0.5	1	16	6.3	3.2	0.06
Developed	0.49	0.1	12	273	4.9	70.0	0.05
Developing	0.17	0.6	1	6	7.4	0.8	0.08

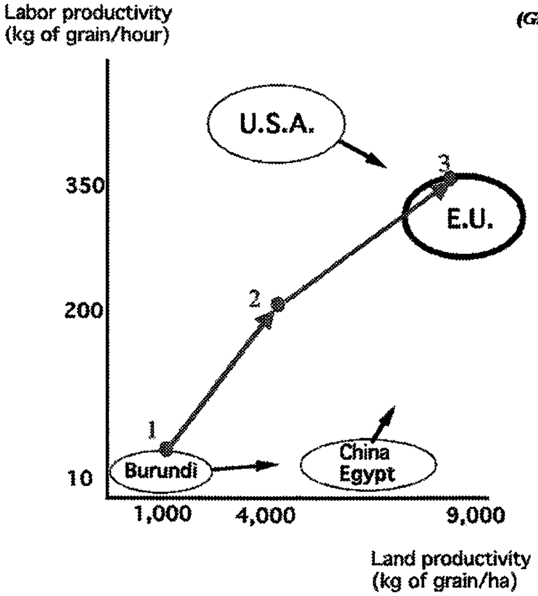


(Giampietro, 1997a)

Fig. 10.1 The link between two assessments based on two definitions of I.V.#3: [1] AP_{hour} and Ap_{ha} at **level *n-1***; and [2] AP_{BEP} - AP_{DP} at **level *n***

Fig. 10.2 **Describing trends and changes in production techniques over a plane "labor productivity" <—> "land productivity"**

(Giampietro, 1997a)



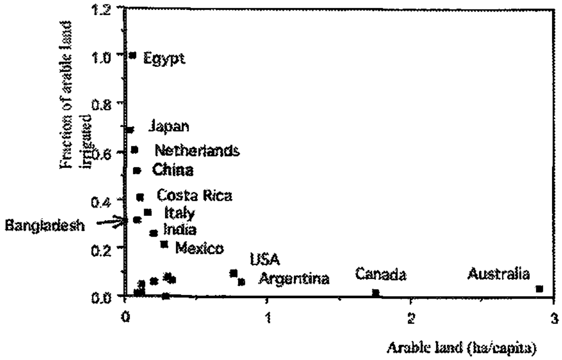


Fig. 10.3a
Irrigation and
Demographic pressure

(Giampietro et al. 1999)

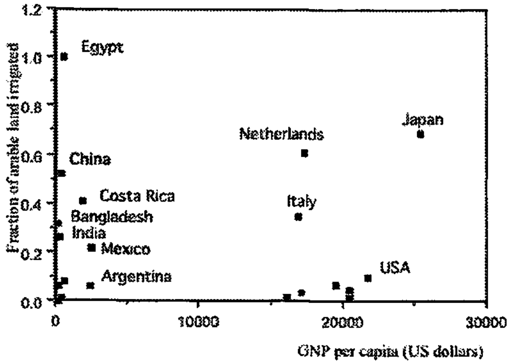


Fig. 10.3b
Irrigation and
Bio-Economic pressure

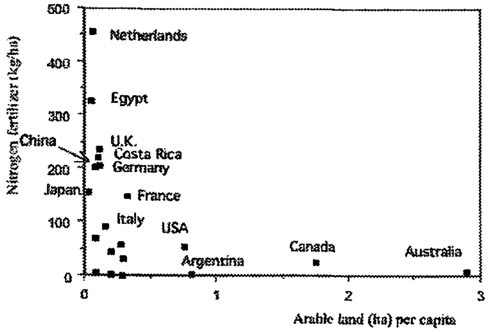


Fig. 10.4a
Nitrogen Fertilizer and
Demographic pressure

(Giampietro et al. 1999)

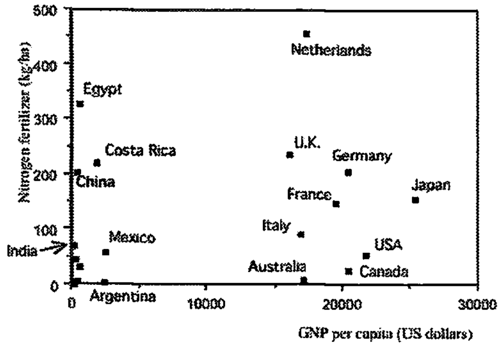


Fig. 10.4b
Nitrogen Fertilizer and
Bio-Economic pressure

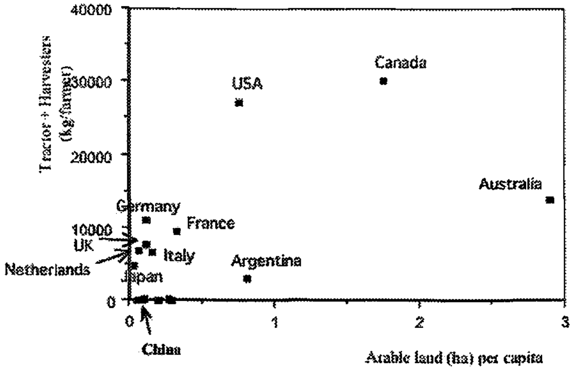


Fig. 10.5a
Machinery and
Demographic pressure

(Giampietro et al. 1999)

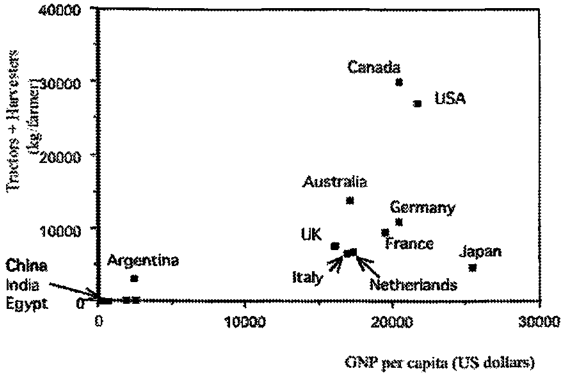


Fig. 10.5b
Machinery and
Bio-Economic pressure

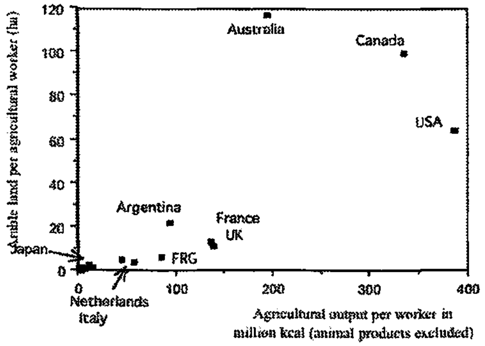


Fig. 10.6a
Biophysical Productivity of Labor
versus
Arable land per worker

(Giampietro et al. 1999)

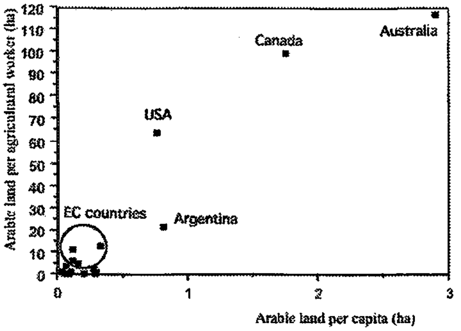


Fig. 10.6b
Arable Land per worker
versus
Arable Land per capita

Fig. 10.7 Combined effect of demographic and socio-economic pressure on technical performance of agricultural production

Indicator of environmental loading: output (food energy) / input (fossil energy)

SOCIO-ECONOMIC PRESSURE

DEMOGRAPHIC PRESSURE	HIGH	LOW	
HIGH	e.g. Netherlands Very low < 1/1	e.g. China Medium ~ 3/1	*Arable land per capita < 0.20 ha*
LOW	e.g. U.S.A. Medium ~ 3/1	e.g. Traditional Subsistence Very high > 20/1	*Arable land per capita > 0.75 ha*
	* Work force: < 7% in agriculture * Exo/Endo > 30/1 * Labor Productivity: > 200 kg cereal/hour	* Work force: > 50% in agriculture * Exo/Endo < 10/1 * Labor Productivity: < 10 kg cereal/hour	*(Giampietro, 1997a)*

▨ output/input energy ratio of agriculture

Fig. 10.8 Adding a third axis to the plane shown in Fig. 10.2

(Giampietro, 1997a)

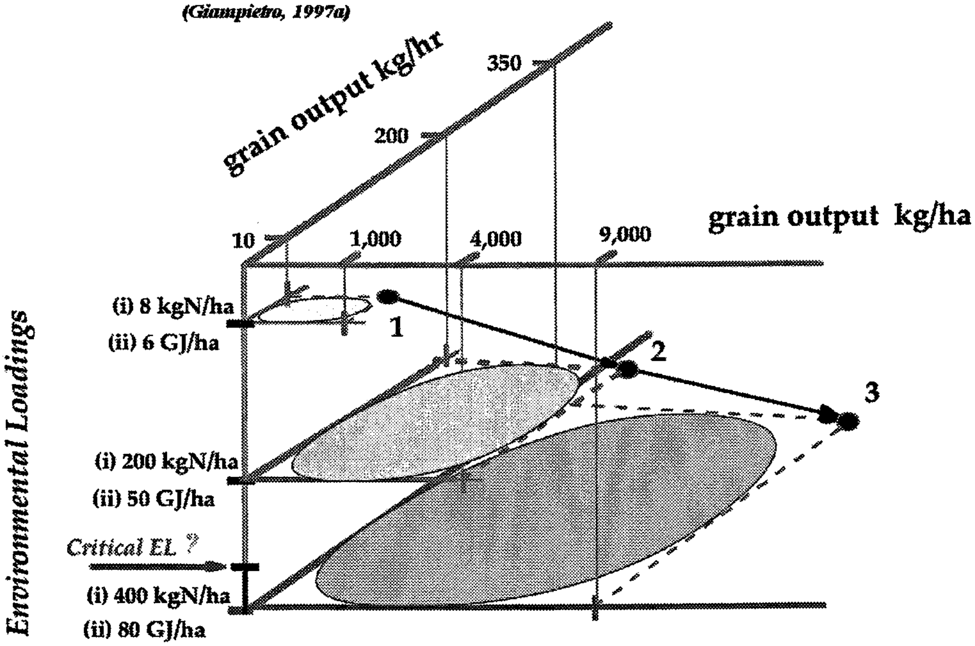


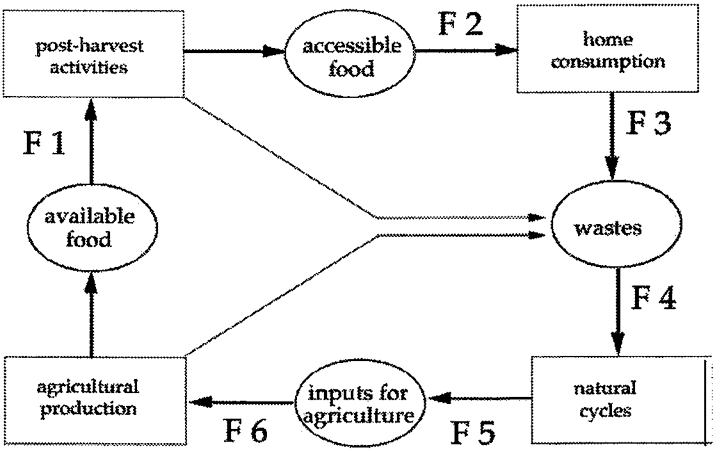
Fig. 10.9 Combined effect of demographic and socio-economic pressure on the Environmental Loading of Agriculture

Indicator of environmental loading: GJ of fossil energy input/ha cultivated land

	SOCIO-ECONOMIC PRESSURE		
DEMOGRAPHIC PRESSURE	**HIGH**	**LOW**	
HIGH	**e.g. Netherlands** **Very high** **> 80 GJ/ha**	**e.g. China** **Medium/High** **~ 50 GJ/ha**	***Arable land per capita < 0.20 ha***
LOW	**e.g. U.S.A.** **Medium/Low** **~ 30 GJ/ha**	**e.g. Traditional Subsistence** **Very Low** **~ 0 GJ/ha**	***Arable land per capita > 0.75 ha***
	*** Work force: < 7% in agriculture** *** Exo/Endo > 30/1** *** Labor Productivity: > 200 kg cereal/hour**	*** Work force: > 50% in agriculture** *** Exo/Endo < 10/1** *** Labor Productivity: < 10 kg cereal/hour**	

(Giampietro, 1997a)

▮ Fossil energy equivalent of technical input application



Legend

Boxes represent the components of the food systems
Ellipsoides describe the nature of flows
The arrows marked by F and numbers indicate:

F1 food crops available after agricultural production and harvest
F2 food accessible to consumer after processing, packaging, distribution and home preparation
F3 food required for food security
F4 wastes and pollutants generated by the food system
F5 wastes and pollutants degraded and recycled by the ecosystem
F6 nutrients consumed by agriculture

Fig. 10.10

(Giampietro et al. 1994)

Fig. 10.11a
Low-input agriculture

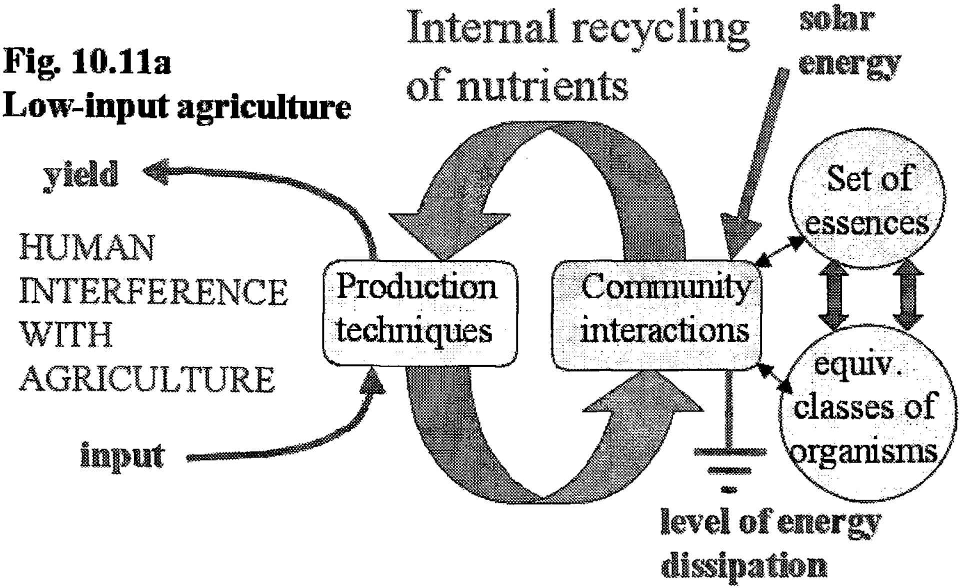
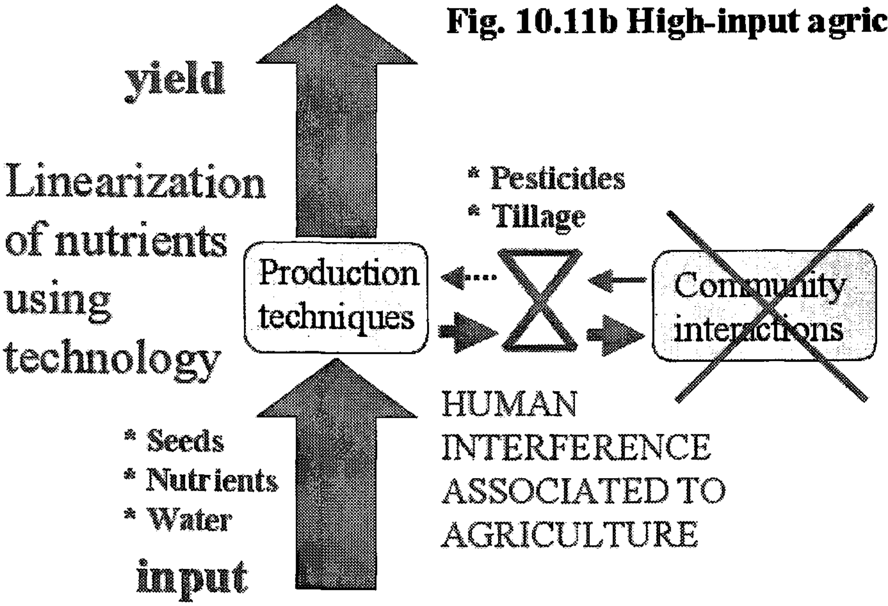


Fig. 10.11b High-input agriculture



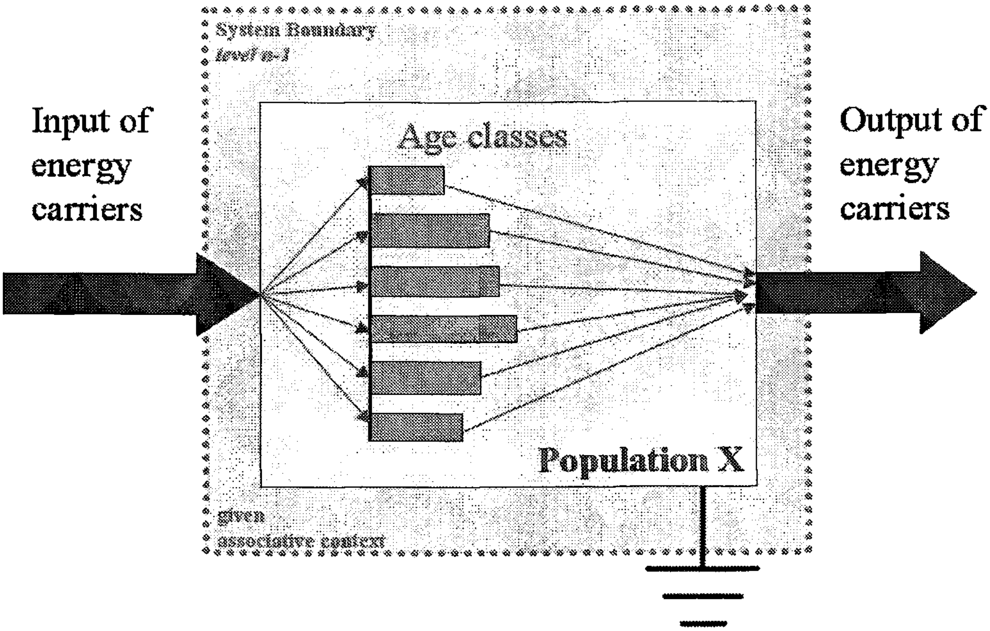
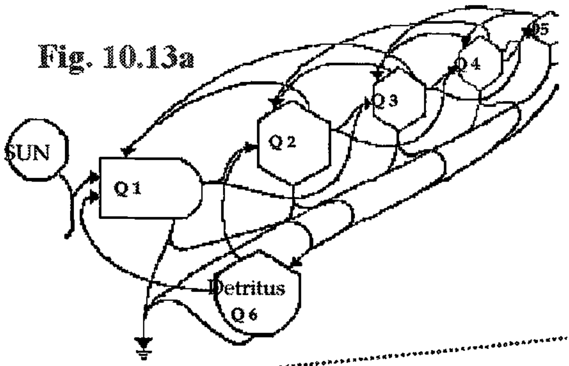


Fig. 10.12 The distribution of input/output of energy carriers **to/from** the biomass of "population X" over age classes

Fig. 10.13a



H.T. Odum graphs:
a natural ecosystem
without heavy human
interference

(Giampietro, 1997b)

H.T. Odum graphs:
representing the effects
of the interference
associated to high input
agriculture

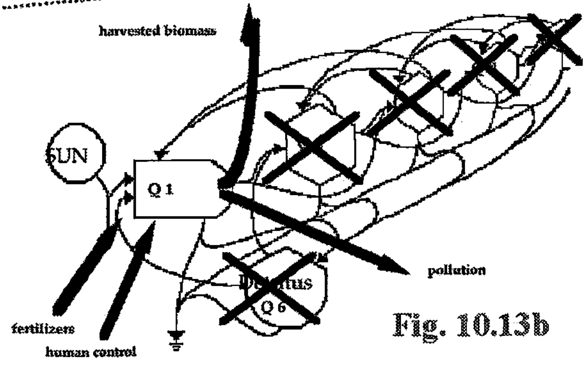


Fig. 10.13b

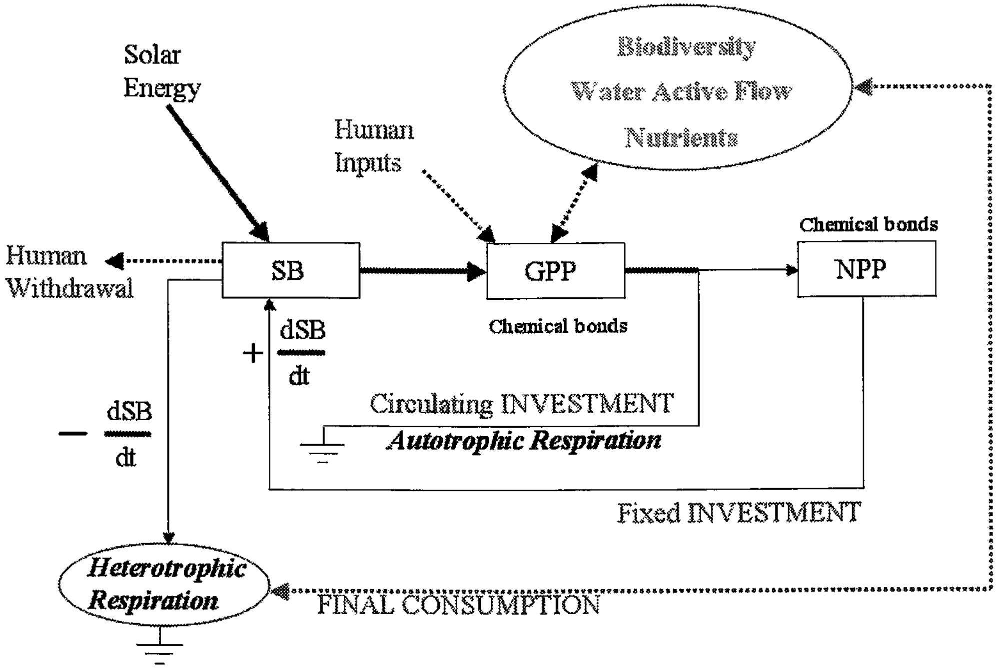


Fig. 10.14 GPP, NPP and Human Appropriation in terrestrial ecosystems (a different view of the impredicative loop described in Fig. 7.6)

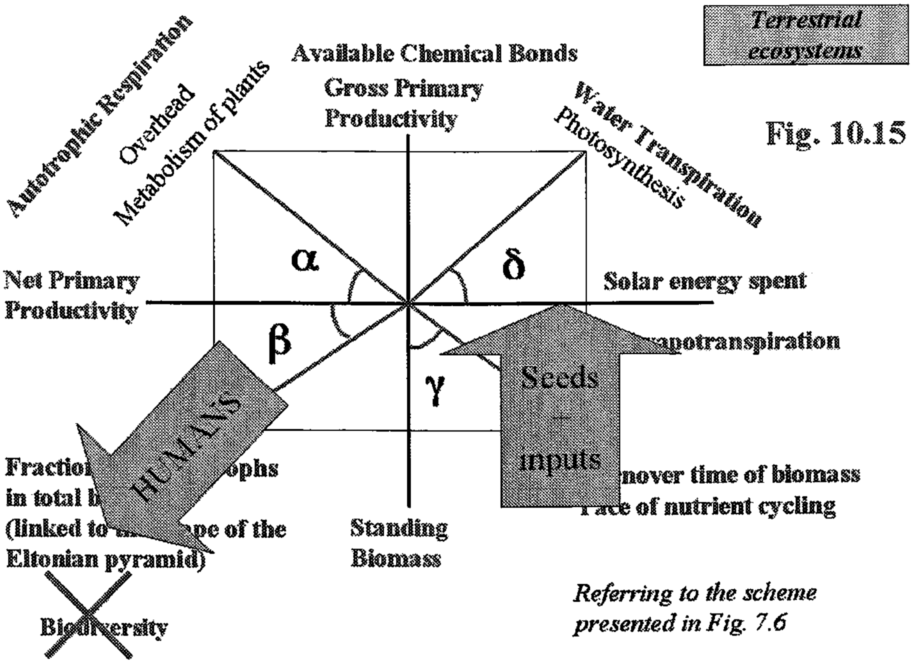


Fig. 10.15

Referring to the scheme presented in Fig. 7.6

Fig. 10.16 Plane to represent the alteration of terrestrial ecosystems (adopting a thermodynamic rationale) - After Giampietro et al. 1992

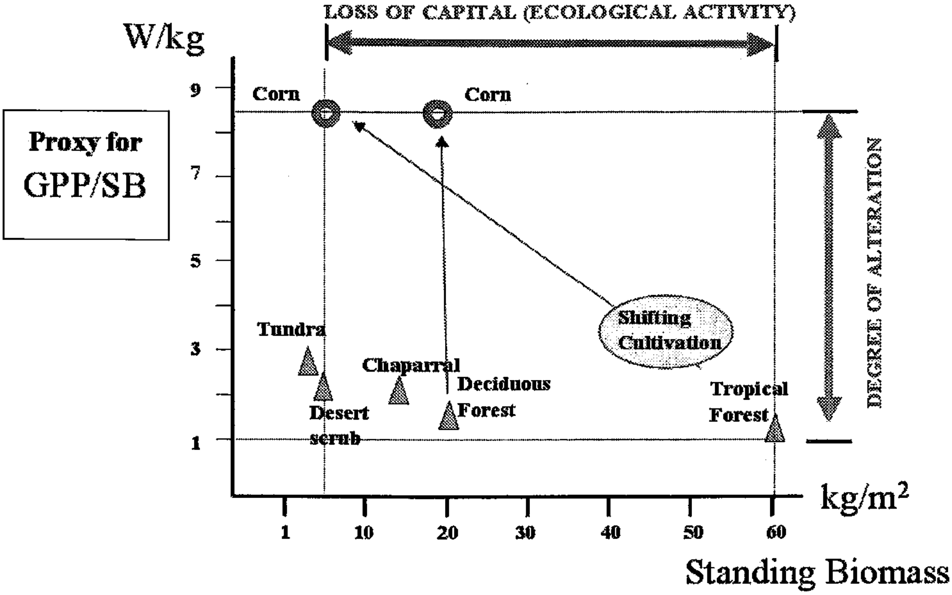
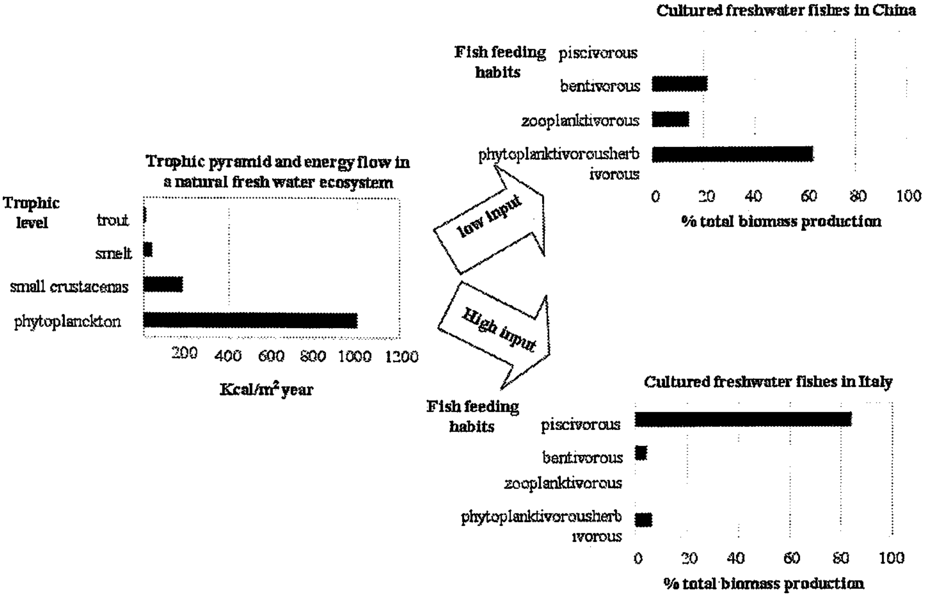


Fig. 10.17 **Trophic piramids in natural and man managed freshwater systems (modified from Gomiero *et al.*, 1997)**



Chapter 11*

Multi-Scale Integrated Analysis of farming systems: benchmarking and tailoring representations across levels

This chapter deals with farming system analysis. A topic which entails dealing with all the typologies of epistemological problems associated with complexity discussed so far. A useful knowledge of farming systems, in fact, has to be based on a repertoire of typologies of farming systems. On the other hand, all farming systems are special, in the sense that their representation must include the specificity of their history and the specificity of local constraints. To make things more difficult the very concept of farming systems implies dealing with a system which is operating within two non-equivalent contexts: a socio-economic context and an ecological context. That is, any real farm is operating within a given typology of socio-economic system and within a given typology of ecosystem. The two identities of these two contexts are very important when selecting an analytical representation of a farming system. In fact, a typology of farming system has to be related, by definition, to an expected associative context. This is the step where concepts such as Impredicative Loop Analysis and Multi-Criteria performance space become crucial. In fact, they make possible to characterize the reciprocal constraints associated to the dynamic budget of the farming system considered, which is interacting with its two contexts exchanging flows of energy, matter, added value. A given selection of typologies used to represent its identity (system, typical size, metabolic flows considered) has to be compatible with the set of typologies used to represent the identities of its socio-economic and ecological context.

