Towards a model of long-run capital substitution: a conceptual contribution and proof of concept analysis with future scenarios through to 2050

Andrés Bucio

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University of East Anglia, School of Environmental Sciences
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Abstract

The idea of "overcoming" natural resource scarcity by substituting man-made capital for natural capital separates classical from modern economic thought. Today, "valuing nature" is deemed essential to warrant capital "trade offs" that are consistent with sustainability (defined as constant capital over time). While the *explicit* valuation of nature via non-market techniques is difficult and often controversial, its *implicit* — often zero— valuation puts us into an uncertain path whereby discussing substitution as a legitimate means to attain sustainability can be futile. This suggests supplementary ways to understand long-run capital substitutability are now in demand. The exploratory notion of "runaway capital" is thus introduced into a hypothetical "sustainable society" model. Runaway capital accounts for "capital" which, far from yielding services people prefer, yields services that "escape" those institutional arrangements that a society on its way to sustainability would demand, hence inducing a sort of "production failure" into the economy. The result is an "appreciative" heuristic model of long-run substitutability that is tested against four "empirical" scenarios to the year 2050 featuring cars, food and green homes as topical entry points. Scenario storylines are assembled to exhibit contrasting degrees of policy implementation of the Hartwick-Solow rule of investment as relevant to a low-energy-density carrier transition. A preliminary proof of concept analysis shows four scenario patterns of substitutability. These are interpreted and followed by model refinements and discussion. Overall, the study stresses the need to grasp long-run substitutability alongside the social legitimation and governance of capital inputs. This may in turn improve the quality of expectations about the internalisation of externalities agenda.

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It is more difficult for he who does not know where he is going to get lost

1 – Introduction

1.1 The topic of analysis

This thesis is about understanding the practical meaning of trying to overcome natural resource scarcity by substituting man-made capital for natural capital (Barnett and Morse, 1963), while in passing perhaps achieve sustainability[1] (Pearce and Atkinson, 1993). It is also about employing hypothetical future scenarios (Foresight, 2002; Ogilvie, 2002) to "test", or at least gain some form of "empirical" understanding about how society's relative valuation of its various capital assets would impact long-run substitution possibilities (Pearce, Markandya and Barbier, 1989). One motivation for putting theory to the test of "empirical content" —insofar as future scenarios can be assumed to provide something like such a content— is inspired by Robert Solow's (1997) observation that good policy requires the advice of theorists as well as "practical people". That is to say, economic theory by itself is always at risk of leading society astray from achieving its goals, including sustainable development.

> "In a simplified, make-believe economy the range of policies one can talk about is pretty simple too, describable only in fairly general abstract terms. You would never leave the making of economic policy to theorists because good policy has to accommodate the particularities and inhabitants of the real world. But I believe it is also a mistake to make and carry out policy for economic growth and for other goals without consulting the theorists. Why? because practical people often pay inadequate attention to fundamental interconnections" (Solow, 1997, p.70-71)

In this study we are interested in finding out both, the "particularities of the real world" that practical people understand, as well as the "fundamental interconnections" that theorists see but practical people do not. We want nevertheless

[1] For practical reasons, throughout this study the distinction between "sustainability" and "sustainable development" (e.g. Pearce et al. 1995) is considered immaterial. **NOTE**: long internet addresses in this document are abbreviated in this way: [383poqd]. To access them add prefix, e.g. [www.tinyurl.com/383poqd].

to "double-check" just how good theorists are at spotting the "fundamental interconnections" that matter to the analysis of future substitution possibilities. Trying to understand the practical meaning of substituting man-made and natural capital in a transition to sustainability is not too far from enquiring about the extent to which sustainable development qualifies as an economic problem (Common, 1995; Norgaard 1984; Cleveland, 1992). After all, the study of "fungible" things is what modern economics is all about (Hargreaves-Heap et al. 1992). The formal approach to sustainable economic growth employed by neoclassical theorists typically assumes smooth substitutability and sustainable development as feasible so that investigating institutional arrangements is easier (Solow, 1974, Stiglitz; 1974; Stern D. 2004 see Appendix for a technical account). Natural scientists, ecological economists and presumably a lot of "practical people" would approach these issues differently. They would question growth, substitutability as well as sustainable development as conceived by growth theorists (Costanza, 1992, Daly, 1971).

