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Review

Complexity, Crash and Collapse of Chaos: Clues for Designing Sustainable Systems, with Focus on Grassland-Based Systems

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Abstract: Terms such as system crash, collapse of chaos and complexity can help one understand change, also in biological, socio-economic and technical systems. These terms need, however, explanation for fruitful dialogue on design of sustainable systems. We start this paper on Grass Based (GB) systems, therefore, dwelling on these terms and notions as review for the insiders and to help interested 'outsiders'. We also stress the need to use additional and/or new paradigms for understanding of the nature of nature. However, we show that many such 'new' paradigms were known for long time around the globe among philosophers and common men, giving reason to include quotes and examples from other cultures and eras. In the past few centuries, those paradigms have become hidden, perhaps, under impressive but short-term successes of more linear paradigms. Therefore, we list hang-ups on paradigms of those past few centuries. We then outline what is meant by 'GB systems', which exist in multiple forms/'scapes'. Coping with such variation is perhaps the most central aspect of complexity. To help cope with this variation, the different (GB) systems can be arranged on spatial, temporal, and other scales in such a way that the arrangements form logical sequences (evolutions) of stable states and transitions of Complex Adaptive Systems (CAS). Together with other ways to handle complexity, we give examples of such arrangements to illustrate how one can (re-)imagine, (re-)cognize and manage initial chaotic behaviors and eventual 'collapse' of chaos into design and/or emergence of new systems. Then, we list known system behaviors, such as predator–prey cycles, adaptive cycles, lock-in, specialization and even tendency to higher (or lower) entropy. All this is needed to understand changes in management of evolving GB into multi-scapes. Integration of disciplines and paradigms indicates that a win-win is likely to be exception rather than rule. With the rules given in this paper, one can reset teaching, research, rural development, and policy agendas in GB-systems and other areas of life.

Keywords: grazing; pastoral; scapes; paradigms; learning; complexity

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1. Introduction

Maturity is the capacity to stand in two paradigms at the same time, preferably conflicting ones (C. West Churchman, quoted by Richard Bawden).

Society increasingly understands that farming and pastoral systems are subject to constant change, like everything else. Heraclites is supposed to have said (some 2500 years ago): 'Pantha Rei', which means 'everything flows', with variations such as: "no man ever steps in the same river twice, for it is not the same river and he is not the same man" (Figure 1). Farming systems indeed, similar to all other systems, vary spatio-temporally. Notions of 'complex adaptive systems' imply such continuing change with intermittent stable states, as well as transitions consisting of crash (in degrees), also called 'mess' and subsequent 'collapse of chaos' and/or emergence of new patterns. A dynamic approach to the study of Farming Systems contrasts with mainstream approaches that define systems precisely, but statically. Work by [1] is an example of recognizing the notion of CAS by describing change from static to dynamic approaches, standing in a German tradition

(Ruthenberg stands in a (German) tradition using dynamic paradigms to study (farming) systems as created by (to mention a few) Goethe, Alexander von Humboldt, Von Thünen and Rosscher [2–4]. Many 'stable-state' descriptions (morphologies) of farming systems exist (for livestock systems, see [5]), but Ruthenberg indeed adds notes on the morphogenesis of farming systems (i.e., change from one into another stable state) at the end of each section (Ruthenberg also mentions shifting cultivation ('slash and burn'), a type of farming that some see recurring on a global scale in modern large scale business operated farming systems, also called 'empire' [6] emphasizing quick profits and mining of resources, eventually leaving the land unproductive). Change of GB systems in space and time can imply shift of production from meat to dairy, from pasture as fodder to pasture for soil conservation [7], as well as from monetary value only (commodity) to inclusion of societal values (community), from focus on large supply chains to a mix of short and large, from less to more sustainable [8,9].

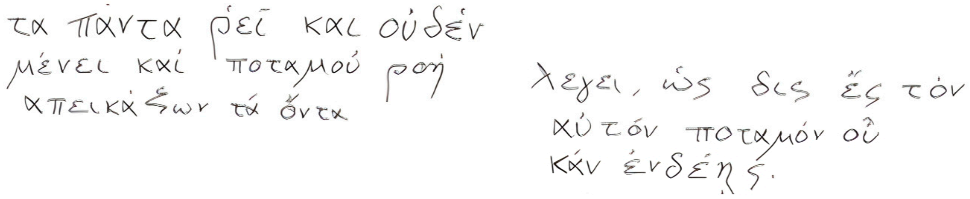

Figure 1. A note on system dynamics from ancient Greece: "one never steps in the same river twice, because the river has changed and the 'man' is not the same anymore" (attributed to Heraclites, some 2500 years ago).

Concerns about sustainability are known from ancient philosophy and holy books, starting with the notion of 'rest' and 'reset' in sabbath years from the bible, probably paralleled in many other religions. We did refer to Heraclites and his 'pantha rei', while Epicureans in ancient Greece saw 'enjoyment' as 'something' of today without 'hangover' tomorrow. The concerns on sustainable development have re-emerged strongly in the past 30–40 years [10], yet 'limits to growth' were known earlier [11]. Climate and geo-political changes are current phenomena driving change as were steamships and railroads as well as dustbowls somewhat longer ago. Each such change can imply crash of existing order, often called chaos. However, 'chaos' is a confusing term implying breakdown (crash) for some while (for us) implying emergence of new forms. Our main underlying point is that understanding of changes/dynamics of farming systems implies use of new (or ancient) parameters and paradigms, seeking a new balance between static and dynamic approaches. In this paper, therefore, we talk more about 'general behaviors' of systems (including GB systems), than about static descriptions/classifications of systems 'as they are'. As systems come and go, the associated insights and paradigms disappear also, and/or they are (re-)discovered later [12]. Many such (re-)emerging notions (on change and dynamics) are referred to in this paper also by quoting recent and ancient 'philosophers' as well as common men.

This paper aims to briefly review terms, methodologies, paradigms, and behaviors used in current debates on design of sustainable and ethical systems. It also aims to provide background on system thinking and basic design laws as well as to give hints and examples on 'design' for sustainability in a broad sense. To start with, we refer to 'default' (also known as lock-in) as the opposite of 'design'. Also, we emphasize change from static (linear) to dynamic (non-linear) approaches in managing (GB) systems. Focus is on overview and interdisciplinarity for design rather than for analysis. The minds of the reader should be prepared for new 'scapes' to emerge, sketched rather than to be described in precise and static terms. Readers should also expect notions on design rather than on default. 'Scapes', in the sense of this paper, can refer to aspects of physics of land, ecology, economics and minds, even paradigms (See also: en.m.wikipedia.org/wiki/Soundscape_ecology#Description). Ref. [13], for example, shows how estimates of feed conversion change by including (or excluding) time scales, costs of breeding, maintaining of stock levels and the like. Our focus on interdisciplinarity requires imagination and translation of concepts and terminologies that are similar or the same, even if not at first sight (Convergence and divergence of terminology is found in all types of systems, not only in language. This issue illustrates the generality of notions discussed in this paper. For example, plant and animal taxonomy abounds with Complex Adaptive Systems of great similarity ánd contrast between 'members' of different families, e.g., between Marsupials and Mammals, and between most of the Cactaceae and certain members of Euphorbiaceae). We, therefore, use '/' to indicate useful similarities.

The outline of the paper is to start with notes on terms, methods, and paradigms (1, this introduction). We then discuss terminology (Section 2) and as intermezzo some hang-ups due to mainstream disciplinary focus (Section 3). We then proceed to provide an intentionally broad characterization (no definition) of GB systems, and a brief review of work with non-linear approaches in farming systems research of the last half century. Sections 4 and 5 explain how to cope with complexity by giving methodology and complex system behaviors, even referring to design rules from thermodynamic theory. We discuss choices on paradigms for design of sustainable (GB) systems with examples from around the world (Section 6). Comprehensive coverage of all backgrounds is impossible and neither do we pretend to be precise on all aspects. Attention to detail can indeed be at the cost of overview and vice versa. We only pretend to give an artist impression, hoping to raise interest among the uninitiated and to invite comments from those who have trodden this path for quite some time. We do use ancient and older insights, cutting corners and wishing to avoid long lists of references. Part of interdisciplinary thought uses associative thinking and dense arguments, not always easy for the uninitiated ones and/or even to be skipped when too distracting. We give key references in the text on specific issues, notably when of 'review nature' (A major source of information regarding philosophy is [14], unfortunately not in English translation). Much of that may seem rather 'old', but illustrating that something novel can long go unnoticed for a locked-in world. Additional (perhaps distracting) background is kept in footnotes and readers may, of course, consult the authors for further information.

2. Chaos and Complexity

GB systems, similar to all other systems, occur as infinite variations of forms and multiple functions, all changing in space and time, an essence of Complex Adaptive Systems [15]. In fact, no system is permanent/static, even if time scales are slower for rocks than for insects. Still, much mainstream work tends to describe and define systems as 'linear' and 'static'. Even calculus used by Newton and Leibnitz was summation of small linear chunks of space-time, within paradigms of linearity! Static descriptions of (always-changing) systems tend to miss the dynamics that are central in any (GB) system. They focus on how systems are at a given moment in time and space, resulting in 'morphologies'. Inclusion of dynamics/changes results in descriptions of 'morphogenesis', which is the focus in this paper (In general system thinking, this is considered as the step from being to becoming). We use the term system both in a spatial sense (how things are) and in a temporal sense (how things change). Combinations of spatial and temporal aspects are implied in notions of Complex Adaptive Systems, which apply to pastoralism, crop, mixed or urban farming systems, as well as science, religions, societies, etc. [16–18]. Dynamics in such systems and the pertaining paradigms can be 'masked' by using a term such as 'working' definitions. We chose deliberately to dynamically 'characterize' rather than to statically 'define' GB systems (Section 3). We thus aim to stress change and existence of different perceptions (i.e., scapes).

Dynamics in systems challenge static approaches to define sustainability. Dynamic approaches also introduce notions of regenerative agriculture as part of eternal processes of sustainability. What was sustainable last year may not be sustainable tomorrow. Moreover, any such dynamic approach to design of sustainable systems implies changing, and sometimes recurring choices on worldview/paradigm (The term paradigm was originally used for 'thought systems/dogma's' at level of society [12]. We intermittently use terms such as paradigm, worldview, and mindset, because of phenomena repeating themselves at basically all systems level (see the fractal notion), also to bridge gaps between different disciplines and divergent terminologies) 'Design' becomes 'default' when not accompanied by critical reflection. 'Scary' for some is that in real life (whatever that be), any landscape has innumerable aspects, such as soil type, vegetation, sociology, and finance. The notion of 'innumerable aspects' implies choice, reflection and more time, away from 'certainty' as implied in the Latin adagio '*festina lente*'. Methodologies for making such choices and reflection are now known (end of Section 3). Under the motto "we do what we are good at", much mainstream work used to focus on criteria and issues that could be handled easily, omitting parts of reality using convention (lock-in). That was cause for short-term success, perhaps, as well as for eventual demise of reductionist science to cope with reality [19]. It was also reason for the rise and downfall of eventually parsimonious models. We argue that attempts to better understand the nature of nature can benefit from conscious choice between (combinations of) paradigms (Figures 2 and 3; see Boogaart, 2009 for application on Dutch and Norwegian dairy systems). Kuhn ('father' of the 'paradigm' notion) already stated that answers depend on questions asked [12]. Popper ('father' of 'falsification') stated that no objective history can be written [20]. "At best", Popper says, "one might describe the point of view (worldview) from which description was done". He thus implies choice, stressing impossibility to describe reality in all its changing aspects at the same time. As said earlier, and despite widespread use of static and linear work, many of the modern notions used in dynamic/non-linear paradigms were around for quite some time around the globe. This paper mainly uses non-linear paradigms, stressing that choice between (a mix of) paradigms is possible and necessary. West Churchman said: "maturity is the capacity to stand in two paradigms at the same time, preferably conflicting ones" (Richard Bawden, pers. comm.)

Choice of paradigm requires that one recognizes the paradigms and hang-ups that one is raised in, and of which one is often unaware (Figures 2 and 4). The 'scapes' in Figure 2 show how paradigms/worldviews/perceptions/'domain setting ([21] talk of domains that 'together' form reality. Considering reality from more than one 'domain' is what they call holistic, opposed to 'staying within a 'default' domain)' are affected by discipline, and by place of the observer in the system and in the hierarchy. One painful illustration of different worldviews is where a Dutch Minister of Agriculture recently was quoted to be "proud of the performance of the agricultural sector". She meant that she was "proud of record exports" (i.e., of the performance of Agri-Business), at a time when many producers feel depressed with hard financial times and environmental stress. The perhaps scary and confusing characteristic of complex reality is that different stakeholders have different points of view, and that each of those is correct in its own right (Especially mass media can (deliberately or not) manage to change meanings (well recognized in complex system thinking), e.g., where Popper's emphasis on 'science through falsification' and 'uncertainty of induction' has eventually led into an almost objectivist certainty that Popper 'helps' to justify 'objectivism [22]). We return to differences among and between stakeholders, such as industry and producers when discussing the 'predator–prey' model (Section 5). A major point here is that different perceptions/interests imply trade-offs (i.e., choices) in one way or another, including use of opposing opinions and even fake news. Trade-offs and choices also show up between levels of the system hierarchy [23], between mainstream economics and ecology, between macro- and micro-economists, between interest groups, rural people and growing farm-businesses, as well as consumers and producers/processors (Box 1). On inter-generational trade-offs, we quote a farmer from south Western Australia, who commented on the salt problems (Salinization in that area was predicted prior to starting the large-scale development of that area (David Lindsay, 1980, pers. comm.)) by saying: "our children will sue us when they see how we handled the land and left it".

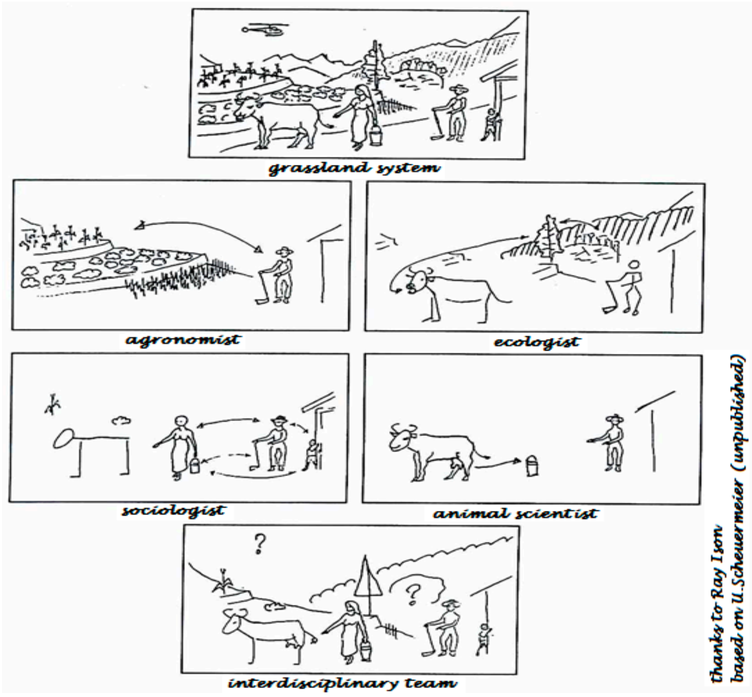

Figure 2. Perceptions of a (land)scape as influenced by education, in this case by scientific discipline.

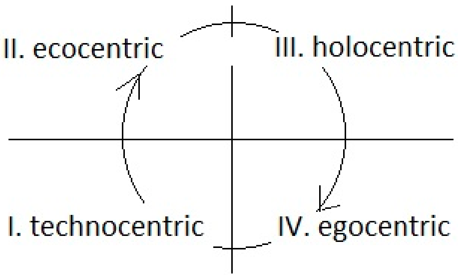

Figure 3. Dynamic paradigm-scapes, also known as the Miller/Bawden quadrant. The circle with arrows indicates that choice for paradigm can be a dynamic process (thanks to Niels Röling, pers. comm.). Note: for those familiar with such dynamic quadrants: the same principle is present in, for example, the learning cycle by Kolb's and Piaget's work as well as in the empirical cycle.

横看成岭侧成峰 远近高低各不同。 不识庐山真面目 只缘身在此山中。	An ancient poem on the wall of West Forest Temple about the (land-) scapes of the mountain and systemic reflection, saying: from the side the mountain is a whole range; from the end, it is a single peak. From far, near, high and low no two parts alike. Why can't I tell the true shape of Lu-Shan? Because I myself am in the mountain. (Burton Watson); Poet SU Shi (1037-1101); (translation thanks to Zhang Xiaoyong; pers. comm.).

Figure 4. Chinese wisdom of some 2000 years ago combines notions of different 'scapes' and 'paradigms', i.e., stating that it is hard to know the thinking (in which one is raised). Note: the idea that one him/herself is (part of) the mountain is reflected in systemic thought in this paper. It is where an 'observer' not only wonders (as outsider) on what is good or bad with the system that is 'observed', but also on the position and role of the observer him/herself.

Box 1. Tensions/trade-offs/choices, communal ideotypes, and 'how to serve many masters'.