This chapter is organized in 3 sections. Section 1 introduces in general terms basic concepts related to farming system analysis found in literature. These concepts are translated into a narrative compatible with the theoretical concepts and analytical tools presented in Part2. Section 2 presents an approach (land-time budget) useful to apply ILA to farming systems. This approach can be used to: (a) individuate useful types across levels for a MSIA; and (b) establish a link between socio-economic types used to represent farming systems across levels. Section 3 illustrates the possibility to link a multilevel analysis of farming systems based on typologies across levels to a multi-level characterization of land uses associated to these types. In this way, a multi-level multi-criteria analysis of farming systems can be tailored to the various "strategy matrices" used by relevant agents. This section ends by providing an overview of how the heterogeneous information space built by adopting the analytical tool kit suggested in this chapter (different ILAs based on Land-Time budget and Multi-Criteria Performance Space associated to land use maps over multiple hierarchical levels) can be handled when discussing of possible policies and/or of scenarios analysis.

* **Tiziano Gomiero is a co-author of this chapter**

11.1 Farming system analysis

11.1.1 Defining Farming Systems Analysis and its goals

An overview of literature about the challenges implied by an integrated analysis of farming systems provides a list, which is very similar to that discussed so far about the challenges implied by sustainability analysis:

(1) Agricultural systems are complex systems operating on several hierarchical levels (= with parallel processes definable only on different spatio-temporal scales). This makes impossible an exhaustive description of them with a set of assumptions typical of a single scientific discipline (Hart, 1984; Conway, 1987; Lowrance et al. ,1987; Ikerd, 1993; Giampietro, 1994a; b; Wolf and Allen, 1995).

(2) Any substantive comparison of farming options would require the simultaneous consideration of: (i) a large variety of different production processes, strategies, techniques and technologies that can be found all around the world; (ii) the need of using agronomic, ecological, socio-economic analyses in parallel to verify the compatibility of farming techniques with different sets of constraints coming from both the biophysical and the socio-economic characteristic of the system; (iii) the need of expanding the range of assessments of the farming system over multiple and alternative views of it, to check the feasibility of proposed solutions in ecological, economic and social terms (Altieri, 1987, Brown et al., 1987, Lockeretz, 1988; Brklacich et al., 1991; Allen et al., 1991; Schaller, 1993).

(3) Specific policies or technological changes are unlikely to generate absolute "improvements" (= when considering all possible hierarchical levels of organization and every possible perception found among stakeholders). We can only expect to obtain trade-offs, when assessing the effect of changes on different scales and in relation to different descriptive domains. "*Recent enthusiasm regarding win-win scenarios in many cases is buoyed by scaling error. Explicit recognition of the implications of necessary trade-offs, both positive and negative, promotes the development of mechanisms to support losers. Failure to confront the fact that losers are consistently produced exaggerates the negative impact they have on system performance*" . Wolf and Allen (1995 - p. 5).

(4) Not always the trade-offs faced when comparing the effects of different options are commensurable (when facing cases of sustainability dialectics). Costs and benefits generated by a particular change in relation to a given criterion and a relative indicator of performance can be measured indeed. However, this can be done only by mapping changes in an observable quality associated to a given descriptive domain (at a given scale) at the time. As soon as we deal with problems of sustainability (when different relevant scales have to be considered simultaneously) and when our selection of relevant stakeholders include several social groups (when the existence of legitimate but contrasting views is unavoidable) the various assessments of heterogeneous perceptions of costs and benefits become non-reducible and incommensurable (Alier et al. 1998; Munda, 1995). A perfect example of this scientific impasse is found when scientists are asked to quantify cost/benefit related to the dilemma: "fighting hunger in the present generation" versus "preserving biodiversity for future generations".

(5) When dealing with the issue of sustainability a substantive definition of rationality cannot be adopted (Simon, 1976; 1983). After accepting that conflicting effects on different levels, when evaluated from different perspectives and values, cannot be quantitatively evaluated by a reduction and aggregation into a single indicator of cost/benefit, we are forced to admit that an "optimum strategy of development" for "farming systems" cannot be selected by experts "once and for all". The very definition and perception of sustainability is inherently sensitive to changes in the analytic context (Wolf and Allen, 1995; Allen et al. 2001). Sustainability in agriculture has to do with conflict management and an adequate support for decision making in the context of complexity (e.g. participatory techniques and multicriteria methods as discussed in Chapter 5). These methods require analyses able to link actions at one scale to consequences generated at other scales. Moreover, the choices made to represent these consequences have to reflect the variety of perceptions found among the stakeholders.

In conclusion, an integrated analysis of agro-ecosystems requires the ability to describe farming systems simultaneously on different space-time scales (e.g. biosphere, regional and local ecosystem, macro-economic, community, micro-economic, farmer level) and by adopting non-equivalent descriptive domains (when considering the economic, ecological, technical, social, cultural dimensions). In particular it requires the ability to tailor the selection of an integrated package of indicators of performance on the set of system characteristics which are relevant for the agents that are making relevant decisions within the farming system considered.

When translating this set of challenges in the narrative proposed so far in this book, we can say that farming system analysis is about selecting a finite set of useful perceptions and representations of the performance of agro-ecosystems in relation to event occurring within a local space-time domain. This entails that within such a representation the farming system is assumed to be interacting with a context which is made of both socio-economic systems and ecological systems. Both of these self-organizing systems, in turn, do have (and have to be characterized by using) a given set of identities.

According to the discussion presented in Chapter 5 the challenge for scientists willing to perform an integrated analysis of farming systems becomes that of finding a useful problem structuring for framing in formal terms the specific problem of sustainability considered. Such a framing has to be able to cover relevant scales and dimensions of analysis. General principles and disciplinary knowledge are certainly necessary for this task. However, at the same time, they are not enough. Crucial disciplinary knowledge has to be tailored to the specificity of a given situation found at a given point in space and time.

As noted in Chapter 5 any multi-criteria analysis of sustainability requires starting with a pre-analytical definition of:

(1) relevant stakeholders to be considered when deciding what are the relevant perspectives to be addressed by the problem structuring [= the set of goals and fears to be considered as relevant in the analysis in order to be able to reflect the relative set of legitimate but non-equivalent perceptions of costs and benefits for relevant agents];

(2) a performance space used for the evaluation [= a set of indicators of performance able to characterize the effects of changes in relation to the set of relevant criteria of performance selected in the previous steps]

(3) a package of models able to generate a Multi-Scale Integrated Analysis of possible changes. This requires the individuation of: (a) key attributes and observable qualities determining the particular set of identities used to represent the investigated system; (b) key mechanisms generating and maintaining the various forms (and relative perceptions) of the metabolism of the system that we want to sustain. The analysis has to deal with the ability to stabilize key flows such as endosomatic energy, exosomatic energy, added value and other critical matter flows (e.g. water, nitrogen) and with the ability to reduce the emission of harmful flows (e.g. pollutants). This implies addressing the problem of how to characterize the identity of the metabolic system as a whole (at the **level *n***) and in relation to this whole how to characterize the relevant identities of its lower level components controlling the various metabolic flows considered as relevant (at the **level *n-1***). These two set of identities within the requirement of sustainability, in turn, have to be compatible with the characteristics of the larger context (**level *n+1***) and lower lower level characteristics associated to the definition of input and wastes (**level *n-2***); (c) the set of existing constraints on the possible actions (policies, choices) to be adopted. The individuation of constraints is related to the existence of non-equivalent dimensions of feasibility (e.g. biophysical, technical, socio-economic, cultural, ecological); and (d) existing drivers which are determining current evolutionary trends.

Only at this point, it becomes possible to gather data, set up experimental designs, in order to operate such an integrated package of models and indicators useful to discuss scenarios and options. The generation of this scientific input has been called in Chapter 5 as the development of a "discussion support system", and this should be considered as a crucial starting point for a sound process of integrated analysis and decision making.

From what discussed in Part 1 and Part 2 we can say that any farming system is organized – as any other complex adaptive system made up of humans – in a hierarchy of nested typologies. This entails that when analyzing these systems we should expect to find several agents operating at different levels. In turn, this requires the consideration of several sets of relevant identities to be studied in a multi-scale analysis. These agents can be individual households (composed by individual human beings), which are organized in larger units - villages and communities (composed by households) that are organized in larger units - provinces and regional administrative units (composed by villages) that are operating within larger socio-economic contexts - countries and macro-economic areas. These socioeconomic systems (perceived at various levels) in turn are embedded in ecological entities which are also organized in nested hierarchies (which are perceived in terms of different identities at different levels of organization).

According to what said in Part 1, we cannot expect to find a standard set of perceptions and representations of performance (associated to the building of a single descriptive model) which can be used once and for all to deal with such a multi-scale integrated analysis of the performance of "farming systems". Any individual model used to assess the performance of farming systems will reflect just a given selection of relevant criteria, key mechanisms and contiguous hierarchical levels. Therefore, no matter how elaborated, mathematical models will be necessarily referring to a single descriptive domain at the time (a given definition of identity for the modeled system), which is associated with a particular point of view. What is needed to get out from this predicament is a characterization, based on a parallel reading of agro-ecosystems at different hierarchical levels. Such a characterization must result rich enough to become useful for the discussion and negotiation of policies among relevant stakeholders. This is the criterion to be used for controlling the quality of a given characterization of a farming system.

This last requirement implies an additional problem. Scientific information has to be packaged in a way that will result useful for the various agents which are in charge for decision making at different levels. As noted in Chapter 8 this implies the ability of considering in parallel the characteristics of different ***observed/observer complexes.*** In the case of farming system analysis, the **observed** are: (i) terrestrial ecosystems managed by humans; and (ii) relevant human agents. Whereas **observers** are the various interacting agents, which are both (a) acting; and (b) deciding how to act. Within this frame, humans making relevant decisions about land use are included in the complex observed/observer two times: (a) as observers and (b) as observed.

Decisions in agriculture may refer to the particular mix of crops to be produced and the selection of related techniques of production. The various complexes observed/observer, however, are operating in parallel at different scales, and they do decide, act and change their characteristics at different paces. For example, in a market economy governments can only implement their choices about the adoption of a given set of production techniques using policies and regulations. On the contrary, farmers can decide directly to adopt a given technique rather than another. In general, we can say that human agents operating within a given farming system base their decisions on:

(a) an option space (= perception/representation of the severity of constraints coming both from the ecological and the socio-economic interface);

(b) a strategy matrix (= the perceived/expected profile of non-equivalent costs and benefits associated to the various options, which is weighted and evaluated in relation to a given set of goals/wants and fears reflecting cultural values).

The couples of "option spaces" and "strategy matrices" adopted by agents operating at different hierarchical levels (e.g. governments versus farmers), are non-equivalent. As noted in Part 1, the combined use of non-equivalent couplet of "option space" and "strategy matrix" often result in the adoption of different strategies (recall the example of "more taxes", which is good for the governments and bad for farmers). This is another way to say that a generalization of a "standard" problem structuring (an optimizing model) providing a substantive definition of "optimal performance" within a farming system is impossible.

To make things more difficult, not only we should expect differences in the definition of both "option space" and "strategy matrix" when dealing with agents operating at different hierarchical levels, but also, it is normal to expect important differences in the characteristics of both "option space" and "strategy matrix" for agents that are operating in different typologies of context (meat producers in Sahel and in the Netherlands) and/or having a different cultural background (Amish and high-tech farmers in Canada). The existence of unavoidable differences in the definition of both the "option space" and "strategy matrix" for non-equivalent observers/agents will obviously be reflected into the existence of legitimate, but contrasting ***optimizing strategies*** adopted by these agents.

For example, pastoralists operating in marginal areas tend to minimize their risks by keeping a certain redundancy (= safety buffers) in their farming system even though this implies not taking full advantages of momentarily favorable situations (= a sub-optimal level of exploitation of their resources on a short time horizon). Often traditional techniques imply to chose/accept to operate in conditions that provide a return which is lower than the maximum which would be achievable at any particular moment. In this case, pastoralists are not considering "the short-term maximization of technical efficiency" as a valid optimizing criterion. Actually, the solution of "keeping a low profile" – so to speak - can increase the resilience of this system over the long period. In the long term, in fact, shocks and/or fluctuations in boundary conditions are unavoidable for any dissipative system. Therefore, the "bad performance" of pastoralists – perceived when representing their performance in terms of limited productivity on the short term, when compared with beef-lots- can be explained, when expecting future changes still unknown at the moment, by the greater ability of a redundant system to cope with uncertainty.

On the contrary, meat producers of developed countries are mainly focused on the maximization of the economic return of their activity (maximizing efficiency in relation to short-term assessment). This is equivalent to grant an absolute trust in the current definition (perception/representation) of optimization for the performance of the system of production (= maximization of output/input under present conditions). This trust is justified by the fact that when deciding about technical and economic choices the physical survival of individual members of the household is not at stake. In developed countries, in fact, the responsibility for guaranteeing the life of individual citizens against perturbations, shocks and unexpected events, has been transferred to functions provided by structures operating in the society at a higher hierarchical level (e.g. in the indirect compartment where, at the country level, one can find organizations in charge for health care and emergency relief). This is another example of how changes in the indirect compartment (more services) can affect changes in the direct compartment (more short term efficiency).

The process of ***selection of techniques and related technologies*** is also affected by the extreme variability of the characteristics of the context. That is, after deciding "what to produce" and the "how to produce it" (basic strategies) farmers have to implement these choices, at the farming system level, in the form of a set of procedures which are linked to the operation of a set of specific technologies. Again also in this case, subsistence farming is affected in this step by the existence of "location specific" constraints (e.g. techniques of food processing in the Sahel areas are not feasible in Siberia and vice versa), whereas farmers operating in developed countries can afford to use "extensive adaptation technologies" (e.g. fertilizers, pumps and machinery used in the USA can also be used in Australia or in The Netherlands).

These examples show again that deciding about the advisability and/or the feasibility of choices made by farmers at a given point in space and time is not a task that can be formalized in an established protocol to be applied to whatever farming system. Concepts such as "**feasibility**" and "**advisability**" have to be checked each time at different levels and in relation to different criteria and different dimensions of performance. This multiple check is required for every step of the chain of choices going from the definition of basic strategies for socio-economic systems (a definition that is obtained at the level of the whole society), to the final step of adoption of production technologies in a given day, at the field level. Different typologies of constraints can only be studied in relation to cultural identity, socio-political organization, characteristics of the institutional context, macro-economic variables, availability of adequate know-how in the area, available knowledge about local ecological processes, micro-economic variables affected by short-term fluctuations.

11.1.2 Farming system analysis implies a search for useful metaphors

After accepting the point that farming systems belong to the class of nested metabolic systems organized in holarchies we should expect that they are affected by the epistemological paradox discussed in Part 1 and Part 2 of this book:

(i) holons are organized according to types. this is what makes possible to make models of them; however, at the same time:

(ii) individual elements of holarchies are all special, since they are particular realizations of a type. Because of this, they have their own special history that makes them unique.

At this regard we can recall the example of Gina and Bertha discussed in Chapter 8. The 4 pictures given in **Fig. 8.1** and **Fig. 8.3** can be seen either as: (a) the same set of 4 types (girl, adult woman, mature woman, old woman) realized by two distinct individualities, or (b) two given individualities getting through a set of expected types. This distinction is important to understand the difference between basic disciplinary knowledge and applied knowledge for sustainability. For example, medicine is interested in knowing as much as possible about typologies of diseases. Relating this to the two sets of pictures shown in **Fig. 8.1** and **Fig. 8.3**, we can say that the 4 typologies are the information that matters for the development of disciplinary knowledge. On the other hand a doctor facing an emergency has to take care of patients one at the time. That is the general knowledge about types given by medicine is required to provide the physician with a certain power of prediction. However, when coming to a specific serious case, it is always the special situation of a particular patient that counts. As discussed in Chapter 4 this situation found often in medicine can be associated to the typical situations faced in the field of Science for Governance (Post-Normal Science). In these cases standard protocols cannot be applied by default. Even the best physician of the world cannot decide a therapy that implies a certain level of hazard without first interacting with the patient to get an agreement on the criteria to be adopted in the choice. Another useful metaphor which can be used to illustrate the difference of relevance of a (scientific) information based on typologies versus an information which is tailored on the special characteristics of an individual realization, is given in **Fig. 11.1.**

In the upper part of the figure there is a graph reporting the trend of suicides in Italy over the period 1980-1992. Using this set of data, it is possible to gain a certain predicting power on the characteristics of the class. For example, it is possible to guess the number of suicides in a given year (e.g. 1987) even when this particular data is missing from the original set. On the other hand, by looking at the poem given in the lower part of **Fig. 11.1** – the last words written by Mayakowsky in occasion of his suicide – it is easy to notice that the information given in the upper part of the figure is completely irrelevant when dealing with actions of individuals. That is, a data set useful for dealing with the characteristics of an equivalence class has a limited usefulness when dealing with the actions of individual realizations. Statistical information about the suicides of a given country is no good for: (i) predicting whether or not a particular person will commit suicide at a given point in space and time: (ii) preventing the suicide of that person.

The limited usefulness of information related to "typologies" for policy making is directly related to the challenge found when dealing with the analysis of farming systems. In fact, it is possible and useful to define typologies of farming systems. These typologies could be: "subsistence farming system in arid areas based on millet"; "paddy rice farming system in densely populated areas"; "high input corn monoculture on large farms"; "shifting cultivation in tropical forests". Starting from a set of typologies we can also get into even more specific typologies by adding additional characteristics (categories) to be included in the definition of the identity of the particular farming system – e.g. "Chinese farming system based on a mix of subsistence and cash crops, characterized by paddy rice and a rotation based on a mix of vegetables sold to the urban market". However, no matter how many additional categories and specifications we use for defining an identity in terms of a "typology" for the farming system under analysis, it is unavoidable to discover that as soon as one gets into a specific place, doing field work, each person, each farm, each field, each tribe, each town, each watershed is special. Moreover, to this special individualities special events are happening all the time. That is, no matter how elaborated is the label that we use to describe a given farming system in general terms, it is always necessary to deal with the unavoidable existence of "special characteristics" associated to a given situation. As discussed at length in Chapter 2 this is an unavoidable predicament associated to the perception and representation of holons, which can only be obtained, by humans, in terms of types and epistemic categories. Any characterization based on a finite selection of types, however, will cover only a part of the relevant characteristics of a real learning holarchy operating in the real world to which it refers. To make things more difficult, the validity of this coverage is bound to expire.

The consequent dilemma for the analysts is to look for a representation which should be able to achieve a sound balance between: (a) the need of adopting general types (what makes possible to learn, compress and transfer knowledge from a situation to another); and at the same time (b) addressing the peculiarity of individualities (e.g. tuning the analysis to a point that it can include the feelings of individual human systems found in the study, taking in account the special history of the investigated system).

A theoretical discussion of this dilemma can be related to the distinction, proposed by Robert Rosen, between models and metaphors when dealing with the representation of complex systems (Rosen, 1985; 1991; Mayumi and Giampietro, 2001):

Model = a process of abstraction which has the goal of representing within a formal system of inference causal relations perceived in a subset of relevant functional properties of a natural system. This subset represents only a small fraction of the potential perceptions of observable qualities of the modeled natural system. A model to be valid requires a syntactic tuning between: (a) the relation among values taken by encoding variables (used to represent changes in relevant system qualities) according to the mathematical operations imposed on them by the inferential system; and (b) the causal relation perceived by the observer among changes in the finite set of observable qualities of the natural system included in the model. That is, after having performed the calibration of a given model to a specific situation, it is possible to check the validity of such a model by checking its ability to simulate and provide predictive power [= a congruence between (a) and (b)] to those using it. As noted in Chapter 8, when dealing with the evolution (sustainability) of complex adaptive systems organized in nested hierarchies all models are wrong by definition and they tend to become obsolete in time. The seriousness of this predicament depends on the number of legitimate but non-equivalent perspectives which should be considered in the problem structuring and by the speed of becoming of: (a) the observed system; (b) the observer; and (c) the complex observed/observer.

Metaphor = the use of a basic relational structure of an existing modeling relation, which resulted useful in a previous applications, to perform a decoding step (to guess a modeling relation) applied to a situation in which the step of encoding is not possible. That is, we are using the semantic power of the structure of relations of a class of models, without having first calibrated a given individual model on a specific situation and without having measured any observable quality of the natural system about which we are willing to make inference.

Translating this technical definition of a metaphor into more plain words, we can say that a metaphor makes possible, when studying a given system at a given point in space and time, to infer conclusions, guess relations, gain insights, only by taking advantage of analogies with other systems about which we have preliminary knowledge. Therefore, metaphors make possible to use previous experience or knowledge to deal with a new situation. A metaphor to be valid must result useful when looking at a given natural system for the first time in our life, to guesstimate relations among characteristics of parts and wholes which can be associated to systemic properties, even before interacting with the particular investigated system through direct measurements. From what said so far, we can say that in order to generate a useful metaphor we have to be able to share the meaning assigned to a set of standard relations among typologies and expected associative contexts. According to this definition the 4-angle figures given in **Fig. 11.2** and **Fig. 11.3** are examples of metaphors.

When coming to farming system analysis the use of metaphor should make possible to apply lessons learned when studying a farming system producing millet in Africa to the solution of a problem of corn production in Mexico. A metaphor can be used to define the performance of a given system in relation to a given criterion of performance (e.g. when assessing the trade-off of efficiency versus adaptability) but using a set of variables (a definition of indicators) which is different from the set adopted in a previous study (e.g. when applying general principles learned about milk production to aquaculture). In order to be able to do that, however, the analysts have to frame their analysis in a way that generate relational patterns within a system which share a certain similarity with other relational patterns found in other systems. When looking for useful metaphors the local validation of individual models obtained using sophisticated statistical test ($P^* = 0.01$) is beside the point. The accuracy of prediction associated to a given model in a given situation does not guarantee the possibility of exporting the validity of the relative basic metaphor (within which the model has been generated) to other situations. When moved to another situation the same model can loose either relevance or predictive power or both. Therefore, the real test of usefulness is whether or not a given set of functional relation among system qualities - indicated as relevant within the metaphor – will actually result useful in increasing our understanding of other situations.

In this sense, impredicative loop analysis provides a common relational analogy (a typology) of self-entailment among the values taken by parameters and variables – used to characterize parts and whole - within a standardized representation of autocatalytic loops (see **Fig. 9.1**). This relational analogy over autocatalytic loops can be applied to the analysis of the metabolism of different systems (see **Fig. 7.14**) using different choices of representation of such a metabolism. By adopting the approach proposed so far, this translates into a selection of: (a) variables used to characterize flows (e.g. the characterization of size as perceived from the context - selection of Extensive Variables #2 – e.g. food energy, solar energy, added value, water, exosomatic energy); and (b) variables used to characterize the black box (e.g. the characterization of size as perceived from within – selection of Extensive Variable#1 – e.g. human activity, land area, kg of biomass).

In conclusion, in order to face the challenge associated to an integrated analysis of agro-ecosystems across hierarchical levels we should base our representation of performance of farming systems on useful metaphors (classes of meta-models), rather than on specific models. This requires developing a tool kit made up of a repertoire of tentative "problem structurings" which have to be selected and validated in relation to a specific situation before getting into a more elaborated analysis of empirical data. This preliminary selection of useful typologies, relevant indicators and benchmarking of expected ranges of values for the variables, will represent the basic structure of the information space used in the analysis. After having validated this basic structure in relation to the specificity of the given situation, the analyst can finally get into the second phase (based on empirical data) of a more detailed investigation.

11.1.3 A holarchic view of Farming Systems (using throughputs for benchmarking)

The viability and the vitality of holarchic metabolic systems can be checked in relation to two non-equivalent categories of constraint:

(a) internal constraints --> constraints associated to the characteristics of the identities of lower level components of the black-box. Internal constraints do limit the ability of the system to increase the pace of the throughput (the value taken by Intensive Variable#3). This limitation can be associated to: (i) humans values expressed at lower level; and (ii) (un)capability of providing the required amount of controls for handling and processing a larger throughput. The presence of these constraints translate into a set of limitations of the value that can be taken by the different variables used as I.V.#3, when characterizing the throughput at the **level *n***. Beside the existence of cultural curtaining on human expansion into the environment due to ethical reasoning (e.g. as in the case of Buddhists or Amish), technical bottlenecks (shortage of technical devices) can prevent a socio-economic element from handling more power (e.g. reaching higher values of EMR_i). We can describe this internal technical limitation as the (un)ability to generate more goods and services in the working compartments (reaching higher values of BPL_i) even when additional input and sink capacity would be available. In economic terms we can describe an internal constraint as the (un)ability to generate more added value per unit of labor (reaching higher values of ELP_i). Within an economic discourse internal constraints are in general related to shortages of various forms of human-made capital (e.g. technology or know-how).

(b) external constraints --> constraints associated with the characteristics (the weak identity) of the environment – **level *n+1***. As noted in the technical section of Chapter 7 the required admissibility of boundary conditions for the black box can be seen as a weak identity assigned to the environment, which is supposed to supply – by default - a certain flow of inputs and absorb the relative flow of wastes to the metabolic system. External constraints are those limiting the value which can be taken by the extensive variables used to characterize the size of the metabolic system (the carrying capacity of the context so to speak). In terms of input and output this refers to a limit on: (a) the available input that can be appropriated from the context over a given period of time; and (b) the sinking capacity of the context (a limited capability of absorbing the wastes associated to the given metabolism of the black box). Put in another way, external constraints entail a limit – referring to the selection of the Extensive Variable#2 and in relation to Extensive Variable #1 - on how big can be the metabolism of the black box in relation to what is going on in its context. Within this representation, external constraints can be characterized – after having selected EV#1 and IV#3 - in terms of the resulting availability an adequate supply of inputs (EV#2) and to the possibility to safely dispose of the relative flow of wastes.

The existence of these constraints is often ignored by neo-classical economists, that assume that economic systems will always be able to replace or substitute limiting resources or limiting environmental services thanks to their ingenuity. Put in another way, an economic narrative tends to neglect the existence of external constraints. Some economists admit that external constraints may exist, but because of the assumption of moderate scarcity (= the economic version of the biophysical default assumption of admissibility of boundary conditions), they are never considering them as ultimate constraints. In economics the potential role of external constraints is accounted for in terms of availability and quality of natural resources and environmental services. Also when coming to the definition of external constraints in biophysical terms, we get into a slippery territory. In fact, the very concept of "weak identity" for the environment, implies acknowledging an unavoidable level of ignorance in the real definition of these constraints (it is impossible to predict all the possible mechanisms of incompatibility with ecological processes that should be included in such an evaluation).

It should be noted that any assessment of external constraints (the limit that ecological processes operating at the **level *n+2*** can imply on the stability of favourable boundary conditions of socio-economic processes considered at the **level *n+1***) would require the ability to compare: (a) the biophysical size of the metabolism of socio-economic system (using the same set of variables for EV#2); to (b) the biophysical size of the metabolism of the ecological system in which the metabolism of socio-economic systems is occurring (using a set of variables for EV#2). Such an analysis would require the study of the nature of the interaction of these two processes of self-organization and the relative interference that the metabolism of socio-economic processes implies over the metabolism of ecological systems. That is, the analysis should study how the value taken by EV#2 used to characterize the size of the socio-economic system affect the value taken by EV#2 used to characterize the size of the ecological processes guaranteeing the stability of boundary conditions. Coming to the possible selection of a mechanism of mapping useful for comparing the relative size of these two self-organizing systems, it becomes obvious that such an assessment cannot be done from within a descriptive domain provided by economics (e.g. when adopting as Extensive Variable#2 - added value). In fact, a monetary variable reflects the representation of the perceptions of "usefulness" for human observers/agents which are interacting within a structured economic process (a view from within). That is, assessments of flows of added value (the relative variable is a proxy of the monetary value associated to perceptions of the of the utility of exchanged goods and services) refer only to the equivalence class of transactions occurring within a given economic process characterized in terms of a specified market, preferences and institutions. This mechanism of mapping of exchange values within a given market (the system quality measured by monetary variables) **does not**, and **cannot** account – when considered as an Extensive Variable#2 - for the perception of the size of the black box (= the socio-economic system) from the outside by those observers/agents determining the identity of ecological systems (Giampietro and Mayumi, 2001; Mayumi and Giampietro, 2001). Put in another way, monetary variables are crucial to check the compatibility of the characteristics of socio-economic system at different levels with human aspirations expressed by elements operating within human holarchies (the economic and socio-economic viability of solutions for the various human elements making up a farming systems). However, monetary variables are not relevant for assessing the ecological compatibility. What humans are willing to pay for preserving trees has nothing to do with the determination of the threshold of interference on the natural mechanisms of control of a terrestrial ecosystem, which can imply a collapse of its integrity (recall the discussion about **Fig. 10.15**).

The impossibility of using a descriptive domain based on an economic narrative for performing an analysis of ecological compatibility should not be considered as a problem. As discussed in previous chapters, when adopting a multi-criteria framework, there is not need to collapse non-equivalent descriptive domains into a unique cost-benefit analysis to deal with integrated analysis of sustainability.

In conclusion, the analysis of internal constraints of a socio-economic system deals with the perception and representation of feasibility of humans operating from within the black box. Such an analysis refers to processes and mechanisms about which the only relevant observers and agents are humans. On the contrary, the analysis of external constraints should necessarily deal with perceptions and representations obtained from outside the black-box. In this case, there are also perceptions and representations adopted by non-human observers and non-human agents (those operating within ecological processes) that count. These perceptions and representations are used by ecological agents which are interacting when generating the process of self-organization of ecosystems. This can seem a trivial consideration. However, this is a consideration which implies that a substantive representation of the metabolism of human societies "from the outside" cannot be obtained. Humans can only perceive and observe them-selves from within their cultures and their social structures. Processes which are operating outside the black-box are determined by decisions taken by non-equivalent observers and agents (elements of ecosystems), which are not sharing their meaning with us. Therefore the mechanisms regulating these processes can only be partially known by humans. To make things worse, many human agents, which are relevant because of their decisions, represent always an unknown context of other human agents.