To comprehensively understand capital substitution one needs to go back to the neoclassical economic model of resource scarcity compounded principally by Hotelling's (1931) postulate of optimal resource depletion alongside Barnett and Morse's (1963) empirical analysis of resource scarcity. According to the neoclassical approach, the means to escape from the Malthusian and Ricardian scarcity lie principally in the resource-augmenting mechanisms of the market where capital substitution, technical change, and returns to scale (Stiglitz, 1974) play the central role in effectively "putting back the day of judgment", as Redclift observes (1992, p.401). In this study, nonetheless, substitution is seen in the more particular and exploratory context of the Hartwick-Solow rule (Hartwick 1977; Solow 1986), which is economic theory's first and most basic answer to the problem of sustainability in a world with finite resources.

A non-academic account of the rule would run much as follows. It is OK for a society to deplete its natural resource base so long as it reinvests the rents in productive capacity rather

than "waste" those rents in ephemeral consumption. It matters little, according to the rule, whether future generations inherit any specific resource, be it natural or man made; what matters is that they inherit the overall *productive capacity* or potential to generate wellbeing for themselves. The Hartwick-Solow rule makes sense provided we understand its place within the economic framework. For non-economists this is sometimes a matter of luck, as explicit accounts in the literature are rare.

> "The "constant wealth" argument does not *advocate* the destruction of natural wealth. It simply says that one should substitute for the other according to society's relative *valuations* of the two. Hence, once again, the importance of giving natural assets a "proper" valuation. Since many of them have no market price, allowing unfettered market forces to dictate the substitution is necessarily incompatible with sustainable development." (Pearce, Markandya and Barbier, 1989, p.50)
>
> "For neoclassical economists what matters is the value of the total stock of capital, which is taken to reflect the value of the total amount of satisfaction of human needs and desires that is taking place. How that total is split between human-made and natural capital does not matter, *so long as it is assumed that market failures due to externalities have been corrected.* If this were not so, then it would be impossible to claim that the prices used to measure human-made and natural capital stocks properly reflected peoples' preferences. If market failures are not corrected when measuring the sizes of the capital stocks, having the total size increase does not necessarily mean that more satisfaction of needs and desires is being delivered." (Common and Stagl, 2005, p.376. Emphasis in the original)

The assumption underlying the Hartwick-Solow rule that "productive investment" is always clearly distinguishable from "ephemeral consumption" is rarely commented upon. But the assumption that substituting man-made for natural capital should be consistent with sustainability has led to ardent debate indeed (e.g. Daly 1997; Solow 1997; Stiglitz, 1997; Perrings 1997). Natural scientists do not like this assumption. They do not like a vision of the future where prosperity is envisioned irrespective of how or whether or not, the natural world exists. This seems understandable enough. Economic growth sceptics do not like it either (Daly, 1992; Jackson, 2009). The interesting question is, why do economists like it so much?

Mainstream economists would probably answer that "fungibility" is at the heart of modern economics; as such, it is more of an *axiom* than a debatable item. Others would playfully remind us perhaps that "an economist is someone who knows the price of everything and the value of nothing" (Bateman, Lovett and Brainard, 2003, p.1). Either by inclusion or by omission, most sustainability debates in economics are, in a certain sense, an outgrowth of the Hartwick-Solow rule.

Its current place in the literature in relation to substitution possibilities is propounded by Turner's (1993, p.9-15) four category classification ranging from *very weak sustainability* — i.e. Hartwick-Solow sustainability, where substitution possibilities between man-made and natural capital are "perfect", (see Appendix); *weak sustainability,* where the sustainability constraint on natural capital is "weak", thus allowing for significant possibilities of substitution*; strong sustainability,* where well defined limits to substitution are assumed in terms of critical natural capital (the ecological economics stance); and *very strong sustainability,* where thermodynamic limits in a zero growth economy make substitution possibilities impracticable or irrelevant[2].

Its serves the exploratory purposes of this study to look at the Hartwick-Solow rule because it captures the flavour and mindset that characterise the standard economic approach to sustainable development. That is to say, the Hartwick-Solow rule takes us to a period of time, where growth theorists began to make the sort of assumptions about sustainability *and* substitution which, originated vast expectation but also miscommunication with natural scientists, engineers, politicians, managers and other people outside the economic profession.