Tensions and trade-offs between scapes are rule rather than exception, across all levels of system hierarchy. Gain for one tends to be pain for someone else. Significance of tension between different viewpoints at regional level first struck JBS in [24], who wrote on trade-offs, e.g., where perceptions of erosion control and water catchment for hillside farmers clashed with those of farmers in the plains. Hill farmers 'catching' water can 'rob' farmers in the plains of fertile sediment and irrigation water. At plant and plot level tension occurs, e.g., between 'individual' and 'communal ideotypes' in plant breeding ánd animal production. Design of plants with high individual yield imply other ideotypes than design of plants that (with others) result in high yields per plot [25]. Animal 'production' knows this in the tension between yields of individual animals vs. total herd, especially when resources are limited [26,27]). In a related set of scapes, trade-offs occur between characteristics such as income, nutrient emissions and milk yields in pasture based dairy systems of the Netherlands and obviously elsewhere [28]. More practically, farmers can choose to accept lower yields to gain on animal vitality while saving on expenses for the veterinarian or they can choose to leave crop-residues on the field for soil quality next year rather than getting immediate cash. In daily life, the examples of trade-offs are where family is neglected for career perspectives of the head of the family. Construction workers and architects balance aspects of structural, economic, functional, and aesthetic scapes. Choices are part of life and 'win-win' is not always around the corner. Running farms, businesses or families is a matter of serve two (or more) masters while knowing that *'one cannot have the cake and eat it'*. All of us walk the tightrope between 'scapes' of economy, ecology, rural life, short-term, and long-term interests. Later on this paper shows how 'scapes' of mainstream economics and those of laws of physics also are likely to be at odds. Last but not least, we show different graphs on trade-offs/choices, with argument possible on the exact shape of these crossing lines, but not on the principle.

The terms 'chaos' and non-linearity were initially used for unexpected behaviors in dynamic models when computers permitted programmers to run models longer than for short time intervals [29]. After time, however, the term 'chaos' became used more positively for 'emergence of new forms', as we do in this paper. In line with that and importantly, the term non-linearity is thus used for unexpected behaviors, not for curvilinearity. We use the term 'crash' for the breakdown of existing (expected) order and 'collapse of chaos' where new forms show up in the 'mess of crash' [30]. Distinguishing 'crash' and 'emergence of order' (Box 2), i.e., 'collapse of chaos' requires attitude and training. The terms reductionist and holistic approaches are 'containers' in the sense that together with other notions they do cover several often-opposing approaches. Reductionist/linear approaches are mainly based on Cartesian logic, aiming to understand the smallest possible parts and from there on to 'mechanistically' rebuild the 'object' of research [31] as if it concerns a set of Jigsaw pieces. That is usually accompanied by disciplinary focus and by focus on aspects of matter rather than mind, assuming that 'things may be complicated but solvable' and assuming ceteris paribus (all other conditions remain equal). Holistic and complex system approaches consider parts, but they pay attention to the interactions between the parts and to several 'disciplinary' aspects rather than a few, stressing complexity (non-solvability), emergence, self-organization, different perceptions, and unexpected behaviors (i.e., ceteris imparibus). The difference between reductionist and holistic/non-linear approaches is reflected in Table 1. Each approach has its own merits with roughly speaking reductionist/linear approaches suitable for the short term (ignoring side effects, trade-offs, and ceteris imparibus). Longer term and (thus!) complex problems cannot be handled well by reductionist/linear approaches but need holistic/non-linear ones (as argued in this paper). A holistic look at forms, drivers, and design of (GB) systems needs use of paradigms that stretch vision to shatter perceptions. Ref. [32] for example, may cause 'crash' of our existing order (comfort zone), but they challenge locked-in paths as needed for design rather than default. We repeat that a scary aspect of such crash is that things become messy, chaotic and/or too diverse to handle. To the uninitiated working with complexity is as scary as (even under proper guidance) jumping in the water to learn to swim, reason for us to give clues on how to handle messiness in Section 4, after an intermezzo on paradigms, hang-ups and 'definitions' of grassland-bases system in Section 3. Taking risk to go beyond 'crash of order' implies effort, even to leave one's comfort zone. It can imply, however, opportunities as well as choices/trade-offs as discussed throughout this paper.

Table 1. Complexity and complication paradigms, based on discussions with Wijnand Sukkel (Wageningen University and Research).

Complicated World	Complex World
Systematic thinking (excluding one's own position)	Systemic Thinking (including one's own position)
Static control mode	Dynamic participation mode
Or-or	And-and
Linear and predicted change	Non-linear uncertain change
Clockwork 'mechanisms'	Living organisms, CAS
Single cause–effect relation	Multiple causes and -effects
Face value	Deeper system thinking
Controlled experiments	Participatory field trials
Goal oriented	Process oriented
Pinning things down	Living with change
1st order system thinking	2nd order system thinking
Closed system	Open systems
(single) solutions	(multiple) coping strategies
Win-win	Trade-offs
Linear growth	Growth, decline and regrowth
Further from equilibrium	Nearer to equilibrium
Separating parts	Combining parts
Focus on differences	Focus on similarities
Use of empirical cycle	Use of empirical cycle

Notes: In systematic approaches, the observer is NOT part of the system studied. In systemic approaches, the observer critically questions 'his/her/their' own role in problem definition, choice of paradigm(s) and subsequent solution(s). The use of the empirical cycle is included to show that some thought-scapes occur in both the left- and right-hand column.

Just one example of work that eventually had to be reassessed is the remarkable but myopic approach to fodder quality in GB systems (Figure 5). It was based on an almost dogmatic obsession on leafy, digestible, and high 'ME' (metabolizable energy) grass in temperate pastoral lands of northwestern Europe, North and South America, Australia, and New Zealand. Eventually, it resulted in lower C/N ratios of the herbage, however, leading to N excesses and consequent problems for the environment and animal health, wellbeing, and welfare [33,34]. Crashes occur due to such linear approaches since the disciplinary focus tends to assume 'ceteris paribus', ignoring other 'things' (side effects, trade-offs) (Figure 5). For example, digestibility increases tend to imply more frequent grass cutting/grazing, i.e., younger herbage and 'thus' crude protein contents above 20%, well above what cows need. Legislation to stop emitting too much N representing crash, are an obvious response to that crash (one form of collapsing chaos). They can lead to the need to add structural carbohydrates (even straw) to the ration for greater C/N ratios and less emissions [34]. Quitting business is another response, just as 'going organic', starting lobbies and so on. A second example of inviting 'crash' occurs due to breeding with focus on one trait that tends to go at the expense of fitness [35,36]. (Note: from here we start a series of associative thoughts that casual readers may skip). A third example is how the default use of more medicine, and other 'quick fixes' are a case of refusing to see pending 'crash of existing order' at the risk of missing opportunities. Accepting emergent new order by accepting lower yields and less stress in animals is a way of many (Dutch) farmers to accept crash and to let chaos collapse into a new stable state that perhaps can be sustained for at least some time longer than the previous one. Crash is often delayed, e.g., by lobbying for status quo and/or by addressing symptoms rather than causes. The longer a crash is delayed, however, the worse it gets (lag time is an important factor in non-linear behavior of systems). A fourth example of refusing to accept 'crash and collapse of chaos' in politicosocial scapes is euphoria on increasing farm size and short-term economic advantages of scale that tend to be at the expense of the involvement of farmers in rural community life (Box 1). Preventing pandemics by forbidding local markets rather than also doing something about large-scale human activities (cities, parties, stadiums, global food chains and tourism) is a case in point. Short-sighted vision implies suppression rather than support for newly emerging systems (examples of collapsing chaos), such as urban, community or organic farming, zero tillage, short chains, agroforestry, and the like. Delaying change can even be seen as 'throwing out a baby with the wash water', if implying trade-offs between missed long-term opportunities for short-term interests due to financial commitments, efficient but rigid production structures (physical and mental), legislation (often to 'save an existing mode'), inflexible teaching and research agendas, as well as by 'hang-ups' on paradigms/worldview. Thus, we use the next section, as intermezzo to discuss paradigms and hang-ups in design of more sustainable (GB) farming and foodscapes. After that, we move to practical aspects of working with 'complexity' in Section 4.

Box 2. 'Collapse of chaos', or how combinations of parts, characteristics, actions and scapes parts 'lead to' emergence.

Complexity accepts the notion of causes and effects, but it stresses that they are hard or even impossible to be 'teased-out'. That contrasts with 'Newtonian' linear cause–effect thinking where, for example, one billiard ball has a predictable (explainable) effect on another. Indeed, if those two billiard balls are separated from the rest, one can assume a linear cause–effect relation but experienced billiard players know that there are more factors at play (the texture and temperature of the cloth, grease on the balls, a good night's sleep, noise from the audience, tilt of the table and so on). 'Worse' it gets when one considers the effect of additional 'balls', just as the behavior of a gas combines the bouncing of innumerable molecules. Complexity 'thinks' (We are aware that 'complexity does not 'think' but we ask readers to not become lost on such semantics) in terms of 'the straw that breaks the camel's back' where one never can know the one-and-only reason for failure or success. Even more, whether something is failure or success depends on the observer who may see other (dis)advantages than any other observer. Complexity thinks in terms of a combination of causes for disease outbreak, e.g., susceptibility of animals, virulence of the germ, velocity and direction of the wind, or farmer's management. Complexity can think in terms of 'the straw that breaks the camel's back' in case the reason for demise of a sector. It does not think about the one and only 'real reason' for bankruptcy, or erosion, or public sentiment that turns sour.

Joint play of several factors and 'subjectivity' of judgment on advantages or disadvantages is part of so-called emergence. To start at molecular level, one water molecule does not 'make' water properties (one straw does not break the camel's back). However, a combination of more water molecules joins to 'produce something' in which 'emerge' the properties of water. Depending on one's paradigm/scape, one may choose to continue a study of molecules. One can also chose to let 'chaos rule' and see what happens when many molecules jointly and combine into something with emergent properties of water, even with different properties. The study of water may benefit from study of its molecules, but the approaches and characterizations may differ. Similarly, one animal is an individual, but many do make a flock, many flocks make a population, many grass plants make swards while enough swards make a grassland (see notions of fractals elsewhere in this paper, and Box 3). One angry person is an angry individual, but many angry individuals emerge into being an angry crowd, even including more peaceful characters that become caught in the movement for reasons unknown to themselves.

Finally, a shift from many individuals into a group (the point of emergence) may be called a tipping point. However, exact and sharp distinctions are hard (if at all) to give. In billiard playing, the 'interaction' between two balls has 'explainability'. Nevertheless, from three balls upward, the predictability of the behavior of the 'flock' of balls changes. In analogy with gases: beyond three (or more) molecules, the behavior of molecules is described by collective characteristics such as pressure and temperature [16]. It relates with difficulties of predicting behavior of individual bodies in Poincare's three body problem (Interested people may consult the authors on rules of thumb that relate with the numbers 3 and 7). Newton calculated orbits of moon and earth by deliberately neglecting the role of a third body (planet or the sun). In addition, Newton looked (in the reductionist tradition) at the world by separating 'things' into parts (white consisted of red, blue, orange, and so on). Goethe looked (holistically) at the world to see what emerged by combining the different colors (thanks to Brian Goodwin). Most wine drinkers may have more 'affinity' with Goethe than with Newton.

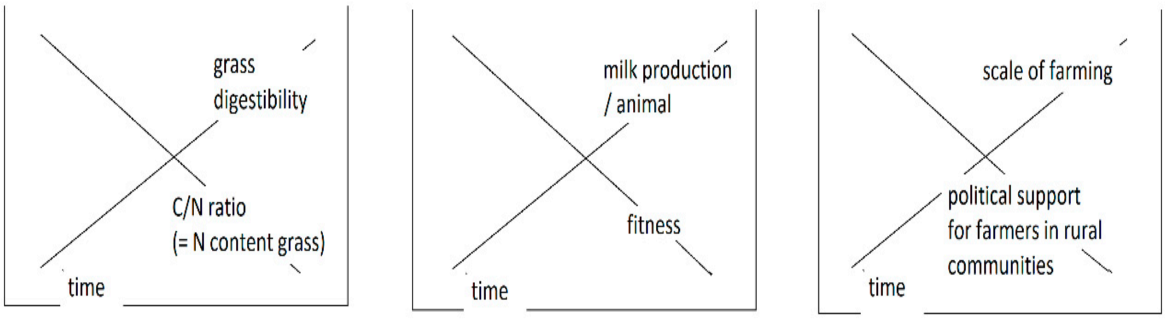

Figure 5. So-called 'cross-hair' diagrams with trade-offs between traits and scape properties, here all on a time scale of—locked in—development (Figure 6 Breman for such diagrams on spatial scales). With time (in the left-hand diagram) a continued emphasis on fodder digestibility led to great increases (management and breeding), accompanied by a decrease in C/N ratio which implied greater risk of nitrogen leaching. Greater emphasis on individual milk yields (middle diagram) can lead to lower fitness in the animal (or need for more support systems in terms of veterinary care, medicine, intensive management). The continued larger scale of farming in the right-hand diagram is associated with less 'political' support in the communities. That can result in even hostile relations between farmers and 'urban-based' people that 'take over' the rural areas, often with demands for 'more nature' and arguments on who must pay for that. Win-win is unlikely to occur across the board. Or also: a gain on one aspect is thus likely to represent a loss somewhere else, generally overlooked with a too narrow 'reductionist' focus. And the lock-in on one aspect with untimely action on 'side-effects' implies a larger lag time, which in 'chaos' terms implies greater crash. Note: The top characteristic in the figure grass digestibility, etc., reflects the left y-axis and the lower characteristic reflects the right-hand y-axis. Also, the 'cross-hairs' are represented as straight lines that intersect somewhere in the middle. That is a simplification, among others because the lines may be curvilinear and because the point of intersection depends on the scales chosen on the y axes (text and Figure 7).

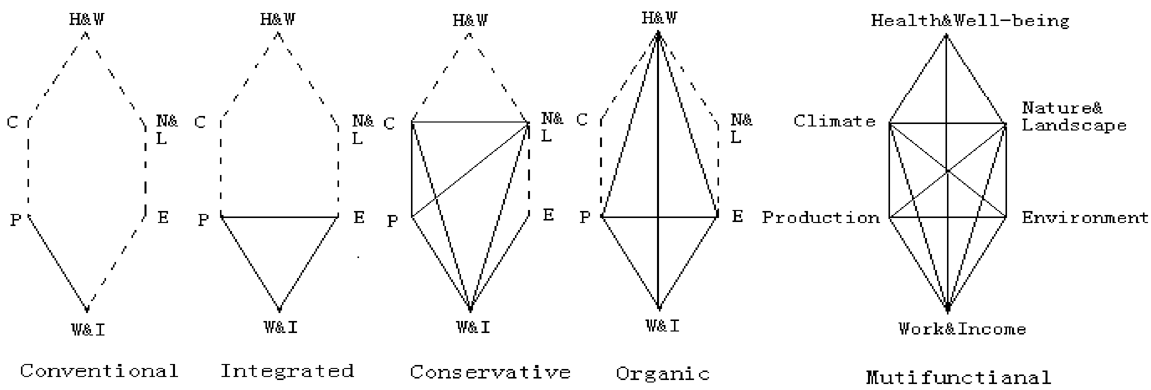

Figure 6. Transition of agricultural systems, incorporation of new and multiple visions as well as more rural functions was important in work by [37] and his team. His work on design of sustainable farming systems in the Netherlands emphasized use of several criteria that reflect different scapes. Important in that respect is that he himself was a man with vision, trained as an ecologist, thus seeing things (scapes) that agronomic colleagues did not easily notice (Figure 2). In this diagram the evolution of 'design' from left to right incorporates different perception of system properties, also requiring different methodologies and mindsets from the 'designer'. Also, note that 'relations' (connecting lines) become relatively more important than 'things' (dots). Moving from left to right one first works with one relation and two 'things' (a ratio of $\frac{1}{2}$), ending up with 13 relations and 6 'things' (a ratio of 13/6). Indeed, work with complexity is more concerned with relations and ratios than with individual 'things' (thanks to [30]). This point is clear from our emphasis on behaviours and from the notion, for example, that the ratio predator/prey is more important than the absolute numbers.

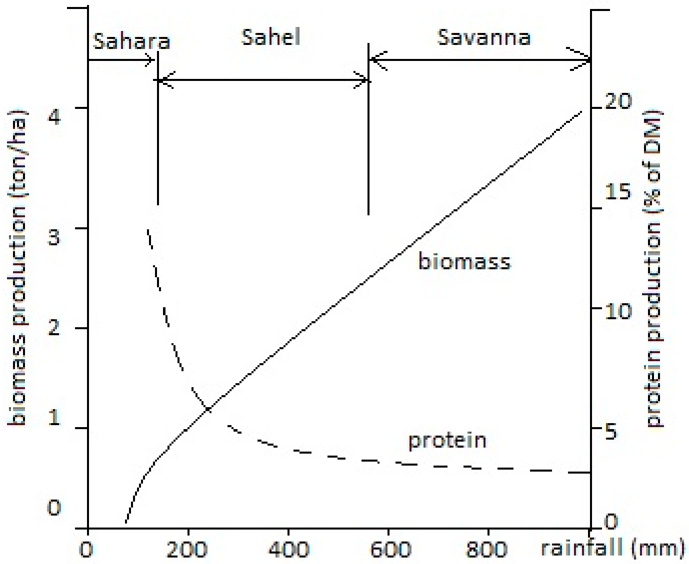

Figure 7. 'Logical scales' with rainfall intensity (reverse of distance to the equator) used as ordering factor to 'collapse' chaos in biomass and protein production of a large variety of pastoral systems [38]. Note: the paper also shows interesting additional information, e.g., on change of systems with 'degree of development' as ordering factor. It shows, for example, a high productivity of presumed 'backward' pastoral systems in the sub-Sahelian zones and high fossil energy use of presumed 'advanced' pastoral systems such as in the US and Australia.