Within this frame, farming system analysis is location specific by default. Therefore, it is unavoidable to expect a large dose of uncertainty and ignorance about how to perceive and represent the role of external constraints, when deciding about how to structure sustainability problems. Using as example the well known scientific debate over the sustainability of human progress, there are scientists/observers that do not see any future problem of sustainability for humans. Some of them (the so-called cornucopians) imagine as possible an unlimited adjustment of boundary conditions (the characteristics of ecological processes and the cultures of other human systems) on their own cultural definition of what human systems should be. This is at the basis of the myth of technological fix. Technology will give immortality to humans both to current individuals (e.g. through clonation) and to current civilization (e.g. through a continuous supply of silver bullets). On the contrary, other scientists/observers (the so-called prophets of doom) see no hope for sustainability since at the moment there is no known solution to accommodate existing trends of evolution of the characteristics of socio-economic systems (expected changes in population and expected standard of living) within the room allowed by the compatibility with ecological processes. A third group of scientists/observers (that we could call, the hyper-adaptationists . . .) imagine as perfectly acceptable and feasible a heavy and dramatic re-adjustment of the characteristics of human systems to less favourable boundary conditions – e.g. back to caves and human muscles, when environmental services will be in shortage, with or without much troubles. Obviously, nobody can decide, in a substantive way, who is right and who is wrong, in this debate. In reality all these positions just reflect non-equivalent definitions of the original problem structuring used for characterizing sustainability.

For this reason, when dealing with integrated analysis of sustainability it is important to characterize and handle in an integrated way and simultaneously the various pieces of the puzzle. It is crucial to focus the discussion on a shared meaning given to the problem structuring. Sustainability, when framed within the metaphor of holarchic metabolic systems has to do with the ability to maintain the compatibility across levels of different set of identities associated with equivalence classes of organized structures (which in turn can be associated to characteristic metabolic patterns) making up the various nested holons. This requires a chain of compatibility between the established mechanisms operating inside the black-box (the metabolism of structural lower level elements) and the set of identities associated to the maintenance of stable boundary conditions on the interface black-box/environment (the essences associated to the validity of relational functions expressed at higher levels) across levels. As noted in Chapter 7 the simultaneous validity of identities of elements of metabolic holarchies requires the forced congruence between the characteristics of processes occurring within the black-box and the characteristics of processes occurring outside the black-box, which are required to guarantee a stable associative context to those metabolic patterns. This reciprocal constraining of characteristics between lower level and higher level is at the basis of impredicative loop analysis. An analysis of these characteristics can result very useful in farming system analysis.

11.1.4 Benchmarking to define farming system typologies

The concept of benchmarking in the context of ILA translates into the characterization of a given typology of farming system in relation to the selection of: (a) a set of extensive and intensive variables; and (b) an integrated set of typologies of activities (investments of human activity or land in relation to densities of flows) that can be used to establish a relation between the characteristics of parts and the whole. An ILA implies looking for a forced relation over the loop associated to a dynamic budget and the pace of a given throughput. An examples of the rationale of this approach is given in **Fig. 10.1**. There the two non-equivalent definitions of throughput (assessed using food as EV#2) are (i) productivity per hectare of investment of total land (EV#1) in the typology "land in production"; and (ii) productivity per hour of investment of total human activity (EV#1) in the typology "agricultural labor". These two definitions of throughput are applied at two hierarchical levels: (1) at the field level. This translates into an assessment which reflects technical coefficients; and (2) at the level of the whole country. This translates into an assessment that refers to demographic and bio-economic pressure perceived and represented at the level of the socio-economic context in which the farm is operating. This comparison of the value taken by the two non-equivalent definition of IV#3 at different hierarchical levels makes possible to compare the relative compatibility of the typologies (defined on two hierarchical levels: the field level and the country level) both associated to this throughput (**Fig. 10.2**). The rationale of this approach has been discussed using theoretical examples of analysis of metabolic systems (the relation between the characteristics of organs and the whole body) in **Fig. 6.1** and **Fig. 6.2** and in theoretical terms in Chapt.7.

Getting more into the details of Impredicative Loop Analysis, we can say that this approach makes possible to establish a relation between the values taken by a set of Intensive Variables#3 used to characterize a given farming system at different levels (e.g. at the level of individual households and/or at the level of a village) and the values taken by the same set of Intensive Variables#3 used to characterize the socio-economic context within which this farming system is operating. The same can be done in biophysical terms when comparing densities of matter flows against land area. This has been discussed in **Fig. 9.1**, **Fig. 9.2** and **Fig. 9.3**. Here we want to discuss more in detail this feature in relation to benchmarking, that is the characterization of a range of values expected for indicators, which can be associated to the identity of a typology of farming system. To introduce the basic rationale we can use two generic ILAs referring to a generic socio-economic entity (either a household or a village) belonging to a given farming system - **Fig. 11.2** and **Fig. 11.3**.

The analysis of **Fig. 11.2** is based on the adoption of assessments of flows of Added Value used as E.V. #2 which are represented in the loop in relation to a given set of typologies of possible human activities

(activities assumed to be typical of the considered farming system):
* **Fig. 11.2a - E.V.#1 = profile of investments of human activity** - This analysis of the impredicative loop starts with a given size of the entity expressed in terms of human activity –E.V.#1 (the size of either the household or the village is expressed by this variable in terms of hours. The reader can recall that THA reflects the number of persons making up such an entity). Then, by using added value as E.V.#2, the 4-angle figure represents on the axis on the right, the level of economic interaction of this entity with its context (the total added value generated and consumed in a year by the household or the village). This represents, at this level of analysis, the equivalent of the total GDP assessed at the level of the country. The peculiarity of his system of accounting should be recalled here once again. Even though we are calling this an extensive variable determining the "size" of the system. This variable indicates the amount of added value produced and consumed per year by this entity when interacting with its context (it indicates an amount of added value per year). At this point we can calculate an Intensive Variable#3, which is characterizing the throughput of the metabolic holon/household (or holon/village) in relation to its higher level holon-country. This I.V.#3 represents the flow of added value per hour of human activity (or per capita per year), which can be associated to the particular typology of household or village characterized with this ILA. An assessment of an I.V.#3_m makes possible to compare the characteristics of the farm/household (at the **level *m***) with the larger holon within which it is operating. For example we can define a I.V.#3_{m+1} for the village to which the household type belongs, and a I.V.#3_{m+2} for the province to which the village belong, and a I.V.#3_{m+3} for the country to which the province belong. Assuming that the village is the **level *m+1***, the province is the **level *m+2*** and the country the **level *m+3***. In this way, the value of the intensive variable "$/hour" can be used to characterize the performance of the economic metabolism of an element defined at the **level *m*** (in this case a household) against the average value of "$/hour" of the village in which the household is embedded at the **level *m+1***. In turn the village can be assessed against the average "$/hour" of the province at the **level *m+2***. In the same way the province can be benchmarked against the values found in the country (recall here the discussion about **Fig. 6.1** and **Fig. 6.2**) at the **level *m+3***. In this way, we can characterize a special household type as being richer than the average found in its village (a local optimum). But at the same time, the analyst can be aware that this local optimum represents a very bad performance when compared with the average of the country. In this way, such an analysis can provide in parallel the big picture (the existence of huge differences related to differences in boundary conditions at the village level) and local fine grain resolution (the ability to deal with small differences that still counts - at the local level – within the village).

Depending on the goal of the analysis the analyst has to select an opportune set of benchmark values to be used in the problem structuring, when reading the performance at different scales and in relation to non-equivalent indicators. The right selection of a benchmark value is crucial. If we adopt an indicator of economic labor productivity tailored (in the step of representation) on average values obtained by Dutch farmers (with ELP in the order of tens US$ per hour) we would not be able to detect even differences of 100% in the ELP in a farming system in Laos. In fact such a change would occur in a range of values expressed in cents of US$.

* **Fig. 11.2b - E.V.#1 = profile of investments of land area** – Another Impredicative Loop Analysis is provided in the lower 4-angle figure, but this time the pace of flows (E.V.#2 is always added value) is mapped against land area. Also in this example it is possible to establish a bridge between different dimensions of analysis. On the vertical axis, we can characterize how the demographic pressure is determining the total available land of this entity. Then, in the upper left quadrant, we can characterize the decision made – let's imagine now to describe the system at the village level – in relation to the Ecological Overhead on Available Land. That is, the angle EOAL, can be defined as the difference between Total Available Land – TAL - and the Colonized Available Land – CAL. This difference is determined not only by the existence of a biophysical overhead (= the fraction of available land that cannot be colonized by humans because of severe biophysical limitations), but also because in general

there is a fraction of "disposable available land area" – so to speak – that is not used for production. This fraction is in general set aside to preserve the diversity of habitats and ecological processes (e.g. natural parks, religious sites). Finally, the lower right quadrant, characterize the saturation index of CAL. That is, what fraction of Colonized Land is used for land uses alternative to agricultural production. The drive toward higher levels of economic activity (associated to an increases in bio-economic pressure) tend to increase the saturation index. This means that to assess this saturation index we have to aggregate typologies of land use within two categories: (a) alternative to agriculture; and (b) associated with agriculture. They both are competing for the same fraction of TAL which is invested into CAL. Therefore, the profile of investments of hectares of CAL over this set of possible land use typologies will determine a complex set of trade-offs. For example, using a larger fraction of CAL for supporting industrial activities can increase the density of added value per unit of area, but it can generate also higher environmental impact through pollution and reduce the internal supply of food. The same analysis can be applied to the mix of typologies of land use adopted within the direct sector. When considering the flow of produced food as E.V.#2, the direct sector becomes LIP (Land In Production). For example, a large investment in the typology high input monoculture - associated to larger yields per hectare - imply a reduction of the requirement of land in production per unit of throughput (the number of hectares required to generate a given internal supply of food input). In terms of trade-offs high input monocultures can imply a higher level of interference with terrestrial ecosystems and a larger dependence on fossil energy for the internal supply.

Again, this is just an overview of this approach and it is no time to get into specific analyses. The main point to be driven home in this section is that an integrated use of non-equivalent ILAs can make easier to deal with multifunctional land uses. Recall here the example of multifunctional land use analysis described in the lower part of **Fig. 6.2**. If a Japanese farmer decide to invest a few hectares of her/his farm land to establish a driving range for practicing golf. With this approach we can characterize how 1 ha of the typology of land use "golf driving range" generates a density of added value which is much higher (of several times) than that of 1 hectare of intensive production of rice. On the other hand, such a choice will not provide any internal supply of rice for Japan. The resulting overall set of trade-offs will depend on the indicators chosen to characterize this choice (the problem structuring chosen by the analyst to characterize and compare the two options).

For this reason it is important to generate an integrated mix of ILAs able of tracking changes in relation to non-equivalent indicators, which can be linked to a multi-criteria analysis. For example the two 4-angle figures given in **Fig. 11.3** are perfectly similar to the two 4-angle figures illustrated in **Fig. 11.2**. The only difference is related to the selection of E.V.#2, which in this case is food. Human Activity is used as Extensive Variable#1 in **Fig. 11.3a**, whereas Land Area is used as Extensive Variable#1 in **Fig. 11.3b**. As observed before, the intensity of the throughput assessed by I.V.#3 at the level of the household or the village can be compared to the average value found in the society in which the farm is operating.

By assessing differences and/or similarities among: (1) the characteristics of lower level elements – e.g. technical coefficients, economic characteristics – which can be associated to the set of activities used to represent the profile of investments of human activity and the set of land uses used to represent the profile of investment of land area; and (2) the characteristics of the system as a whole (the value taken by EV#1 and EV#2 at the **level *n***); it becomes possible to generate indicators characterizing the performance of different types of households and/or villages.

The common metaphor shared by the 4-angle figures shown in **Fig. 11.2** and **Fig. 11.3** makes possible to use the average characteristics of the system under analysis - defined at the focal **level *m*** - as indicators. When considering a farm in this analysis, an useful indicator can be obtained by the value of the variable "income per capita" - \$/hour – I.V.$\#3_m$, which is associated to the angle in the upper right quadrant. This indicator is comparable with the indicator used to assess the performance (in relation to the same criterion) of the larger socio-economic element to which the farm belongs (the larger context, which can be used as benchmark to characterize the performance of the household)– the average GDP p.c. –> I.V.#3$_{m+1}$. At the same time, lower level characteristics – the economic labor productivity of the direct compartment of human activity (= related to the mix of activities in which the household invest labor to generate added value) – can be analyzed and characterized using the same variable I.V.#3$_{m-1}$.

All these indicators can be related to the characteristics of the same Impredicative Loop applied at various levels. That is, the pace of throughput of added value per unit of human activity (the level of $/hour in the upper right quadrant - I.V.#3$_{m}$) can be related to: (a) the fraction of human activity lost to Physiological Overhead on Human Activity – how much THA cannot be considered as Disposable Human Activity, because of age structure, sleep and other activity dedicated to personal maintenance (the upper left quadrant); and (b) how much of the Disposable Human Activity is invested in activities generating added value versus alternative activities (the angle in the lower left quadrant). Finally, within the direct compartment dealing with the internal generation of E.V.#2 we can still focus on the characterization of: (i) the set of possible options/tasks (in this case possible investments of human activities in performing different tasks associated to the generation of added value); and (b) the actual profile of investments of human activity, within the direct compartment, over this set of possible options/ tasks. That is, when adopting this approach, the average Economic Labor Productivity of labor in the direct compartment - I.V.#3$_{m-1}$ – can be expressed as a function of the average economic return of each of the possible tasks defined at the lower level (I.V.#3$_{m-2}$) and the profile of investment of human activity chosen by the farmer over this set of tasks.

The values taken by the variables used to characterize the loop in the various quadrants do reflect key characteristics of the system on different hierarchical levels. These characteristics in turn are associated with the identity of typologies that can be compared with other typologies found in different farming systems in different contexts. To make things more interesting, with ILA it is possible to look at the congruence (or lack of congruence) between: total consumption and internal production. The resulting assessment (an internal supply which is larger, equal or smaller of the total demand) can be used as an additional indicator. In this way, after having determined how an individual household is doing, in terms of metabolism, in relation to his larger context (an assessment related to the total consumption of EV#2), we can also look at the various processes generating the internal supply in the compartment defined as direct (according to the choice of variable for the assessment of EV#2). In this way, we can individuate limiting factors (different bottlenecks in relation to different dimensions) on the internal supply in relation to different definitions of flows (e.g. added value, food).

In the case of economic reading, it is possible to do a benchmarking by comparing the level of ELP***m*** achieved in the element considered in this analysis (the average return of labor of the farm under analysis) against the average value found in the socio-economic system in which such an element is operating (ELP***m+1*** that is, the average return of labor of the society within which the farm is operating). This value can also be used to compare the average return of labor of the farm under analysis with the average economic return of other farms belonging to the same typology of farm or rural village (remaining within the level ELP***m***). This will indicate how special is this farm in relation to the typology to which is supposed to belong.

By moving at the level ***m-1*** we can characterize the average economic return of labor referring to individual techniques of production (or tasks) over which working hours are invested in this farming system (ELP***m-1***). That is, we can explain the value ELP***m*** using our knowledge of lower level characteristics [ELP***m-1***]$_i$. In the same way, we can also compare the various economic returns of individual tasks (e.g. the added value generated in a working hours in producing rice, aquaculture, flower production) within the average values found for the whole farm, at the level m-1. That is, with the average return of labor obtained for the same set of tasks in other farms belonging to the same farming systems or even to farms belonging to different farming systems. In this way, the effects and the constraints associated to changes in bio-economic pressure (from **Fig. 11.3a**) and demographic pressure (from **Fig. 11.3b**) at the level of the whole country can be understood and linked to changes in boundary conditions perceived and represented at the level of the farm.

At this regard, we want to recall and comment again three examples of ILA, which have been briefly discussed in Chapter 7. These three examples are applications of ILA aimed at investigating the existence of bottlenecks and biophysical (external) limits for a particular characterization of a dynamic budget associated to the metabolism of farming systems.

* **Fig. 7.14** - an ILA of the dynamic budget of Net Disposable Cash – at the household level - based on Land Area as E.V.#1 and Added Value as E.V.#2 -. This example points at the critical shortage of available land in relation to the relative required flow of added value for the rural household type considered. That is, according to the identities of "land use types" found in this farming system and the profile of distribution of CAL over these "land use types" this rural household type does not have enough land in production (size of LIP) to cover not even a significant fraction of the required flow of Net Disposable Cash.

* **Fig. 7.15** - an ILA of the dynamic budget of Net Disposable Cash – at the household level – based, this time, on Human Activity as E.V.#1 and Added Value as E.V.#2 -. This ILA is based on a characterization of the set of lower level typologies of investment of human activity that are included in the direct compartment. In this analysis, the direct compartment includes investments of human activity in tasks generating Added Value. In this case, not all the activities generating flows of added value require the availability of a relative amount of land in production. It is only, because of the option to perform this additional set of tasks (independent from land) that it is possible, for this type of rural household, to generated an adequate internal supply of Net Disposable Cash. At this point, it is the average Economic Labor Productivity of this household type which is the most relevant parameters. In presence of very severe shortages of land, the average ELP is mainly determined by the average economic return of tasks performed in the off-farm compartment (e.g. off-farm wages). Actually, the particular profile of investments of the resource Human Activity over the set of options considered in the Working compartment can be used to label this typology of rural household. Off-farm rural household are those households that are investing in the category "off-farm activities" a fraction of their investment of human activity in Working, which is higher than the fraction invested in "on-farm activities".

* **Fig. 7.16** - an ILA of the dynamic budget of food – at the household level – applied to shifting cultivation in Laos at different speeds of rotation (i.e. 3, 5 and 10 years) – which is based on Land Area as E.V.#1 and Food as E.V.#2. This ILA has been used to detect a constraint of a different nature (a non-biophysical one) which enters into play because of an increase in demographic pressure. In this system, a higher demographic pressure makes more difficult to maintain the coherence in the reciprocal entailment of identities (of parts and wholes) which would be required in order to maintain coherence over the pattern of shifting cultivation operating over a 10-year time window (for more details see the discussion given there).

In general terms, we can say that different mixes of ILAs based on two choices of E.V.#1 (both "Human Activity" and "Land Area") and two choices of E.V.#2 (both "Added Value" and "Food") can be used to characterize in agricultural systems the (lack of) congruence between: (a) total requirement; and (b) internal supply at which the particular entity is operating. This check can be used to develop indicators and to characterize the particular role (e.g. related to a particular definition of E.V.#2) that the entity plays within the food system. Households producing much more food than that consumed are households of farmers, whereas households producing less food than that consumed are just rural households. By using this distinction we can find either rich farmers or poor farmers depending on the level of added value consumption that the household manages to stabilize in time. In the same way we can find, well nourished rural household and malnourished rural household looking at the flow of nutrients that a household manage to stabilize in relation to the requirement.

An example of several ILAs performed in parallel is shown in **Fig. 11.4**. The one indicated in **Fig. 11.4a** can be used to check the internal supply in relation to total demand of food. This analysis is useful to determine the degree of coverage of food in terms of subsistence. In the same way, another ILA – **Fig. 11.4b** - can be used to check the internal supply of Net Disposable Cash in relation to the constraint represented by land. This analysis provides an indication of the existence of a bottleneck associated to the requirement of land (given the existing characterization of the possible set of activities generating added value in crop production). The ILA represented in **Fig. 11.4c** indicates that even if the bottleneck of land were not there, the considered set of farming activities (determining the average return of labor - $/hour - associated to the given mix of produced crops – I.V.$\#3_{m-1}$) would be, in any case, not enough to support the flow of Net Disposable Cash required. The requirement of NDC is determined by the typology of consumptions associated to the characterization of household life style obtained in the upper right quadrant (the flow of Net Disposable Cash per capita per year – I.V.$\#3_{m}$). In this example, the set of ELP $_i$ associated to the set of agricultural activities would be too low to make these farmers rich. That is, even if an adequate amount of land would be available to saturate all the available internal supply of working time (no external constraints), this particular selection of lower level activities (mix of crops produced and relative technical coefficients and economic variables) implies the existence of an internal constraint on the flow of added value that can be produced in this way.

When we consider these three ILAs in parallel we can appreciate the existence of a clear trade-off which is reflected by the relative changes in the two indicators: (i) degree of internal coverage of food security with subsistence crops, versus (ii) level of internal generation of Net Disposable Cash from agricultural activities. In fact, a larger fraction of the Land In Production which is allocated to subsistence crops (to obtain a better coverage of subsistence need) will be reflected in a smaller fraction of LIP that can be allocated in generating Net Disposable Cash. The terms of this trade-off can be analyzed (using the trick discussed in **Fig. 7.14**), by including in the analysis (as an additional reduction of LIP) the amount of land lost to buy technical input to boost the production of crops, both for subsistence and cash. At this point, in order to analyze the technical aspects of this trade-off one can analyze how lower level characteristics (e.g. technical coefficients) related to the productivity of land and labor for both subsistence and cash crops will affect each other, when considering different options. An example of this analysis is illustrated in **Fig. 11.4d**. This relation will be discussed more in detail later on (**Fig. 11.9**).

An integrated sets of indicators to characterize the performance in relation to non-equivalent descriptive domains (using these multiple parallel non-equivalent readings) is given in **Fig. 11.5**. This figure is based on a radar diagram containing different axes. The various indicators associated to these axes are aggregated in 4 quadrants over 4 categories:

NORTH – Intensive variables (return on investment).

This set of indicators of performance is based on a list of output/input ratios reflecting a choice of variables relevant for characterizing the performance of the system. In semantic terms, this section deals with the "return" (the output) on an "investment" (the input). These inputs are called within the economic narrative "production factors". According to the approach presented so far, assessments framed in terms of "return on investment" can be considered as members of the semantic class of I.V.#3 variables. In particular in the selection given in **Fig. 11.5** we included:

- Produced Output per hour (e.g. kg/hour) - biophysical narrative: biomass output per unit of investment of human activity in agricultural labor.
- Produced Output per hectare (e.g. kg/ha) - biophysical narrative: biomass output per unit of investment of Land In Production.
- $ Output/hour (e.g. US$/hour) – economic narrative: added value generated per hour of agricultural labor.
- $ Output/hr (US$/ha) – economic narrative: added value generated per hectare of Land in Production.
- Produced Output per unit of consumed fresh-water (e.g. kg/kg) - biophysical narrative: biomass

output per unit of consumption of available fresh-water.

- Produced Output per unit of consumed fresh-water (e.g. US$/kg) – economic narrative: added value generated per unit of consumption of available fresh-water.
- Produced Output per unit of consumed fossil energy (e.g. kg/exoMJ) - biophysical narrative: biomass output per unit of consumption of fossil energy input.
- Produced Output per unit of consumed fresh-water (e.g. US$/kg) – economic narrative: added value generated per unit of consumption of available fresh-water.
- Economic Return On Investment (e.g. US$/US$) – economic narrative: economic return per unit of economic investment

SOUTH – Extensive variables – Total requirement of investment

These indicators represent the extensive variables associated to the intensive variables considered in the previous list.

- Total Work Supply (hours of human activity invested in agricultural work per year) – This is total amount of working hours which is required to run the given entity (e.g. a farm or a village) at a viable productivity level.
- Total Land in Production (hectares of land area controlled by the entity invested in production) – This is the total amount of hectares required to run the given entity (e.g. a farm or a village) at a viable productivity level.
- Total Freshwater consumption (cubic meters of fresh-water consumed by the entity in a given year to obtain the given biomass production) – This is the total amount of fresh water consumption required to run the given entity at a viable productivity level.
- Total Fossil Energy consumption (based on one of the possible assessments of Giga-Joules of fossil energy embodied in the technical inputs consumed by the entity in a given year to obtain the given biomass production) – This is the total amount of fossil energy required to run the given entity at a viable productivity level. This can be assumed to be a proxy of the technical capital requirement.
- Total Economic Investment (based on one of the possible assessments of the requirement of capital - fixed and circulating) – This is the flow of capital required to run the given entity at a viable productivity level.

Before getting into an analysis of the two set of non-equivalent indicators included in the other two quadrants it is important to pause a moment for some considerations. The values taken by the two sets of indicators in the North quadrant and in the South quadrant can be interpreted using the metaphor of the 4-angle figures. Within that frame, they are assessments that refer to: (i) angles (those belonging to the family of "returns on the investment"); and (ii) lengths of segments defined on axes (those belonging to the family of "total requirements of investment"). Because of this fact, the two set of values taken by these two sets of variables **are not** and **cannot considered** as independent. This trivial observation is particularly relevant when considering - as indicated in the orange box in the bottom of the figure – the huge differences that can be found when characterizing in this way – in terms of benchmarks - different farming systems in the world. Examples of ranges of values of the IV#3 - level of capital requirement per worker - are given on the left (expressed by adopting both an economic and a biophysical narrative). The two assessments on the right are related to the different degree of conditioning of the context in terms of existing levels of: (i) demographic pressure (societal average of land in production per worker); and (ii) bio-economic pressure (societal average of labor productivity). The relative differences between possible values found in the feasibility range are in the order of hundreds times. Actually, when coming to the economic narrative, which is more sensitive at human perceptions of gradients of usefulness, we arrive at a range of differences which is in the order of a thousand times. In relation to the analysis of biophysical constraints (both external and internal), we can see that a level of labor productivity of hundreds of kg of grain per hours (a threshold value that, within developed countries, translates into rich farmers and a work force which is mainly allocated to the operation of the industrial and service sectors) requires an amount of land per workers, which must be, at least, in the two digit-range in terms of number of hectares. To make things worse, the heavy mechanization of agriculture associated to western models of production, not only requires a large amount of LIP per worker, but also the possibility to invest huge amount of financial resources in the agricultural sector. On the other hand, in spite of this high requirement of capital per worker, not always the agricultural sector is able to reach the same level of Economic Return on the Investment reached by other economic sectors (especially in an era of globalization).

These are well known considerations in the field of farming systems, however, the link between the value taken by the variables represented in the quadrant North and the value that can be taken by the variables represented in the quadrant South is often neglected by those working in technical development of agriculture. A few analysts seem not to be aware that whenever we start with less than 1 hectare of land in production per worker, there is very little that can be done to increase the labor productivity of farmers (that is, their economic performance). Especially, if these farmers are also required to produce (at a high level of demographic pressure) food for themselves and to pay taxes in top of that. **When facing a major biophysical constraint** (a crucial shortage of LIP) **and when experiencing a growing gap in the consumption level of the household in comparison with the socio-economic context** (= when farmers feel that they are remaining behind in the process of economic development occurring in the socio-economic system to which they belong), **farmers will stop investing a large fraction of their resources to the optimization of agricultural techniques.** Rather, they will start looking around, **that is outside their farm,** to diversify their investments of "human activity" and "land area" looking for a mix of economic activities and land uses **that includes also agricultural production.** In this case, the decision about how to use available resources to farm is determined according to a multi-criteria evaluation of performance, in which the agricultural production is evaluated in relation to non-equivalent definitions of costs (and cost-opportunities) and benefits (and benefit-opportunities). In this situation, keeping the focus of the analysis on a standard agronomic definition of performance (= the optimizing goal are linked to a continuous increase of the productivity of production factors) it is not always a wise choice. On the other hand, this optimizing goal still represent the basic assumption used to justify the transfer of production technologies developed within developed countries (high-input, high capital agriculture) to farming systems operating in socio-economic and ecological contexts in which these technologies do not make any sense.

Let's now get back to the analysis of **Fig. 11.5**. On the two quadrants indicated as East and West we included, in this example, two sets of indicators referring to a characterization of such a system in relation to the ecological dimension. Obviously, we could have included in these two quadrants other indicators related to the compatibility with the socio-economic dimension, as will be illustrated later on in different examples.

EAST - Indicators assessing local environmental stress

Such a list, in this example, must be necessarily very generic. As discussed several times so far, it is not possible to indicate "a sound list" of indicators of local environmental stress in general terms. Therefore, since the special characteristics of the entity considered in this analysis have not been specified we cannot indicate what should be considered as a valid selection of indicators. Just to make possible to indicate in the graph a set of generic indicators we are assuming that this integrated analysis is related to a farming system producing grains. The list in this quadrant, for the moment, has the only goal of preserving the general overview obtained with this approach (an example of a real selection of indicators, referring to real systems is given in **Fig. 11.6**).