> "Economic analyses of sustainability generally start from a premise that natural and other forms of capital are adequately substitutable for each other to make nondecreasing wellbeing over time achievable. In other words, broadly speaking, sustainability is held to be feasible, though it is by no means guaranteed by the operation of unfettered markets." (Pezzey and Toman, 2005, p.130)

[2] Hence the label *absurdly strong sustainability* position (Pezzey and Toman, 2005)

When not communicated properly these are the type of assumptions that have failed in the past to produce clear interpretative reactions from other sciences (Wilson, 1998)[3] Most natural scientists, for instance, find it very disconcerting, even demoralising, that long run resource scarcity impinging on economic growth is perceived by mainstream economists almost as an impossibility because "rising scarcity is assumed to automatically sow the very seeds for its amelioration" (Cleveland, 1992, p.292; Barnett and Morse, 1963). Notwithstanding these sort of controversies, there is a realistic side to substitution possibilities beyond those in the abstract world of economic theory.

Almost defining human history, many forms of "substitution" have occurred for hundreds of years: the loss of forest cover on the planet almost exactly equals the gain in cropland and pasture, for example (Pearce 1994). We can see the indirect effects of substitution in the erection of cities, in the size of our brains or in the way we earn a living. Interestingly, it is hard to tell where substitution will take us in the coming decades, where nearly "miraculous" technology and rapidly changing social norms and individual values suggest a very different set of issues and challenges ahead.

Of interest is to note that the idea of substitution potentially challenges the notions of coexistence and harmony underpinning the spirit of the sustainable development agenda (O'Riordan 1998). Clearly machines are "artificial" while biodiversity is "natural". However, many new technological innovations combining artificial and natural elements (Rose 2007) alongside the possibility of owning "intellectual property" over the outcome (Boldrin and Levin 2008), are making it hard for analysts to understand whether long-run *substitutability* prospecting is a technical or an economic possibility (Ayres 1998; O'Neill 2009); a positive or a normative duty (Stern 1995); an inter-temporal or an inter-geographical requirement (Cleveland and Ruth 1997); a moral or an immoral discussion (Sachs, 1998; Daly, 1997); or indeed everything at

[3] Wilson calls this the requirement of *consilience*. The methods and assumptions of any field of study are robust to the extent that they are consistent with the known and accepted facts in other disciplines (Wilson, 1998)

once. In the long run, substitution possibilities are largely dependent on future economic growth prospects, which in turn are dependent on energy sources (Ayres and Warr 2009, Stern D. 2011). Closer to people, substitutability in the long run will also be dependent on small scale technology and consumer preferences which are unknown to us today (Costanza 2000); how "food miles" or genetic modification will be seen in the future is moot.

> "Whether man-made capital can be relied upon to substitute for natural resources is, at base, an empirical issue. But, it is an empirical issue that can be settled only with information forthcoming in the always receding future. Predictions about this future relationship are clouded by uncertainty, human ingenuity and existing resource availability" (Castle, 1997 p. 305)

As suggested at the beginning of this introduction, one methodological implication coming out of these observations is that future substitution possibilities may need to be appraised *contextually* and *empirically* (Gowdy, 2004, Castle, 1997, O'Neill, 2009; Neumayer, 2010; Pearce, 1997; Barnett and Morse, 1963).

> "Consider the ozone layer. As far its functions of protecting human beings against excessive UV radiation are concerned, substitution might consist of hats, sunglasses and suitable clothing. But it is far from clear what [man made capital] substitutes exist to prevent the damaging effects on other living creatures, biomass in general or ecosystem functioning." (Pearce 1997, p.296)

Still, because empirical analysis about the future is impossible in theory and in practice, an exploratory approach to modelling and theorising substitution has a very special appeal.

An appreciative and contextual approach to modelling

Given the foregoing issues and anticipating what is explained further in **Chapter 2**, our topic of analysis demanded both, an *appreciative* approach to modelling (Nelson and Winter 1982), see **Box 1.1**; and the development of (four) future scenario tools (Foresight, 2002; Ogilvie, 2002), providing some real-life "empirical" material from which to contextualise and appraise capital substitution possibilities through to the year 2050.