Food for Thought

'Real life' is constantly changing and complex, often impossible to completely unravel and predict since it is no set of Jigsaw pieces. At limited ranges of space—time scales—this 'real life' can be understood by linear paradigms (worldviews) and reductionist focus on detail. However, inherent variation of (GB) systems as Complex Adaptive Systems, implies choice for non-linear paradigms and holistic approaches that also consider trade-offs. Depending on the situation, one can (must) choose for a combination of paradigms, even conflicting ones. We refer to 'crash' as 'unexpected non-linear behaviors'. What is sometimes called 'chaos' is, however, in this paper called 'crash of existing order'. 'Collapse of chaos' is, in our terminology, where one sees emergent 'new order', always with advantages and disadvantages [30]. Design of 'new order' can be suppressed by counterproductive lobbying and/or 'fear' for change. Default can imply throwing the baby (promising developments) out with the wash water, eventually leading to bigger crash.

Box 3. Fractals in Chinese Philosophy from over 2000 years ago.

All things are micro-cosmos of the Tao; the world a microcosmic universe, the nation a micro-cosmos of the world the village a microcosmic nation; the family a village in microcosmic view, and body a microcosm of one's own family from single cell to galaxy

3. Intermezzo on Paradigms, Hang-Ups and Defining Pastoral Systems

Linear work and default focus on familiar details rather than also on overview. They have the advantage that at least in short-term since they tend to yield quick straightforward results that suit ruling paradigms and existing order. Choice for new vs. existing order does imply choice between design and default. Indeed, narrow focus on details tends to ignore unknown/unfamiliar (trade-offs) elsewhere (a point that holistic approaches try to avoid). Often impressive successes of reductionist linear approaches may even foster irreversible 'arrogance' of mainstream linear science, until 'nature' strikes back when trade-offs do start to show up (think of climate change, social unrest, declining groundwater tables). This section, therefore, as intermezzo, aims to list paradigms and hang-ups implied in design with associated choices for topics and methods that are elaborated in Section 6. Without aiming to be comprehensive, we thus mention just a few insights from non-linear approaches to challenge ruling practice and to make 'default and disciplinary hang-ups' more explicit.

- Dependence on initial conditions in non-linear approaches implies that results of a model depend, among other things, on durations of runs, rounding-off of initial values, i.e., on the chosen number of decimals (Arbitrary choice (by an individual by a group), is considered to be 'objective' but it affects the outcome). Minute differences in initial condition can have large consequences (e.g., the so-called 'butterfly effect', where the flap of a butterfly's wing may affect the course of a tornado elsewhere in the world). Setting of boundaries can stop such cascading processes, a lesson to remember when professing the blessings of globalization and when aiming to control pandemics that start as a minute change of molecular dimensions [29].
- In non-linearity, nothing is either good or bad across the board. Indeed, 'beauty is in the eye of the beholder'. Short-term courses of action, however successful, need to be continuously reconsidered before making them standard practice since sudden change of perception is rule rather than exception. In academic language, one says that objectivism and positivism give way to constructivism [39]: what is true for one is often not for another, or in another point of space and time. Non-linearity also shows up as gradual change, e.g., where [40] says "neither too much is good, nor too little". Paracelsus said some 500 years ago: *"sola dosis facit venenum"* (the dose determines whether a substance acts as toxin or medicine), possibly following Aristotle's notion of the golden mean.
- Complexity hardly, if at all, knows of 'one question one answer' issues. Instead, complexity is accustomed to handle questions with multiple or even with no answers. As a simple example, $\sqrt{4}$ has two answers (+2 and -2), both of which are true. Also, the number 'π' cannot be written out, only approximated. And the $\sqrt{-1}$ has no answer in the 'world' of 'rational' numbers. Even linear programming (e.g., for allocation problems such as ration formulation) uses ranges (slacks and surpluses), rather than exact values to achieve 'optimal' answers. Non-feasibility indeed is a well-known term in linear programming.
- Linear thought, in terms of single cause–effects, is based on Newtonian notions (students often forget/simplify/freeze original reasonings/theories of a great masters. Thus, we need not specifically blame Newton (or any other 'father/mother') of great ideas for subsequent mis-use of those ideas) to solve simplified problems. 'Linear thinking' denies complexities in the real world but it (therefore) appeals to the psychology of the 'general public'. For example, in the sixties, increased nitrogen levels in the North Sea were easily blamed on increased fertilizer use in the UK. Eventually, it became clear that plowing of grasslands during World War II for production of grains was a greater cause. It was indeed the decomposition of huge root-biomass stores two decades earlier that led to the increased N-leaching (Herman Van Keulen, pers. com.). In the same way, one may argue that a cow develops milk-fever because 'she' has just calved, when one might also ask what the manager has achieved in previous feeding and caring for 'her'. The dustbowl can be blamed on drought, but what about the wind, tillage practices, mono-cropping and so on [41]. Simple cause–effect thinking is attractive, but it tends to be misleading. Ultimately, 'a manager' (or 'leader') is to also wonder about what role he/she plays in the system. A 'systemic' approach to problem solving in this sense implies that the observer/manager is part of the 'problem', not an objective/neutral outsider. The systemic approach also implies the step from control to participation that we refer to elsewhere in this paper.
- Much 'western' thought has linear connotations of progress, where development starts at one point and then continues to grow ever greater, higher, bigger [42]. It contrasts a

worldview in which life fluctuates, from high to low and back, as in the Phoenix notion of the mythical bird that arises from its ashes [43]. In other words, rather than to fight 'crashes' and their associated 'mess', one might sooner decide to accept a 'setback' (new order) and make the best of that (especially larger systems tend to understand 'benefit of the doubt' reasoning that they are 'too big to fail'). An example of accepting 'new order' is where producers chose to abandon (default) chemical weed control in favor of mechanical weeding despite the challenges. A non-linear wording would be that those farmers go 'forward' to mechanical weeding again, rather than 'backwards' to old practices. The same applies to consumers that again (design to) attend local stores rather than (default) to larger chains: that can be labeled as a move forward rather than backward.

- Goal thinking in linear thought reflects notions of 'telos' from Aristotelian philosophy (Authority of ancient Greeks was challenged in the Renaissance, after Muslim scholars translated and interpreted the ancient texts, permitting rediscovery and re-interpretation in Europe [44]). It can be seen as the opposite of 'process' thinking, as in Hindu holy books, where the Gods say, "Do your thing, not for the results", while adding 'with speed and clear direction', and 'work is worship' (Provenza quoted Robert Farrar Capon: "We live in a time when nearly everything from food to furniture, music to humour, is delivered to us finished, demanding no sustained, creative attention. We are in a hurry to have, to use and to discard. Yet no great work has ever been done by people interested only in results. The bread maker is delighted with how water turns flour into batter-and with the way more flour turns batter into dough, with the way the mindless time of kneading paradoxically refreshes the mind, with the way the loaf rises in its own sweet time, not ours. If you can bring yourself to relish the process, you have the makings of a baker"). Process thinking is not only a Hindu notion, however, and many Hindus perform goal thinking. But that is besides our point here. Notions of process thinking are also central in a Spanish poem (Table 2) that suggests walking one's way while constantly adapting, perhaps with only a direction in mind. This may be nonsense (to say the least) for those raised in 'goal-traditions'. But it is the survival of the farmer for hard times to timely change goals and 'make the best of it' while having a direction in mind. Goal setting is a matter of deciding 'what one wants', while process thought tends to 'start from what one has'. The notes on thermodynamics in Section 5 explain that goal setting tends to generate more entropy (disorder) than process approaches. Most challenging for design is the alternative to goal setting in the notion that "things do not have a goal; they can be given a goal".

Table 2. A poet on continuous adjustment rather than rigid goal setting.

"Caminante, son tus huellas	Traveler, your footprints
el camino y nada más;	are the only road, nothing else.
Caminante, no hay camino,	Traveler, there is no road;
se hace camino al andar.	you make your own path as you walk.
Al andar se hace el camino,	As you walk, you make your own road,
y al volver la vista atrás	and when you look back
se ve la senda que nunca	you see the path
se ha de volver a pisar.	you will never travel again.
Caminante, no hay camino	Traveler, there is no road;
sino estelas en la mar."	only a ship's wake on the sea.

Poem by Antonio Machado;
https://www.poetryfoundation.org/poems/58815/traveler-your-footprints acceded on 14 February 2023

- It is crucial to think and act considering several system levels at the same time, i.e., to not only look at what happens at the level where one is working. The notion of 'communal ideotype' describes how design for total plot, or herd yield requires different ideotypes with often lower yield of individual plants/animals then when grown/fed in isolation [25–27]. The paradigm issue is here to recognize a usual tension between individual or group interest, a tension usually handled differently in 'reductionist' than in 'holistic' approaches.

- A final one in the list of non-linear issues is the Jevons Paradox/Rebound Effect' [45]. It states that higher 'resource use efficiency' often tends to lead to greater resource use, rather than to reduce net resource consumption. Linear work on 'efficiency', thus, can achieve the opposite of what it wants, a case of perverse behavior (Section 4). One point is that focus on greater efficiency in certain production modes (e.g., less greenhouse gas, or less fuel use, or less pasture wasted) can have a reverse effect.

Generalizing the need to recognize 'hang-ups', one can say that default use of mainly 'linear' paradigms such as right after WWII in the green revolution suggested that 'positive' goals might (initially) have impressive positive results. However, eventually the linear focus in the 'ceteris paribus' paradigm gave unexpected and often negative trade-offs [19]. High input use can give great yield increases indeed. However, it could also result in groundwater exhaustion, soil organic matter depletion, urbanization, and related social change. Of course, too little use of inputs can also do harm, a typical case of '*sola dosis facit venenum*' and the linear adagio 'ceteris paribus' had to be accompanied with the non-linear 'ceteris imparibus' (to say the least). Ref. [46] calls unexpected results (crash of order) due to internal/autonomous system dynamics "the ghost in the machine". Stuart Kaufmann (pers. comm.) says: "God (Kaufmann's reference to God goes beyond this paper but it is a powerful notion in this context) is back in the system". In our view, both Koestler and Kauffman imply that the 'enlightenment paradigm' of 'a linear universe with man as master of all' is to be balanced with one of a humbler 'man' that "participates with nature rather than to control nature" (Brian Goodwin, pers. com.). Table 2 summarizes some differences in approach when moving from Goodwin's control to participation. In that line, things become 'complex' (Complication refers to situations in a mechanistic clockwork universe, where problems can be solved, even if with lots of work. Complexity 'plays' in the 'real' world with intricacies such as many or no solutions. Issues such as on how to feed all people (food distribution vs. production) are complex rather than complicated) indeed, and hard, if not impossible, to control when more than one production goal enter the picture (Figure 6). That issue reflects the mathematical three body problem of Poincaré (late 19th century). Newton ignored the interactions (at other system levels) with and among other planets (bodies) on the orbits of the two bodies (e.g., earth and moon) that he focused on.. In such a case, sticking to linear approaches and rigid goals (rather than using a more 'flexible' direction) will complicate things in the long term. Significantly, unlikely approaches and answers tend to require more control of the system and resources, as discussed in Section 5 on thermodynamics.

Usefulness of statically defining (GB) systems is also affected by the dynamics of complexity. That makes us, in this paper, choose to deliberately stretch our imagination by characterizing rather than to define (GB) systems. We use different scapes/paradigms, representing a shift from reductionist definitions with precise (but limited) scope towards holistic 'characterization' of GB systems as Complex Adaptive Systems (We use the term Complex Adaptive Systems for the time being (a case of 'lock-in'), agreeing with Provenza that one might talk of 'creative' rather than 'adaptive' systems. In that thought Homo sapiens is participant in creation, moving views (scapes) even further from linear, deterministic worldviews [47]). In that broad sense, GB systems can refer to widely divergent systems with dairy, beef or sheep in New Zealand or anywhere, as well as systems with camels and goats and/or some cows in sub-Saharan Africa. Additional classification criteria include GB systems near to and distant from markets, in politically stable and/or war-torn countries, associated with cropping and/or isolated and purely grazing, on small and on large scale and so on. To add even more 'scapes' and 'mess', the concept of grazing is not restricted to ruminants or any other herbivore eating grass. For instance, grazing as an adjective locates grass eaters in place and time where they naturally graze or are grazed by 'us'. If used as a verb, grazing can also apply—usefully—to browsing of the internet, foraging of ATP-sources by rumen microbes, and so on. In that sense 'scapes' can really refer to all kind of notions and system levels from food- to thoughtscapes. Resources can be physical, mental, energy as well as information in several guises.

Broad characterization may raise 'fear for mess', but the resulting chaos can collapse by using more generic system-categories that are more useful for 'beholders' in their local condition. Broad definitions lose precision, which is misleading in variable conditions anyway. Broad (holistic) categorization gives, however, options to use analogy (with caution) from other areas of science and daily life. Going from a narrow focus on grazing to more general system thinking, one can gain significant insight from apparently unrelated fields of science (see the work by early workers such as [16,43,48–51] and the like, with special mention here of an excellent more recent paper by [21]).

At the end of this intermezzo, we touch on some issues of Cartesian thought since much reductionist tradition can be traced to the work of [31]. Even the 'Cartesian paradigm', however, consists of several 'scapes'. Descartes did much work on mathematics (useful for the Dutch army), and he lived in times where rulers did not favor just any opinion; what is new? He is mostly associated with the idea to split a problem into the smallest possible details, to be sure that nothing is lacking, and to then linearly rebuild (as with Jigsaw pieces) the grander solution for grander issues. That leads to the reductionist approach to focus on DNA to solve a world food problem while ignoring geopolitics, climate change and the interplay of other such non-linearities. It is also similar to focusing on the nitrogen content in forages to solve farmer's problems with the environment while the bank-manager and urbanite neighbors are looking over the farmer's shoulder. Such reductionist notions clearly run counter to those on holistic non-linear approaches which doubt (to say the least) such linear cause–effect relations of the Jigsaw piece world. We stress that choosing the proper combination of the two approaches may be more fruitful than to religiously announce one as better across the board than the other.

Notably, Descartes also stressed that one needs to doubt everything unless one is 'absolutely certain' and his "*cogito ergo sum*" was founded on use of reason because he distrusted empiry. Apart from doubts on 'across the board' use of empiry (With 'empiry' we refer to the approach that uses observation and experience rather than reason), there is a very practical need to use reason when discussing sustainability. Indeed, design of the future, if possible at all, depends on use of reason (often scenario studies). Design, by definition, refers to situations that cannot be observed empirically beforehand. Descartes, however, also accepted and strengthened notions of differences between 'categories' such as humans and animals or men and women that still ring (disturbingly) in present day discussions. Last but not least, he was a sort of founding father of dualism (distinction of matter and mind), even if he did, rather artificially, allow for a link between matter and mind via the pineal gland. Notions to clearly distinguish matter and mind, as well as to sharply distinguish people from animals and men from women, are out of date, together with Jigsaw-piece notions in which one can predict the whole by knowing all details [52]. Use of empiry as well as reason, both stress on doubt till absolutely sure, are in our view to be strengthened in a world where the story of the new clothes of the emperor is told and retold, often even as pseudo-facts.

The final point of this intermezzo is that many shades of work with complexity paradigms are already used in modern Farming Systems Research, which also had to overcome fears for mess and reluctance of referees/decision-makers already many decades ago [19]. Much was indeed achieved over past decades to achieve new combinations of reductionist and holistic thought, of static and dynamic approaches, of science and humanities, and of empiry or reason. Resource rich systems had the luxury to resist crash, so non-linear Farm Systems Research originates (emerged) largely from work in 'poorer' countries. Over time, however, more well-to-do farming systems also started to employ more holistic and non-linear methods, since they too started to face restrictions of resources, 'clean environment' and public pressure [19,53,54]. Landcare in Australia was in part a response to an Australian dust storm in 1983, similar to what happened half a century earlier in the 'dustbowl' of the US. Landcare itself was helped by politicians, who chose to act favorably to rural development. Landcare work also leaned, at least in part, on people with experience in 'poor' countries [54]. Thus, new paradigms and methods to cope with complexity/holistic approaches emerged and matured to suit dynamic conditions of what can be called 'the real world'. For example, use of perceptions of common men/scapes in rural communities was championed by people such as [55]. Partly in his footsteps, refs. [56,57] went further to also apply complexity (and the Phoenix model) to handling GB systems, mainly in Africa. Notions of self-reflection and systemic thinking were part and parcel of Landcare work (https://landcareaustralia.org.au/ acceded on 14 February 2023). Remarkably, part of all this used interdisciplinary approaches based on work to cope with dynamics in chemical industries and on much of what is useful in business [58]. In the dynamic approaches, the 'ceteris paribus' is replaced by 'ceteris imparibus' [23], a notion reflecting that of 'Pantha Rei' (Figure 1). Static definitions of (GB) systems may assume that they are valid for today as much as for tomorrow. However, today is never the same as yesterday or tomorrow. Flexibility of definition is crucial to cope with change, i.e., dynamics.

Food for Thought

New combinations emerge of static and dynamic approaches. Linear hang-ups are challenged by butterfly effects, and by shifts from objectivism to constructivism, from one to 'no or even many' solutions, from notions with linear- to wave-like evolution (the Phoenix model), from goal to process thinking, all with Jevons paradox as a very typical case of 'ceteris imparibus'. We did refer to notions of 'the ghost in the machine' and the idea that 'God is back in the system' when dealing with autonomous system dynamics. All this indeed implies a need for new combinations of enlightenment ideas that 'man is master', on the one hand, with participation paradigms with 'man as participant' on the other hand. Last but not least, we show that use of notions and paradigms from complexity already entered much of Farm Systems Research of the past half century. That is to encourage the fearful ones of today, to give homage to the pioneers, and to say that nobody at this stage needs to re-invent the wheel.