- Soil loss

- Nitrogen load into the water table
- Indices based on spatial analysis – e.g. vegetal diversity assessed on grids at different scales, an assessment obtained through remote sensing.
- Indices based on spatial analysis – e.g. fractal dimension (ratio perimeter/area) of LIP, an assessment obtained through remote sensing.
- Index related to pesticide use

WEST – Indicators of techno-boosting (system openness)

Indicators considered in this quadrants refer to the lack of congruence between: (a) the total requirement of a natural production factor; and (b) its internal supply (= the amount of this production factors that would be available according to naturally generated boundary conditions). Put in another way, this indicators assess what fraction of the flows (EV#2) that are consumed by a farming systems are not made available by natural processes included in the definition of boundary given to the system. In this example, the selection includes:

- Fossil energy per unit of area – this energy form is related to a depletion of stock. Therefore, we can associate the typologies of farming system metabolism heavily dependent on fossil energy as sustained by a stock-depletion within the system. When considering stocks of fossil energy as resources stored under human control we can conclude that the system is not in a quasi steady-state situation, but rather is eating itself.
- Exo/Endo Power Ratio – also in this case, this indicator points at the existence of a hypercycle of energy forms (humans control machines that eating fossil energy make available more machines and more fossil energy to humans) which is logically independent from the autocatalytic loop of energy forms which use to sustain the human species when operating in a full "ecological mode" (within the natural essence that ecological systems negotiated in the past for the species "homo sapiens").
- Water consumed/available – the flow of fresh water consumed in LIP is often boosted through irrigation based on stock depletion and import. In this way, humans mange to use for the production of useful biomass more water than the amount that would be naturally available. Mining fresh-water (pumping out irrigation water at a pace non-compatible with the pace of recharge of the water table) should be considered as an analogous of mining fossil energy or mining the soil.
- Nitrogen consumed/available – the flow of nitrogen input consumed in LIP is often boosted by importing fertilizers. The ratio between the actual consumption of nitrogen versus the amount of nitrogen that would be available in production according to natural processes of supply represents an indicator of technoboosting on the cycling of nutrients.
- The ratio level of dissipation per unit of standing biomass assessed for the altered ecosystem compared with the level associated to the expected typology of ecosystem in the area. This is an indicator that has been discussed in Chapter 10 (**Fig. 10.16**).

The discussion of the various indicators used in the integrated representation of **Fig. 11.5** (whether this particular selection is adequate or not; how to calculate and measure individual indicators) is obviously not relevant here. The only relevant point here is the emergent property represented by the shape obtained when considering the profile of values over the various sets of indicators arranged in the different quadrants (the overall message obtained when using this type of representation). To discuss this point let's imagine to compare two general typologies of systems of production using this graphic representation: the two shapes illustrated in the graph in **Fig. 11.5**. The first system is characterized using the solid line, and we can associated this expected shape to a high-input western-type farm. Whereas the second system is characterized using a dotted line, and we can associated this expected shape to a low-input farm typical of a poor developing country. When adopting this integrated analysis we characterize the performance of these farming systems in terms of intensive and extensive variables. In this case the values taken by the productivity of land and labor for the high-input farm are higher than the values relative to the low-input farm. However, this difference can be easily explained by the "larger size" of the farm obtained when characterizing its size using a set of extensive variables (the scale of the system is bigger in terms of land, fossil energy, capital, fresh-water).

But this is only a part of the story. In fact, not only the size of the farms belonging to these two generic typologies is very different when considering extensive variables (the total economic investment associated to the typology of farm, the total amount of exosomatic devices associated to the typology of farm, the total amount of land associated to the typology of farm . . .), but also the lack of congruence between what is consumed by the metabolism of such a systems at the local level and what is generated by environmental services in terms of local favourable boundary conditions is widely different. The high-input western-type farm is not only bigger in size, but also using flows of inputs that are boosted by technology at a pace which would be "unthinkable" according to the natural associative context implied by internal constraints (the physiological conversion of food into power) and external constraints (the input supply and the sink capability imposed by ecological boundary conditions). As noted earlier a farmer driving a 100 HP tractor is delivering an amount of technical power equivalent to that of 1,000 human workers. In a pre-industrial society 1,000 human workers (and their dependents) could not have worked and be sustained by that single farm. Moreover, the continuous harvesting of a few tons of biomass per hectare cannot be sustained in a normal terrestrial agroecosystem without the external supply of fertilizers.

An expected consequence of the massive effect of technoboosting (very high values for all the indicators included on the East quadrant) is that the indicators of local environmental stress (on the East quadrant) should also indicate a higher level of stress. That is, when characterizing in this way the performance of a high-input western-type of farm versus a low input farm operating in a poor developing country we should also expect the existence of certain relation between the values taken by the indicators on the left and the values taken by the indicators on the right.

When looking at the graphical pattern generated by the two lines (solid and dotted) over this selection of indicators we can observe that the pattern - higher values for the solid line and lower values for the dotted line – is reversed only for two indicators: (a) return on investment of fossil energy (in the quadrant North) – according to the "maximum power principle effect" already discussed in Chapter 6; and (b) Fractal Dimension of LIP, since the crop fields in low-input farms are organized in small scattered plots, whereas they tend to be organized in large plot in mechanized agriculture. This confusion in the visual pattern is generated by the particular procedure of representation adopted in this graph (higher values for the variables considered for the various axes/indicators are positioned far away from the origin of the axis). To avoid this problem one should handle representations of this type in a way that makes it possible to generate more evident systemic patterns on the integrated representation. This can be obtained by: (i) normalizing the values in relation to a given range for each indicator; and (ii) giving a common orientation to the various indicators in relation to the preliminary definition of a criterion of performance. With this organization, within the feasibility domain, far away from the origin = GOOD; close to the origin = BAD. An example of this organization is given in Fig. 5.5.

Coming back to the analysis provided in **Fig. 11.5**, which implies expected patterns in the shapes, we can say that at this point the two shapes indicated on the graph should be considered as another example of metaphorical knowledge. As a matter of fact, the profile of relative values over the various axes indicated in **Fig.11.5** are not reflecting experimental data. Rather the two shapes represent a typical pattern of expected differences (reflecting the particular characterization indicated in that figure), which can be associated to the typologies of farming system considered. The question at this point becomes, is the metaphor indicated in **Fig. 11.5** an useful metaphor? As noted in the previous section, the only way to answer this question is to look to a totally different situation, applying this tentative problem structuring for organizing the information space. An example of this is given in **Fig. 11.6**, which presents a comparison of two typologies of aquaculture (in rural China and in rural Italy). A detailed presentation of this comparison and the data set used to make this graph is not relevant here (but available in Gomiero and Giampietro, 2003). What is important about this figure is the clear similarity of the pattern found in **Fig. 11.6** - when comparing two systems producing/cultivating fishes in China and Italy using a real data set - and the pattern associated to the metaphor suggested in **Fig. 11.5** – when comparing two hypothetical systems producing cereal in a developing and a developed country using "typical expected values" for these systems. The West and East quadrants in these two figures are only sharing the same semantic message ("openness of the system" and "generation of local environmental stress"), whereas in terms of the formalization of these concepts in the form of indicators (proxy variables and measurement schemes) the two analysis are totally different.

11.2 Individuating useful types across levels

11.2.1 The land-time budget of a farming system

The examples of ILA provided so far should have, hopefully, clarified to the reader the meaning and the usefulness of the rationale of the 4-angle figures. So that finally we can move on, now, to practical applications of this methods no longer based on the use of these class of figures. In particular, we start by introducing a method that has been named as "land-time budget" which is used, in the next example, to characterize the chain of choices faced by a given household in relation to its livelihood. With this method, it is possible to characterize a relevant set of choices made by a household in terms of two profiles of investments of the original endowments of: (i) human time [EV#1: "human activity"] and (ii) land [EV#1: "land area"]. A graphic view of this approach is given in **Fig. 11.7**. In this way, it is possible to characterize the decisions made by the household according to the rationale of ILA as discussed using the 4-angle figures. The set of choices made by farmers when deciding how to use their production factors are translated into a graphical representation of a chain of "reductions" applied in series to the initial budgets.

The analysis given in **Fig. 11.7** is tailored on a farming system operating in China, therefore, the selection is neglecting financial capital among the relevant production factors to be considered. The supply of the two production factors – tracked as EV#1 – in this figure is represented using solid arrows along compartments indicated by ellipsoids. Whereas, the consequences associated to a given profile of choices (e.g. the level of internal supply of EV#2 achieved or the profile of EV#1) are illustrated by the value taken by purple rectangles. In this example, the three purple rectangles coincide with three variables that can be used as indicators of performance for the household in this farming system.

In the example given in **Fig. 11.7** the chain of decisions of a given household is represented starting from left and right with a: (a) a definition of an amount of disposable human activity for the household – EV#1 - (labeled as BUDGET of Disposable Human Activity). This represents the amount of investment of this resources that can be allocated according to the decisions of the household within its option space. In this example, such a budget is of 14,000 hours/year (the meaning of this value is explained in **Fig. 7.15**). (b) a non-equivalent definition of disposable investment (E.V.#1), which is related to the amount of land area for the household (labeled as BUDGET of Colonized Available Land). In the example given in **Fig. 11.7** such a budget is of 0.5 ha (this value is related to a study of a farming system in populated areas of P.R. of China, which is discussed in detail in the rest of this section).

With this approach, different choices made by different households can be characterized in terms of different profiles of investments [expressed in terms of fractions of the 2 available budgets] of: (a) disposable human activity - over the set of possible typologies of activities; and of (b) colonized available land - over the set of possible typologies of land uses.

The chain of choices that a given household can perform when deciding how to use (and invest) these two budgets over activities dedicated to either production or consumption of a flow of EV#2 (e.g. food or added value) are indicated in **Fig. 11.7** by the set of yellow diamonds with red numbers. The reader should recall here the theoretical discussions about impredicative loops and complex time. In spite of the ordinal sequence suggested by the numbers written within yellow diamonds, it is important to avoid to think in our mind that these various choices are occurring one after another in simple time.

Let's start with the yellow diamond marked with a red 1. This refers to a decision determining what fraction of the Disposable Human Activity is invested in the compartment labeled as "working" versus the investment of Human Activity in the compartment labeled as "non-working". This first decision has two consequences: (a) it determines the value taken by an indicator of quality of life (called in this example Societal Overhead on Work). In fact, an increase in the fraction of disposable human activity invested in non-working translates into more education for children and youngsters, more social interaction and more leisure for adults in the household. (b) it determines the availability of the resource working human activity required to perform the tasks associated to the stabilization of the metabolism of the household (a crucial production factor for food and net disposable cash).

In parallel with choice#1 it comes also choice#2 . Choice#2 deals with the decision of what to do with (how to use) the available colonized land. In general, the investment of a part of TAL for preservation of ecological processes (the reduction associated with EOAL discussed in **Fig. 11.2b**) is decided at a hierarchical level higher than the level at which the household is operating. Therefore, in general, at the household level the option space for the farmers is related only to how to use their CAL for practical tasks. That is, about how to choose among land uses associated to crop production (LIP) and other land uses which are not associated with crop production. This decision is indicated by the yellow diamond indicated as #2. Another relevant choice made by the household is that indicated by the yellow diamond #3. This is the decision related to how to split the available amount of working human activity over the two compartment labeled as: "off-farm work" and "farm work". This choice forces us to deal with the complexity implied by such an analysis. In fact, at this point, the two choices related to how to use the available budgets of: (1) human activity invested in "farm work"; and (2) hectares of colonized land invested in "land in production" are no longer independent of each other. When deciding how to invest a certain amount of hours of working activities (the first yellow diamond 4* on the left) and a certain fraction of the hectares of land in production (the other yellow diamond 4* on the right) over the two compartments: "Subsistence crop production" and "Cash crop production" we have that these two sets of choices are conditioned by a reciprocal entailment. These choices are affecting each other in relation to the characteristics of other lower level elements determining the ILA (see for example **Fig. 11.4d**). That is, depending on: (i) the mix of crops produced (both in "Subsistence crop production" and "Cash crop production"); and (ii) the set of technical coefficients characterizing the various production (e.g. productivity of land and productivity of labor), we can determine the existence of a link between the effects of the choices indicated by the two yellow diamonds 4* (the two choices must be congruent with each other).

After having defined the lower level characterization (profile of investment of labor and land on the given mix of crops and technical coefficients for each crop), the amount of land and labor invested in "Subsistence crop production" will directly define one of the three indicators of performance selected: the degree of food self-sufficiency. As noted before this criterion can result totally irrelevant for a farmer operating in USA or Europe, but it can be very relevant for a farmer operating in a marginal rural area in China or Africa.

In order to characterize also the economic performance of this household we have to include the effect of additional choices. In particular, a choice related on how to invest the amount of hours of human activity of adults, which are invested in the compartment "off-farm work" - the choice indicated as #5. This amount of hours of off-farm work are allocated on a mix of jobs according to a set of criteria, considered as relevant by the household. In the same way, the farmer will chose - according to the decision indicated by the yellow diamond #6 - the special mix of crops cultivated over the hectares of LIP invested in "cash crop production". This will imply supplying the relative hours of human activity (determined by technical coefficients) which have to be invested in the compartment "cash crop production". According to the scheme indicated in **Fig. 11.7** the two choices indicated as #5 and #6 will determine the overall value of IV#3 - Economic Labor Productivity - for the hours of human activity invested in $-Work (= "off-farm work" + "farm work"). The combination of the two EV#1 (the hours of human activity invested and the hectares of land invested) and the two IV#3 (the economic labor productivity and the economic land productivity) make possible to: (a) define another crucial indicator of performance for the household – in this case the level of Net Disposable Cash; (b) individuate the existence of internal constraints (bottlenecks) over such a throughput in relation to the available budget of land and/or human time. An example of such an indication has been discussed in **Fig. 7.14**. When analyzing that ILA, in fact, it becomes quite clear that the typology of household considered in that example has a very limited option (given the relative ELP) when using the available LIP to sustain the actual requirement of Net Disposable Cash.

The analysis of the land-time budget presented in **Fig. 11.7** – in relation to the household level - can be standardized for a given farming system as illustrated in **Fig. 11.8**. We say standardized, since this second overview can be applied also to a hierarchical level higher than the household. For example, this makes possible to use large scale analyses of land use to define ecological indicators of performance.

Starting with a given budget of hours of human activity (in the upper white box on the left) for a given socio-economic entity and with a given budget of hectares of land (in the lower white box on the right) we can represent the two chains of reductions as a chain of decisions splitting the available budget into two lower level compartments. Depending on the selection of E.V.#1 (THA or TAL) different sets of lower level typologies have to be used to define the size of the two lower level compartments generated by the splitting of the higher compartment. After the split only one of the two compartment is considered for the supply of EV#1 to the direct compartment in the next splitting (see **Fig. 11.8**).

We can go quickly, once again, through the list of acronyms/labels used to characterize and standardize the chains of reductions.

Starting with a total budget THA (indicated in green in the upper left box), this budget is split into **(a) POHA** - Physiological Overhead on Human Activity – this is the amount of hours invested in sleeping and personal care and the hours of human activity of persons that do not belong to the working force; and **(b) HADF** - Human Activity Disposable Fraction – this is the maximum amount of human activity that could be invested in working.

The HADF is the relevant compartment in terms of the fraction of resource (E.V.#1) that can be invested in the direct compartment. The size of HADF (indicated now in yellow) is then split into two other compartments: **(a) L&E** - Leisure and Education; and **(b) HAWork** - Human Activity in Work. This is the amount of hours of human activity that is invested in working. The fraction of HADF which is not used in HAWork can be used as an indicator of social performance (the reader can recall here the ratio THA/HA_{PS} discussed in Chapter 9, which is a good indicator of development also at the level of the whole country). At this point it is the compartment HAWork, that becomes the relevant compartment determining the supply of hours of human activity for the direct compartment (now indicated in orange). The compartment **HAWork** is split into two lower level compartments: **(a) Wsub** – Work in subsistence. This includes chores, which are required for the production of goods and services contributing to the material standard of living of the household, (the monetary value of these services can be included in the assessment of the income of the household). The food produced and consumed in subsistence, however, does not generate market transactions and therefore does not generate monetary flows of added value to be included in the assessment of Net Disposable Cash; and **(b) W$ - Work** in cash generation. This includes the various activities associated to monetary flows. The compartment W$ - light blue - is now the relevant compartment for the supply of hours of human activity invested in generating NDC. This compartment is split between: **(a) W$-Offarm** – Work for money in off-farm activities. This includes the various activities aimed at the generation of flows of money, which do not require a land investment, or at least a demand of space negligible; and **(b) W$-land** – Work for money on farm. This includes the various activities aimed at the generation of flows of money, which requires an associated given amount of investment of farm land.

The representation of the chain of decisions [preserving the closure of the various compartments at each step] in relation to land area – as EV#1 - is given in the white lower box on the right of **Fig. 11.8.** This time, the chain of decisions considered is generating a profile of investments expressed in terms of fraction of the Total Available Land. Starting with a given amount of total available land (**TAL**), we have to split this amount of hectares into two lower level compartments: **(a) EOAL** - Ecological Overhead on Available Land – this is the amount of hectares which are left not managed by humans; and **(b) CAL** – Colonized Available Land – these are the hectares which are controlled (managed) directly by human. This compartment is then split into two other compartments: **(a) LNAP** – Land Not in Agricultural Production; and **(b) LIP** – Land In Production. The names of these two compartments are self-explanatory. Then the compartment **LIP** is split into two lower level compartments: **(a) LIPsub** – Land in Production allocated to subsistence. This includes all productions contributing to the material standard of living of the household, (the value of these services can be included in the assessment of the income). But this production does not generate market transactions and therefore monetary flows of added value accounted in the assessment of Net Disposable Cash; and **(b) LIP$** - Land in production used for cash generation. This includes the various productions of the farm associated to monetary flows. Then the compartment **LIP$** can be split between: **(a) L-NDC** – Land providing Net Disposable Cash – this is the fraction of land that is generating a net flow of added value (after discounting a fraction of land lost to generate cash crops, whose revenue is used to pay for input); and **(b) L-PayInpts** – Land allocated to cash crops, which is subtracted from the total to account for the loss of land associated to the cost of production (to pay for inputs used in agricultural production).

In the overview provided by **Fig. 11.8** it is possible to appreciate that the resulting analysis can be used for:
(1) an integrated representation of the performance of the system. For example, we can imagine to use this structuring of the information space to obtain several non-equivalent indicators of performance of this farming system (as done in **Fig. 11.6**). For example, the level of leisure and education of the household can be used as an indicator of performance when addressing the social dimension (an indicator of material standard of living). The level of self-sufficiency of the farming system can be used as an indicator of food security (in those systems in which such an indicator is relevant). In economic terms we can calculate both: (i) the income of the household; and (ii) the net disposable cash; which are two non-equivalent indicators of economic performance. The analysis of land use related to the density of flows of input and output can be used to develop indicators of environmental impact.
(2) an analysis looking for internal constraints, which are reducing the option space of different typologies of farmers. Depending on the expected values of the variable used as indicators of performance we can study the possible limiting effects of the forced relation between the value taken by extensive variables (e.g. availability of natural resources) and the intensity of throughputs (e.g. internal supply versus total requirement of food or added value). This can be studied by considering the relative technical coefficients and economic variables.
(3) verify the relevance of a particular representation of the farming system in relation to the strategy matrix adopted by various agents in the farming system considered.

In relation to this last point, it should be noted that the two chains of decisions indicated as linear tree choices in **Fig. 11.8** (using a representation that preserve the closure across levels and compartments at each choice), **in reality, are not either sequential or linear at all.** On the contrary, the various agents deciding at different levels within a given farming systems are choosing simultaneously **a given profile of investments** in relation to both the budget of land and the budget of human activity. This choice is based on: (a) an expected set of costs and benefits which are associated to the selected profiles of investments; and (b) the existing perception of a set of biophysical constraints. Put in another way, the various agents when deciding what to do with their budgets of land and time are not dealing with a chain of binary decisions that can be handled one at the time (as represented by **Fig. 11.8**). Rather they have to go for a selection of a given profile of values (depending on the agent considered) in relation to a set of choices that must result: (i) congruent over the various non-equivalent definitions of constraints; and (ii) effective in relation to the goals. To make the life of agents more difficult, non-equivalent definitions of constraints can only be studied by adopting different ILAs. That is, by representing in non-equivalent ways different dynamic budgets of extensive and intensive variables for the same metabolic system.

In practical terms, the only way out for real agents operating in a real situation (in a finite time with imperfect information) is to go for a validation of a tentative set of choices determining the profile of investments of THA and CAL. This validation has to be obtained, in relation to: (a) the acceptability of the resulting indicators of performance on the socio-economic side; (b) the compatibility of the resulting indicators of performance in relation to ecological processes; (c) the feasibility according to the existing technical coefficients determining the relation of biophysical flows across parts and wholes. In this way, we are back at basic concepts which have been discussed in Part 1: a Peircean semiotic triad which has to be applied in relation to the three incommensurable and non-reducible dimensions of sustainability, when looking for satisficing solutions.

11.2.2 Looking for mosaic effect across descriptive domains

When discussing of the various yellow diamonds representing choices in **Fig. 11.7** we observed that a few of these choice are not independent from each other (e.g. the two choices indicated by the two diamonds marked as 4*). The nature of this link can be explored using the concept of mosaic effect across scales (Chapter 6). That is, the density of relevant flows (e.g. non-equivalent definitions of I.V.#3) at **level *m*** (e.g. the farm) can be linked to the density of flows (e.g. non-equivalent definitions of I.V.#3) at **level *m-1*** (e.g. technical coefficients for individual activities) using the same mechanism illustrated in Chapter 6. In our case, this requires applying to the farming system a system of accounting of the type illustrated in **Fig. 11.7** and then characterizing the various lower level activities (e.g. producing rice, producing piglets) in terms of: (a) technical coefficients (requirement of hectares and requirement of hours of work per unit of biophysical flow); and (b) economic variables (economic return of both labor and land). This information refers to perception and representation of events at the **level *m-1***. The profile of investment of E.V.#1 (either human activity or land area) over the various activities considered in the lower level compartment (e.g. working in agriculture) will then define the characteristics of the relative intensive variables at the **level *m***. Put in another way, we can use the specific mix of crops produced (profile of investment over the set of options) and the characteristics of individual crops to estimate aggregate values of flows referring to the agricultural compartment as a whole.

Examples of the mosaic of relations are given below.

Starting with the I.V.#3 – ***ELP*** - Economic Labor Productivity - assessed over the compartment "working" – at the **level *m*** - we can write:

$$[\textit{level } m]\ \mathrm{ELP}_{W} = [\textit{level } m\text{-}1]\ (X_{OFF} \times \mathrm{ELP}_{OFF}) + (X_{ONF} \times \mathrm{ELP}_{ONF}) \qquad (1)$$

Where:

* ELP_{OFF} and ELP_{ONF} are the characteristics of the two lower level compartments. These are two IV#3 – that is the two levels of economic labor productivity (assessed in $/hour) of the two compartments "working off-farm" and "working on-farm";

* X_{OFF} and X_{ONF} are the fraction of the total amount of hours of human activity of the compartment

"Working" that are invested in the two lower level compartments "working off-farm" and "working on-farm". Since we can write: $X_{OFF} + X_{ONF} = 1$; These two values represent the profile of investment of the fraction of resource THA invested in the compartment Working (at the **level *m***) over the possible set of lower level types.

We can express - at the **level *m-1*** – the two values of ELP_{OFF} and ELP_{ONF} in relation to lower lower level characteristics – to identities referring to the **level *m-2*.** For example:

[level m-1] ELP_{OFF} = *[level m-2]* $(X_{job1} \times wage_1) + (X_{job2} \times wage_2) + (X_{job3} \times wage_3)$ (2)

Where:
* $\mathbf{wage_i}$ is the characteristics of lower level compartments (the IV#3 – economic labor productivities – characterizing the various off-farm tasks, labeled as $\mathbf{job_i}$). We assume that in this case there are three types of off-farm jobs accessible to this household - $\mathbf{job_i}$ - and that they can be characterized by a variables that we call $\mathbf{wage_i}$.

* X_{job^i} are the fraction of the total amount of hours of human activity of the compartment "Working off-farm" that are invested in the off-farm task "$\mathbf{job_i}$". Since $\sum X_{job^i} = 1$; These three values represent the profile of investment of the fraction of the resource THA invested in Working off-farm over the set of lower level types of off-farm task: "$\mathbf{job_i}$".

The same reasoning can be applied to the characterization of the other IV#3 – **level *m-1***:

[level m-1] ELP_{ONF} = *[level m-2]* $(X_{crop1} \times ELP_{cr1}) + (X_{crop2} \times ELP_{cr2}) + (X_{crop3} \times ELP_{cr3})$ (3)

Where:
* $\mathbf{ELP_i}$ is the characteristics of lower level compartments (IV#3 – the economic labor productivity of the various on-farm tasks, labeled as $\mathbf{crop_i}$). We assume that in this case there are three types of crop produced in this system - $\mathbf{crop_i}$ - and that they can be characterized by a variables that we call $\mathbf{ELP_i}$.

* X_{cr^i} are the fraction of the total amount of hours of human activity of the compartment "Working on-farm" that are invested in the on-farm task , labeled as "$\mathbf{crop_i}$". Also in this case $\sum X_{cr^i} = 1$; Therefore, these three values represent the profile of investment of the fraction of the resource THA invested in "Working on-farm" over the set of lower level types on-farm task: "$\mathbf{crop_i}$".

We can establish a bridge between economic and biophysical variables when defining the lower IV#3. In fact, the Gross Economic Labor Productivity of each of these three crops [the **i** crops considered in relation (3)] can be written as:

$$\mathbf{GELP_i} = [(Yield_{cropi} \times Price_{cropi}) - (Yield_{cropi} \times Cost_{cropi}) / Work\text{-}hours_{cropi} \qquad (4)$$

The cost of a crop (crop ***i***) can be related to the level of consumption of inputs. Imagining three types of inputs (e.g. A = fertilizer; B = pesticides; C = irrigation), the total requirement of each of these three inputs can be written as:

$$\text{Tot. Req. Input A} = \sum (\text{kg input A/hectares})_{cropi} \times (\text{hectares})_{cropi} \qquad (5)$$

$$\text{Tot. Req. Input B} = \sum (\text{kg input B/hectares})_{cropi} \times (\text{hectares})_{cropi} \qquad (6)$$

$$\text{Tot. Req. Input C} = \sum (\text{kg input C/hectares})_{\text{crop}i} \times (\text{hectares})_{\text{crop}i} \qquad (7)$$

The information given by the three relations (5), (6), and (7) is not only useful for the determination of costs, but also useful for the direct calculation of indicators of environmental impact (e.g. amount of pesticides, consumption of fresh-water in irrigation, leakage of nitrogen in the water table) and/or indices of efficiency in relation to the use of inputs.

The total cost of crop *i*, at this point, can be written as the combination of the costs related to the inputs used in production. In this simplified example, this can be written as:

$$\text{Cost}_{\text{crop}i} = (\text{Input A} \times \text{cost}_{\text{input}A}) + (\text{Input B} \times \text{cost}_{\text{input}B}) + (\text{Input C} \times \text{cost}_{\text{input}C}) \qquad (8)$$

Technical coefficients can also be used to calculate the Biophysical Labor Productivity per different types of crops (for the assessment of subsistence coverage):

$$\text{BLP}_{\text{crop}i} = (\text{Yield}_{\text{crop}i} \times \text{hectares}_{\text{crop}i}) / \text{Work-hours}_{\text{crop}i} \qquad (9)$$

At this point we have all the ingredients required to calculate Economic Labor Productivity by mixing together the information provided by relations (1) -> (9) [$ELP_i = GELP_i - Cost_i$].

However, it would be unwise to continue to write down these "semantic relations" with the goal to obtain a full formalization. As discussed already several times, the series of relations going from (1) to relation (9), should be considered as a set of relations obtained through a combination of intensive and extensive variables over an impredicative loop. The numerical values assigned to the various labels making up these relations do affect each-other. In fact, agents operating at different levels are using the relative values taken by these variables as relevant signals for action. Therefore, depending on the time differential which results relevant for a particular goal of the analysis some of these labels have to be considered as variables, other as parameters, other as constant. To make things more difficult, the predicament of an arbitrary definition of categories (the choice of the set of formal identities to be used in the model) is also in play. Put in another way, the particular procedure which has to be used to formalize the structure of these relations in practical situations has to be decided according to the circumstances.

For example, relation (2) includes the assessment of three different wages associated to three different typologies of job. In this case, how to deal with "commuting time"? That is, how to account for the time spent by the worker to move from the house to the work place? This may be accounted as human activity invested in the compartment "working off-farm". In this case, this choice would result in a reduction of the value assigned to the variable "wage" [$/hour]. That is, let's assume that the wage actually paid in **job1** is 1US$ per hour, and that commuting requires the addition of a 10% to the actual working hours in **job1**. Then the wage relative to job1 should be reduced, in this system of accounting, of 10%. On the other hand the time spent in commuting can be accounted for, as human activity which must be invested in the compartment "chores" (= activities necessary for stabilizing the metabolism, but not generating a direct return of added value). A third alternative choice of accounting could be, if the commuting is done by bus where the worker has a pleasant social interaction or some leisure time – e.g. reading a book – to account for that investment of human activity in the category "leisure".

It should be noticed that nowadays the challenge of keeping coherence and congruence in a system of accounting of this nature has been greatly simplified by the availability of powerful software that can be run on every PC. Actually, the very popular Excel (of Microsoft) makes possible already to establish an interface between the mechanism of accounting applied to a data base and a graphic form of representation of multiple indicators (e.g. the radar diagram illustrated in **Fig. 11. 6**). Another useful and popular software that can be use when structuring the analysis of systems organized in different hierarchical levels is STELLA, which makes possible to: (a) visualize in the form of graphs the set of relations across levels and (b) to keep separated class of variables belonging to different descriptive domains (e.g. economic reading versus biophysical reading). An example of the analysis of the set of relations discussed before is given in **Fig. 11.9**. Details are not relevant now. What is relevant is the clear distinction which can be made between the parameters defined within an economic domains (selling prices and costs of inputs) – visualized in a blue box - and the parameters defined within a biophysical domains (productivity of production factors) – visualized in a yellow box. Then, when moving up to a higher hierarchical level and when characterizing the productivity of labor at the level of the farm, we can notice that this "economic characteristic" – at the **level *m*** - in reality is affected by "biophysical characteristics" of the system – perceived and represented at the **level *m-1***. In the same way "biophysical characteristics" such as the "productivity of land" – assessed in terms of biophysical output per hectare – are affected by economic characteristics (e.g. the possibility to afford the purchasing of a lot of technical inputs per hectare). Because of this reason, we believe that it is important to develop an integrated analytical approach that explicitly address the reciprocal entailment of economic and biophysical characteristics at different level within a given farming system.