Box 1.1 — The notion and role of "appreciative theorising" in economic modelling

"When economists are doing or teaching theory *per se,* or reporting the results of empirical work designed to test a particular aspect of theory, the theoretical style is stark, logical, formalised. In contrast, when economists are undertaking applied work that is of interest for policy reasons, or are explaining to an audience interested in that question *per se*, why certain economic events happened, theoretical ideas tend to be used less formally and more as a means of organising analysis. These two different styles of theorising we shall call *formal* and *appreciative*. Although they are quite different, both kinds of theorising are necessary for economic understanding to progress satisfactorily, and there are strong if subtle connections between them. The adherents of a broad theoretical structure share a way of looking at phenomena, a framework of appreciation. A theory defines the economic variables and the relationships that are important to understand, gives a language for discussing these, and provides a mode of acceptable explanation. Implicitly, therefore, a theory classifies some phenomena as peripheral, unimportant, and theoretically uninteresting; also it implicitly characterises certain ways of talking about economic phenomena and certain kinds of explanations as ill-informed and unsophisticated. In its role of providing a framework of appreciation, a theory is a tool of inquiry, and in skilful applied research, that tool is used flexibly, bent to fit the problem, and complemented by any other tools that happen to be available and that appear to be useful."

Source: *An evolutionary theory of economic change*.
(Nelson and Winter, 1982, p.46)

Notwithstanding the impossibility of empirically assessing future substitution without a time machine, it is still possible to use future scenarios as a way of "working with a range of answers"[4] (Norgaard, 1989), in order to appraise what the context of those possibilities might be, using existing

[4] In opposition to the "long-standing belief in a right way of knowing and precise prediction". (Norgaard, 1989, p. 38)

information and knowledge with regards to trends (e.g. social, technological). In our particular case, the most important advantage of an appreciative approach to modelling is that it allows us to capture some of the practical implications —in terms of substitution— of implementing the Hartwick-Solow rule. It also offers the possibility to "empirically" *contextualise* the principal dimensions of substitution that appear in the literature (and that are schematised for later discussion in **Figure 1.1**)

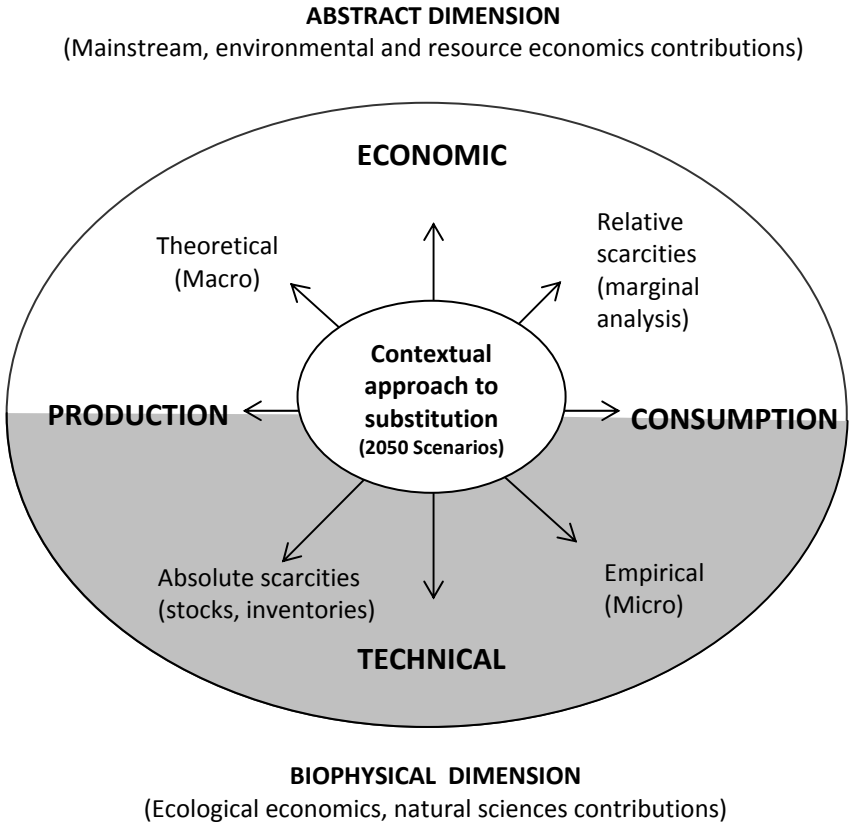

Figure 1.1 - A "contextual" approach to modelling long-run substitutability whereby scenarios to 2050 are used as "case studies" to contextualise the various dimensions of substitutability in the literature