4. Working with Complexity: Methodologies and System Behaviors

Depending on mindset (due to training and wiring) some people find it easier than others to work with complexity, i.e., to accept mess and recognize new patterns when 'chaos collapses' [30,59] (See also: en.m.wikipedia.org/wiki/Big_Five_personality_traits, accessed on 14 February 2023). Thus, training and use of special methodologies/concepts can assist the transition (also crash and collapse of chaos) from comfort zones (stable state) of 'certainty' into what may feel similar to the uncharted territory of uncertainty. Indeed, one can actively develop brain wirings to see new patterns in collapsing chaos faster by using lessons and methods available in the literature and common sense. In that sense, a meteorologist friend said that he was taught to particularly seek newly emerging patterns (butterflies, sort of) to better predict weather for longer term (Rob Groenland, pers. comm.). He was thus trained to seek and interpret newly emerging (weather) patterns. Also, management schools are abound with courses for lateral and/or creative thinking. This section aims to provide tools to map uncertain terrain by introducing some such methodologies, including use of the typically dynamic notions that we call 'behaviors', also known from for example Stoic and Chinese philosophy.

Our first method to cope with complexity is from an anthropologist, Clifford Geertz, who studied farming systems with physical, social, economic, anthropological, and other 'scapes' in Java. His motto was: "seek complexity and order it", reflecting (a) the method of our friend the meteorologist (see above), and (b) to stretch the imagination by gathering information also beyond one's own discipline while trying to order it later on (Figures 2 and 5). Indeed, one can 'see' chaos collapse only if one permits chaos to become large enough, beyond one's hang-ups and comfort zone.

A second method is implied in Geertz's search for other perceptions/scapes, to be clubbed under the term 'system literacy'. Color of a soil, behavior of an animal and/or growth of a particular weed can tell farmers what is going on in their farm. Work in early participatory Farming Systems Research looked for such 'symptoms' and alternative 'scapes' [55,60,61]. That approach first took hold in tropical Farming Systems Research [53]. But [62] tells how children in Australian Landcare programs were sent home (from their biology lessons) to ask their parents about species lost and gained in their lifetime. At first, that confused parents, but the ensuing crash and successive 'collapse of chaos' resulted in increased awareness of communities of environmental aspects. It even triggered (emergence of) action to (re-)install notions of stewardship. Similarly, a field visit in India taught one of us (Johannes B. Schiere, henceforth JBS) that 'scapes based on labor films' were a bigger issue for farmers than 'scapes based on feed fiber contents'. Another example of emerging system literacy is a Dutch work to develop software for decision-making on fungus control in wheat, which involved farmers counting number of infections. The result was that farmers had learnt the trick by the time the software was in place [63,64]. These are all great cases of ceteris imparibus and behavior of CAS. Farmers in Southern Australia were shaken up and initially confused when they realized that 40 kg of topsoil was lost for every kilogram of wheat produced. The collapse of that chaos was towards a significant change and mindset regarding cultivation practices (Peter Doyle, pers. comm.). The crash due to the US Dustbowl [41] similarly opened eyes of 'teaching' communities and individuals to reconsider their farming practices, to include other scapes and/or to re-read their ecologies. It shook people from their comfort zones and ensuing 'collapse of chaos' led to adjusted thinking and acting on farming. Environmental dramas such as those should be avoided, but they achieve awareness on use of hitherto unthought 'scapes', beyond moldboard plows and planting of ever more cotton (People first looked at failing rains ('something' beyond their own reach), but eventually they started to look at their own role in affecting such drama, a shift from systematic to systemic thinking). Acid rains had a similar effect on rethinking and redesigning intensive livestock farming in Western Europe in the eighties [33]. As a typical case of 'questions having more than one answer' (see 'the fan' in Section 5), some farmers modified the intensive mode; others redesigned farms and food chains in different ways, and still others left farming altogether. One may hope that recent bushfires in Australia and across the western US have an effect on reconsidering paradigms and choice of 'scapes'. And what will we learn of the collapse of chaos after the current COVID-19 pandemic? And how will lobbies respond that tend to defend the status quo? One of us (JBS) learnt a lesson in system literacy when asking a colleague (Wijnand Sukkel) to stroll through a potato field that JBS had just then started with his wife. Sukkel was asked to spot things that JBS had not thought of, and one question was on whether JBS had seen Colorado beetles yet. The reply of JBS was 'no, not yet', upon which Sukkel showed small (black) larvae that would grow into beetles if nothing were changed. It opened the eyes of JBS to things unknown (not being a potato man at that stage). A very special final case of 'system literacy' and inclusion of other 'scapes' is work by Temple Grandin, a remarkable and autistic lady. She tries to understand animal behavior from her own autistic point of view by even crawling through the slaughtering lanes to see (i.e., by inviting mess) what animals experienced. She changed part of the US meat industry on key aspects of animal welfare [65]; www.grandin.com, accessed on 14 February 2023. How many of us crawl, as did Temple Grandin, on a pasture to see how cows experience herbage?

Third, seeking similarities can be more useful than focus on differences. Work on similarities is part and parcel in work with models, including metaphors, analogies, narratives, and parables. They all explain complex reality in ways often beyond words and figures. A central tenet of complex system thinking is that all things are different, while also being similar. Focus on differences and fear of analogies is often an excuse for not having to learn, and/or not getting involved (fear of crash). A standard approach of both of us (JBS and Pablo Gregorini alias (henceforth PG)) is indeed to seek useful analogies of any 'problem' (Some system thinkers prefer to talk of issues or challenges rather than problem. The term problem 'freezes' an issue into something difficult, ignoring that a problem for one can be a solution for someone else, and that crash tends to 'HURT' (caps by authors) while it may precede a useful 'collapse of chaos') at hand since one essence of complexity is indeed that all 'things' are similar as well as different (Box 4). Seeking analogies in deliberately divergent organisms and contexts can help understand a problem and/or scape that at first sight is quite unrelated. Perhaps unthought similarities abound also in GB systems, e.g., in 'Mediterranean' systems (in terms of agro-climatic zones) that occur in Southern Australia, South Africa, the southern US and around the Mediterranean. Understanding one such a system helps understand and predict what happens elsewhere. Seeking similarity as a third way to cope with complexity thus can help identify new order in the collapse of chaos. As another example, comparing New Zealand and Sahelian GB systems can help identify blind spots in one's own thinking on seasonal feed supplies. And learning about 'grazing behavior' by bacteria can help recognize unidentified patterns in grazing behavior by cows or sheep. Quoting the once famous rumen microbiologist Hungate: "rumen bugs that produce most ATP per time unit are more successful than the ones that are most efficient in terms of ATP produced per unit of substrate". He did refer to contexts with plenty resources but his comment on grazing bacteria (in a resource-rich environment) helps understand that velocity and turnover in (farming) systems can be more important than (often unspecified) 'efficiency' alone. To complete this argument, ref. [49] shows that, in case of resource shortage the slower and more efficient resource users may perform better (see Section 5 on r- and K-organisms in the adaptive cycle). A special and final case of similarities is when they occur across scales of space and time, a phenomenon called fractal behavior [66] (We use the 'fractal notion' primarily to seek similarity across system levels. Sometimes it is used to (in our view) rather artificially 'better measure the coastline' and to ignore the original implication that either the coastline is "infinitely long", or else "there is no coastline"). Smoke of a cigarette whirls such as a whirlwind in a hayfield, or a hurricane, or galaxies and so on (of course, each also with their own characteristics). Cells similar to animals, plants, farms, cities, consumer groups and institutions all transform resources (energy in various forms), requiring input and generating output. Fractal behavior was also noted thousands of years ago in China (Box 3). It also shows in Figure 8, where space scales ('rings' with different farming systems) around population centers repeat on larger and smaller grids (See the text on Von Thünen one paragraph lower).

A fourth way to cope with complexity is to seek 'logical scales' [7,67], i.e., arrangements in the variation of scapes according to resource flows and other production factors. An important 'trick' is to shrink and/or stretch the scales to better observe what happens over shorter/longer time–space scales. Regression analyses basically tries to do the same thing, based on empiry, to explain system behaviors on logical scales. Exploration of the rules of nature by using logical scales in our case can also use reason combined with empiry (sensitivity analysis) in mathematical modelling. Logic of change in (GB) systems may be explained by radiation being more intense in one place and rainfall more intense in another place (Figure 7). Note that Figure 7 also shows an interesting trade-off/choice between feed biomass (tons/ha) and quality (protein as % of the dry matter) with radiation and rainfall as explaining factors. An example of seeking and finding 'logical scales' some 150 years ago is the work on the Location Theory by Von Thünen, who used distance (in space) from a city to explain change in farming systems (Figure 8). His work was basically carried further by Rosscher and colleagues who described change of farming systems over time. These are all cases of work on Complex Adaptive Systems *avant la lettre* [2]. Explaining factors can be distance to markets, rainfall, time, cost of labor and leisure, access to money and the like. The main 'tricks' to better see logical scales are to be conversant with the systems and their characteristics at hand (i.e., using system literacy), as well as to allow enough variation into the analysis as to start seeing their 'logic'.

Box 4. Similarities, differences, models, metaphors, scapes, sheds, and coastlines.

A central point in complexity is that everything is different as well as similar, across system levels in space and time. An illustration is that Germany (like other places of the world) has two mountains locally known as 'die Gleichen'. The term 'Gleichen' in German means 'the same' even if all agree that the two mountains are similar but NOT the same. One journalist (reference lost) quotes a geographer saying: "the two mountains differ in almost any aspect (form, location, property structures and so on)". The only thing the two 'Gleichen' have in common is the distance from one to the other. As a related case is handling of 'similarity' in hard and soft system thinking about 'models'. Ref. [39] extends the landscape metaphor of Figure 2 by explaining how hard system thinking (linear and first order thinking) tends to assume that a model 'is' reality rather than just one of many 'representations of reality', as achieved in soft system thinking (non-linear and second order thinking). The use of clear distinctions may be convenient (as part of Cartesian thinking), but it is also very tricky and often less than useful. For example, most people agree that rats, pigs and monkeys are in many aspects quite different from people, while accepting that such animals serve to test medicines to be used on humans. Similarly, a mathematical model on the dynamics of predator–prey systems is nothing more (or less) than a representation of such dynamics. It is incomplete and incorrect in many ways, but useful to understand what is going on. Statues, poems, narratives and parables can all be seen as different 'things'/phenomena. However, they are quite similar and useful when used as 'models' (also 'metaphors') as in Figure 2. In that way they all can offer useful representations of certain aspects of reality. Complexity implies that no model can be made that is complete 'in the smallest detail possible'. Work with several simple models may be more fruitful to understand reality than perfection of one single (and impossible) comprehensive model. The notion of 'scapes' and the 'in our view' for this paper 'usefully' related term 'sheds' are new names for old concepts that can help build bridges and find common ground rather than to further dig into trenches. A final note on similarities across space and time is implied in the term fractal. That comes from work by [66], relating closely with the 'Coastline Paradox' attributed to Richardson in the 1920s. It is about a young engineer who is given the task to measure the circumference on an island. Happy on his first assignment he soon must report that "either the coastline cannot be measured" or that "the coastline is infinitely long and/or it does not exist". The reasoning is that by using a yardstick he cannot follow exactly all the curves that a coastline normally takes. A smaller yardstick makes the coastline longer since it follows the curves and coastline cracks more closely. A rope is even better but there again a thin rope measures more coastline than a thick one. And the coastline gets longer as the yardstick becomes shorter (or as the rope becomes thinner. The young engineer thus runs in a problem of measuring the cracks and bends of the rocks. There again, the same problem occurs of finer grid and longer measure (We tend to think that use of fractal dimensions is similar to the use of calculus to cope with curvi-linearity. It may be useful in many cases, but it bypasses rather than to accept complexity). The recurrence of similarity (self-similarity) at different levels of system hierarchy in space and time can be called 'fractal behavior' (Box 3). Predator–prey dynamics occur at many levels of nature, so do learning cycles and other behaviors in this paper. Eventually, the engineer, by measuring with ever finer 'yardsticks, gets lost in intra-molecular cavities where the coastline disappears. Many researchers will recognize that they become further away from the original question as they attempted to 'get into the Cartesian smallest detail'.

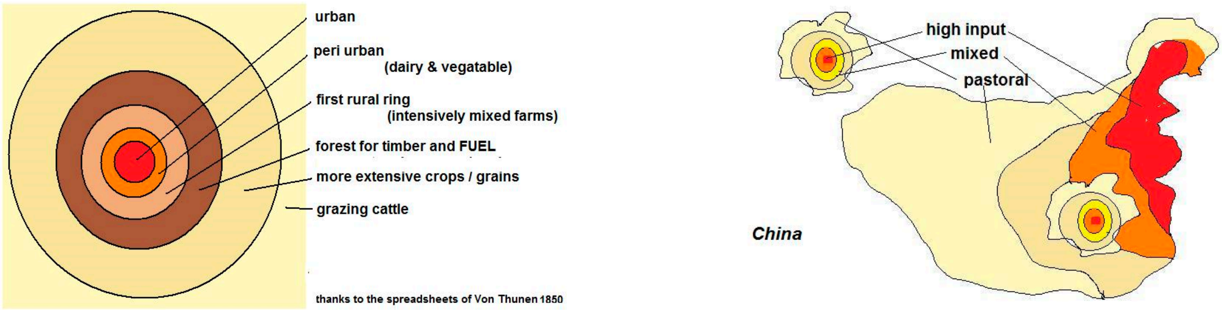

Figure 8. Logical scales reflecting Von Thünen's Location theory. Distance to a population center (city on regional scale) or populated regions on a national scale explains differences in farming systems. The figures are both 'artist impressions' (JBS). The one to the left is an idealized one on regional scale from the original work by Von Thünen (see [4]). The one to the right contains two fractal levels, one as found around many cities (in this case Guiyang) and one on the national scale of, in this case, China (see text and Box 3).

A fifth way to handle diversity and complexity is use/recognition of what we call system behaviors. In essence they reflect the behavior of a (complex adaptive) system as it moves on the logical scale. Behaviors can refer to growth and change of economies, shrinking of business, ailing of institutions, and budding of enterprises. Behaviors exist in many other forms such as addiction, weathering, decline, hibernation, competition, symbiosis and so on. All these behaviors refer to GB systems, as well as supply chains, interest groups, communities, etc., across system levels, well-fitting the notion of fractal behavior and stressing that we talk of general system behaviors, not only of behaviors in grass-based systems [16]). Essentially, the wish for 'generalized' understanding was and is the drive behind the International Society for the System Sciences (ISSS.org). Here, we mention only a few behaviors that may help one cope with complexities when understanding and designing sustainable end ethical GB systems:

- Self-organization is the notion in which combinations of internal and external dynamics result in a particular behavior without outsiders giving explicit orders. Self-organization occurs across system levels, and it can have positive as well as negative connotations. Perhaps self-organization is an 'invisible hand' with positive as well as negative connotations, driven autonomously and/or by outside factors. Mind you, cancer is a form of self-organization, so is corruption and the flowering of a fruit tree or grass growth. Gleick [29] mentions self-organization when seeing food supply to New York, not ordered from above, but running "as if organized by itself". Predator–prey and associated behaviors are forms of self-organization, and so is formation of a round soap bubble result from more or less autonomous (internal and external) factors such as surface tension, molecules 'seeking' a state of maximum entropy, ambient temperature and atmospheric pressure (among others). Self-organization may be the 'idealized invisible hand' of Adam Smith, where too little is good neither too much. If left unchecked, self-organization can get out of hand, as in the 'tragedy of the commons', also a kind of cancer. The tragedy of commons is a controversial (The notion is controversial since exceptions occur, inherent in what we say about non-linearity and 'surprise') and ominous notion developed by William Forster Lloyd already in 1833, later used by [68]. In management of (pastoral) resources it is accompanied by methods 'to protect the commons' [69], processes that are all somewhat autonomous and self-organized.
- The 'red queen' is a behavior (just one form of self-organization) where in evolutionary and/or arms races an organism must run always 'faster', while the competitor also runs 'faster'. The metaphor comes from Alice in Wonderland's encounter with the Queen of Hearts. They run and seem not to move, upon which the Queen says: "in this place you have to run twice as fast to get somewhere". Eventually, both predator

and prey run much faster at greater energy expense (more speed costs more energy), while neither gained any evolutionary advantage [70]. They both reach a point where they should wonder/reflect on what they are doing: either 'continue the race' (default) or 'seek other ways' (design).