There is another important point to be made about the existence of mosaic effects across levels and dimensions. When looking simultaneously at **Fig. 11.5**, **Fig. 11.7** and **Fig. 11.9** we can appreciate even more the discussion already made about the severe challenge faced by individual agents when selecting a given profile of investments (making a multiple and simultaneous choice in relation to all the yellow diamonds illustrated in **Fig. 11.7**). When doing that an agent has to consider: (a) the existing set of constraints (the set of existing relations between economic and biophysical characteristics illustrated in **Fig. 11.9**); and (b) evaluate the performance of the farming system considered (the actual shape over the package of indicators used to characterize such a performance versus the expected shape, as illustrated in **Fig. 11.5**) in relation to the existing goals.

The reciprocal entailment across levels of characteristics and the requirement of congruence over those choices that implies the sharing of the same pool of production factors (e.g. the two yellow diamonds #4* in **Fig. 11.7**) implies that individual farmers, for example, cannot modulate their profiles of investments of both human activity and land area in a continuous way. On the contrary, we can imagine that the reciprocal entailment among characteristics of lower level elements (feasibility on the biophysical/structural side) and the reciprocal entailment among characteristics of higher level (desirability on the cultural/functional side) should imply a sort of "quantization" of the option space for farmers. That is, we can hypothesize that agents tend to follow "attractors/typologies/packages" of profiles of choices in terms of investments of production factors and tend to adopt "attractors/typologies/packages" of profiles of weighting factors when dealing with the selection of a strategy in face of the unavoidable presence of incommensurable sustainability trade-offs (e.g. minimization of risk versus maximization of return, preservation of cultural values versus integration in a fast changing socio-economic context) and uncertainty.

The analytical tools presented so far make possible to study this phenomenon both: (a) on the side of the analysis of different profiles of investment of production factors; and (b) on the side of the analysis of the different profile of weighting factors adopted when selecting an overall strategy in terms of achievements on the Multi-Criteria performance space. A given profile of investments of production factors, in fact, can be associated to a given shape of the characterization of the performance in relation to a given multi-criteria performance space. An analysis of this type is briefly discussed below, applied both to the hierarchical level of household and village.

Again, one has to be very careful about imagining that it is possible to formalize this type of analysis. In fact, it is important to always keep in mind that the data set used for such an analysis is derived from an Impredicative Loop Analysis. That is, the data do reflect already a representation of the reality which is biased by the set of preliminary choices made by analyst. When trying to apply the analytical approach

presented so far, we are confronted by questions such as:
* what should be considered as managed land and natural land?;
* what should be considered the size of the household in terms of human activity when dealing with hired work? (e.g. should we stick with the household THA and consider hired work as an economic input accounted for only by a reduction of ELP and L-NDC?);
* what should be considered the size of the household in terms of land when dealing with input – such as feed – which have embedded a land requirement (the land used to produced the feed elsewhere)?
* how to deal with the assessment of fixed capital (e.g. actual value and depreciation) when assessing gross and net economic return?
* how to calculate with accuracy the value of goods and services obtained by the household outside market transactions?

As soon as one accepts (or better acknowledges) that this type of analysis requires working with useful metaphors rather than with substantive models, the unavoidable arbitrariness in the original data set is no longer a problem. The ambiguity entailed by these questions is only lethal when attempting the construction of "exact substantive models".

On the contrary, analysts looking for increasing the "quality" of their integrated analysis of complex systems should consider the challenge represented by ambiguous questions (such as those listed above) as an opportunity. Ambiguous questions that pop up as soon as one tries to do an integrated assessment of a real farming system should be viewed as opportunities to check with other non-equivalent observers the quality of the problem structuring. In this way, it becomes possible to explicitly discuss the implications of the assumptions and the selection of identities and categories used in the problem structuring. Such a discussion has to be done not only with other scientists dealing with the same system but operating in different disciplinary fields, but also with non-scientists that are relevant stakeholders in the problem to be tackled.

11.2.3 An example of selection of useful typologies

The following example of an analysis of useful typologies in a multi-scale integrated analysis of farming system is based on the results of a 4-year research project in China entitled "Impacts of agricultural intensification on resources use sustainability and food safety and measures for its solution in highly-populated subtropical rural areas in China". This project was including a "farming system analysis group", and an overview of the research activity of this group has been published on a Special Issue of *Critical Reviews in Plant Sciences* - vol. 18, issue 3 - 1999.

The goal of this section is just that of providing a general overview and a qualitative presentation of the nature of the analysis. Therefore, graphs and figures presented below do not have the ultimate goal of explaining in detail the choices adopted when formalizing the analysis in this case study. Interested readers, can get a more exhaustive explanation of the procedures adopted in this study checking the three relative papers: *paper #1* Li Ji, et al. (1999); *paper #2* Giampietro and Pastore (1999); *paper #3* Pastore et al. (1999).

As a matter of fact, it was during the processing and the analysis of the data gathered during this project (working in parallel at the household and at the village level) that the group of farming system analysis realized that the most important "findings" of this analysis were linked to the ability of characterizing that farming system using an integrated selection of useful typologies. For an integrated selection of useful typologies we mean: a set of tasks and a profile of investments to be used to characterize household types; a set of household types and a profile of investments to be used to characterize villages; a set of village types and a profile of investments to characterize the aggregate performance of the farming system at a larger scale.

The frame used to compare Household and Village types

In this section we present an example of characterization of a set of typologies of households (at the **level** *m*) which can be linked to a set of typologies of villages (at **level** *m+1*). Such a characterization is based on a multi-objective integrated representation of performance – the profile of values taken by a package of indicators over a radar diagram **Fig. 11.10** - which can be associated to a given profile of choices over the set of yellow diamonds illustrated in **Fig. 11.7**.

Let's start with an example of characterization of two typologies of household which are compared in **Fig. 11.10** (Type 6 and Type 4). These are just two out of a total of 6 typologies of household individuated in the farming systems considered. This representation and characterization, obviously, reflects the preliminary selection of a set of relevant criteria associated to the indicators included in the radar diagram, which is in common for all the typologies.

The radar diagram is divided into 4 quadrants organized over two axes of symmetry. A vertical axis divides the two quadrants on the left, which refer to indicators of socio-economic performance, from the two quadrants on the right, which refer to indicators of ecological impact. The horizontal axis divides the two upper quadrants, which refer to a local perception and representation (indicators) of performance, from the two quadrants in the lower part which refer to information characterizing the farm in relation to its larger context. The two set of indicators included in the two lower quadrants, however, provide information of different nature. The selection of indicators dealing with the socio-economic dimension, on the left, reflects the perspective of agents operating in the larger socio-economic context (e.g. administrators of the province, the government of China) about the performance of the farm. That is, these are systems quality of the household which are relevant for the higher level holon (= the village or the country) within which that household is operating.

When coming to the representation of the effects that the characteristics of the farm can have on the larger ecological context, it is not possible to use, at this level, indicators of environmental impact for large scale ecological systems. In fact, there is a mismatch of scale between the local disturbance generated by the specific characteristics of a given household and the large scale which would be required by an ecological analysis of sustainability. Moreover, the possibility given by the exosomatic metabolism to stabilize useful flows in the short periods by relying on: (a) stock depletion and abuse of sink capacity; (b) trade of environmental services and limiting natural resources, makes impossible to associate the effect of local patterns to events occurring elsewhere or at a different scale. For this reason, the lower-right quadrant includes a set of indicators which are labeled as "technoboosting". This is a set of indicators which is useful to define how bad is our representation of the metabolic system as a system which is in steady state. A high level of technoboosting required and used to keep the pace/density of relevant flows much higher than natural rates implies: (a) a high dependency on external inputs (which generally is associated to stocks depletion somewhere else); (b) a high probability of generating harmful interferences with the natural mechanisms of regulation of flows within terrestrial ecosystems (see Chapter 10).

The idea of using in parallel different sets of indicators to reflect the different perspectives of non-equivalent agents can be related to the rationale discussed in relation to **Fig. 5.3**. A Multi-Criteria performance space entails characterizing the same system using a set of different indicators that reflect non-equivalent perceptions and representations of what is good and bad in relation to different dimensions of sustainability and in relation to different agents operating at different levels. In this example, referring to the two set of indicators of socio-economic performance (upper and lower part on the left side of the radar diagram) we have:

(i) indicators reflecting the perceptions of performance at the level of the household

The three selected criteria are: (1) minimization of risk (the goal here is to make individual members of the household as safe as possible against external fluctuations in markets variables and from external perturbations such as climatic and political disturbances); (2) maximization of the level of social interaction of the household with the socio-economic context, in relation to the exchange of good and services within the economic process. This criterion becomes very important in those cases in which the set of activities expressed by a particular household in the compartment "leisure and education" is different and less diversified than the set of activities expressed in the same compartment by the "average household" in the socio-economic context; and (3) Maximizing the fraction of Total Human Activity which is invested outside the compartment "working". As noted in Chapter 9, this criterion is (which is useful also at the level of the whole society) can be related to the possibility of expanding the potentiality of human beings - e.g., better education, better social interactions and processing of information, traveling.

Coming to the numerical assessment the relative selected indicators are:

1. Minimization of Risk in terms of Food Security = the degree of coverage of food requirement through subsistence production. **This indicator is related to the difference between the requirement of food products associated to a given diet of the household and the mix of food products available through subsistence to the household.**
2. Maximization of socio-economic interaction = Maximization of the flow of Net Disposable Cash [as noted earlier this is different from an assessment of income, since it does not include: (a) the monetary value of subsistence food consumed and additional goods and services obtained outside the market; and (b) consumption of added value associated to the depreciation (discount) of fixed investment and the direct loss on circulating investments]. **This indicator is related to the ability of the household to interact with the socioeconomic context in relation to those activities requiring monetary transactions.**
3. Maximization of the ratio "Total Human Activity/Working Time". In practical terms, this reflects the fraction of disposable human activity of the household not invested in working activities. **This indicator is affected by: (a) level of education of children; (b) leisure time for workers; (c) work load for children; (d) work load for elderly.**

(ii) indicators reflecting the perceptions of performance of the government of China

In this study, the government of China was considered as a relevant agent when deciding the selection of indicators. In relation to this choice, the three relevant criteria selected were:
(1) Minimization of negative gradients between the income of the rural household and the average household income of the country. This is a very sensitive issue in China, were big gradients of wealth between rural and urban population already generated in the past social tension and even revolutions. (2) Maximization of the surplus of food per household. This is a crucial indicator in relation to the double goal of: (a) guaranteeing a good coverage of internal food security; and, at the same time, (b) reduce the work force engaged in agriculture. Since this work force in agriculture is facing, in any case, a severe biophysical constraint in terms of shortage of LIP, it is important for China to move an increasing fraction of the Human Activity invested in the "working compartment" to other economic activities to foster the economic development of the country. On the other hand, such a process of development, implies that the internal food security of an increasingly urban population depends on availability of food surplus produced in rural areas. An analogous criteria could be the maximization of the surplus of rice produced per unit of area of a given household typology. (3) Minimization of the cost of food security for Chinese economy. This is an obvious economic criterion, which does not need explanations.

In relation to this selection of criteria, the three indicators used for the characterization of the farming system are self-explanatory.

For the moment we skip a discussion of the criteria and indicators used to deal with the ecological dimension. This will be done late on, when discussing of the integrated representation over different hierarchical levels. In fact, ecological stress can be defined at different levels and scales, and this requires the adoption of different criteria of analysis and relative indicators.

The same approach used in **Fig. 11.10** to characterize two typologies of households can be used to characterize also typologies of village. This is illustrated in **Fig. 11.11**. The structure of the two radar diagrams (including the selection of the 4 sets of indicators for the various quadrants) is exactly the same. The only difference is a different hierarchical level, which implies a larger size, when considering the selection of extensive variables EV#1 (human activity and land area) and EV#2 (added value, and food) for the entity. However, when the representation of this farming system at two different levels (household and village) is based on the same selection of extensive and intensive variables, it becomes possible to apply the mechanism of mosaic across levels to bridge different levels of analysis. According to what said in Chapter 6, we can obtain the representation/characterization given in **Fig. 11.11** in two non-equivalent ways: (a) by a direct measurement of the characteristics of a village (e.g. through a direct survey) – at the **level** ***m+1***; (b) by a simulation of the characteristics of a "virtual village" based on our knowledge of its lower level components and their organization into a whole – at the **level** ***m***. In order to estimate the characteristics of a "virtual village" made up of typologies of households we need to specify: (i) a set of household types making up the village: (b) the curve of distribution of the population of households over the set of typologies; (c) complement the information about parts of the villages, which are not made up of households (e.g. communal land, roads, societal infrastructures).

This possibility to obtain a double check in the empirical analysis of a given farming systems is very interesting. Unfortunately, in this specific case study, this option was discovered only when the field work of this project was over. Because of this fact, the final selection of typologies used for a MSIA (required to get a full closure of EV#1 across the two levels: household and village) was not totally compatible with the original choices of sampling procedures for the empirical study of households and villages.

Before, getting into a more detailed analysis of the integrated analysis over two levels in this study, it is necessary to briefly explain the type of field work used to gather data.

The first step was an analysis of general trends of agricultural development (to obtain benchmark values useful to characterize the situation of Chinese agriculture compared with the other countries). The second step was an analysis of historical trends within Chinese agriculture (to obtain benchmark values useful to characterize the situation of the province under analysis compared with the other provinces). Third step was an institutional analysis and overview based on interaction with local stakeholders of the targeted area to characterize relevant aspects of the farming system focus of the study. In this way 5 villages were selected as representative villages of special local situations ("close to a big city", "very severe shortage of land", two "generic, with various crop mixes", "in the middle of nowhere"). Then a "random" sampling of 250 households was selected over the 5 villages. Data collected provide: (i) a general overview of socioeconomic parameters (household size, household composition, age structure, life span, average income, other conventional indicators of development); (ii) assessments of land availability and profiles of land use; (iii) assessments of time allocation, with a particular focus on profiles of working time use; (iv) an assessment of cash flows by source and profiles of cash expenditures; (v) degree of food self-sufficiency (based on assessment of internal production versus levels of food consumption).

This information was gathered using questionnaires and discussed by the households with Chinese Ph.D. students involved in the research. In addition to the direct interviews, a parallel analysis of technical coefficients for the various cropping systems, and an analysis of land use, made possible to generate a mosaic effect across levels in relation to the congruence of different profiles of land-time budgets declared in the questionnaires. At this point, it was possible to check whether or not the various solutions were able to balance a given supply and consumption of: (a) goods and services out of the market; and (b) Net Disposable Cash.

Characterization of useful household typologies

The characterization of "household types" was done in relation to the profiles of investments of human time and land area.

The six types of households individuated by that analysis were:

* type 1- "almost totally off-farm" - households that allocate more than 80% of their total working time to off-farm activities;

* type 2 - "mainly off-farm" - households that allocate between 50 and 80% of their working time to off-

farm activities;
* type 3 - "mainly cotton-cropping" - households that allocated more than 50% of their working time to farming activities and that have the largest investment of their harvested land in cotton (special typology related to a special local situation)
* type 4 - "mainly vegetable-cropping" - households that allocate more than 50% of their working time to farming activities and have the largest investment of their harvested land in vegetables;
* type 5 - "mainly cereal-cropping" - households that allocate more than 50% of their working time to farming activities and have the largest investment of their harvested land in cereals;
* type 6 - "traditional farming" - households that do not perform any off-farm productive activities, but allocate 100% of their working time to agriculture.

The individuation of Type 1 and Type 2 refer to a single choice illustrated by the yellow diamond #3 in **Fig. 11.5**. Whereas, the individuation of Type 3, Type 4 and Type 5 are related to the choices labeled as #4* and #6 in **Fig. 11.5**. In this analysis, it was concluded that the choices labeled as #1, #5 and #2 are less relevant when determining the formulation of strategy of these agents. A few comments taken by the text of the original paper can be used to explain this point.

When opportunities for investments of net disposable human activity into the compartment "off-farm work" are available – whenever there is a supply of off-farm jobs - we are in a situation in which the amount of working activity that can be allocated to the generation of Net Disposable Cash is not affected by an external biophysical constraint (e.g. demand of land area per hour of work investment). Put another way, a farmer working in producing rice can not work 2,000 hours/year when cultivating only 0.1 ha of land (the available land is the bottleneck for the possible investments of human activity in the working compartment). When the same farmer has the option of working part-time in a factory making tennis shoes, she/he can decide also to work overtime (above the basic work load) if the wage perceived is judged economically convenient. As noted by Georgescu-Roegen (1971) the number of labor hours that can be allocated to agricultural work per hectare per year are determined by a set of biophysical constraints and lag-times determined by the speed of natural processes (e.g., the lag-time between transplanting and harvesting rice).

This makes possible to explain the peculiar fact that household types that are "better-off" in economic terms (higher NDC) have a lower average return of labor in terms of net disposable cash generated per hour. The maximum power principle is still at work here. A larger throughput of EV#2 for the worker (a higher NDC over the year) is often paid by a lower output/input (a lower IV#3 - the average ELP). In fact, after having saturated all those available tasks which provide a very high ELP_i, in order to gain more money, the farmers are forced to accept to work in activities with a lower ELP_i. In the farming system considered, we found, in fact, that very small investments of human activity in raising small livestock, aquaculture and cash crops were characterized by levels of ELP_i larger than the wages obtained in off-farm activities. The problem with this set of tasks was rather linked to the existence of external biophysical constraints that were limiting the amount of hours of human activity that could be invested in raising piglets and in producing fishes using organic by-products.

Any profile of investments which satisfies the conditions of: (1) saturating the existing budgets of land, labor time an capital; and (2) operating within the feasibility domain of the selected set of indicators of performance, should be considered as a viable technical option for farmers and therefore it represents a possible state (a potential type) for the farm. Each state defined in this way implies a certain combination of trade-offs for the environment and the national economy. This implies that different shapes over the Multi-Criteria performance space – **Fig. 11.10** – can be used to study different strategies adopted by farmers (e.g., maximization of economic return versus minimization of risk, different choices about how to use production factors)

Two general points about the analysis performed in this case study are.

* **Point #1** - the average value of the size of farm (in this case, the most relevant is EV#1 = land area) can be used for benchmarking. In this case, such a value is 0.53 ha per farm (0.12 ha per capita with an average size of 4.4 persons per household) over the sample of 250 households. The range of values found in the sample: (i) smallest 0.33 ha per farm for Type 3 - cotton cropping type (0.08 ha/per capita with an average size of 4.1 persons per household). (ii) largest 0.70 ha per farm for Type 5 – cereal cropping type (0.16 ha/per capita with an average size of 4.4 persons per household). The largest endowment of land - 0.16 ha per capita of arable land invested in production - would be considered as a very small amount of land under any international standard (against an international benchmarking of possible contexts). However, within our local context, a value of 0.16 ha per capita of arable land is **the double** of what available to household belonging to the cotton-cropping type.

At the local level, we can see that the mechanism associated to the bottleneck of land can explain the choices made by households belonging to the totally off-farm *Type 1* (0.10 ha/capita) and the partially off-farm *Type 2* (0.12 ha/capita). In the same way, also households belonging to the traditional farmers type (Type #6) do have a limited budget of land (0.11 ha/capita), and this can also be one of the factors determining their "low profile-low risk" strategy. The only difference with Typologies #1 and #2 is that either because they are located in the "middle of nowhere" or for cultural reasons (older age) these households do not have the option "off-farm working" as available, and therefore, they simply reduce both risks and work loads. What is relevant of this example about our discussion of MSIA of farming system, is the ability of this analysis of providing in parallel a general and local benchmarking. That is, we can say that the situation of this farming system is characterized by a very severe demographic pressure, when comparing the level of LIP in China with those available to farmers operating in other countries. This means, that a difference in the budget of land of 0,2 ha in Land in Production for two farms is totally irrelevant in explaining the choices of a farmer operating within the USA. On the contrary, this difference can result crucial in the farming system considered in this case study.

* **Point #2** - In this particular case study, the farming system considered is based on the adoption of multiple cropping per year and on forced rotation patterns of crop mixes. This implies that different crops are: (a) cultivated in "packages" rather than individually; and (b) over cycles operating over a time period longer than individual years. At the beginning, the handling of the analysis of different rotation patterns, which generate multiple cropping per year in relation to cycles expressed over periods longer than a year appeared to be a major complication. On the contrary, when useful typologies of household were individuated this characteristics resulted into a major simplification for ILA. The existence of naturally occurring packages of rotation and crop mixes can be associated to the existence of mosaic effects across dimensions and levels as illustrated in **Fig. 11.9.** In fact, among the bound, but still large, set of possible combination of crop mixes and crop rotations that are "feasible" according to the reciprocal constraints imposed by internal mosaic effects, farmers tend to converge on those solutions that provide a larger overall satisfaction according to their particular perception of performance (which is affected by culture, religion, and personal feelings). In other words, some farm types can be associated to profiles of allocation of production factors, the ones giving the most satisfying shapes of the Multi-Criteria Performance Space. These standard profiles of allocation of production factors can be seen as a sort of "attractors" for farmers belonging to a given farming systems when deciding how to organize their farm (e.g. farmers will imitate those neighbors doing "better"). Because of social interactions and societal regulations based on patterns, these attractor types will be amplified over a larger scale due to establishment of systemic mechanisms of stabilization – e.g. economies of scale in the generation of supply and processing of output. This, in turn, will increase the predictability of the mechanisms generating these pattern, a major plus for an adaptive system.

Because of this mechanism of lock-in we can expect that a consistent fraction of farmers in a rural area, sharing some internal characteristics and the same typology of boundary conditions, will tend to settle-down into the same household typology. In turn, the characteristics of these amplified farm types will affect with their specific "pros" and "cons" other hierarchical levels (changes in values of indicators of performance belonging to different quadrants). Even in a uniform ecological and socioeconomic context and under a common set of constraints operating on households (same technology, prices and credit access), heterogeneity in farmers' characteristics (e.g. age, aspirations, fears) will guarantee the existence of several distinct farm types, unless the socioeconomic or ecological context are overwhelmingly powerful in dictating farmers choices. Arctic households and European farmers in the 80s were forced to converge on very few uniform farm types that are more or less imposed on them by the context. In any case, the study of the distribution of farm households over possible farm types requires always a significant input from the social sciences.

Analysis of the strategies behind household typologies

The convenience of adopting a particular profile of investments of production factors and later on a particular cropping pattern rather than another depends on four classes of factors:
External factors: (1) demographic pressure (CAL per capita); (2) socioeconomic pressure (minimum acceptable fraction of NDHA in non-working activities, and minimum acceptable flow of NDC), and ***Internal factors***: (3) technical coefficients (yields, labor demand, input demand); (4) economic variables such as revenues of produced crops, cost of inputs (real cost and subsidies), taxes and off-farm job opportunities (wages).

Factors belonging to the classes (1), (3), (4) are completely outside the control of households, whereas a small room for free decision can be found in class (2) variables. Households can accept to live with a flow of NDC lower than the average and compensate with a higher Net Disposable Human Activity in non-working (more leisure time). However, this room for decision is increasingly reduced as the difference in standard of living between farmers and the rest of China increases. When the gap in material standard of living grows too wide, it becomes imperative for farmers to adjust their life-style to get closer to average values of the socioeconomic context within which the farming system is operating. Moreover, a dramatic reduction in the budget of available land (increase in demographic pressure) has the effect of reducing the options on how to use land and working time in the LIP. This increasingly forces the household to obliged choices.

At this point it should be noted that factors belonging to class (3) - technical coefficients - are slow to change; factors associated to class (1) - demographic pressure - are slow and difficult to control (China has a vast experience in this field); and, finally, factors belonging to class (2) - fast economic growth in all developing countries - are affected by large global dynamics that are difficult to control. This makes factors belonging to class (4) - economic variables - the only ones on which it is possible to operate in the short term through policy making. This, however, requires the availability of financial resources for those willing to implement the relative policies.

The formulation of policies affecting economic variables is made at the provincial or central government level. Therefore, it is important that at the moment these policies are formulated due consideration is given to possible side effects that changes in economic variables will induce on the various levels of the system and in relation to different dimensions of analysis. For example, in this case, the relative high convenience of a farm type based on total cotton production (which has to result both feasible and advisable for local farmers) was mainly generated by government policies. In this case, the goal of the country (getting hard currency with exportable goods – cottons - generated at rural level) drove special policies helping cotton growers in terms of lower taxes, lower costs and therefore higher revenues. Ecological side effects or long term effect of such a choice on Chinese food security, obviously, were ignored. This can be done without prejudice if such a solution is limited in size (it affects only a limited fraction of the land endowment of this farming system). In order to be able to verify this point, in any case, it is important to have an integrated analysis of this solution (a local solution over a part in relation to the effect on the whole).

In general terms, the fast economic development of China is implying a quick change in the characteristics of the socioeconomic context of this farming system. This translates into the need of a dramatic increase in the cash flow of farmers, which is coinciding with a dramatic decrease of available land per household. We are in a case in which both bio-economic pressure and demographic pressure are pushing this farming system into a difficult situation. A general solution to this double challenge - in this investigated farming system - has been obtained through a dramatic shift of rural households to off-farm work. Actually, a remarkable finding of this study was that the set of activities generating added value, without a direct requirement of arable land (livestock + aquaculture + off-farm wages) **were the most important source of NDC for this farming system.** It is important to keep in mind that this is the rice basket of China. On the other hand, as soon as one perform a ILA associated to a Land-Time Budget Analysis such a choice seems to be quite unavoidable under present conditions. Moreover, this is a choice very difficult to be reversed in the near future.

When setting two goals (formalized with variables referring to 1997, when the study took place): (i) a disposable cash over 2,000 yuan/year/capita; plus (ii) a good level of food security at the household level; it is easy to prove that these two goals cannot be achieved by allocating the available budget of working time only to farming activities, *when at the same time* the budget of available land is less than 0.10 ha per capita. One important consequence of this fact, is that in spite of the common definition of "agricultural area" activities not related to the compartment LIP are the most important economic activities. This means that the challenge posed by the development of rural China can not faced by considering only agricultural factors and by implementing agricultural policies. Ignoring the consequences of industrial policies, which are determining the availability of off-farm opportunities where to invest the abundant surplus of Disposable Human Activity will just miss a crucial piece of information. More and more in the future, we can expect that the availability of off-farm jobs and their characteristics will determine the agricultural choices of the majority of households in this province.

In general terms one can guess that the clustering of choices over profiles of investments of Human Activity should map onto the adoption of: (i) a given integrated representation of costs, opportunity and constraints; (ii) a given strategy matrix which is used to structure and validate later on the particular choice of typology. For example, we can generalize and aggregate according to common goals the 6 types considered before:

- Farmers that maximize the net disposable cash (NDC) through cultivation of cash crops and off-farm labor, even though this means taking risks (neglecting subsistence crops and reliance on the market) and a heavy work load (a low value for the indicator Net Disposable Human Activity invested in non-working).
- Farmers that minimize their risk by growing mainly subsistence crops and that maximize their leisure time (a high value for the indicator Net Disposable Human Activity invested in non-working)by avoiding off-farm jobs, even if this implies remaining behind in the fast process of modernization of China (low NDC);
- Farmers that operate combining the minimization of risk (relying on subsistence crop) and a maximization of net disposable cash (off-farm jobs and cultivating whenever possible also cash crops). This choice is paid for by heavy work loads (a low value for the indicator Net Disposable Human Activity invested in non-working).

Getting back to the analysis of the case study, farm type #1 implies higher income for farmers but at the same time a larger environmental load and a total lack of rice surplus to feed the urban population of China (actually these farmers are net consumers of rice). If farm type #1 would be the only one practiced in entire rural China, the country would no longer be able to feed its urban (and rural) population without heavy relying on import. In addition, the large amount of labor time invested in off-farm activities implies that farm type #1 is not based on traditional environmental-friendly [but time-demanding] farming techniques. Indeed, when assessed at country level a massive switch of rural households to farm type #1 can have negative implications not only for food self-sufficiency but also for ecological processes (e.g. they are stopping all environmental friendly tasks).

A detailed discussion of other farm types are graphically illustrated and discussed in Pastore et al. (1999). We just want to emphasize here that each of these farming types – defined at the household level – can be linked to a certain pattern of landscape use (defined on the space scale of the farm) and to certain socio-economic effects (when aggregated on a large scale) on the national economy. This means that by scaling up potential effects of choices made by individual farmers [= given a spatial distribution of rural villages in a determined area and assuming several different distributions of the population of rural households over the set of possible farming types], it is possible to link this type of analysis to (i) changes in landscape use (and therefore related environmental impact indicators) and (ii) effects on the national economy generated by the (simulated) changes in the area. In this way, we can also study the effect of government policies or technological changes by simulating the effect that they will have on the distribution of households over possible farm types. Clearly, dramatic changes both in technology, farmers feelings, environmental settings, and governmental policies can scramble the existing picture by introducing new possible farm types, making existing ones obsolete, generating dramatic changes in the distribution of individual households over the accessible set of farm types. These types of non-linear events can not be predicted and this is the subject of the last section of this chapter.