The "contextual" and "appreciative" approach to modelling we have briefly outlined, allows us to address such things as the difference between "wasteful" consumption and "productive" investment, which is often treated as self-evident in formal economic modelling (e.g. Hamilton et al. 2006; Nordhaus 1999;

Stern 2006). When economists talk about the Hartwick-Solow rule they tend to refer to productive capacity in terms of twentieth-century infrastructure, equipment and technological knowledge (Solow 1993); but since "renewability" does mean that resources would renew themselves (Pearce, 1993, p.73) can "productive capacity" not also be bequeathed in such things as twenty-first-century organic productive capacity such natural soil fertility (Wrigley 2006); or in the form of carbon sequestration sinks; or in countless environmental services which have been partially lost and appear to be only retrievable through large capital investments?

In a second example, it has been suggested that many types of knowledge do not lead to benign environmental outcomes (Costanza 2000; Murdoch and Clark 1997; Ehrlich et al. 1999; Coombs et al. 1999). Assuming this as true, is education always an investment as the World Bank suggests (World Bank, 2006)? Should certain forms of education not be regarded as "wasteful" commodity consumption as has been suggested in the past? (Rosenzweig, 1996; Jacob, 2003). Improving basic living conditions is the best "contraceptive" in poor regions (UNCED, 1992). Should that be seen as ephemeral consumption or as productive investment in the context of the Hartwick-Solow rule? In posing these sorts of questions —not yet our research questions— our purpose is to exemplify the type of issues that are not yet captured though formal economic modelling, amongst other reasons because of

> "arithmomorphism (an over-reliance on numbers) in economics (and the sciences) has gone too far. A much better balance needs to be achieved between these and dialectic concepts (which emphasise form and quality)." (Peet, 1997, p.294)

Thus, to address issues such as the above we need an approach to modelling that is "appreciative" rather than formal and that allows us to contextualise the future "empirically" even if we do not have a time machine. This could be done by employing future scenarios, and there are at least three reasons why.

The **first** reason**,** mentioned at the start of this introduction, is that future scenarios can provide a real-life "empirical" context from which to "test" —with a view to improvements— the extent to which formal models and assumptions can be used to talk about long-run substitutability. This seems a particularly good reason given the untold level of confusion that the "perfect substitutability" assumption made by weak sustainability proponents (Pearce and Atkinson, 1993) has caused in many professional circles outside economics —including perhaps parts of government— not to mention natural scientists and ecological economists (Pearce 2006; Stern D. 2004). We come back to this point several times throughout the thesis. A **second** reason —emanating from the first— concerns relative "sustainability prices" or "sustainability relevant value" (Stern D. 1995, p.13; Pezzey and Toman; 2005, p.132). The idea, in a nutshell, is that economic assessments about future substitution possibilities cannot be conducted reliably with prices defined on markets. Particularly world markets. Consider the market price of goods and services cheaply produced and cheaply made accessible to consumers in an economy running on cheap fossil fuels (Smil 2006). Price forecasts —of say, agricultural products relative to home appliances— outside the complex array of interdependencies that results from running a market economy on cheap hydrocarbons, is not something that can be done with existing market data. Hence the market price of a beehive relative to a pair of contact lenses in the year 2050 is beyond econometrics or good market statistics[5]. Consequently, substitution possibilities are exceptionally difficult to approach formally. A growing literature suggests the challenges that relative sustainability prices pose to the formal analysis of long-run substitution possibilities are deeper and more expansive than they appear on the surface (Pezzey and Toman, 2005; Mäler 2007; Sterner and Persson, 2008; Stern N. 2009; Stern D. 2011). Consider the implications of the following piece of analysis:

[5] Apparently, there is no way of knowing whether these goods will only, or will still, be traded in conventional markets via conventional currencies.