- Lock-in, also called 'mission creep' or 'path-dependency' occurs when systems continue to run the same way for too long, usually based on default/convention rather than on rules of nature. Convention, as lock-in based on comfort zones and not due to nature, makes 'normal' clocks run with a right-hand turn. English typewriters use QWERTY keyboards originally designed to avoid jamming of little 'arms' that no longer exist in laptops [71]. Paradigms and rigid referees are also causes of lock-in, together with emphasis on standardized packaging and planting distances. Importantly, efficiency gains often imply loss of flexibility, i.e., of resilience, a trade-off/choice that needs to be better understood. By the way, the uninitiated may find good and complementary views on resilience in [49,72]. By the way, the opposite of lock-in (also 'in-breeding') is lock-out (also 'out-breeding'), which in our terms is a deliberate introduction of new genes, ideas, etc., not shunning mess, crash and/or collapse of chaos.
- The ratchet principle is that 'successive' and 'rather irreversible' modes of farming, industry, etc., tend to require additional resource qualities and quantities. The terms 'resource quality and quantity' are here replaced with 'resource flux', referring to the resource density/quality per unit of time and space. A cow cannot just eat more straw or poor-quality herbage if it is to yield more. Straw then needs to be replaced with good fodder and/or concentrates of greater resource flux. Thus, efficiency of Zebu cows cannot usefully be compared with that of Friesians by simply using feed conversion or energy efficiencies. Zebu cattle are more efficient on straw and dry grasses, while Friesians only yield more on greater quality feeds with greater digestibility, accompanied by greater protein contents, minerals, housing, specialized labor, and veterinary care. As said before, when discussing scapes and basics of complexity, nothing is either good or bad across the board! Level playing fields are highly unlikely.
- Hysteresis is when system change is hard to be reversed (much related with lock-in). Eroded soils can develop hard crusts that are not easily reversed into permeable ones that again absorb water as before the erosion went past a 'tipping point' beyond which the hard crust was formed. Such tipping points are subject of 'catastrophe theory' to understand sudden changes [73]. They occur at levels of grazing ruminant behavior [74], as well as in societies that lose farmers and (farming) practices that cannot easily return. Global warming is just another 'behavior' that is probably hard to reverse.
- Perverse system behavior occurs where signals to markets, society, or ecology (subsidies, rules, pesticides) have a reverse effect to what is intended. The Jevons paradox is a case in point where resource use tends to increase when resource use efficiency is improved [45]. Perverse behavior also occurs when too much 'control' tends to have unintended opposite effects, while costing progressively more (the essence of 'silent spring' [75]). All this provides lessons for control of smuggling, drinking of even pandemics. In very profane terms: drinking (booze) to suppress misery tends to be a medicine worse than the cure, adding, rather than diminishing, the misery and need for medicine (Box 5).
- 'Empire', as a form of self-organization [6] is where strong players appropriate more resources, eventually leading to formation of oligarchies by inherent/autonomous dynamics. That, in turn, can result in smaller players (peasantry) having to work with less/lower quality resources that, by the way, they sometimes upgrade in the process (remarkable and noteworthy). Ultimately, and in times of crisis (if not well managed), societies tend to even 'subsidize' large (ailing) institutions for being 'too big to fail', a sad case of lock-in and a case of 'non-level playing fields'. 'Empire',

and the resulting concentration of resources and production facilities into a few hands, can be orchestrated (conspiracy), but it can also happen as autonomous self-organization (simply good or bad luck). A typical example is that farmers (or investors) put manure (or money) where it yields most, often on better land or the stronger business [6,76,77]. It is also (thanks to Fred Provenza) illustrated powerfully in the Rand report for the U.S., as summarized in TIME magazine: "the Top 1% of Americans have taken $50 trillion from the bottom 90%, and that's made the U.S. less secure (https://news.yahoo.com/top-1-americans-taken-50-133022127.html, accessed on 14 February 2023)". The relevance of noting such disparity is among other, that matter (money) and mind (wellbeing) are related in a non-linear and non-cartesian way. In addition, it is an example of (too much) change in one scape (the narrow focus on 'we do what we are good at') that affects properties of other scapes, also a trade-off/choice.

- 'Vergetreidung ('Getreide' is grain in German, 'Vergetreidung' is the 'graining' of farming systems)' is the last 'behavior' in this paper on GB systems, occurring where grazing is replaced with cropping to feed growing populations [78]. Not all soils and climate permit such a shift to cropping, but Vergetreiding does explain the strife between pastoralists and crop-people that may even be a root to the metaphor (?) of Cain murdering Abel [67]. Also, farmers in the UK had to plow their grasslands to produce grain in WWII from pastures to crops, as said, ultimately leading to much Nitrogen leaching into the North Sea. Some additional 'associative thought' on complexity, in which exceptions are rule is that, in (densely populated western) Kenya, grass for milk is more profitable than food or cash crops. Growing of flowers tends to give greater returns than crops to feed people. In this case the money of a few overrules the stomach of the many. British legislation to evict sharecroppers from land to be used for profitable sheep-production is a case in point. And, the Irish potato famine, as well as the great Calcutta famines were due to trade-offs/decisions in the economy- and socio-political-scapes rather than to shortages in food [79]. Another exception (non-linearity) to 'linear' interpretations of consumer trends is where mainstream thought is/used to be that more wealth implies more demand for animal protein. The fact is that many wealthy and educated consumers tend to eat less meat, whether to save grain and the planet, for reasons of animal welfare or whatever other arguments [80]. In that sense, meat and milk produced 'artificially' from plant-sources are trends to be taken seriously by al those who 'design' GB systems for the future.

Box 5. Perverse behavior in ancient Chinese philosophy, reflecting similarity with 'over'-use of agrochemicals, concentrate feeds, scale of farming and the like.

The greater the number of laws and restrictions,
the poorer the people who inhibit the land.
The sharper the weapons of battle and war,
the greater the troubles besetting the land.
The greater the cunning with which people are ruled,
the stranger the things which occur in the land.
The harder the rules and regulations,
the greater the number of those who will steal.

Food for Thought

People with some mindsets grasp complexity and discern newly emerging order in collapsing chaos easier than others. Several methods and concepts are known, however, to assist work with complexity such as: (a) seeking chaos rather than avoiding it (learning to swim by jumping into the water) and (b) by seeking aspects and scapes beyond one's training (system literacy). Then (c) seeking of logical scales can help explain change (i.e., variation). That can be acompanied by (d) learning to discern and apply models, analogies and metaphors known as behaviors of Complex Adaptive Systems.

5. Special Behaviors, with Rules for Design

Four additional and special system behaviors deserve mention before moving to section six on choices. The first three behaviors are (a) the predator–prey model, (b) the adaptive cycle and (c) the fan. The fourth and most profound one concerns the tendency (behavior) of any system to lose form and function gradually, unless provided with resources from outside. That last behavior is the domain of thermodynamic theory, too often ignored in design of sustainable/regenerative systems.

The predator–prey model as our first special behavior is relevant for any sustainable system design. It relates performance of a system with its resource base, and it introduces dynamics, both crucial points in this behavior. It may be nice to have large litters, high fodder yields or record exports, but high performance may be a Pyrrhus victory if it does not match the available resources of the particular scape. The essence of even a simplified one predator–one prey model is that large predator numbers result in lower prey numbers. Eventually, that leads to reduced predator numbers, again leading to greater prey numbers with greater predator numbers, and so on (Figure 9). Predator–prey models have different basic shapes (Figure 9) all with some sort of a wave function (reflecting the phoenix paradigm discussed under hang-ups) which can be transformed into what the first 'chaos people' called 'attractors' [23,29]. Almost half a century ago, Holling [49] described by using this behavior how stability (small amplitude to 'equilibrium'/average) inversely relates to resilience (larger capacity of a prey population to bounce back, expressed as a greater amplitude). In other words, he explained the trade-off (=choice) between resilience/flexibility and stability. That trade-off deserves more attention in discussions on sustainability. For example, becoming accustomed to a steady/stable supply of food may lead to a less flexible/resilient chain. Relevant here is the issue of paradigm, i.e., whether stable 'average' between high and low populations exist at all (as assumed in linear development models), or whether development is basically always a wave without even a 'static' equilibrium. Another lesson is that 'carrying capacity' fluctuates; meaning it is a dynamic parameter. It is misleading to ask the question on 'what IS the carrying capacity' (CAPS by authors). Better is to ask about the range and fluctuation of carrying capacity. Another lesson indeed is that (GB) system design needs to take account of the carrying capacity, with offtake considered in relation with the remaining resource base (Discounting methods are misleading in case of finite resources). Again, a few lines of associative thought: common folks and holy books knew this model long before it was formalized. And so do farmers know the hog-cycle as manifestation of such waves. Most people 'of the land' also know the need to 'rest' land to ensure that offtake does not exhaust the resource base or to ensure that certain weeds/diseases are kept in check. For example, farmers rotate potatoes (prey) to control the predator (the nematode). At another fractal level, some nematodes even sense (biochemically) that they overgraze their prey (the potato), leading them to move into a less aggressive foraging mode (Bert Lotz, pers. comm.). Pastoralists with restricted access to resources also know that maximum offtake is only a useful parameter in relation to the resources. Business leaders and politicians should know that high exports of a sector are only useful indicators of sustainability if they relate to health of the resource base and the producers! In that vein, the Gross National Product (GNP) tends to ignore the resource base (growth vs. development), contrary to the Indicator of Sustainable Economic Welfare (ISEW (Table 3). Farmers know the implication of the GNP versus ISEW tension in their operations (Table 3). High short-term yields, for example, can 'ignore' soil quality, in terms of for example soil organic matter levels, soil-life and related resilience. And in our view, at property level, land-renting should aim at maintaining or improving the resource base, preventing highest bidders to exhaust the land in the short-term.

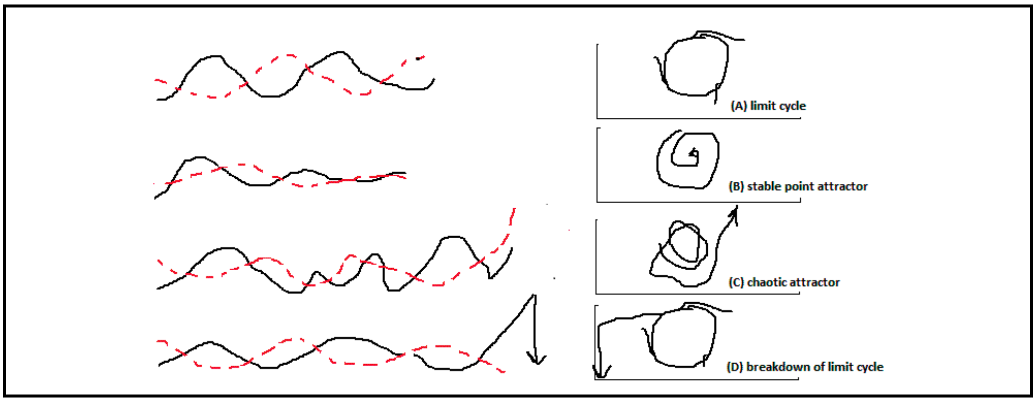

Figure 9. An artist impression of four basic shapes of the predator–prey model, with the 'wave' representation to the left and the associated attractors to the right. Red dashed line is population size of the predator (fluctuating of course) and black line represents the fluctuating population size of the prey (vice versa same story). Note 1: conversion from 'wave' (left) to attractor (right) shapes is relatively easy [23,49]. The wave shape does plot both predator and prey numbers on the vertical axis against time on the horizontal axis. The phase space diagrams (attractors) to the right plot the predator population on the vertical axis and the prey population on the horizontal one, with time within the attractor. Note 2: the basic shapes are known as limit cycle (dynamic equilibrium) where the 'wave' continues rather in the same way and irrespective of (reasonable) internal/external disturbance. The stable point attractor represents a wave where the amplitude 'dampens out'. That leads to a stable equilibrium which underlies equilibrium thinking, as in mainstream economics where temporary irregularities dampen out into a stable situation, also called climax vegetation in ecology. Chaotic attractors have less regular behavior (wave) and in the 'breakdown' of the limit cycle a crash occurs when for example the predator grows even if no predator is left. Note 3: Cutting corners one may say that the top row wave has a relatively large resilience 'elasticity'/amplitude versus low stability (large deviations from the equilibrium line). The equilibrium wave (second row) has little bouncing (low resilience) and high stability. Trade-off here is that stability (achieved against the odds of variation) implies low resilience and vice versa.

Table 3. "Health" of a national economy (expressed as growth/capita per year in % ages) in terms of resource flow (GNP), and with 'corrections' for resource depletion (ISEW) Daly and Cobb (1990).

	Gross National Product (GNP)	**Index Sustainable Economic Welfare (ISEW)**
1951–1960	0.97	0.84
1960–1970	2.64	2.01
1970–1980	2.04	−0.14
1980–1986	1.84	−1.26

Note: the analogy between 'yield only' (as GNP) and yield corrected (as in ISEW) is that 'progress/performance' of farming is measured by output only without paying attention to the health of the resource base and/or producers (remember the agricultural minster's quote), or corrected for loss of resources such as soil organic matter, clean water in aquifers, oil reserve or even aspects of bio-diversity, rural structures and skills.

Adaptive cycles (Figure 10), our second special behavior, also stress that linear growth and stable equilibria (as in climax vegetation paradigms) are unlikely. Here too, the Phoenix 'paradigm' takes over from the paradigm of linear growth. The 'adaptive cycle' is best understood by starting in the lower left quarter, i.e., in situations (contexts) with abundant resources (prey), of course always relative (Relative refers to few (claimed) resources (e.g., after disaster) relative to even less remaining 'predators', a phase that favors early claimants with cowboy style, which quickly grab much space (like rumen bugs of Hungate earlier in this paper that are quick rather than efficient in converting resources into ATP) to the abundance of organisms (predators). That situation occurs when opening new lands, when 'finding' uninhabited space after a war or a flood, or where many other 'predators' have left the scene. In the lower left quarter of Figure 10 (the r-phase), it is important for any colonizer to 'grab' available resources quickly, as many as possible. It is an 'exploitation mode', as in land grabbing or (at higher fractal level) in global races for 'undeveloped' resources: the tragedy of commons at many or all levels of system behavior [68]. Associative thoughts, as on GB systems (and other 'businesses'), calls the r-phase the 'cowboy phase' with relatively much individualism versus cooperation, and low resource use efficiencies. So, the design of 'sustainable output' again becomes a paradigm issue, being co-determined by the resource availability of the context, and not being a static and 'neutral' notion. The r-phase is followed by a phase where 'cowboys' start to compete. One response (coping strategy) is to fight until death as presumed in the tale of the Easter Islands [81]. Another one is to collaborate and exchange resources; Ref. [69] while the systems move towards the K-phase (upper right). An epitome of the K-phase is a tropical forest [82], where all resources (except energy) are recycled with great efficiency, but at the cost of (solar) energy, and with low 'useful' offtake (Use of inverted commas indicates that each word deserves a sentence or a chapter. Readers should try to catch the meaning rather than to become lost in arguments on exceptions). Small farmers in the K-phase may have little 'net' output, but they are efficient in nutrient use ([6] argues that peasantries are masters at upgrading low quality (high-entropy) resources by using their labor and ingenuity and by making the best of it). They are 'efficient' at the cost of human energy—using little fuel. However, this implies reward for human energy rather than for fossil energy, with implications for equality in society [77,82]. Trade-offs and choices for design abound. The r-phase is called an exploitation mode, using much external energy (fossil fuel), having little interconnection, but being resilient only as long as resources are abundantly available. The K-phase is called 'conservation mode', with much 'stored capital'. It is highly connected and internally interdependent, being rigid and, thus, not very resilient. Both distribution and recycling of food does cost energy (Larger scale tends to imply more road transport, higher energy costs and higher CO_2 emissions) (e.g., as human energy for farmers with wheelbarrows and/or as fossil energy for trucks/trains when moving on intra-regional scales). And, as fossil fuel takes over, so does the balance of reward from human to fossil energy, another trade-off. Hidden in these arguments is the need for caution when advising farmers (pastoralists, microbes, companies) to improve on the mode (stable state) in which they are. Each mode is transient, and increased lock-in (the ratchet!) tends to eventually cost more energy. This is perhaps where Schumpeter has a point with his 'creative destruction' [83,84]. Creative destruction takes place all along the adaptive cycle, from the r-phase in the lower left to the K-phase of the upper right, and so on, and back again. Creative destruction cannot be avoided easily. But creative destruction hurts, and it can be smoothened by teaching, research and management that promote diversity, redundancy and forward thinking for smoother and more diverse transitions. Finally, yet importantly, focus on 'creative destruction' innovation as goal (Goals set according to wishes of 'the designer' tend to imply more control (and, thus, also resources, than processes that emerge more in line with realities of the context (see text on entropy)) in itself) is as wasteful as emphasis on 'more of the same'. Both too much r- and too much K-strategy lead to crash.

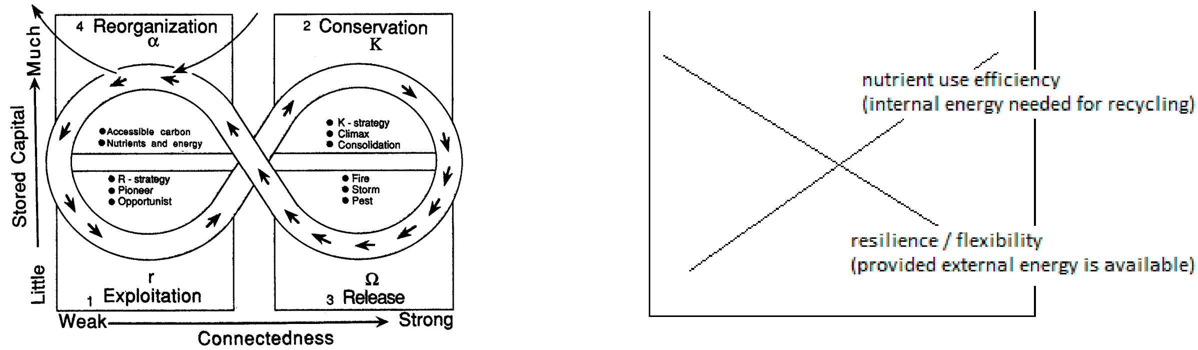

Figure 10. The adaptive cycle, also known as 'lazy eight' on the left [85], with to the right the trade-off between resilience, stability, efficiency, and output. (See text and note on trade-offs under Figure 8). Symbols and terms are maintained as in the original Holling diagrams for their 'richness' in concepts. Note: resilience (as in the bottom left quarter) is achieved thanks to relative abundance of (external) resources in an r-phase. The right-hand upper quarter with the K-phase is rather 'stable' but not very resilient (hence it can collapse into the release phase of the bottom right). The K-phase uses tight networks to enable efficient recycling. Hence there is a trade-off between resilience (elasticity) with low resource use efficiency and high outputs on the one hand (bottom left) and high efficiency of resource use but low output and high stability in the K-phase. High input as well as extensive (pastoral) systems both tend to belong in the r-phase. They include the stereotype post-war pastoral systems with high levels of fertilizer as well as the extensive pastoral systems in New Zealand. Remarkable indeed how seemingly different systems operate in a quite similar way. Systems with high levels of recycling and usually relatively lower outputs tend to sit in the top right K-phase. They include high input systems where public pressure restricts input use, organic farming systems as well as labor intensive small farmer systems. Note 2: a confusing factor is that spacing of arrows indicates duration of the processes (phases). Distant spacing implies slow processes, dense spacing implies fast processes (especially during collapse). Both the r- (exploitation/cowboys) and the K-phase (tropical forest), as well as the re-organization can last long while (obviously) the release can proceed very quickly.