Trade-offs faced at the household level by the various household types can be discussed as done in **Fig.11.12.** Such a graph has on the two axis the variables: (a) ratio NDHA/Working, that is "hours invested in Disposable Human Activity" divided "hours invested in Working"; (b) "Net Disposable Cash". For those household types face external constraints that prevent an increase in NDC (shortage of land and/or no off-farm job opportunities - type 6 and 5) it becomes reasonable to focus on the other parameter determining their satisfaction – that is increasing the coverage of food security with subsistence and reducing the fraction of NDHA invested in working time (going for the maximization of NDHA/working). Traditional farmers (household type #6) therefore, focus on a profile of investments of production factors that maximizes the return of labor and food security (self-sufficiency) even though this is paid for in terms of a lower NDC. This implies a lower integration with the process of evolution of the socioeconomic context. A side effect of this choice is that these household types are "frozen" in their present situation. By sticking with this choice they have little hope to change in short time their present status by participating in the process of fast modernization of China. On the other hand, this household type minimizes the risk of food security (in the short-term) in the case market perturbations or big economic crises should hit the economy of China.

On the opposite side, we find household types that maximize NDC with a low NDHA/working ratio (e.g. type #1). Household types 'off-farm' (Type #1), 'mainly off-farm' (Type #2), 'mainly vegetables' (Type #4), and 'mainly cereals' (Type #5) accept to work for more hours at a lower return than household belonging to the 'traditional farmer' type. In this way, however, they are able to remain in touch with the pace of change of their socioeconomic context. This choice points at a strong aspiration (personal feelings) for a dramatic improvement in the near future. Peculiar is the situation of households belonging to the farm type "cotton cropping" (Type #3) with a high NDC and a high NDHA/working ratio. This "win/win" situation in relation to these two criteris, however, is not only due to the 'bold' choice made by these households (which abandoned completely the goal of risk minimization through self-production of food), but also by the existing government policy regarding cotton (no taxes and higher revenues for this cash crops). Moreover, it should be noted that when the ecological dimension is also considered, Type #3 is the one with the largest emissions of pesticide per hectare.

Characterization of useful village typologies

The original goal of this study was the characterization of 5 villages considered as relevant examples of typologies of rural villages of this area. However, the decision of recording empirical data about a population of 250 households operating under different combinations of socioeconomic and ecological constraints, made possible later on to analyze the same data set also at the hierarchical level of household. That is, the total sample of households was analyzed, without any reference to the village of origin, looking for "clusters" of profiles of working time investment over the set of various productive activities. Unfortunately, at this point, it was found out that the choice of a "random" sampling of 50 households per village was not compatible with this non-equivalent use of the original data set. After individuating the 6 relevant household types listed before useful for a ILA, it was discovered that the sample of household types presented a very skewed distribution within the population of households of the original 5 villages. Obviously, cotton farmers were mainly present in the cotton village and villages close to the city had a different profile of typologies from villages in the middle of nowhere. Unfortunately, households belonging to the 6 typologies were not adequately sampled. The problem in this case was that the empirical analysis should have adopted a stratified sampling procedure, at the beginning, according to the typologies selected at the end (another example of chicken-egg problem . . .).

Demographic pressure (defined as the ratio between total population and available land) was found to be very high in all five villages – 0.12 ha per capita - and to be the major constraint to the development of this rural population. As noted earlier, this value is less than half of the world average. Available LIP ranges from 0.06 hectare per capita in Qun Lian (village 5) to a maximum of only 0.16 ha/capita in Zhuang Chang (village 2). Differences in land availability are only partially compensated by different intensities of land exploitation as measured by the multiple cropping index (MCI = harvested area / available land) and other indices of technoboosting.

The five villages are:

Village 1 - located near the main town and is representative of villages open to the market and with many off-farm activities. Production of cash crops is important as source of income but less relevant than off-farm work.

Village 2 - located in the low land and relatively far away from the town market. It is representative of farming systems focused on intensive cultivation of cereals, although off-farm activities are an important source of income

Village 3 - located in between the high and low lands is representative of "traditional subsistence agricultural patterns" with few off-farm activities. The main cropping pattern is rice-wheat rotation. Cotton is the favorite cash crops, although its cultivation is restricted to only a small fraction of the land.

Village 4 - located in the low land relatively near to a large market (as is village 1). It is representative of farming systems open to the market with a lot of off-farm employment. In contrast with village 1, cash crops are more important than off-farm work as source of income.

Village 5 - located in the highlands and has been selected for its specialization in cotton production. A large fraction of land is allocated to cotton production at the expense of cereal cultivation. Besides cotton cultivation, a large fraction of working time is allocated to off-farm employment. This village therefore is the most dependent on market variables (revenues from off-farm activities and from cotton, cost of inputs, and prices of food commodities) for its food security.

A characterization of these villages in terms of "types" implies selecting some criteria that can be use to define the "types" we want to describe. Actually, this operation has been done, at the beginning of this project, when selecting these 5 villages according to the advice obtained by the experts. Such a characterization, however, was not formalized in terms of a set of parameters or variables to be considered in the definition of typologies.

In this example, the characterization of typologies of villages has been based on the same set of indicators and profiles of production factors used for the analysis of household typologies. This choice makes possible to use mosaic effects and therefore the possibility of expressing the characteristics of villages in relation to two non-equivalent external referents: (i) empirical data gathered in relation to the villages (e.g. when adopting a survey at the village level, as done in this case study); and (ii) simulating villages using information gathered about household types. This makes possible to use theoretical and empirical analysis in parallel to: (a) validate the assumptions adopted in the simulation (both in terms of definition of types and in terms of shape of distribution curves); or (b) validate the selection of types in the lower level analysis used to do the scaling from one level to the other.

For example, this study found that the geographic location of villages (implying a different access to market and off-farm jobs opportunity for household belonging to different villages) was a significant factor affecting the distribution of farmers over the possible farm types. Similar hypotheses could have been tested when considering the physiological and social characteristics (age and sex structure, ethnic origin, level of education) of households as possible factors affecting the distribution over the existing set of farm types. The problem was that this double analysis was not planned at the beginning.

The metaphorical knowledge generated by this type of analysis makes possible to compensate, in part, the mission impossible associated to the existence of chicken-egg processes in ILA. In fact, if it is true that by applying this method, one can find out how to do a better sampling in step 2, only after having done a sub-optimal sampling procedure in step 1. It is also true, that a good understanding of the set of basic mechanisms (parallel ILAs) determining the definition of useful typologies within a given farming systems represent in any case a useful result, independently from the statistical significance of the relative data set. In fact, such an understanding will make possible, in a successive empirical study, to start the field work with a much better problem structuring, and a much better set of hypotheses to be tested. Probably, a new MSIA done in the same area (based on the findings of this first study) will end up with a new set of questions associated to a more refined problem structuring, rather than with a definitive set of answers proved with statistical tests. However, what is important for the quality of the research is that each new generation of questions be associated to a higher level of understanding of the investigated problem and a higher level of communication of non-equivalent observers (scientists and stakeholders) about the common problem structuring. An additional problem is represented by the fact, that when getting back to the same villages after 7 years one is at risk of not even recognizing the place any more. The pace of change in rural areas undergoing a quick process of transition is so high that is important to rely as much as possible on metaphorical knowledge rather than on sound statistical data. The lag time required to understand "what" should be sampled and "how", guarantees that the original problem structuring already lost its validity.

We suggested in **Fig.11.11** the possibility of generating "virtual villages" belonging to a given farming system, by simulating their focal level characteristics from our knowledge of lower level farm types found in the same farming system. For example, we can imagine that the village described in **Fig. 11.11** on the left, is characterized by a majority of farmers that optimize the net disposable cash (this simulation is based on a distribution of 80% of farmers belonging to farm type 1; 10% to farm type 2; and 10% to farm type 3). Whereas, the village described in **Fig.11.11** on the right is characterized by a majority of farm households practicing traditional agriculture, hence minimizing risks and time allocated to work (simulation is based on a distribution of 80% of farm households belonging to farm type 2; 10% to farm type 1, and 10% to farm type 3).

Thus, there are two type of differences between the two graphs in **Figure 11.10** and those in **Figure 11.11**. In **Figure 11.10** we have two characterizations: (a) referring to the household level; and (b) which are based on empirical data, while in **Figure 11.11** we have two characterizations: (a) referring to the village level; and (b) which are simulated using lower level information. Obviously, the space-time domain of the two characterization is different: the village in **Fig. 11.11** is larger both in terms of Human Activity (1.75 million hours) – associated to about 200 people – and in terms of land in production - about 20 hectares. Villages are also slower in reacting to changes.

Considering the shape of the profile of values taken by the various indicators selected in the Multi-Criteria Performance Space in **Fig. 11.11**, we see that the first virtual village – Village A on the left (market-driven choice based on off-farm work and intensive production of cash crops) - is the one that generates by far the highest environmental loading and is to the larger extent dependent on coal and oil for food production. From the national perspective, this village does not produce any surplus of rice, on the contrary, it erodes the rice surplus produced by near-by villages. As expected, however, what is detrimental to the environment and the food self-sufficiency of the country also has its positive side: a high net disposable cash for farmers. The productive pattern adopted by Village A is therefore benign to the villagers and to the people of the close-by town that have access to cheap supply of fresh vegetables and other food. On the contrary, the second virtual village – Village B on the right – is the village providing a high surplus of rice (good for self-sufficiency of China) and generating a moderate environmental impact (good for the environment). This environmental benign solution is paid for in terms of low net disposable cash from agriculture. People living in Village B are at risk of loosing contact with the dramatic socioeconomic transformation which is taking place in China. A general amplification of Village B type will imply locking a large part of the Chinese rural population into a situation of poverty and lack of modernization.

We believe that the analysis of these links is useful from a policy-oriented perspective. This can be used to study general trends, which could result useful to understand the evolutionary behavior of agricultural systems in different geographic areas or socio-economic conditions. In fact, the amplification of village types and farm types can be directly related to the spread of relative patterns of landscape-use and to changes in vertical power relations across levels. Since some of the possible types are more benign to a level perspective compared to others, we can expect that the shape of the distribution curve of individuals over types will reflect power relation among levels' perspectives. For example, if the Chinese government wants to slow down spreading of the land-use pattern typical of Village A type (dramatic reduction of rice cultivation, abandonment of environmental-friendly farming techniques) it has to negotiate alternative solutions with farmers, for example guaranteeing higher income to young farmers attracted by farm typology #1. This could be achieved by changing the combination of options available to farmers at the local scale, for instance by offering "off-farm jobs" **only to those farmers that plant rice on their land**, or by taxing cash crops and rice alike. Clearly, each of these interventions will induce as side-effects a re-arrangement of the profile of the values taken by the various indicators on different levels and dimensions. Hence each potential change will produce food for further thought!

As done with the example of household type, it is possible to perform a trade-off analysis also at the village level as shown in **Fig. 11.13**. In this example, we get back to the original data of the study of Pastore et al. (1999), which are based on real characterization of the 5 villages described before. The two axis selected for this analysis are: "net surplus of grain per unit of area of farming system" - assessed in kg/ha; and "Net Disposable Cash from agriculture per unit of area of farming system" - assessed in yuan/ha/year. With this choice we check the trade-off between the two criteria: (i) the ability of China as a country to feed urban population with the available arable land used by existing farming systems; (ii) the stability of agricultural activities in rural areas (in fact patterns of crop production which provide a level of NDC too low will be selected against by households' choices).

A quick look at this graph indicates an evident problem. An excessive "industrialization" of rural areas carries the risk of eroding rice surpluses. In fact, Village 1, which is operating in a full market mode (high rate of off-farm and conventional cash crops), and Village 5 (high rate of off-farm and cotton production) do not generate any surplus of rice to feed China's growing urban population. Actually they are already net consumer (they are both below the threshold of self-sufficiency). The village with the highest production of rice surplus (village 2) is the one far-away from the town market and with the lowest NDC from agriculture. However, off-farm activities in Village 2 are able to sustain the income of the villagers. Village 3 is in a worse situation, its low NDC from agriculture is not compensated by a large revenue from off-farm activities. Therefore, from the perspective of self-sufficiency of the whole country (availability of enough surplus of rice produced in rural areas to support urban population moved into the cities by the industrialization process) China should be careful in sustaining those combination of investments of production factors (ILAs) that generate surpluses of rice at the rural level. However, due to the shortage of land, the only way to make such an option appealing to farmers is either: (i) to change the economic variables in a way that increase the overall performance of a profile of choices generating rice surpluses (pay more the rice to farmers) or (ii) to make available to villages specialized on cereals production off-farm job opportunities with high wages in the off-farm compartment. This could compensate the lower ELP of the choice of producing rice. Clearly, coming to the perspective of China as a country solution (i) would increase the cost of surpluses for Chinese economy, whereas solution (ii) would increase the control of the planners on both industrial choices (e.g. by imposing a rule that only part-time farmers planting rice can be assumed by rural factories) and farmers' choices (in order to get access to well paid jobs they have to plant rice). On the other hand, when considering the dynamic of demographic and socioeconomic pressure and the actual critical condition, it is also important to keep a tight control over the directions taken by economic growth in relation to food security and environmental security.

However, to include in this Multi-Scale Integrated Analysis the ecological dimension of sustainability, it is necessary to bridge the typologies used to represent household and village types in terms of parallel investments of human activity and CAL to a representation of energy and matter flows at the landscape level. In this way, different typologies of farming systems can be related to the level of interference they generate on the system of control expressed by the terrestrial ecosystems embedding them. An example of how to establish such a bridge is given in Section 11.3.

To conclude this section it is important to note that the basic rationale adopted in the analysis of this case study is not that of telling the Chinese people how to run their agricultural sector or how to plan strategies of economic growth. This analytical approach does not individuate what is the best solution or what should be considered as the optimal use of production factors. In our view, the goal of Multi-Scale Integrated Analysis is that of providing a richer understanding of the complexity of relations found in an evolving farming system. Therefore, this analysis is only descriptive and - on purpose - tends to avoid any normative tone. As observed in Chapter 5 a MSIA of agroecosystem should be considered as an input related to a discussion support system. This means that a parallel process of Societal Multi-Criteria Evaluation is required with the goal of translating such a richer understanding into action.

11.3. An overview of the MSIA tool kit and the impossibility of multi-agent simulations

11.3.1 Linking alfa-numerical assessments to spatial analysis of land uses across levels

The previous section illustrates the possibility of using mosaic effects within an alfa-numerical data set, which can be used to generate an integrated characterization of a farming system on different levels. Mosaic effects can be used to select a set of useful typologies that can be adopted in an impredicative loop analysis useful to study the socio-economic sustainability of farming systems at different levels. On the other hand, a multi-level analysis of ecological compatibility of an agroecosystem requires an information of a different nature. Alfa-numerical data sets can be used for the analysis of matter and energy flows, however, to be useful in relation to the ecological dimension, they have to be integrated in spatial maps whose identity is based on land use typologies. For this reason it is important to establish a link between a characterization across levels of household typologies based on alfa-numerical assessments (in the form of packages of indicators over a feasibility domain) and spatial analysis of land use.

This section provides an example of how it is possible to link a MSIA of a farming system (the socio-economic analysis described in the previous section) to an analysis of land use at different levels. The goal of this section is just that of illustrating an examples of application of this method. That is, it describes the general structural organization of the information space adopted in a different case study (in Vietnam), which is based on tables, graphs and maps. At this point, it is not necessary to get again into a discussion of technical aspects of the analysis, characteristics of the given farming system or to get in a narrative regarding the implications of the analysis (i.e. what the farming types individuated mean in relation to the objectives of the analysis). Data and figures of this sections are taken by a published paper - Gomiero and Giampietro, (2001) where this information is available.

In this case study, the MSIA method has been applied in an ex-post evaluation of a project aimed at rural development of marginal areas in Upland Vietnam (on the border with Laos). The project. whose effects were evaluated, had the goal of involving ethnic minorities in a program of re-forestation. In relation to this goal the project was not particularly successful. Against this background, a MSIA of this farming system had the goal of checking whether or not the actions suggested and supported by the program (with the proposed development policy) were compatible with the option space as "seen" and "perceived" by the various household typologies found in this farming system. The conclusion of the study was that especially in relation to the household typologies representing the ethnic minority, the options proposed by the program were both not feasible and not advisable according to the strategy matrices and option spaces associated to these household types.

Definition of lower level characteristics and household types

By assessing the profile of investments of human time and land in production related to the tracking of flows of added value and food (total consumption and internal supply), it is possible to identify a finite set of tasks which can be used to describe the activities of the various household. This set of task has to be defined in order to obtain: (a) closure over the two budgets of human activity and colonized available land, and (b) a finite set of possible compartments. In particular, it is important to have a fine resolution in relation to the identities referring to the mix of tasks of the direct compartments. The direct compartments are those compartments that are related to the stabilization of the metabolic flows (food and added value). The result of this analysis is a set of tables. An example of this type of information is given in **Tab. 11.1, Tab. 11.2, Tab. 11.3, Tab. 11.4**.

Definition of household types

At this point it is possible to use different profiles of investment of Disposable Human Activity and Land In Production over this set of possible activities to characterize household types. In this case study, 4 typologies of household were selected in this way. The set of possible typologies of investments of hours of human activity in agricultural work were based on packages of techniques (which are reflecting established patterns found in this typology of farming system in South-East Asia).

The 4 typologies individuated can be divided into two different categories. Typologies that do not depend heavily on the forest for the stabilization of their metabolism: (1) Type #1 - based on a mix of off-farm and conventional crops; (2) Type #2 - based on husbandry and conventional crops. The other two typologies – mainly adopted by the ethnic minority – heavily depend for the stabilization of their metabolism on the exploitation of tropical forest: (3) Type #3 - that has a large investment of land in slash and burn; and (4) Type #4 - that has a large investment of working time in the extraction of Not Timber Forest Products.

After selecting a set of indicators to be used to build a Multi-Criteria Performance Space, it is possible to characterize these various typologies of households in two non-equivalent ways, as done in **Fig.11.14** and in **Fig.11.15.**

Looking at **Fig. 11.14** and **Fig. 11.15** we have: (i) on the left alfa-numerical data organized within the MCPS; and (ii) on the right a characterization of the typologies of land use (mapped in terms of extensive variable – square meters – per typology of land use). A simple comparison of the two typologies of land use shows the huge difference in terms of requirement of forest land between these two household types.

But also in this case, it is important to make a distinction between a local perspective and a larger scale perspective in order to be able to appreciate the real effect that the various household typologies play in the characterization of a given farming system. In fact, in general, households performing slash and burn are those usually accused to be "the ecological villains" in farming systems operating on the edge of tropical forests. On the other hand, when an analysis of land use is performed at a larger scale (at a level higher than the one of individual villages) it is easy to discover that households belonging to this typologies were using less than 10% of the CAL – when defined at the level of the Thu Lo Commune (an administrative unit including the three villages considered in this study). Put in another way, when looking at the big picture we can appreciate that the decisions of individual households, in this situation, were affecting only 10% of the forest area considered in this study. The remaining 90% was managed by national owned company. This means also that the activities related to this land use were decided by agents operating far away (in the capital of the province or in the capital of the country). When perceiving the various relations of cause and effect on multiple levels, it becomes evident that it is unfair to blame ecological problems of this forest on the actions of local households. Since the most important driver of environmental impact is associated to the activities of management expressed by the national company.

Moving to higher hierarchical levels

This example of mismatch between the picture obtained at the local level and the picture obtained at a larger scale is important. It focuses on the need of scaling up in terms of MSIA. Especially when dealing with the issue of sustainability (long term perspective) and the ecological dimension (ecosystem perspective) it is important to reach a level of scale, in the analysis of land uses, at which it becomes possible to have the right level of analysis to address the environmental problem of concern. In fact, it is only when the various effects of policies and techniques of production are considered within the appropriate frame (perception and representation referring to the right scale) that it becomes possible to detect whose choices are more relevant for the sustainability of these forests. Obviously, different categories of land use require the use of different indices of environmental impact. Again this points at the need of having a multiple reading on different levels.

At the level of the village, as shown in **Fig.11.16**, it becomes possible to associate alfa-numeric indicators of performance referring to the socio-economic dimension of sustainability to an overview of land use associated to the identity of the village. In fact, at this scale it becomes already possible to apply to this land use analysis a representation based on remote sensing. This implies that it becomes also possible to apply techniques of elaboration of data generating indicators of environmental stress (e.g. diversity of vegetal species over a given grid). In the socio-economic analysis of **Fig. 11.16**: (a) the characteristics of lower level households (specified before); and (b) the profile of distribution of actual households over this set (illustrated in the lower-right quadrant in the radar diagram on the right of the figure) are used to infer some of the characteristics of the village. Obviously, additional information is required to fill gaps of information about land use. These gaps refer to land uses decided at the level of the village, which are not included in the analysis performed at the household level. This can include, for example, schools, communal buildings, roads and infrastructures, which have to be inserted, in the scaling up, using additional sources of information (referring to non-equivalent measurement schemes applied at the village level).

The same approach can be used to move the integrated analysis to a higher hierarchical level. In this case study - **Fig.11.17** - this higher hierarchical level was represented by the "Thuo Lo" Commune, made up of three villages.

Also in this case study, the geographic location of villages in relation to the city and the internal characteristics of households (ethnicity, age, level of education) resulted to be significant factors to explain different profiles of distribution of household types in the villages.

An overview of the organizational structure of the information space

Finally, an overview of the relations established among different typologies of information within such a Multi-Scale Integrated Analysis is provided in **Fig. 11.18**. The process starts with the characterization of the set of possible activities at the lower level of the household (using the land-time budget). In this way, it is possible to individuate useful typologies of households (using the ILA on different metabolic flows to be stabilized) as discussed in Section 11.2. At that point, a profile of distribution of the population of households over the given set of household typologies generates different typologies of villages. Each typology of village can be associated to a map of land uses, which is related to the typologies of land use within the compartment CAL defined at the level of households. In turn these typologies of villages can be related to a higher level typology of entity belonging to the same farming system, but defined on a larger space-time domain (in this case the Thuo Lo Commune).

It is important to acknowledge the need of additional sources of external information whenever one wants to perform a scaling from lower level characteristics (at a **level *x***) to focal level characteristics (at a **level *x+1***). This is required by the simple consideration that the holon considered at the higher level is expressing emergent properties and therefore requires the use of additional categories not included in the characterization of lower level entities.

The set of relations illustrated in **Fig. 11.18** provides an integrated vision of how it is possible to keep a certain level of coherence in a Multi-Scale Integrated representation of the performance of a farming systems in relation to various dimensions and hierarchical levels. However, also in this case one should not expect too much from this approach in terms of the building of formal models able to handle such a multi-scale integrated analysis. This approach provides some coherence, but cannot provide a full predictability of changes, as discussed in the next two sections.

11.3.2 Multi-objective characterization of performance for different agents

The analytical tools presented so far can be used to describes the effect of changes in a farming system in parallel on different hierarchical levels (space-time scales) and according to a given selection of perspectives (those selected in terms of indicators in the four quadrants). However, this multidimensional representation which is required to provide a useful input to the discussion of pros and cons related to a given decision making in agriculture (e.g., to evaluate possible scenarios) implies a few steps which makes impossible a substantive (formal) analysis.

1. The selection of a finite set of indicators to describe the effects of a particular change (the representation the system in terms of states on a MCPS) on different levels and according to different perspectives, is just one in a virtual infinite set of possible option. This implies that this is always an arbitrary operation.
2. The various "perceptions" and "representations" of the states of the system on different scales and in relation to different dimensions of analysis are not reducible to each other in formal terms. They refers to non-equivalent descriptive domains (incompatible definitions of simple time and space).
3. Models used to link changes perceived and represented at one level to changes perceived and represented at a different levels works only in a direction. They define a direction of causality according to the assumptions required for the triadic filtering to get out of hierarchical complexity. Therefore, their usefulness is local and it depends on the credibility of the relative assumptions.

Very often these basic problems are amplified by the fact that those looking for a substantive, optimal solution for the sustainability of a "farming system" (in relation to all the possible dimensions of analysis, in relation to all the possible hierarchical levels at which relevant identities are expressed, and in relation to the various legitimate perspectives of all possible agents) get themselves into a "mission impossible" in epistemological terms. On the other hand, if one attempt to analyze only the perspective of one agent at the time, things can become a little bit easier. At least, the epistemological challenge to be faced is reduced within the window of reality of competence of that agent.

As a matter of fact, the various analytical tools presented so far can be used to study the behavior of households seen as agents. An overview of this analysis is given in **Fig. 11.19**. Depending on how we decide to characterize a given farming system using extensive and intensive variables over an Impredicative Loop, we will end up by determining an option space for the households, which is determined by the information contained in the three boxes on the left of the figure. In this example, the green box includes information that has been labeled under the category "parameters". Then the yellow box, referring to the available budget of production factors considered in the ILA, has been labeled using the category "constraints". Finally, the pink box includes system qualities that can be changed according to the decisions made by the household/agent, therefore this box has been labeled using the category "variables". We have to repeat again that what is relevant here is the "semantic" of the categories used for these boxes and not the selection of items included in them. Depending on the situation and the hierarchical level of analysis, the list of items to be included in the various boxes can change.

Depending on a given strategy matrix (what are the goals of the agent and the perceived priority among them) the agent will select **a possible state** over the option space. This choice will generate a result which can be characterized in terms of: (a) a given shape on a Multi-Criteria Performance Space (which is relevant in relation to a socio-economic dimension of sustainability); and (b) a given pattern of land use (which is relevant in relation to an ecological dimension of sustainability). In a way, this integrated characterization (MOIR stands for Multi-Objective Integrated Representation) can be related to the concept of pay-off matrix (the effect associated to a given choice made by the agent).

As discussed in the previous section, decisions taken at the household level by individual agents when aggregated on a larger scale (e.g. village level) will determine the pattern of land use at that scale. That is, the choices made by individual farmers about farming techniques (crops selected in the mix, techniques and technologies adopted, which will determine the intensity of cultivation) and about the amount of work allocated to farming and off-farming activities will determine the characteristics of a given farming system at a higher level. An overview of the mechanism through which it is possible to aggregate the effect of individual farmers choices – using useful typologies of households – is given in **Fig. 11.20.**

The various characterization of the effects generated at the local level by the decisions of the various agents can be related to the effects generated at the level of the village. At this point, however, the peculiar nature of complex systems organized in nested hierarchies enters into play. Whereas, decisions of individual agents (e.g. households), when considered one at the time, are not relevant for higher level agents (e.g. the government). When lower level agents converge on a given set of typologies and these typologies are amplified by some mechanisms operating across levels the situation changes dramatically. A lower level pattern (associated to a given agent behavior) can be amplified to a scale large enough to become relevant for higher level agents. At this point, holons of different levels interacting within a healthy holarchy, are able to interact in a way that is impossible to model using conventional formal system of inference (we are dealing with complex time, and an open and expanding information space).

11.3.3 The impossible simulation of the interaction of agents across levels

An overview of the information given by **Fig. 11.19** and **Fig. 11.20** is given in **Fig. 11.21.**

If we assume that the behavior of lower level agents (households) is organized over typologies and that the mechanisms of self-entailment across levels is able to express identities at the **level *n*** determined by: (i) the set of characteristics of lower level states accessible for the element at the **level *n-1***; and (ii) the profile of distribution of lower level elements over the set of possible states. Then we have a system of interaction that it is impossible to formalize. In fact, the definition of what should be considered as a possible state for a household will depend on different types of information (what is socially acceptable, what is ecological compatible, what is economically viable and what is technically feasible), which can only be defined on non-equivalent hierarchical levels. That is, if we try to define such an option space in formal terms, we face again the well known problem of identities and perceptions referring to non-equivalent descriptive domains.

In particular, there is a dimension of sustainability which is related to human feelings and aspiration (cultural and economic variables), whereas there is a dimensions of sustainability which is related to ecological processes and biophysical constraints. Everything, within this information space is changing in time, but with different paces. The formation and evolution of typologies within the human side (associated to changes in institutions, laws, cultural rules, ethical principles) has a different speed from the formation and evolution of typologies within the ecological side (recall here the discussion about the definition of ecological essences in Chapter 8 and Chapter 10). To make things more difficult also the strategy matrix and the perception of constraints, costs and opportunities of agents operating at different levels change at a different pace. Technical coefficients and economic characteristics (such as prices and costs) which are parameters for households, are variables for national governments. Agents at the national level can decide programs of technological innovation and/or economic policies of subsidies. In a situation of parallel decision making across scales it is impossible to guess from the beginning whether or not, in the long run, the aggregate behavior of farmers will affect the decisions made by the government or viceversa. But even imagining that at a particular point in time we can guess a direction of causality in the short term (a given policy of the government will affect the choices of the farmers), this prediction will have, in any case, a limited validity in time. The change imposed from the higher level will induce a re-adjustment of lower level characteristics. This can just generate a temporary feed-back in terms of economic variables in relation to the choices made at the government level. For example, subsidies to produce a given crop can generate an excessive move toward the production of that crop that implies an excessive drop in the relative price. On the other hand, the change induced by government policy can be more drastic such as the eradication of a given technique or technology from a farming system (e.g. elimination of animal power in rural transport). Put in another way, the continuous interaction across levels can imply either a simple readjustment of the profile of distribution of lower level elements over a give set of possible states, or in alternative the "emergence" of new possible states and the "elimination" of obsolete states from the original set.

We can relate this discussion of the analysis of the evolution of the information space to the metaphor of the "lazy 8" proposed by Holling (in Chapter 8). The introduction of new states (a phenomenon of emergence) can induce a new definition of useful typologies within a given ILA (the reader can recall here the general overview of ILA given in **Fig. 9.1**). A major re-adjustment over the loop can lead to the individuation and a definition of a "new metabolic system" in a population of interacting observers. Then this new metabolic system will change in time during its evolution. This will be obtained by changing the profile of distribution of its Extensive Variables #1 over lower level types, deleting obsolete types, amplifying those types that result more useful for the whole according to boundary conditions. In this process some typologies are improved both in terms of better organized structure and better definition of functions (the reader can recall here the description of the evolution of car types given in Chapter 8). Finally, the accumulation of changes will become so relevant that for the population of observers will be easier to deal with this system by changing its initial definition of identity. The cycle of creative destruction reached a point that for the observers it becomes more useful to adopt another basic definition of what this metabolic system is. A new definition which is based on a different integrated set of useful typologies.