> "One limitation on the use of market prices is that they may suggest that any one nation can largely deplete its natural resources now, become a "knowledge nation" reliant on human capital, import most of its resources in the far future, and perhaps remain sustainable. However, this is not an option for the global economy, since not every nation can be a resource importer, and if they all tried to be, resource prices would rise dramatically." (Pezzey and Toman, 2005, p.132).

There is no formal, analytically easy, way out of the question of "relative-price-dependent" substitution possibilities. The place of money itself as the dominating means of debt and exchange is not inevitably permanent (Fergusson, 2008). Furthermore, though there is no way of knowing how far they can get, there is some evidence that alternative currencies such as time banks and local exchange trading systems (LETS) are gaining popularity (Seyfang, 2008). We think once again, that scenarios offer an opportunity —particularly if we use several— to sketch the likely or desired conditions under which society's relative valuation of different forms of capital will take place. A **third** and final reason for experimenting with a scenario-based approach to capital substitution is connected to the argument that —technical difficulties aside— the economic valuation of natural capital neither addresses the empirical uncertainties, nor provides the quality and quantity of information that is required to inform policy choices. Toman (1998) sums up various critiques in the literature, connecting them in passing, with the problem of relative prices:

> "Cost–benefit analysis and economic valuation [of ecosystem services] are not informationally rich enough to determine policy choices. Critics assert that there are simply too many empirical uncertainties about these values, even if one does not accept more philosophical objections to the concept of economic valuation. These uncertainties reflect our limited understanding of the physical world (we do not know all the ways that ecosystems provide services, and how they are changing), and economic uncertainties (the difficulties in reliably ascertaining people's own perceived priorities between current economic benefits and investment in ecosystem protection or damage amelioration, and how those priorities might change with changes in information or social context). In addition, since ecosystem changes and policies to alter these patterns of

> changes can have important distributional consequences over space and time, and since there is no social consensus on how these changes should be evaluated, it is impossible to produce a complete evaluation only through a calculation of monetized net benefits." (Toman, 1998, p.59)

Of interest in this study therefore is examining the extent to which a stylised, heuristic[6], scenario-based investigation of people's relative non-monetised valuation of assets can assist the task of "valuing nature" (i) more meaningfully (Toman, 1998), (ii) more "explicitly" than "implicitly" (Pearce et al. 1991, p.2), and (iii) in a way that is relevant to the goal of knowing "whether the overall stock of capital is constant and therefore whether society is or not, on a sustainable development path" (Pearce et al., 1991, p.2). Valuing natural capital is crucial to deter "unfettered market forces" from "dictating" unsustainable forms of substitution (Pearce, Markandya and Barbier, 1989, p.50). However, if valuing nature turns out to be more arduous (Fisher et al. 2008), less encouraging (Pearce, 2007), more controversial (Costanza et al. 1998; Norgaard et al. 1997) or perhaps less explicit (Pearce et al. 1991, p.2) than we would like such a valuation to be, then there might be good reasons to assess capital substitution by supplementary non-monetised means which, paraphrasing Costanza and colleagues, "do not preclude or supersede other ways of approaching the problem" (Costanza et al. 1998, p.69), including the conventional one.

The academic dimensions of substitutability

The previous methodological considerations become all the more important when we consider the academic dimension of the problem. To understand "substitutability" as a topic, the first problem faced by non-economists —and not few economists themselves, one can imagine— is the way in which the topic is laid down and unfolds throughout the literature. While botany is the study of plants and crystallography is the study of crystals, the study of economic problems often has to

[6] **Heuristic**. Adjective, **1** enabling a person to discover or learn something for themselves. (Concise Oxford English dictionary, eleventh edition)

start with the study of economists themselves, of their way of thinking and communicating. Part of the environmental economics literature "is not easy reading" and this is explicitly and constantly recognised by economists themselves (Pearce, Markandya, Barbier 1989, p.49; Norgaard, 1990; Stern D. 2004; Pezzey and Toman, 2005). Moreover, the number of economists who are kind enough to specify the workings of economic models where substitution is assumed, is very limited (i.e. Stern D. 1997; 2004), so limited that sometimes personally contacting the author is the only way to get a sense of reality and reliability about their arguments. It is not an accident that "substitution" has been isolated as a topic and taken outside the economics framework causing much methodological misinterpretation and debate with people outside the economics profession (Pearce 1994; Stern D. 2004; Cleveland, 1992). To understand how such a state of affairs was reached in the literature, what its significance for the academic debate is, and what the consequences for our particular approach to the subject are, our first task is to review the meaning of the concept in its original state and before it became used in debates about the environment. This will allow for more conceptual clarity when we introduce our model of capital substitution in **Chapter 2.**