Fanning, the third special behavior, is a notion probably linked with 'bifurcation' in chaos theory. We use 'fanning' for a behavior where 'evolution of systems' implies (emergence of) a variety of systems rather than one single answer to one single question. In this case, 'convergence' and 'divergence' describe two opposing development paths but they are general for any system behavior (footnote 4). Many examples of fanning exist (Greek thinking occurs in a 'fan' of ideas, so does thermodynamics, and the International Society for the System Sciences (ISSS.org) has many branches as so-called Special Interest Groups. Fans exist (are part of life) for any thinker and/or thought system, religion and the like, organic and/or conventional farming [6,86,87]. Focus on definition can lose this variation and (mis-)lead one into misplaced discussions on virtual scapes) also from GB systems though much design of farming systems implicitly focuses on one 'model'. Figure 11 shows fanning in Dutch dairy development from some 40–50 years ago, when mainstream policy indeed assumed a converging set of 'development scenarios' into one 'stable state' [87]. Generality of fanning is illustrated where geneticists recognize 'fanning' as speciation. Ref. ([88] p. 310) wrote: *"It might require a long succession of ages to adapt an organism to some new and peculiar line of life, for instance to fly through the air; but [that] when this had been effected, and a few species had thus acquired a great advantage over other organisms, a comparatively short time would be necessary to produce many divergent forms, which would be able to spread rapidly and widely throughout the world."*

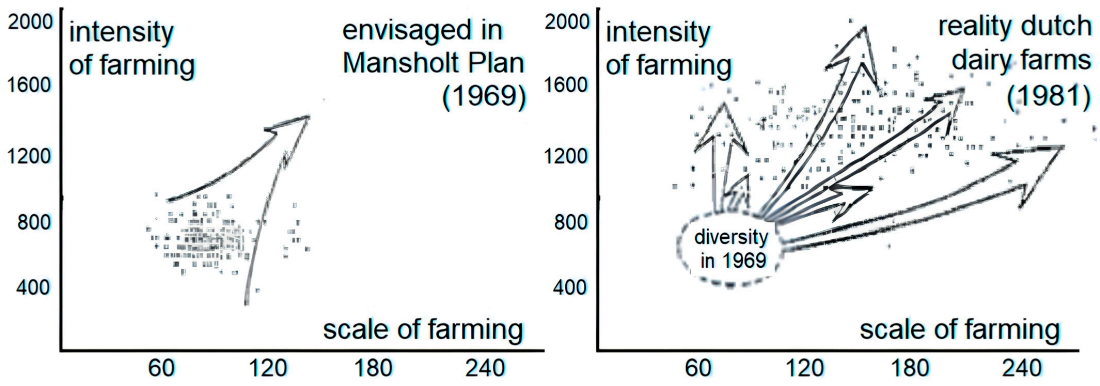

Figure 11. Expected uniformity in farming styles of the Mansholt Plan (a large re-organization/ modernization of farming in the 1960s–1970s juxtaposed against the fanning that happened in practice [87]. Farms are 'classified' based on resource use intensities.

The fourth behavior is the tendency of 'things' and/or 'energy' (~resources) to degrade, a behavior of a 'deeper' order than behaviors discussed so far. Degradation and, thus, qualities of energy and resources in general are at play when predators use prey to survive, when animals convert feed into meat, milk and excreta, or where erosion transforms the land base by causing degradation upstream and soil enrichment downstream. Even if 'new order' is 'created', the net effect of such conversions is always a net increase of poor-quality resources (waste, disordered). In addition, need for system maintenance (against degradation) is basic in animal nutrition, in running of cars, cities, databases, companies, forests and libraries. Tendency of things and resources to degrade is well studied and described in at least three different branches of thermodynamic theory (see below), with their two main laws. The first law states the impossibility to destroy or produce energy. It stresses that 'the only thing we can do' is to transform one kind of energy into another kind of energy, and it leaves open the possibility that energy/resources can be endlessly recycled, from one form into another and vice versa. In that view one can equally well convert solar energy into energy embodied in carbohydrate energy as the other way around. The second law, however, stresses irreversibility (Simple examples of 'irreversibility' are painting of a house, writing of a letter, burning of oil and so. Paint can be scratched from the house, however, increasing mess rather than really getting back into the original state), since at each transformation the tendency to disorder (greater entropy) is bigger than the tendency to order (lower entropy) (Thermodynamic reasoning primarily uses probabilities of large numbers (behavior of groups of molecules). Therefore, 'unlikeliness' in mainstream thermodynamics practically implies 'impossibilities'. Work with smaller numbers more properly uses the notion of 'possible but highly unlikely'). Typical implications of the second law are that the net effect of any conversion is always a greater disorder, and that it is easier (more likely) to degrade than to regenerate resources, whether oil, soil-organic matter, gene pools, knowledge bases, infrastructures, and farms (The degree of degradation is confusingly measured as entropy (i.e., S). Degradation implies increased entropy (disorder). High quality resources are, thus, low-entropy resources. Waste can be considered a resource depending on one's mindset as well but wastes are high-entropy (highly disordered) resources, nevertheless. Practice helps to overcome this confusion of terms). More laws of thermodynamics are proposed, and indeed, 'fanning' of interpretations exist between 'schools of thought' even in thermodynamic thought. However, likelihood towards greater disorder if things are left to themselves is the basis for all those schools, which also all agree that form can be maintained and/or emerge only if resources are added from outside. That is known by common men and ancient civilizations as the trade-off 'no gain without pain' (Figure 12). Adding some associative thought: thermodynamics did not invent or own tendency towards disorder (if all left to itself), but thermodynamics did very well describe the physical processes, together with its cousin 'information science' or 'cybernetics' doing its own part [89].

Figure 12. 'Kooch konahe kooch panahe', an ancient Hindu expression for the second law, translated as 'it takes something to gain something'.

All schools on thermodynamics indeed do agree on overall validity (This is perhaps a strange and deep-down case of 'universal truth' that keeps one wondering) of the first and second law. However, non-linear complexity thinkers (other than linear thinkers) would focus on the use of basic concepts rather than calculate exact 'entropy-quantities' involved (Mario Giampietro, pers. comm.). Of the three schools of thermodynamics that we mention here, the first one focuses on development and use of these laws in so-called 'closed systems'. It can be called the 'classical school' that emerged some two centuries ago with work on steam engines, primarily using empiry. A second school, led by Boltzmann (https://en.wikipedia.org/wiki/Ludwig_Boltzmann, accessed on 14 February 2023, also reflecting 'fights' between 'dogmatic' paradigms (refusal to accept crash and allow collapse of chaos)) supplements those lines of thought, using reason rather than empiry to assign odds to forms and arrangements of parts (such as atoms). Boltzmann reasoned that some forms (i.e., arrangements of parts) were more likely than others. Applied to this paper, and assuming that many other things are in place (e.g., for photosynthesis), he might have said that formation of starch from solar radiation is more likely than formation of fats or proteins. Transformation of photosynthetic products into more unlikely forms such as fossil energy (coal, oil, methane) requires yet another (giant) step, and lots of energy (also generating entropy), involving eons of time with very high temperatures and pressures (no gain without pain!). To follow 'Boltzmann's logic of probability, we now introduce a 'dense' argument that is NOT TO BE MISSED (caps by authors). The point is that probabilities depend on the context (on the size and shape of the dice, the players and the playing field). For example, in a context with high-energy fluxes (i.e., with many low-entropy resources), the odds of unlikely forms are higher than in contexts with low energy fluxes (high-entropy resources). We repeat that in GB systems terms, a zebu cow is more likely in low-flux contexts, and a 'turbo-Friesian' is more likely in high flux contexts [90]. In terms of automobiles: Formula 1 racing cars are unlikely in a remote desert town and oxcarts are unlikely on racing courts (Ox-cart races do occur indeed). Level playing fields in terms of 'resource contexts' are hard to envisage. The third school on thermodynamics sort of fuses notions of complexity with those of open systems [51], or also complex adaptive systems [15]. It is perhaps best known to the general public from the work on non-linear dynamics (see [43]). It can be used by some parties to 'sort of' bypass and/or sideline the notion that everything tends towards disorder. This school can do so by working on open systems where low-entropy resources are imported to compensate the eventual loss of form/order in closed systems. Our use of thermodynamics in this paper focusses on thinking in terms of odds/probabilities in the design/emergence of form and organization (The argument that thermodynamic notions apply to both issues of matter and mind is beyond this paper but interested people may contact the authors for further explanation), primarily combining notions from the 'second and third' school. Another point, also NOT TO BE MISSED (caps by authors), is that translation of arguments from thermodynamics in real world phenomena should consider that thermodynamics uses large numbers (e.g., working with many molecules in the order of Avogadro's number). Life and thought in farming system development tends to work with smaller numbers and even individual farmers, cows, pasture plots, etc. [87]. In work with 'big data', the near certainty of using large numbers is on the way, e.g., in politics, business and social media.

In all realms, thermodynamic theory stresses the basic notion of trade-offs, i.e., the notion of 'no gain without pain'. Such trade-offs imply choices on how we design distribution 'internalized benefits' and 'externalized costs', i.e., the gains and the pains in design of sustainable systems. Also, thermodynamics stresses the need to distinguish (qualities and quantities of) resource fluxes, as in the adaptive cycle, from r to K. That should make designers be alerted to not assume too many averages, whether in feed conversion, feed intake, purchasing power and so on. They should also be keen to maintain enough 'prey' (where prey can range from knowledge bases, via oil and soil organic matter to clean water in clean aquifers) [23].

More can be learnt from thermodynamic theory than only the notion that everything tends to go to disorder (Thanks to Niek Koning for asking: "is there more to be known than that everything becomes an entropic soup?"). Based on discussions with a deceased colleague (Hans Lyklema) we now list some rules for design of sustainable (GB) systems based on thermodynamic theory. Helped by the probability reasoning the rules appear to make a lot of sense:

- Mixing, by definition, implies an increase of entropy. Mixing is performed when packaging and/or blending foods to help prevent spoilage and increase the 'added value' in mainstream economic terms. Still, the odds are that entropy increases more with greater intensity of processing/packaging, especially with processes that are more sophisticated (~unlikely). Another example (of the many) is mixing of plant-nutrients (concentrated, i.e., low entropy) from fertilizer mines, eventually with soil, groundwater and/or run-off. That may increase yields, but then again, eventually the nutrients are left dissipated, implying much less access to those nutrients for the longer term.
- Less likely systems (high yielders on poor grasslands) require much import of low-entropy feeds, i.e., they probably generate more entropy (waste) for given 'offtakes' than more likely processes of robust cows on the same pastures. The odds are indeed that high input GB systems yield more, but that they also cost more (non-linearly) in terms of low-entropy resources when the local contexts do not themselves support those high yields. Finally, as a case from 'cropping', strawberries for Christmas in Northwestern Europe are likely to imply more entropy than strawberries in season [9].
- Faster and larger scale is less likely than smaller and slower (These faster and larger systems are 'farther from equilibrium', with entropy generation approaching zero when a system is in equilibrium. The notion of 'faster' comes from Mario Giampietro, implying more intensive production and higher amounts of low-entropy resources on scales of time and space) systems, thus with disproportionate generation of entropy. Freeze-drying (a fast process) does not allow large crystals to form as does slow freezing. That is an advantage in some case, but it implies greater entropy generation. And as an associative thought: what if one relates this analogy of 'fragmented ice crystals' due to high-speed freezing with the effects of a fast society on social networks? Social media can replace local social networks, but odds are that they do so at disproportionate generation of entropy through unlikely communication systems (large space scales, high-speed and perfection). Also, in terms of speed and entropy generation, colliding cars are more likely to have serious casualties than colliding pedestrians, fast trains need tracks with wider bends than slow trains, and distant large-scale transport requires more sophisticated packaging, lawyers, storage, and planning than local markets.
- Notions of diversity (being more likely than uniformity) and associated different qualities (fluxes) of resources as in the first law imply that each ecosystem has its own resource flows (we repeat: level playing fields are unlikely). The odds are, therefore, that acceptance of variation/diversity in farming systems and regions can be a way to reduce entropy generation per unit of product, against mainstream economic thought

focusing on 'economics' of scale and standardization. Unlikely standardization is likely to also cost more energy (low-entropy resources), while generating 'added value' in mainstream economics (partly offset by cheaper handling of uniform products).

- Self-organization based on local rather than external resources are (by definition) likely to require less low-entropy resources. As a side effect it also shifts relatively more 'reward' in the countryside since it implies less import of external resources. The trade-off/choice is that total yield on local resources may be lower even if it is more efficient. The option to modify/adapt consumption levels is a hard political and personal choice.
- As implied, reasoning and 'scapes' of the entropic worldview and mainstream economics are often at odds, most visibly in the choice between local and global, between increasing entropy (disorder) while 'adding value', between odds of slow and fast, as well as between logic of mass production and extensive distribution. That is a point to remember when discussing and designing our future.

Food for Thought

We discussed four special behaviors that apply to any system, thus also to GB systems. One is the predator–prey model, the others are the adaptive cycle, fanning and last but not least a general tendency to disorder, i.e., entropy generation. Each of these imply a need to distinguish between different resource qualities/fluxes. Thus, linear design focusing on average resource quality is likely to be tricky (to say the least). In addition, the predator–prey model illustrates system dynamics due to interaction between predators and prey, or also between cultivated and non-cultivated land, between good farmland and rangeland that might better be left to forest. It also illustrates a trade-off between resilience and stability, and it relates wave diagrams with attractors (the Phoenix paradigm) that underlie notions of 'basins of attraction' and 'stable states'. A major point of a predator–prey model is to relate 'offtake' by a predator with health (so to speak) of a resource base (the prey), a central point in management and design of GB systems. The adaptive cycle supports the notion of the Phoenix model in development, thus challenging design paradigms/worldviews/thought-scapes that assume steady linear growth and eventual climax vegetation and/or that aim for stable systems on the long term. Indeed, long-term persisting stable states (of climax vegetation) are unlikely and the design of static (long-term) stable food systems is an illusion if it ignores the energy required. Flexibility and redundance (inefficiency) are thus needed for adaptation, implying also flexible consumers preferences. The point is to be sustainable by walking on two legs (the two paradigms), surviving well in one state, while having strategies and mindsets in line for the next mode. All this implies paradigm shifts that allow us to at least properly walk on the two legs of goal and process approaches, of morphology (states) and morphogenesis (behaviours), of static and dynamic thought and practice, of matter and mind, and/or as well as systematic and systemic attitudes. The first three behaviors, thus, stress the need for ensured resource bases and design of systems mixes that handle varying fluxes with varying 'organisms', much similar to the (GB) systems in unpredictable contexts [91]. Behavior reflected in the first and second law of thermodynamics enforces all these notions, adding that 'likelihood' relates with 'need for resources', i.e., that unlikely systems (e.g., faster and more standardized) require more system control. Applied to sustainability, as Epicureans say: "enjoy life today by avoiding a hangover for tomorrow". Thermodynamic logic challenges design choices by questioning much of 'the beauty of the emperor's new clothes' and by reviving the common wisdom of a well-known trade-off, i.e., the choices (no gain without pain). Such choices are illustrated in trade-offs between low and high speed as well as small and large scale. The thermodynamic logic also implies tension/choice between logic of mainstream economics and 'the nature of nature'.

6. Choices for Design, Issues of Mindset

When discussing choices in design, we start by distinguishing two approaches/paradigms. In a way, this section resembles the earlier section on 'hang-ups' but is more about philosophical approaches. Real life is a mix of the extremes, but 'juxtaposition' of polarities can help to clarify things. In that sense one paradigm is goal-oriented, starting not necessarily with reflection, but with a question on 'desired functionalities' followed with 'what is needed' and a rather inflexible attitude to achieve that goal. The other paradigm is process oriented, preferably starting by reflection on 'who am I', then going to 'what is available' and then flexibility towards 'what can be done'. This latter approach does not generally have a clear goal, even if it can have clear direction and overall context in mind, e.g., nitrogen fixing legumes or zero emission of phosphorus: "a horse for a course". The first approach can be called a 'systematic' and 'control' approach. The second is called 'systemic' and 'participatory' in which a 'designer' reflects on whether/how he/she should change his/her mindset to be 'happy' with the outcome (Table 2). In our experience organic and conservationist farmers in general tend to wonder what they (themselves) do wrong (or can do better) when they see a weed or disease. Conventional farmers may first go into the mode of attack on the dangers from outside without wondering about their own mindset. After a choice for control or participation the next choice is on being prepared (or not) to see (or to ignore) that crash is pending and/or when/which chaos starts to collapse. That is in terms of this paper a choice for either 'lock-in' or 'lock-out' implied in Brian Goodwin's 'control or participation' (as mentioned earlier). This section discusses design choices, also on mindset that much determine the outcome.