If we accept this explanation of the metaphor proposed by Holling about the evolution of metabolic systems in relation to the issue of sustainability, we have also to accept, that when dealing with the analysis of this process applied to farming system analysis, metaphorical knowledge is much more relevant than formalized characterizations. Put in another way, in farming system analysis it is better to use a mix of high tech tool kits, gut intuitions, political skill, common sense – to be a "007 researcher" – rather than to base the research activity on a mix of formalisms, statistical tests and complicated mathematical models (to be a "$p \approx .01$ researcher").

Table 11.1 Time allocation per household type (Gomiero and Giampietro, 2001)

INDICATORS	Total sample	Type 1 Off farm Crop.$_{mix}$	Type 2 Husbandry Crop.$_{mix}$	Type 3 S&B Crop.$_{mix}$	Type 4 NTFP Crop.$_{mix}$
Total Time Allocation					
Total Worked Time per household (hr/yr)	3,630	4,016	4,550	3,236	2,066
% Worked Time/ DisposableWorkingTime	27	32	32	24	19
Worked time per capita (hr/cap/yr)	706	854	820	619	428
Worked time (hr/worker/yr)	932	1,107	1,059	815	612
Chores (as % Tot Available Working Time)	17	18	18	16	16
Worked time allocation (% of Total Worked Time)					
Home garden	13	10	9	14	**49**
Paddy	5	3	4	7	8
Crop land	23	7	**25**	**30**	13
Husbandry	21	13	**37**	10	0
S&B	17	4	10	**33**	5
NTFP	4	0	2	5	**23**
Off farm	15	**62**	12	0	0

NOTE: S&B = Slash and Burn; NFTP = Non-Timber Forest Products;

Table 11.2 Land-use pattern per household type *(Gomiero and Giampietro, 2001)*

LAND USE (ha)	Total sample	Type 1 Off farm Crop.	Type 2 Husb. Crop.	Type 3 S&B Crop.	Type 4 NTFP Crop.
Total land					
TOT	85.3	2.4	25.0	52.1	3.3
per HH	2.19	0.34	2.10	3.57	0.66
per capita	0.32	0.13	0.26	0.52	0.14
%	100	100	100	100	100
Land outside of the commune S&B land					
TOT	64.7	0.7	16.3	44.6	1.0
per HH	1.66	0.10	1.36	2.97	0.20
per capita	0.24	0.02	0.18	0.41	0.04
%	76	29	16	86	31
Land within the county					
TOT	20.6	1.7	8.7	7.5	2.3
per HH	2.04	0.24	0.73	0.50	0.46
per capita	0.08	0.05	0.09	0.07	0.09
%	24	71	84	14	69
Home garden					
TOT	8.3	1.0	2.8	2.9	1.6
per HH	0.21	0.14	0.23	0.19	0.32
per capita	0.03	0.03	0.03	0.03	0.07
%	10	41	11	6	50
Paddy					
TOT	4.1	0.4	1.3	2.0	0.4
per HH	0.11	0.06	0.11	0.13	0.08
per capita	0.02	0.01	0.01	0.02	0.02
%	5	16	5	4	12
Crop					
TOT	7.8	0.3	4.6	2.6	0.2
per HH	0.20	0.05	0.39	0.18	0.05
per capita	0.03	0.01	0.05	0.03	0.01
%	9	14	18	7	7
Note:					
*Pasture land**	*5.8*	*1*	*12*	*5*	*0*
*Forest land for NTFP***	*230*	*0*	*166*	*300*	*500*

(*): Assuming 8 ha pasture per cow per year feeding in low quality pasture (Vu and Nguyen, 1995). Pasture land in Thuong Lo in quite degraded, most of it on sloping fallow land that surround the commune.

(**): NTFP, mainly rattan a climbing palms (e.g. *Calamus* gen.), and cap leaves. Forest surrounding Thong Lo commune is secondary forest, impoverished by the collecting pressure exerted in the last decades. For that reason rattan collection requires long time to be spent in the forest, a very harsh and risky activity.

▪Tab. 11.3 Technical coefficients of activities *(Gomiero and Giampietro, 2001)*

▪ ▪Activities	▪Type 1 ▪Off farm-Crop$_{mix}$ ▪(kg/ha/yr)	▪Type 2 ▪Husb.-Crop$_{mix}$ ▪(kg/ha/yr)	▪Type 3 ▪S&B-Crop$_{mix}$ ▪(kg/ha/yr)	▪Type 4 ▪NTFP-Crop$_{mix}$ ▪(kg/ha/yr)
▪ *Home Garden*	▪	▪	▪	▪
Starchy roots	▪–	▪–	▪2,000	▪2,000
▪Corn	▪–	▪400	▪400	▪400
▪Beans	▪200	▪200	▪200	▪200
▪Vegetable	▪500	▪500	▪500	▪500
▪Fruits	▪1,000	▪1,000	▪200	▪200
	▪	▪	▪	▪
▪ *Paddy field*	▪	▪	▪	▪
▪Rice^{wr}	▪2,200	▪2,200	▪2,200	▪2,200
▪				
▪ *Crop land*	▪	▪	▪	▪
▪Rice^{dr}	▪–	▪1,000	▪1,000	▪1,000
▪Cassava	▪–	▪4,000	▪4,000	▪4,000
▪Corn	▪400	▪400	▪400	▪400
▪Beans	▪200	▪200	▪200	▪200
▪Vegetable	▪1,000	▪–	▪–	▪–
▪				▪
▪ *Husbandry*	▪–	▪40^{H}	▪40^{H}	▪–
▪				
▪ *Slash &Burn*^{SB}	▪	▪	▪	▪
▪Rice	▪–	▪1,000	▪1,000	▪–
▪Cassava	▪–	▪3,500	▪3,500	▪–
▪		▪		
▪ *NTFP*^{NT}	▪–	▪–	▪	▪
▪Rattan			▪300	▪300
▪Honey			▪3	▪3
				▪

▪(wr): wet rice, generally with two crop per year
▪(dr): dry rice, one crop per year
▪(SB): considering a cycle of 2 years of cultivation (rice-cassava) and 4-5 years of fallow
▪(H): assuming a cow feeding on 8 ha of pasture land
▪(NT): this activity is carried on over several hundreds km2 of forest (Rattan is obtained by climbing
▪the palms of the *Calamus* genus, and it is used to make forniture)

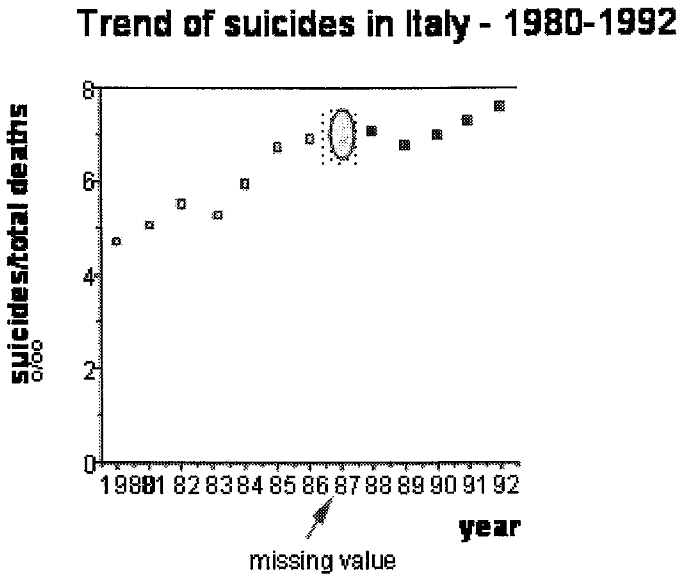
Table 11.4 Economic throughput per hour of work (ELP) and per hectare of tasks

(Gomiero and Giampietro, 2001)

▪*Economic performance*	▪*Type 1* ▪*Off farm-Crop.*$_{mix}$ ▪	▪*Type 2* ▪*Husb.-Crop.*$_{mix}$	▪*Type 3* ▪*S&B-Crop.*$_{mix}$	▪*Type 4* ▪*NTFP-Crop.*$_{mix}$
▪*Home Garden* ELP_{HG}(VND/hr) ▪ $\$supply_L$ (VND/ha)	▪ ▪4,000 ▪7,000,000	▪ ▪2,000 ▪5,000,000	▪ ▪500 ▪1,000,000	▪ ▪500 ▪1,000,000
▪*Crop land* ▪ELP_C(VND/hr) ▪$\$supply_L$ ▪(VND/ha)	▪ ▪1,000 ▪5,000,000	▪ ▪1,000 ▪5,000,000	▪ ▪800 ▪4,000,000	▪ ▪800 ▪4,000,000
▪*Husbandry* ▪ELP_H(VND/hr) ▪$\$supply_L$ ▪(VND/ha)	▪ ▪- ▪-	▪ ▪1,000* ▪125,000	▪ ▪1,000* ▪125,000	▪ ▪- ▪-
▪*Slash&Burn* ▪ELP_{SB}(VND/hr) ▪$\$supply_L$ ▪(VND/ha)	▪ ▪- ▪-	▪ ▪2,080 ▪1,000,000	▪ ▪2,080 ▪1,000,000	▪ ▪- ▪-
▪*NTFP* ▪ELP_{NTFP}(VND/hr) ▪$\$supply_L$ ▪(VND/ha)	▪ ▪- ▪-	▪ ▪- ▪-	▪ ▪1,750 ▪1,000	▪ ▪1,750 ▪1,000
▪*Off farm* ELP_{OFF}(VND/hr)	▪ ▪3,000	▪ ▪1,500	▪ ▪2,000	▪ ▪-

(*): considering two cows

NOTE: VND = Vietnamese Dong (1 US$ = 12,300 VND in 1997)
NTFP = Non-Timber Forest Products; HG = Home Gardening
S&B = Slash and Burn; C = Crops; H = Husbandry; OFF = Off-farm



At the level of the equivalence class

Fig. 11.1 Information about suicides

At the level of individual realizations

As they say, "the incident is closed"
Love's boat smashed on the everyday.
Life and I are quits,
and there's no point
in countering over
mutual hurts,
harms,
and slights.

Best of luck to all of you!

Vladimir Mayakovsky - 4/12/30

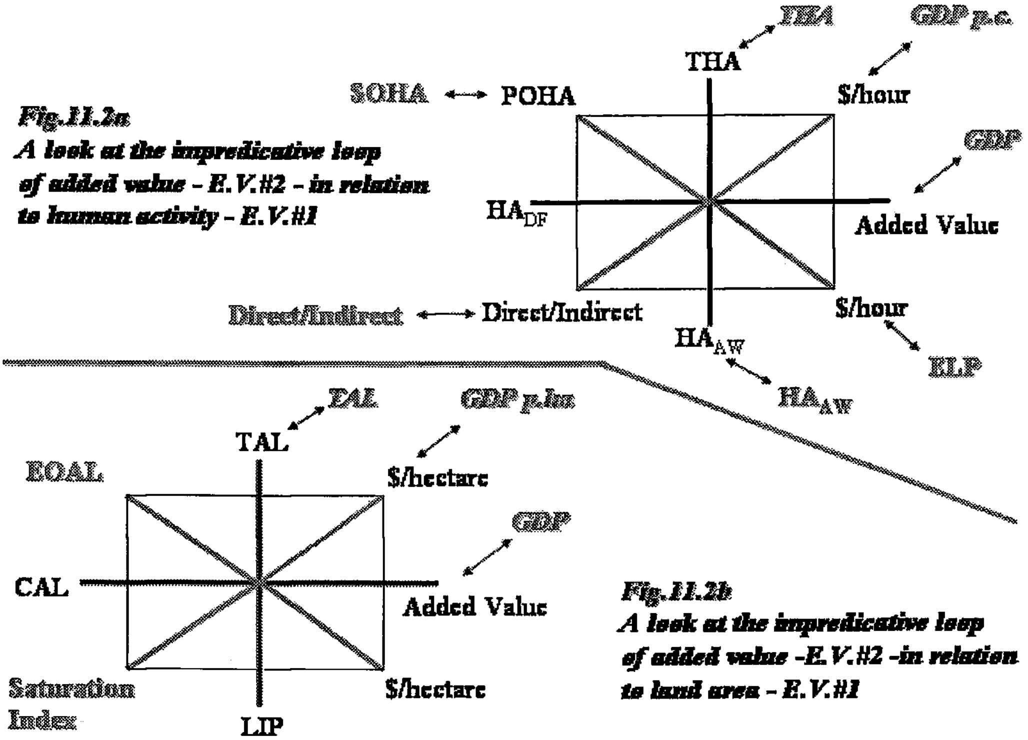


Fig. 11.2a
A look at the impredicative loop of added value - E.V.#2 - in relation to human activity - E.V.#1

Fig. 11.2b
A look at the impredicative loop of added value -E.V.#2 -in relation to land area - E.V.#1

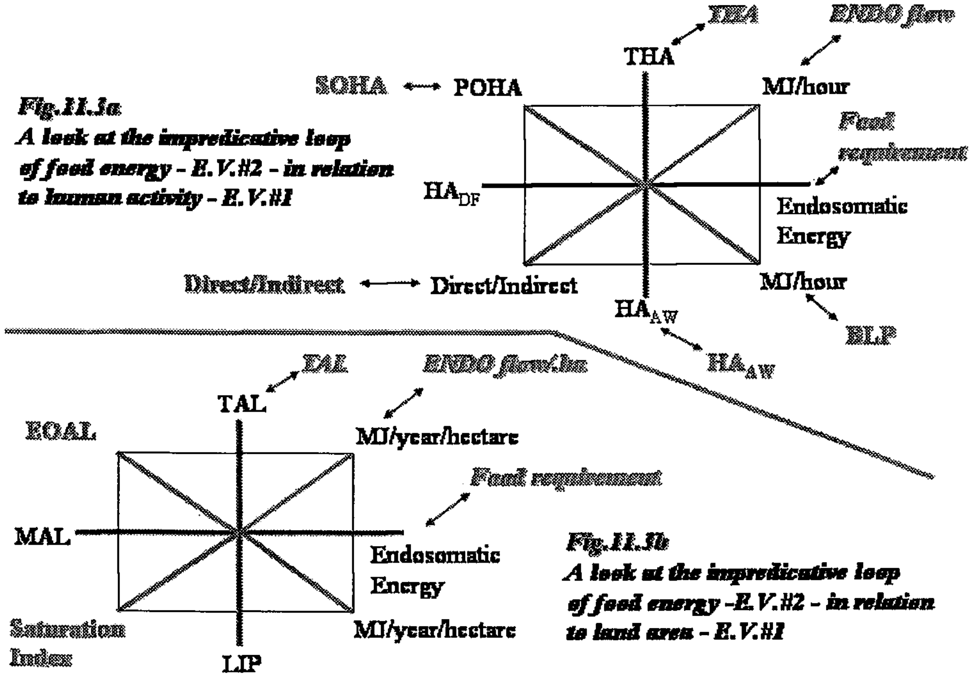
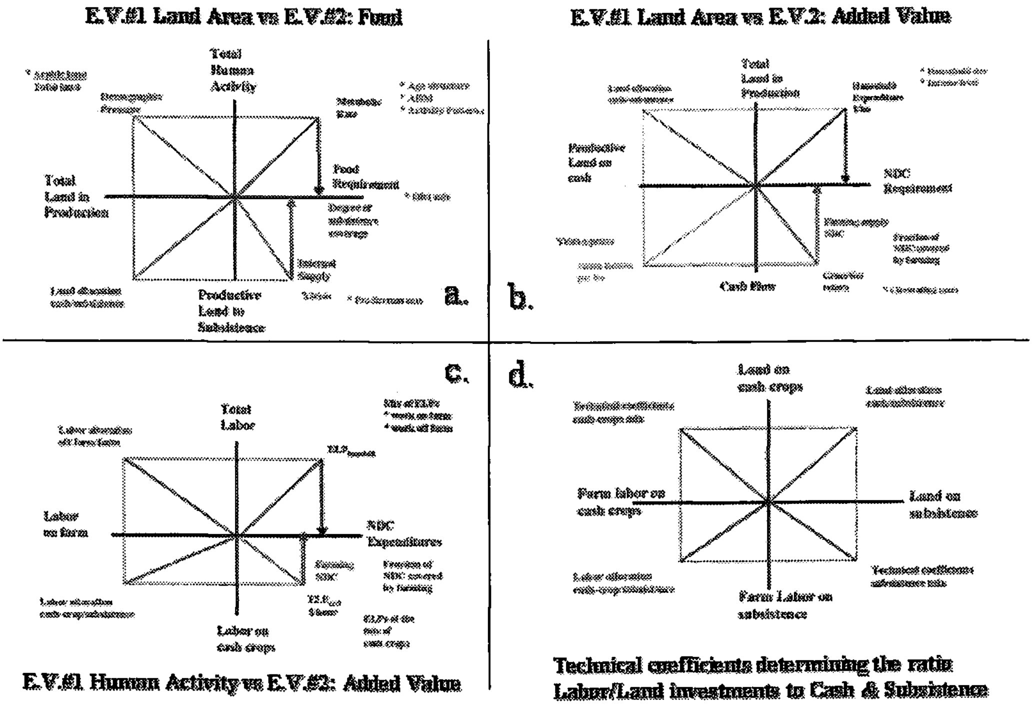


Fig. 11.3a
A look at the impredicative loop of food energy - E.V.#2 - in relation to human activity - E.V.#1

Fig. 11.3b
A look at the impredicative loop of food energy -E.V.#2 - in relation to land area - E.V.#1



E.V.#1 Land Area vs E.V.#2: Food

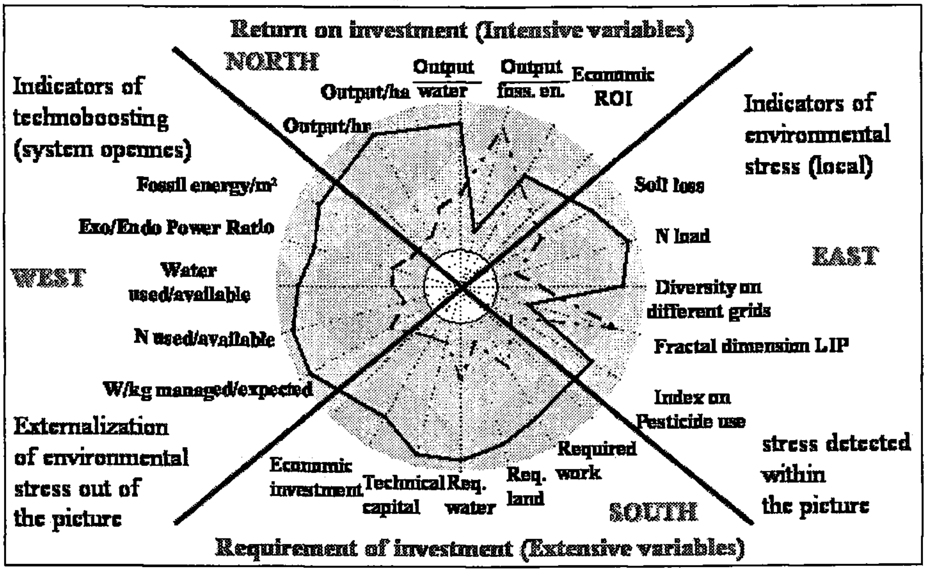
E.V.#1 Land Area vs E.V.2: Added Value

E.V.#1 Human Activity vs E.V.#2: Added Value

Technical coefficients determining the ratio Labor/Land investments to Cash & Subsistence

Fig.11.4 - Mosaic of constraints affecting the characteristics of the throughputs

Fig. 11. 5 Integrated representation at the farm level



Fixed investment/worker ($): 100 <—> 100,000 **Land/worker (ha): 1 <—> 500**
Technical capital/worker (MJ/h): 1 <—> 300 **Labor Productivity ($/h): 1 <—> 300**

Fig. 11. 6 Comparing freshwater aquaculture system for China and Italy

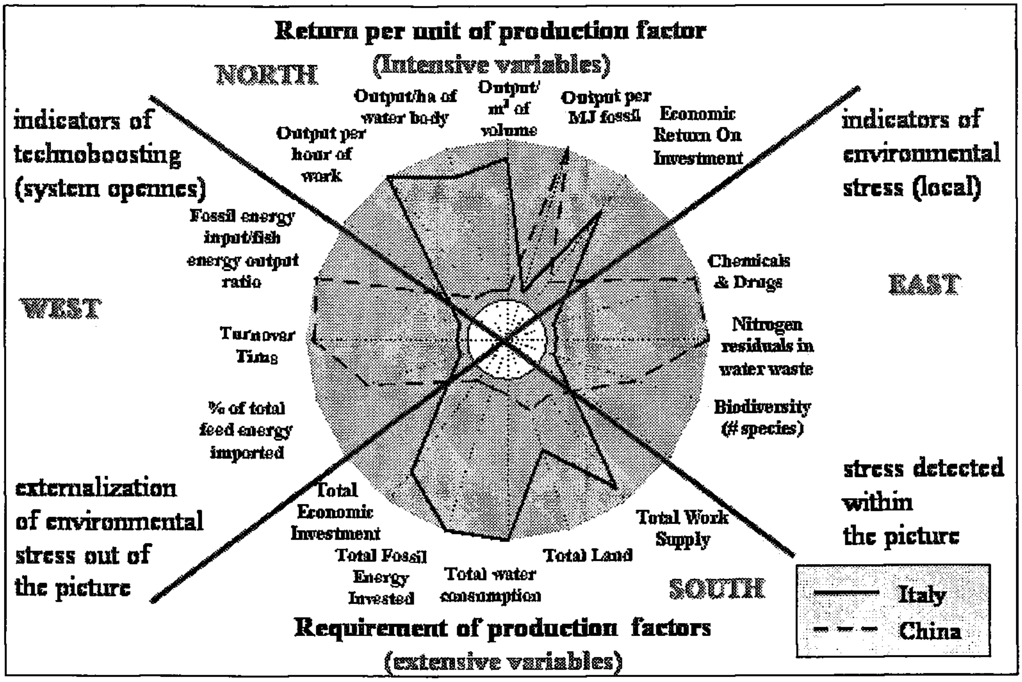


Fig. 11.7 Looking at farmers' choices

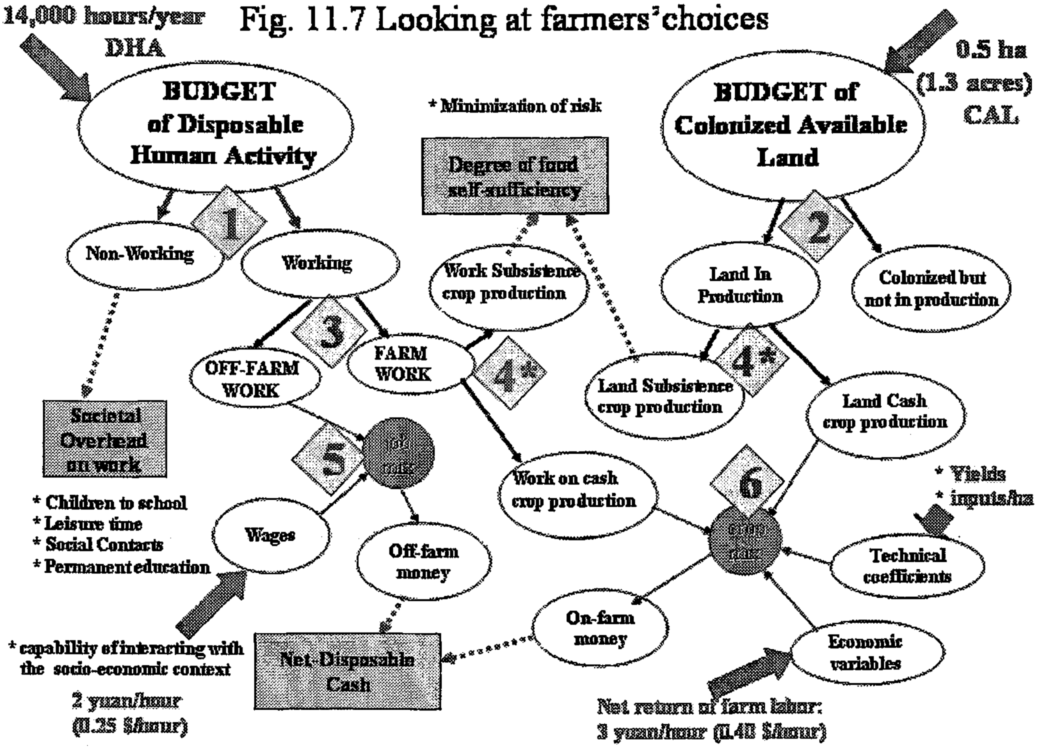


Fig. 11.8 Parallel representation of the impredicative loops shown in Fig. 11.2 and Fig. 11.3

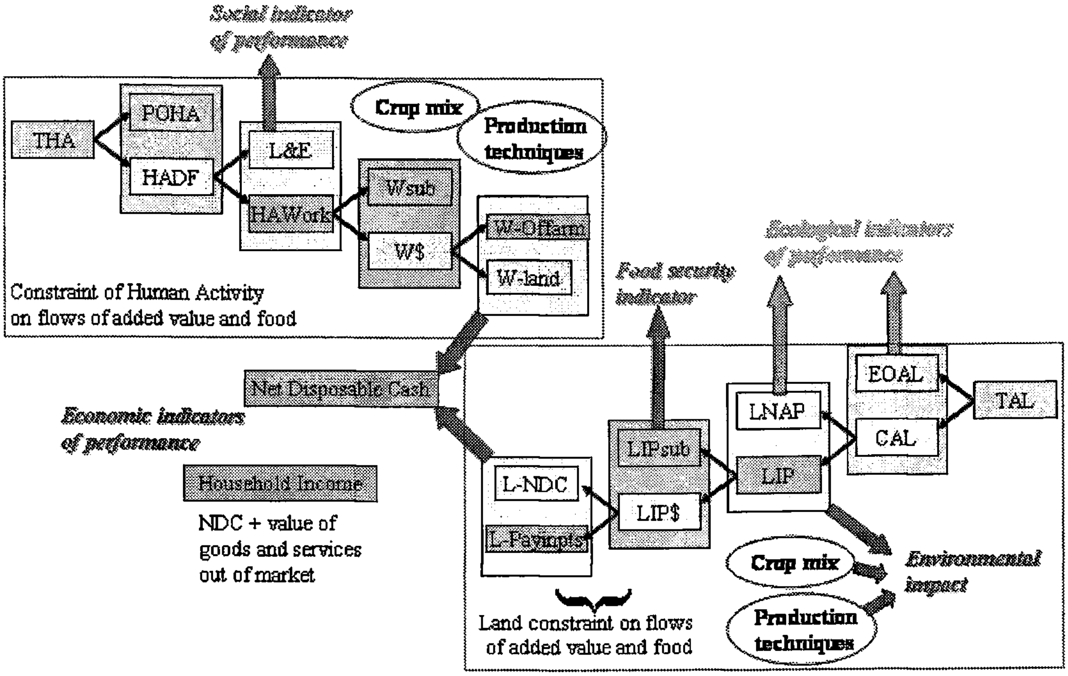


Fig. 11.10 Typologies of household on a Multi-Criteria performance space

(Giampietro and Pastore, 1999)

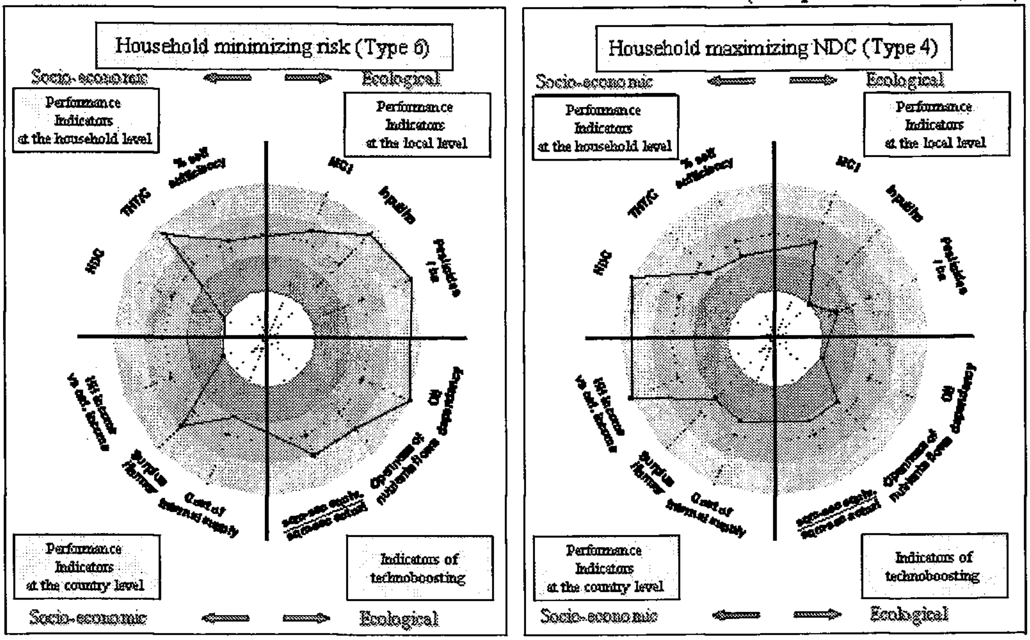


Fig. 11.9

Characterization of the relations among various "ELP$_i$" and " BLP$_i$", "NDC", "houschold income", using a STELLA diagram