Our focus here on philosophical aspects of choices comes from being convinced that 'steps for system design' are well known [92] (Use of such older references is deliberate. They provide overview and review, while stressing that the wheel need not to be re-invented; see notions on 'the end of science' in concluding remarks). Their implementation depends primarily on (choice of) mindset and perhaps on refinement of 'method'. For the uninitiated, however, we give a well-accepted sequence of such steps in design: (a) setting a goal (functionalities) and/or doing a reconnaissance/characterization of the system; (b) identifying resources and/or bottlenecks with opportunities; (c) testing opportunities with sensitivity analyses/field trials, and/or do more research; (d) make prototypes; and (e) test and/or monitor the 'innovations' in practice. Such set of rules for design is surprisingly similar between manuals on design, even if they are handled differently by the different mindsets.

We thus continue to move forward to differences of mindset (i.e., philosophic choices of paradigm and their impact on implementation of design principles. First, much design uses terms such as 'goals and functionalities', perhaps in line with Aristotle's notion of 'telos' (goals). Second, Hindu thought tends to stress process and 'direction' rather than goal (It is amazing how much modern 'oriental' management rushes to the 'goal' notions attributed to Aristotle) The Phoenix 'wave' model is a third way of thought (somewhat related to Hindu approaches) and an alternative to linear growth paradigms as in mainstream equilibrium thought. Each of these mindsets (out of many) lead to other implementation of design steps. Other contrasting mindsets are (a) between win-win thinking and thinking in terms of trade-offs (among others on where to locate the gains and the pains (See Genesis 4:9 on "am I my brother's keeper?")); and (b) emphasis on individuals in uncontrolled self-organization (leading to the tragedy of the commons) versus attention to the 'whole', e.g., with interventions from the public sector. 'Self-serving control minds' tend to see self-organization (as invisible hand) representing 'freedom' to act without outside constraint. Focus on short-term and narrowly defined efficiency tends to result in 'frozen'/inflexible/non-resilient systems, collectivist regimes, and modern large scale food chains (When getting used to notions of system hierarchies (and fractals) it is common to find 'trade-offs' between one level and another, e.g., with more control at enterprise level implying a need for more 'freedom' at society level (again, to control at enterprise level). Or also, higher standardization at one level implies greater diversity 'at the edges' (often called 'mess' by large scale operators). It is very tempting to think that this reflects the 'no gain without pain' notions so fundamentally described in Thermodynamic Theory). Then, (c) there is stark difference between focus on details (Cartesian tradition) and holistic approaches, where the designer regularly sits back to consider the whole in order to decide on 're-iterating the process' or towards further refinements of details. That is the choice between 'doing things right and doing right things'.

While juxtaposing different paradigms, we note that Aristotle stressed the 'middle way', using a proper mix of polarities rather than to become lost in one extreme or the other. That is along the lines of '*sola dosis facit venenum*', of [40] on '*neither too little nor too much*'. Important, the 'middle way' in our view is not a mathematical average, e.g., of farm sizes and yields, but a diverse mix of resilient–stable, small– large, short- and long-term and so on. A variation of farming systems, thus, is closer to 'the middle way' than a set of similar standardized farms with average cows, owners, and consumers. Such variation is hard to administrate, but administrating diversity can be learnt, and it is part of '*standing in two paradigms at the same time*'. Scanning for other philosophic choices we look at Cartesian thought of which we like to discard ánd to keep some 'principles'. When discussing design in a complex world the first cartesian principle to keep, in our view, is to 'doubt anything until we are absolutely certain', to avoid lock-in and noting that absolute certainty is anyway impossible in complexity. This Cartesian rule on doubt is paraphrased, by an architect friend of ours who says, "design is the continuous critical reflection of one's presuppositions". That is nothing else than referring to H.C. Anderson's fairytales: "to continuously question the beauty of the emperor's new clothes". That implies courage in seeking complexity, by using 'system-literacy' to see early signs of crashes, and by seeking order in newly emerging patterns. Regular (not endless) iteration should be part of the process. Also, lobbying for a sustainable future should, thus, permit renewal (without making innovation a goal in itself), rather than to aim for 'more of the same' (i.e., lock-in). More of the same tends to be cause rather than cure for pending crash.

Cartesian's second rule on use of reason is also to be treasured, implying design by use of scenarios, more so since the future cannot be measured with empiry. At best, the future can be 'sort of' pre-assessed by using analogies/behaviors/models from other/earlier realities/scapes. We challenge, however, the Cartesian rule to seek the minutest of details and to rebuild from those details (Exception is a need to seek details (butterflies) that matter, as by our meteorologist friend earlier in this paper). Other Cartesian 'rules' to be left out from the main stage are distinctions between matter and mind (a convenient distinction but a misleading generalization), between animals and humans, or between men and women. Apart from being valid or not we think that the focus on distinction should shift to a good mix of distinctions as well as on similarities and relations which are so central in coping with complexity, e.g., by using metaphors and discerning general behaviors.

More can be said on choice of mindsets and first we wish to challenge the use of control paradigms, a leftover from the enlightenment. We do this by using a few 'narratives' (We think, operating in different scapes on a generally valid topic, that priest(esse)s, common men, poets, novelists and other 'artists' have insights to supplement the science of this paper. To mention a few examples on the complexity of development: Steinbeck (Grapes of Wrath), Gabriel Marcia Marques (Cien anos de soledad) and Tolstoy's 'how much land does a man need'. We did mention Antonio Machado in (Table 2)). We thus start to address the question on choice of mindset over two design approaches/paradigms by using a quote from a rabbi and by referring to Plato's 'Ideal State' and its successors. The point to show is that (a) design is of all ages, and that (b) designs usually work out different from what was intended. The rabbi said that "if we want to make God laugh then tell him our plans". That is a Yiddish way to remind us to be modest on expectations (but NOT to idle). Plato wrote of the 'Ideal State', as a sort of Utopia, followed by many others on this theme (Thomas More, Karl Marx, neo-liberalism, sectarian groups, 1984, 'Brave new World', and perhaps private enterprises that promise to deliver what they proclaim that the state could not). A literature review of 'Utopias' showed their general tendency to totalitarianism as one notices in all kind of chain control systems. It also shows that none of them succeeded on the long-term [93]. That may make us feel helpless, but also more ambitious when embarking on work with complexity. A Greek friend (Manoulis) told us that 'tragedies' are cases where 'Gods' toy with people. In 'comedies' the people 'toy' with Gods. "Real life"—our Greek friend continued—"is tragicomic". Brian Goodwin (pers. comm., 1997) combined these notions on 'tragicomedy' into the phrase: "from control to participation", referring to the dynamic interplay between people and 'nature', between their wishes and realities, and/or between trade-offs. That theme is also found in the notions about at least partly autonomous system behavior, mentioned by [46], who talked of a "ghost in the machine" and by Stuart Kauffman (pers. comm.), who said "God is back in the system". Static notions and fixed goal thinking in design paradigms need be balanced with notions of direction, interaction, and constant change (not as goal in itself), participating with the laws of nature in the broad sense (matter and mind). Rigid focus and lock-in are to be re-balanced with flexible and open-minded experimentation with the future (that applies to many banks, legislators, entrepreneurs, (religious) leaders and teachers). Customary emphasis of teaching on solvable linear problems (easy marking for teachers) is to be re-balanced with work on problems that cannot be solved and/or that have multiple coping strategies. 'Ceteris paribus' paradigms must thus at least share their space with those of 'ceteris imparibus', recognizing the role of internal and external dynamics. Choice overrules certainty!

A final category of choice on mindset is on 'incremental change versus overhaul'. It is reflected in a poem by the poet/philosopher Omar Khayyam (an 11–12th century Persian scholar in the modern tradition that helped carry Greek philosophy into the European Renaissance [44]. This poem again shows that system thinking for design is of all ages and places. He rhymes:

- *Ah love, could thou and I with fate conspire*
- *To change the sorry state of things entire*
- *Would we not shatter it to bits? (≈overhaul)*
- *And remold it nearer to our hearts' desire.*

In general, 'overhaul' tends to become more urgent when incremental changes are used longer, basically accepting lock-in. Choice for or against 'incremental change' and 'overhaul' depends on mindset and tradition. At the same time, overhaul becomes harder to swallow when farmers, sectors and societies have long relied on incremental change. The general complaint is then: "look what we have done already to perform better", unaware that they have worked too long 'locked-in' in an outdated mode. Moreover, as tensions increase, the fuse tends to become shorter, another serious trade-off. To accept crash and to see collapse of chaos (to escape lock-in) takes strong individuals and leaders, rather than followers.

Choice of mindset in design and trade-offs between objectives are our main issue when talking about design. This is very much in line with Buddhist traditions that 'blame' our desires (mind) for being unhappy with the world. Choice on mindset is, of course, to be accompanied with choice on 'criteria of successful change', whether on reduced N and CO_2 emission, on corporate benefits or more equitable distribution of income, faster vs. slower systems and so on. All such choices imply the trade-offs reflected in: "no gain without pain". Some choices on mindsets and criteria are illustrated in what we call choice diagrams with practical cases below (Choice diagram is a synonym for the diagram used in 'competitive advantages').

The first-choice diagram in this paper was on 'changing' paradigms, a deliberate choice to show the dynamics of choices for paradigm (Figure 3). A second-choice diagram on mindset displays choice of 'farming style', i.e., individual preferences according to which (Dutch dairy) farmers run their farm (Figure 13). Van der Ploeg [87] even shows that income needs not differ much between these farming styles, even if cost/benefit structures and resource use differ vastly. Two more choice diagrams are presented in Figure 14, as sort of 'ex-ante' analysis on choice of technologies in relation with values on environment and society. The lower left quarter tends towards local farming and short food chains, with the upper right one tends towards larger chains and more industrial nature of farming. The Figure 15 illustrates that the default 'choice' towards modernized (often more unlikely (In 'entropy-terms' they can be called 'slow' and/or 'distant from equilibrium)) dairy production modes imply more intensive systems, which tend to imply more resource use and associated greater CO_2 emissions, aquifer depletion and the like [94]. This 'default' does not reflect much critical reflection on laws of nature (e.g., on entropy), which call for diversity, smaller scale, and slower processes. Hans Christian Andersen's warning sounds on the background: "beware of the beauty of the emperor's new clothes".

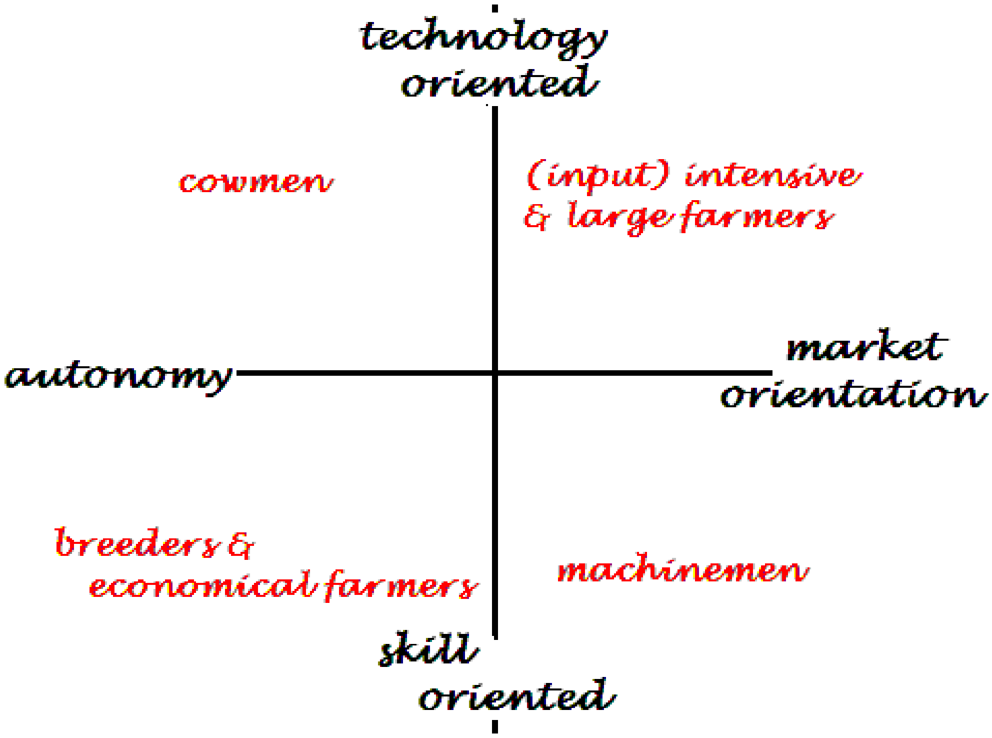

Figure 13. Choice quadrant with 'preferences' for farming styles in Dutch Dairy (Van Der Ploeg, 2004) [95]. Trade-offs between advantages and disadvantages of one choice over another are implied. For example: choice for autonomy (large degree of independence from the markets) tends to go at the expense of skills to manage markets. It also, however, may imply less need to know the market (trade-offs left-right). So does focus on cows (breeding/feeding) inevitably take time and attention from focus on machines. Here too, focus on cows may even imply lesser need for attention to machines (trade-offs top left–lower right). (See also notes under Figure 13).

To wrap up, we now list some practical examples on (re-)design and/or crash (extinction) in GB systems (References and further reading are available from the authors). First is on default that was rule in Friesian dairy breeding of some 60 years and longer ago until 'the academe' challenged breeders on what it was that they really wanted (to design). Ultimately, breeders started to see the reality of the 'emperor's new clothes' when their 'famous and beautiful animals' lost market share in the sixties. Crash was noted, comfort zones were reconsidered, and chaos collapsed into new breeding patterns that brought Dutch dairy breeders back on world stage (even including crosses with zebu cattle). One of us (JBS), as student at that time, had one of his own paradigms on animal production crashed in Indonesia, when he found that lower productions on cheap feed could be more profitable than higher yields on prime quality feeds. Later, he found that, the profit from New Zealand cows was greater than in Dutch farms with cows yielding double [96]. Another 'crash' occurred when JBS learnt (in the Philippines) about high CH_4 emissions in deep litter, what he thought was an ideal N-saving practice. Choices between CH_4 and ammonia-scapes are inevitable [34].

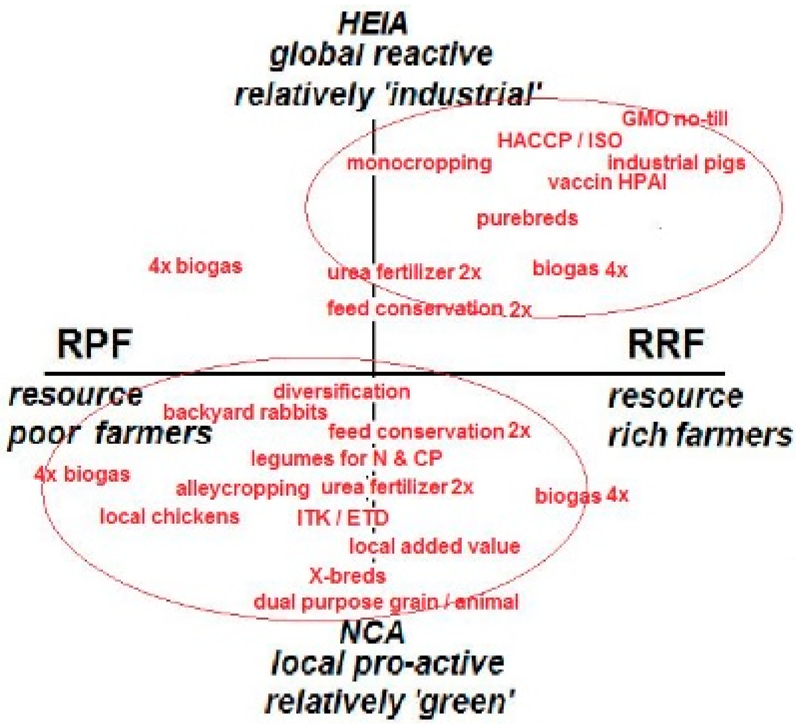

Figure 14. An ex-ante analysis of suitability of dairy technologies with choices for different development scenarios in the Philippines, explicitly with 'physical and mental' aspects/scapes of farming [8]. This kind of diagrams, also the one in Figure 12 on Farming Styles is quite similar to the ones on 'competitive strength' in which relative strength of particular products is plotted against the niche of particular consumer styles/habits. They are also very similar to Learning Cycles as in Figure 3. The point of such choice diagrams as this one is that for 'technologies in the broadest sense' the design for those that serve resource rich farmers in global markets are to be different than those for resource poor farmers in local markets. Choice of technology is thus not neutral. Policy choice for mature development 'that stands in two paradigms at the same time' requires balanced development and combinations of different approaches.

Paradigm shifts (with crash and eventual collapse of chaos) come and go indeed. Some come uninvited (pandemics, wars), others come in a guided way when leaders in the sector have guts and/or time to adjust. In that later line, many pastoral systems around the globe slowly evolved rather gradually (no forced and accelerated innovation at the cost of extra energy) from exploitation of rangeland (still common in countries with forest clearing (the r-phase)), via cow-calf operations and crossbreeding for milk to dairy systems with pastures, eventually into intensive dairy using recycling (the K-phase) or urban dairy systems based on concentrate feeds (crash of K 'back' into a new r-phase), or from grass into grain (Vergetreidung), vegetarian meat and milk, into flowers, or even into urban estates and airports (a new r-phase). The more they are locked-in and the faster the processes, the more they hurt due to forced crashes of worldviews and greater difficulty to see the collapse of chaos into new systems.

Challenges for the sector are, in our view, to accept that (extensive) livestock keeping in this world is only useful when land is plenty, when that land cannot be used for crops, horticulture, forestry, nature and so on. Also, we may have to accept that animals regain a place, primarily as converters of waste or non-human edible/digestible carbohydrates and protein, with associated (and more likely) levels and kind of production. Nowadays, some think to see a 'collapse of chaos' with vegetarian butchers (producing milk and meat-like products directly from plant-materials), by people eating insects or by consumers eating less meat altogether, or by 'activists' that abhor (intensive) livestock industries. This kind of crash and collapse of chaos is told in stories from around the world, sometimes decades ago. One such crash/collapse case comes from the hill village of Sukomarji (Northern India), some decades ago. Deforestation and drying wells there, combined with good leadership made people wonder whether they preferred water catchment and fuel wood as new mode over customary and deeply felt cultural (default-mode) of free-grazing [24]. Similarly, a traditional system of free grazing and environmental degradation in Machakos (Kenya) 'crashed' and was replaced by crops on terraces with animals left to use fodder produced as by-product of soil protection or as 'left-over' from grains [97]. Other cases of change in production priorities are around in the world, in livestock as well as crop production. Bakker et al. [21] illustrate that nicely for lock-in and treadmills in pesticide dependence. Too often it takes 'a mindset' to see the obvious, rather than a bucket full of evidence.

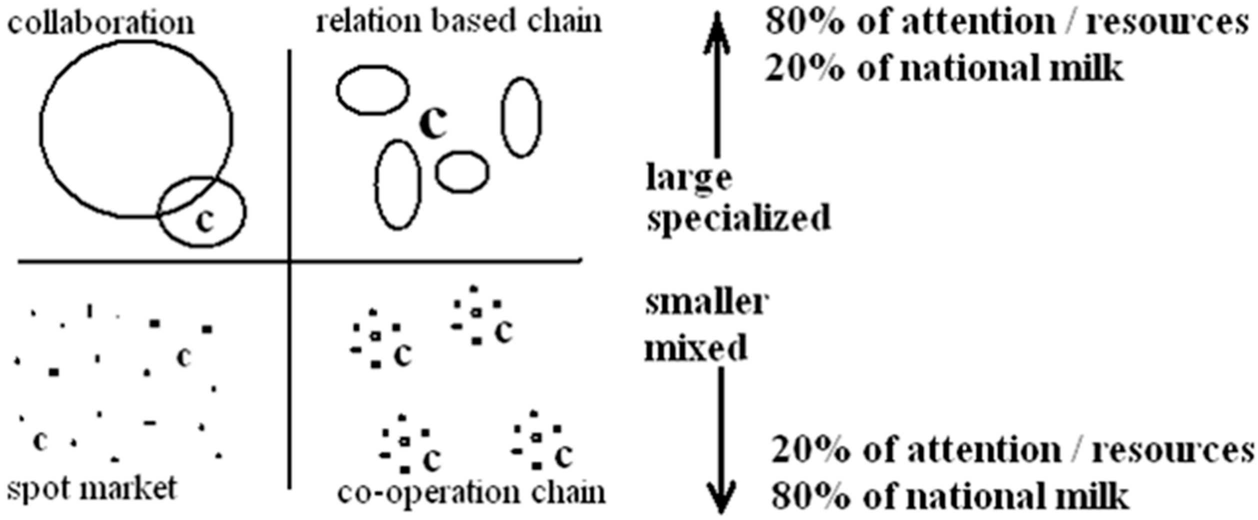

Figure 15. The analysis of developments in (Chinese) dairy chains (as we found in other countries) showed a pattern in which the collaboration mode of large enterprises with full control of the chain is quite similar (It is a great case of similarity emerging where differences seem to rule. Details are complex and found in the original document) (apart from scale) to the short chains as occurring in the spot markets of the small farmers. Both these are found in the left-hand half of the diagram. The right-hand side contains the 'chains' (large and small) with less direct and more anonymous partners. The main point is the difference between large and specialized farms on the one hand (upper half) and the smaller mixed farms in the lower half. Analysis showed that the upper half produced (at that time) some 20% of the total milk in the country while the lower half produced some 80%. The 'farming styles' that produce, however, 20% of the milk obtain some 80% of the attention and resources. Could it be true that the ones of the upper half are less likely, in 'Boltzmannian' terms? Is that a universal pattern and/or what would all that mean for our choices on scenarios for pastoral (dairy) systems?

A few more examples of change (with good leadership) (Mention is to be given of the agricultural policies by Mansholt, Dutch/European minister of agriculture after WWII. His innovations gave spectacular results, but are in the danger zone now, due to their own success. He himself did change his mind, after reading 'the writing in the wall' in the report of the Club of Rome [11]. However, the knowledge system failed to grasp early and even late signs of crash):

- Nutrient emissions from animal farming can be debated on magnitude, but not on substance. Dutch dairy after WWII initially went fully for (default) r-strategies with large imports of feeds and fertilizers. Being profitable (to many) in terms of short-term economics, the sector managed to sideline concerns as found in public thoughtscapes. Collapse of chaos eventually came (though still disputed by some) when government together with farmer organizations and an environmental group started to collaborate on designing a mode change, also overhaul (as now happening in NZ), from more than 500 kg pure N/ha per year from fertilizer to less than 150 kg N, even aiming for zero balances on phosphate. Work with an environmental group after traditional powerbases crashed was 'scary' for some, or even 'work with the enemy'. But for others, the chaos collapsed and collaborations with new sections from society became common, also in sectors such as with pigs and poultry. The idea to work with zero phosphate balances and low N levels caused fear for crash and 'thus' even near-panic to some farmers, leaders and scientists. Some first came to see why it could not work, and five years later (when the chaos had collapsed) they came to see how to make it work [28,98]. Things are easier said than done, but from 'fear of crash' they went for 'love of collapsing chaos'. Of course, success only lasts until the next challenge (as in the Phoenix paradigm).

- Dutch crop farming had its share in designing incremental and/or mode change. We mentioned Pieter Vereijken as leading figure [37]. Others such as Frank Wijnands and Wijnand Sukkel, together with innovative farmers were part in introducing GPS systems, in low- or zero-tillage (without herbicides), organic farming, in strip-cropping, alley farming and the like. Much was based on farmer innovation (The GPS system in the Netherlands was started by people such as Jaap Korteweg (who later was successful as 'vegetarian butcher: https://www.thevegetarianbutcher.com/, accessed on 14 February 2023) It failed at first due to an intent to make the system too perfect at the start (Jaap Korteweg pers. comm.). Leaving 'unlikely' perfection for later stages and accepting 'half-cooked' systems is often more realistic in design than realized), but also on the individual researcher's quests to design new systems. Importantly, the organic sector pioneered things that were initially against mainstream thinking (mechanical weed control, crop rotations, use of diversity, disease resistant varieties). Later, their work served the mainstream to gain a new lease on life. The organic sector was also instrumental in designing shorter food chains with more of the 'added value' being retained by producers.
- Numerous other examples of crash and collapsing chaos can be quoted on changes that were unthought of until they took place. What to think of pig and dairy farmers to quit use of antibiotics, or of producers that refuse to import cheap feeds that are produced at the expense of soil fertility elsewhere? Or of greenhouses in the Netherlands that generate 'heat' for electricity and housewarming of the neighborhood, where earnings on 'energy' for urban heating can even became more important than earnings directly on the crops.

Unfortunately, but necessary to repeat, we paraphrase ourselves: "no change without pain". Many farmers gave up due to lock-in caused by rigid paradigms, heavy financing, too much fast and unforeseen change at society level (Faster change tends to cause more collateral damage (see section on thermodynamics)), uncooperative (urban) neighbors that colonized the countryside. Other factors play a role too, of course, making things even more complex (even if one can argue on 'degrees of complexity'). In that line, an Australian outback rancher said once: "my biggest risk is that my wife leaves me, not the complexity of the climate or market". The story of design and change is one of blood, sweat and tears for many good willing producers. Public, business, consumers and rural communities each have their own 'scapes' and roles to play in keeping the farming sector variable, resilient and viable enough to innovate [99]. As implied in thermodynamic theory, unlikely design by forced and unlikely goal setting is likely to need more energy (resources) than processes that 'happen' in accordance with local conditions.

Food for Thought

Transition from default to design requires choice between criteria of 'progress', between mindsets i.e., paradigms. Basically, that is a choice on 'who am I' and on 'who do I want to be'. One may even have to often stand in several conflicting paradigms simultaneously, e.g., between control or participation, between goal and process, between standards and diversity, between Cartesian and complex system thinking. Such choice/reflection on paradigm is of equal or greater importance than the choice on method and sequence of design steps. Choices on mindset are to be made and 'no gain without pain', or also, 'blood, sweat and tears' are part of the process. Reference to a long list of historical Utopias shows that no 'final solution' can be believed. 'Final' solutions even tend to have totalitarian leanings. Indeed, choice of mindset is to be accompanied by choice of 'technical criteria' and their trade-offs, e.g., on emissions, resource use, advantages of local vs. global. A look at examples in system design with successes and failures provides inspiration and food for thought.

7. Concluding Comments

This paper reviews 'modern and ancient' methodologies/paradigms for the design of sustainable (GB) systems, while stressing changes/behaviors (morphogenesis) rather than static descriptions (morphologies). By doing so, this paper distinguishes 'design' from 'default', focusing on 'design for/through renewal' by accepting 'crash' and by seeking newly emerging order (the collapse of chaos). Default is 'doing more of the same', often solving short-term problems, thus avoiding 'crash' on the short-term and accepting further 'lock-in' on the long term. Our discussion of 'modern and ancient' methodologies/paradigms implies acceptance of complexity paradigms, i.e., about work and strategies with unexpected change, unsolvable issues, dynamic/flexible definitions, and multiple perceptions/scapes. We consider the linear paradigms as useful to handle the short- rather than the long-term. Our notions of complexity imply regular non-linear changing 'rules of the game' and constant serving of several masters while knowing that clear solutions are exception rather than rule. All this also implies use of terms and concepts such as chaos, non-linearity, Complex Adaptive Systems or even Continuously Transformative 'Creative' Systems [47]. This paper also has a view of mankind as participant rather than rulers of nature. Such notions have been around for long time in many cultures, and among philosophers, as well as among common people. However, an 'avalanche' of short-term successes of more linear science, mainly based on Cartesian traditions of the past few centuries has snowed them under.

Thus, languages and methodologies of non-linear approaches may have to be rediscovered, redesigned and learned to, in fact, 'create' (=design). Work with complexity involves the coping with varying (dynamic) perceptions and scapes of reality and GB systems, whether ecological, economic, technical, and sociological and others. It is a learning process and rediscovery of older approaches that started to take-off fifty years ago in areas of mainstream science and business in Farming Systems Research [19].

This paper aimed to provide an 'artist impression' of a host of concepts, stressing the need for choice, away from objectivist notions that are associated with 'universal truths'. Complexity approaches imply choice of 'scapes' and their pertaining paradigms, together with (often unconventional) system properties (resilience vs. efficiency; global vs. local scales, fast vs. slow, commodity vs. community, 'men' as ruler or participant). Ultimately, it also reflects choice between entropic worldviews (with resources considered to be finite) and cornucopian worldviews (with resources considered to be in-finite and/or endlessly recyclable or substitutional).

Choices on paradigms, thus, imply awareness on one's own (often 'western' linear) scientific traditions, reason to devote one section to hang ups and paradigms. Furthermore, the step from linear and (rather) static and objectivist approaches can benefit from knowledge and awareness of system dynamics (change and movement in systems), away from 'how things are' (static morphologies) and towards 'how things are becoming' (dynamic morphogenesis). That was reason to include two sections on behaviors, even including notions from thermodynamics. One overall set of conclusions becomes then that trade-offs/choices are rule rather than exception, and that change is the only constant in life. The serving of many masters requires understanding of 'the nature of nature', i.e., of the notions of scapes of behaviors.

We did, to top it up, also assess some of (our) philosophical roots, including a need to look at those from other cultures and even heartscapes [18]. Cartesian roots were reassessed as underlying much mainstream western thought of the past centuries. We did leave intact the need to doubt everything 'until it is absolutely certain'. We did highlight the Cartesian focus on use of reason alone, but we stress that reason needs to be accompanied with use of empiry (and vice versa). In our opinion, however, three others Cartesian rules can even impede work with complexity. One is the notion of a linear Jigsaw piece 'nature of nature', i.e., 'building the whole by knowing the parts'. We also sidelined the usefulness to study each system in the minutest detail, especially when at the expense of understanding relations (and choice of paradigm). Finally, yet importantly, we oppose the use of sharp distinctions, such as between matter and mind, 'animals' and humans, as well as between men and women (We choose 'to stand in two paradigms at the same time': stressing similarities as well as differences (Box 3). Thus, we gave a broad and dynamic characterization of pastoral and grazing systems (to permit learning). We thus refuse lock-in on differences that blind one for 'useful' similarities). So much can be learnt from similarities between systems that energy spent on 'knowing' distinctions amounts to throwing the baby (of relations) out with the wash water.

To wrap up, we now refer to a notion from an inspiring book by [83] on economic theories. The last chapter in that book is called 'the end of economics', a phrase that we here change into 'the end of pastoral science'. Heilbroner's first point here is that much is done and said already on the science of economics. That could be reason to end further work, in our case on the science of pastoral (or and GB systems). Such further work could even become counterproductive by studying things in 'the minutest detail possible' at the expense of overview. Holistic approaches need to complement focus on details (too much is not good nor too little). Indeed, both of us (JBS and PG) know research topics that are 'out'-researched. Heilbroner second point is, however, that 'the end' can also refer to 'the goal' of a science. In his case that refers to economics and in our case to (GB) livestock production systems. We state that, if our work is towards the design of a vibrant, and resilient/adaptable and creative pastoral sector, it then is to be accompanied by attention to values rather than things. Values are not only monetary, but also societal values, nature values and so on, all pooled as environmental values. Moreover, such work is to be accompanied by flexible process management and orientations rather than by rigid control goals. This implies work in a multi-scape dimension, other than only and narrowly on 'food and fiber' production, on N or ME contents of herbage, or only calculating short-term and narrowly defined monetary profits.

Asking ourselves about the 'end' (i.e., goal/direction) in the design of sustainable and ethical GB systems, we conclude that:

- Much is known on details and pending 'crash' of 'wholes' (at many fractals system levels) continues to challenge the 'beauty of the emperor's clothes'. Reconsidering hang-ups is crucial and knowledge of behaviors is becoming mature.
- Boltzmann's probability approach can be a powerful tool to make educated guesses on sustainability criteria such as resource use and associated waste emissions, based on "the more unlikely, the more resources are needed (the more gain the more pain)"
- Choice of (mixes of) paradigms/scapes for design vs. default is necessary, reflecting on ruling paradigms. Such shift in use of paradigms is required to handle 'chaotic periods, i.e., when changing from one existing (and 'crashing') stable state into (a combination of) newly emerging stable states when chaos collapses (i.e., where new forms become discernable).
- Broad and dynamic 'definitions' of GB systems can cause confusion, but the positive trade-off is that it permits learning from other systems, other scapes and other (fractal) levels of the system hierarchy, in terms of method, as well as practical challenges.
- System dynamics are due to a combination of external and internal factors, including the interaction between 'parts' within systems. That is illustrated in behaviors such as predator–prey, adaptive cycles, the fan, and tendency to greater disorder (entropy).

- Design rules emerge from better understanding these behaviors and general laws, e.g., on the dynamic nature of carrying capacity, multiple contexts, and strategies at different stages of development, and on the tension between mainstream economics with laws of nature.

Throughout this paper, we aimed to present concepts and methodologies without shunning use of dense information, associative thought, and confusion (learning implies crash of existing order). We aimed, however, for an artist impression and not for being comprehensive 'to the minutest' detail, even avoiding the excessive use of references. Regarding design of GB systems, we stressed and did not shun issues of personal/subjective/systemic choice, even on mind aspects of paradigms and worldviews (thoughtscapes). We think that they should be part of a holistic approach and we illustrated some such choices for design (evolution) with practical examples of (perpetual) change in GB systems.

Concluding, we use five quotes on choices for design. Each of these aims to invite 'crash' on one's paradigms. First is the one by Descartes on need to doubt until it is certain (i.e., to be critical even on 'the default of emperor's clothes'). Second is a quote from Mandela: "I exist because we exist". That quote reflects a holistic thought (ubuntu), known from Southern Africa and other places in the world. It relates our own wellbeing and 'heartscapes' with that of our grasslands and rangelands, with their grazing systems and with that of the physical- and thoughtscapes in general. Aldo Leopold [100] here used the term 'land ethic' and Maori say: "Ko au the Whenua, Ko the whenua ko au (I am the land, the land is me)". Hawaiians talk about Aina. And South American indigenous people think of the 'pachamama'. The third quote is the one from West Churchman, on the holistic need to recognize and live in more than one scape at the same time: "Maturity is the capacity to stand in two paradigms at the same time, preferably conflicting" (quoted by Richard Bawden). The fourth quote reflects choice on values from Boulding, paraphrased by Rapoport [101] and here further by us. The gist of that quote is, in our view, that one can distinguish (as choice for values) three modes of social control: exploitation, trade and love. In sexual terms, the analogy of exploitation is rape (if I do not take it someone else takes it), the analogy for trade is prostitution (you give, and I pay) and the analogy for love is genuine care (for land- and resource-scapes). We take care of our children, our land, etc., because they are our ('Our' in this case is meant as an 'adjective' and NOT meant to be used as 'possessive pronoun') children, not because they threaten us. That is legacy from many other great people such as Chief Seattle and Mahatma Ghandi, from the wisdom of common men, philosophers and holy books. Thus, fifth and last a challenge posed in the book of Genesis: "Cain, where is your brother?" Such choices and challenges are in our view the basis for design of dynamic, ethical and sustainable GB farming systems for the future of the ones to come.

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