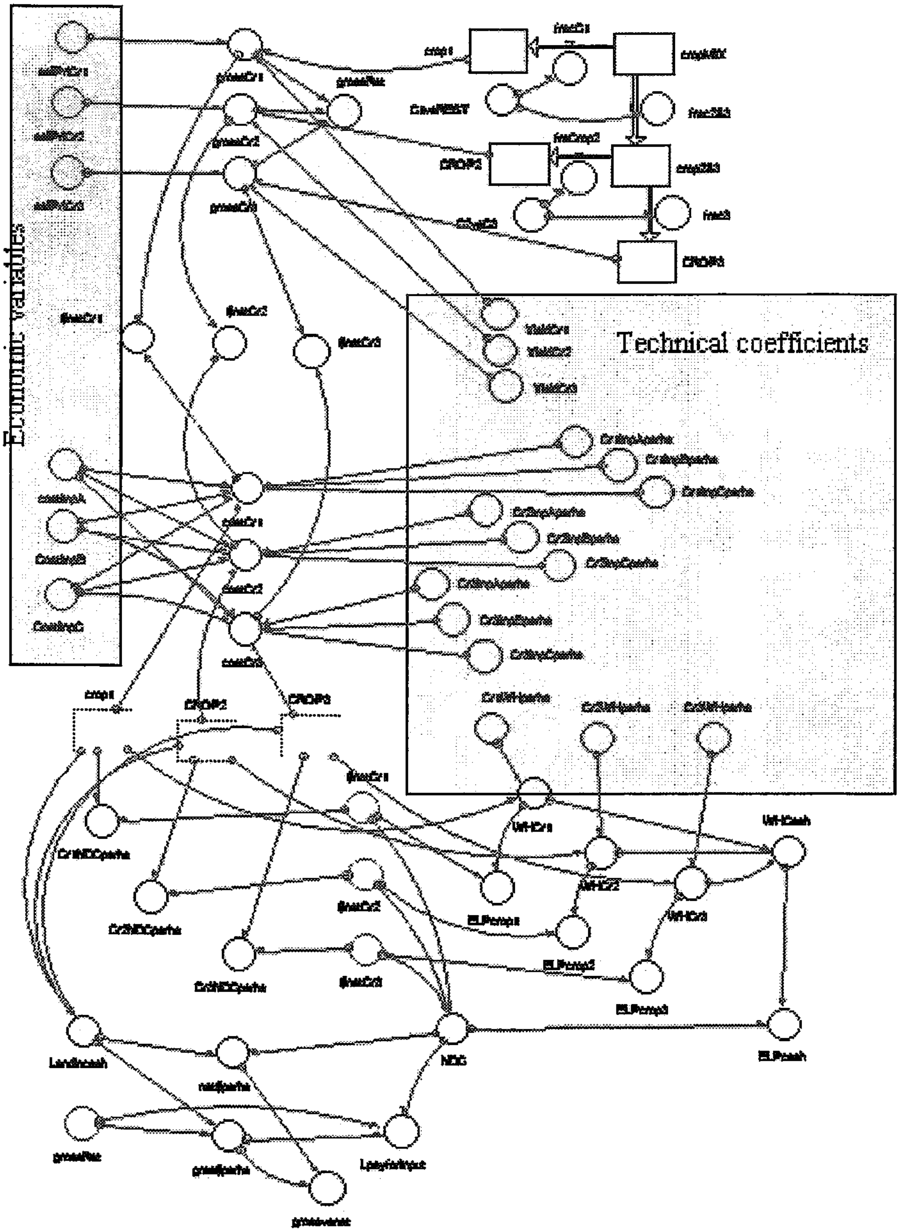
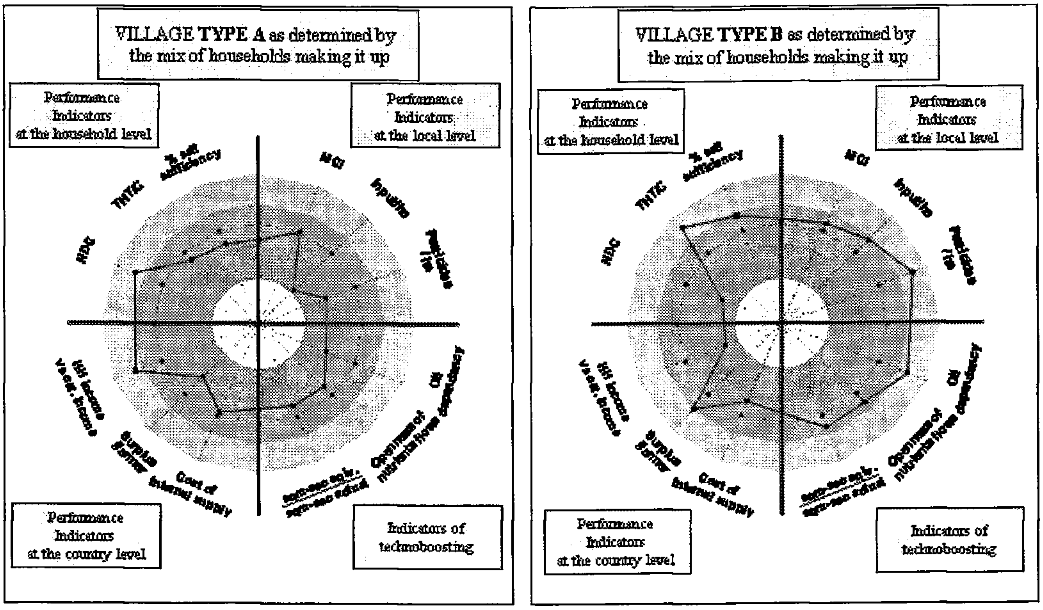
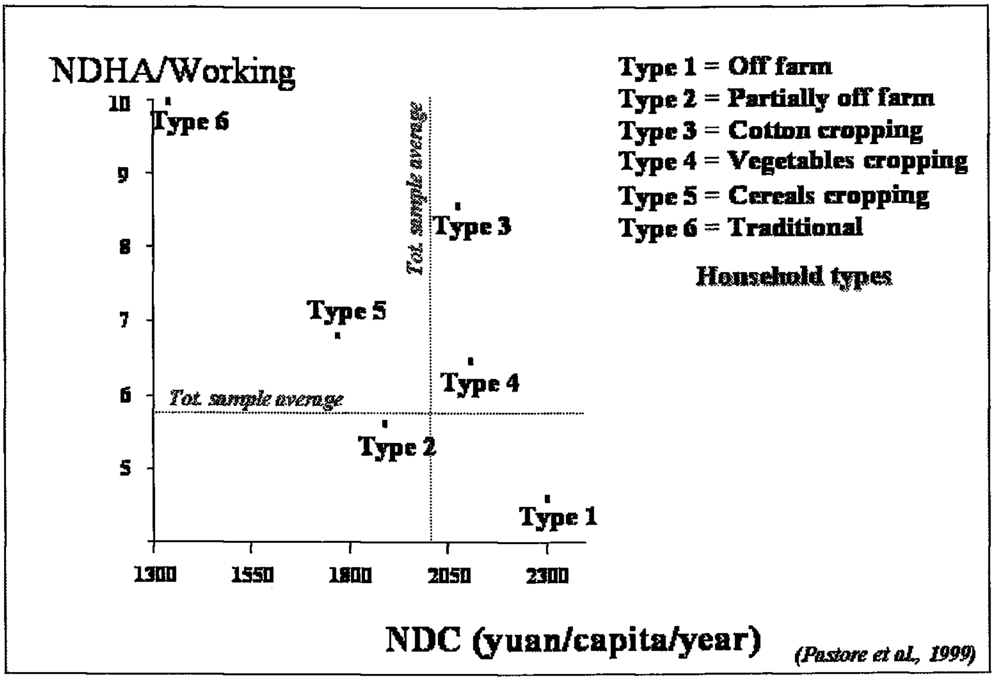


Fig. 11.11 Typologies of rural village reflecting a different mix of household types

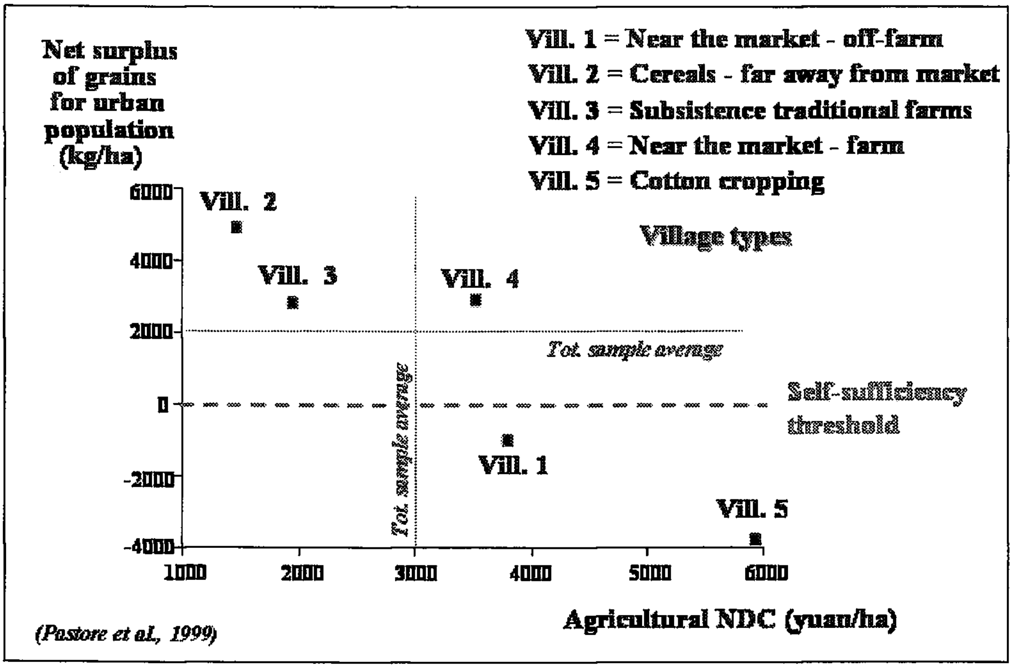
(Giampietro and Pastore, 1999)





(Pastore et al., 1999)

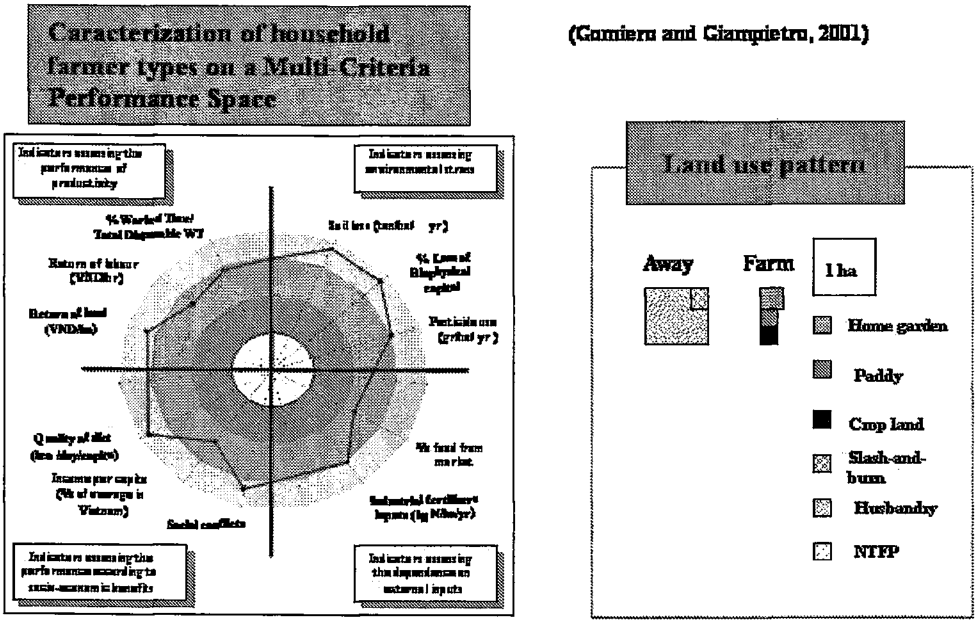
Fig.11.12 Representing the choices of household types in relation to two different criteria



(Pastore et al., 1999)

Fig.11.13 Representing the performance of Village types in relation to two different criteria

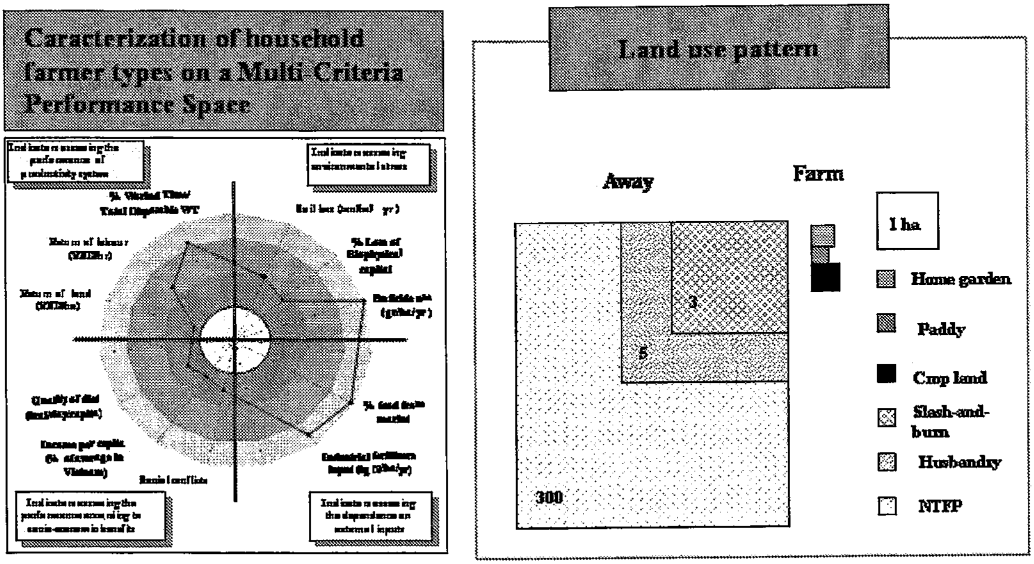
Fig. 11.14 Household type #1 - Vietnam Upland



(Gomiero and Giampietro, 2001)

Fig. 11.15 Household Type #3 - Upland Vietnam

(Gomiero and Giampietro, 2001)



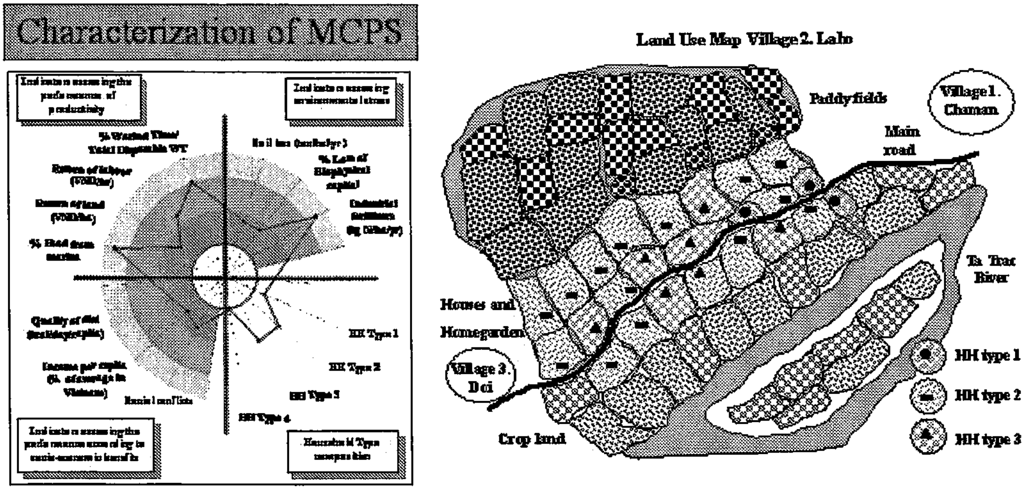


Fig. 11.16 Village 2 (Laho) - Upland Vietnam

(Gomiero and Giampietro, 2001)

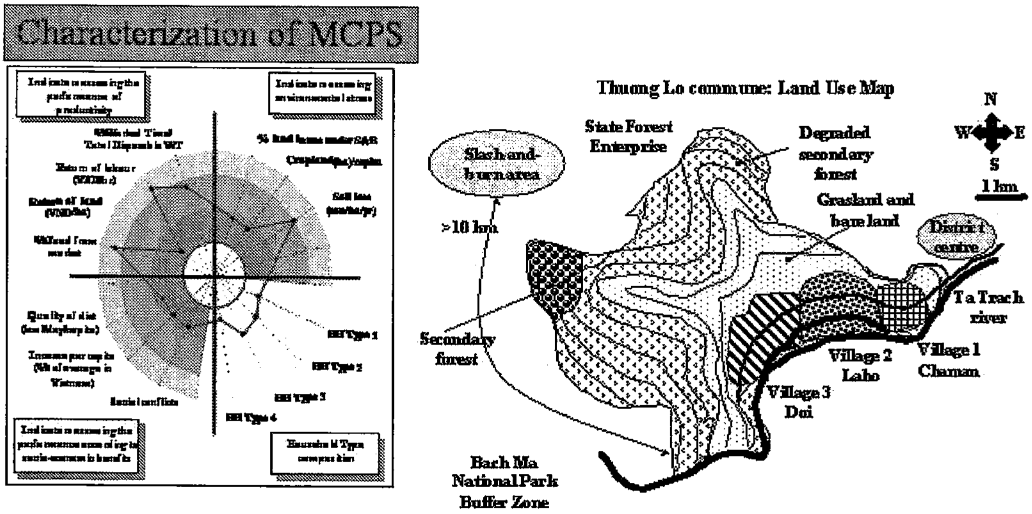
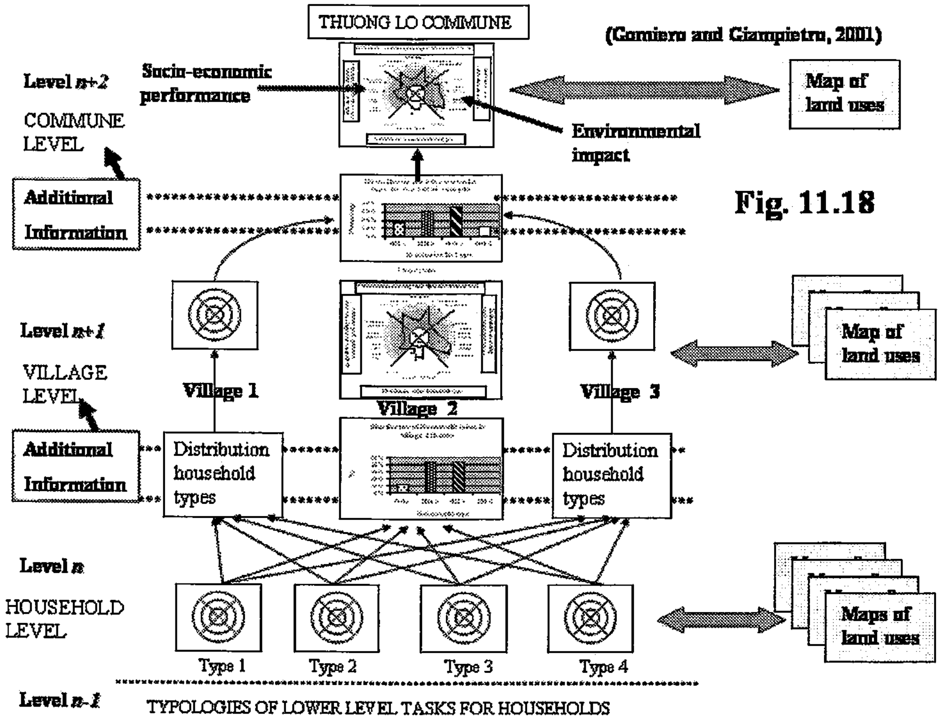


Fig. 11.17 - "Thuong Lo" commune - Upland Vietnam

(Gomiero and Giampietro, 2001)



(Gomiero and Giampietro, 2001)

Fig. 11.18

Fig. 11.19 Households seen as agents

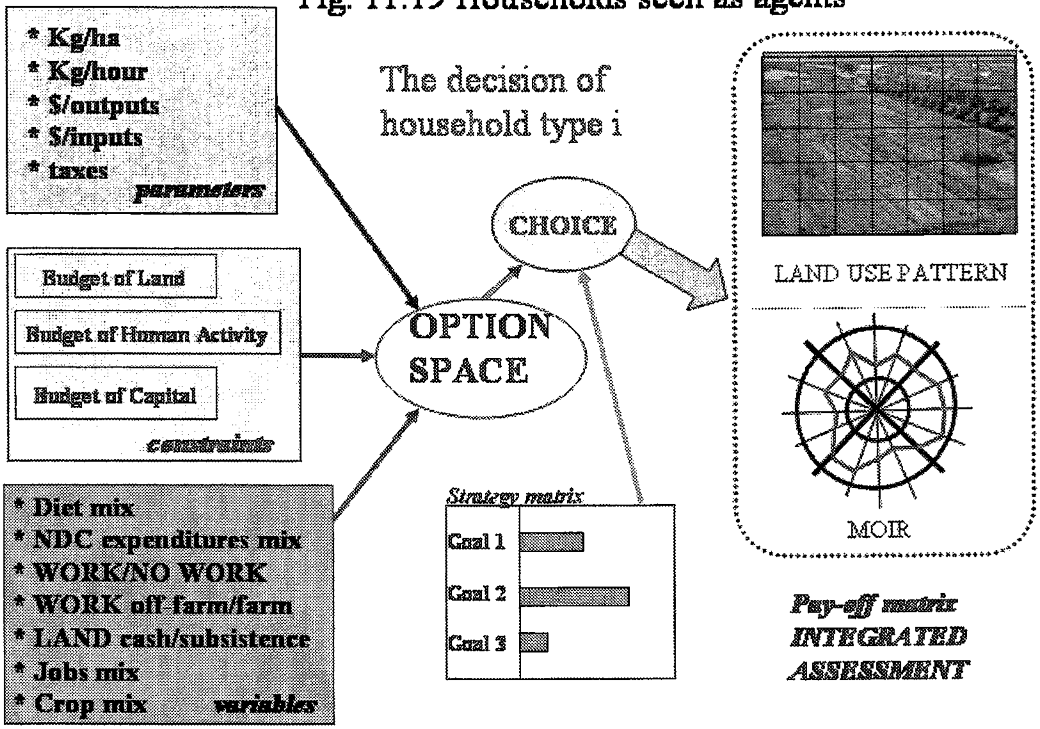


Fig. 11.20 Scaling up the effect of households choices

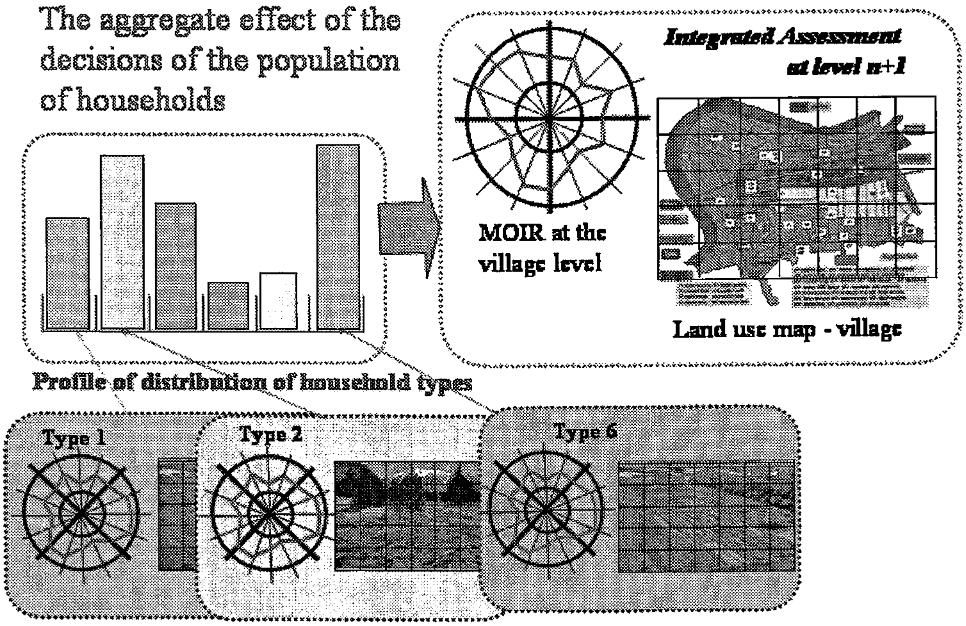
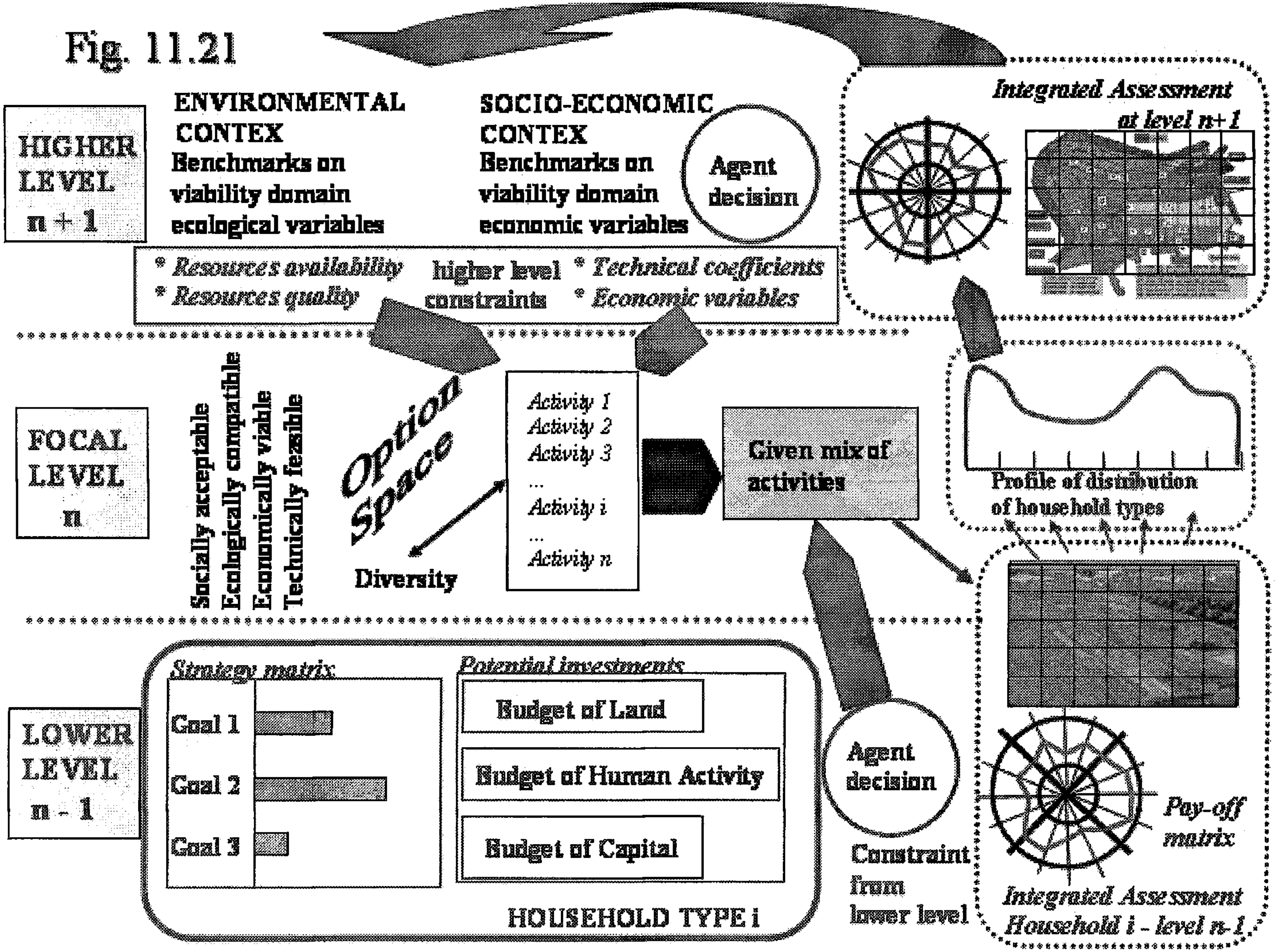


Fig. 11.21


HIGHER LEVEL n + 1
ENVIRONMENTAL CONTEX
Benchmarks on viability domain ecological variables
SOCIO-ECONOMIC CONTEX
Benchmarks on viability domain economic variables
Agent decision
Integrated Assessment at level n+1
* Resources availability
* Resources quality
higher level constraints
* Technical coefficients
* Economic variables
FOCAL LEVEL n
Socially acceptable
Ecologically compatible
Economically viable
Technically feasible
Option Space
Diversity
Activity 1
Activity 2
Activity 3
...
Activity i
...
Activity n
Given mix of activities
Profile of distribution of household types
LOWER LEVEL n - 1
Strategy matrix
Goal 1
Goal 2
Goal 3
Potential investments
Budget of Land
Budget of Human Activity
Budget of Capital
HOUSEHOLD TYPE i
Agent decision
Constraint from lower level
Pay-off matrix
Integrated Assessment Household i - level n-1

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