The meaning of "substitution" in standard economics

Some authors at particular moments in history, tend to capture more of the "spirit" of a concept than others. As for the *spirit* of substitution in standard economics, Barnett and Morse (1963), in *Scarcity and growth* told the famous story that long run natural resource scarcity could be best assessed through relative scarcity indicators and that the relationship between natural resources and growth was not dictated by the "iron law" of diminishing returns as classical economic thinkers such as Malthus and Ricardo had thought. Instead, self-generating socio-technical change and substitution possibilities would enable humanity to escape scarcity.

> "A limit may exist, but it can be neither defined nor specified in economic terms. Flexibility, nor rigidity, characterises the relationship of modern man to the physical universe in which he lives. Nature imposes particular scarcities, not an inescapable general scarcity. Man is therefore able, and free, to choose among an indefinitely large number of alternatives." (Barnett and Morse, 1963, p.11) […] "Things that are not alike in a physical sense may be economic substitutes. For example, broadcasting may be substituted for newsprint; sedentary vacations for peripatetic ones; public transportation for operation of private cars; wintering in Florida, or emigration to southern California, for fuel. And food is a significant example. An average caloric in-take of, say, 3,000 calories per day has variable acreage implications, depending upon the type of food consumed. Animal proteins and dairy products require several times as much acreage per calorie as root foods and cereals. The scarcity effect on food prices would, if substantial, set in motion a major adjustment in the composition of diets." (op cit., p.131)

Most of the time however, the concept of substitution occupies a less melodramatic place in microeconomics. The term substitution conventionally refers to rational economic individuals having substitutable preferences with regards to either capital goods (production theory), or with consumption goods (consumer theory). In most microeconomics textbooks a good is said to be a *substitute* for another good if replacing one for the other does not change the overall level of welfare or utility[7] (e.g. happiness, pleasure, satisfaction, joy) of the person making choices (Hargreaves-Heap et al. 1992). Similarly, consumer theory refers to the "marginal rate of substitution" as the rate at which a consumer is ready to give up one good in exchange for another good while keeping the same level of welfare (Walsh, 1970). It is in this same context too that economists make reference to "indifference curves" (Hicks 1971) and substitution elasticities (see **Appendix**) Underlying these technical concepts is the principle that rational individuals have preferences about things which are always substitutable for one another within particular "consumption bundles". That is to say, no choice is absolutely essential, there

[7] Although, technically speaking, *welfare* is an aggregate over time of the instantaneous *wellbeing* or *utility* that people get from consumption (Pezzey and Toman, 2005)

is always a substitute option and individuals always seek to maximise their satisfaction. These axioms have in turn implications for the study of welfare, which rests on the principle that general market equilibrium exists (i.e. Pareto optimum), and that there is efficiency in production, distribution and allocation of resources in line with consumer preferences (Hausman 2008). The axiom of *substitutability* is seen as a basic component of a preference-satisfaction theory of wellbeing (Hargreaves-Heap et al. 1992). Finally the study of wellbeing is key to understand the standard economics approach to sustainability (Bateman et al. 2010).

> "In its modern version the [neoclassical standard] model has economic person holding the preference structure of indifference and operating on the basis of constrained satisfaction (utility) maximisation. The economic (instrumental) value of marketable commodities, unpriced environmental goods and services, or the sympathy for future generations, is determined according to the amount of personal utility yielded. Economic person makes trade-offs at the margin to identify positions of equal personal satisfaction. The preferences of individuals are revealed by the choices they make, and efficiency and consistency of choice reflect rational behaviour" (Pearce and Turner, 1990, p.10).

For the criterion of social desirability and wellbeing to be expressed in terms of market equilibrium (Pareto optimum) some standard assumptions need to hold true as well **(Box 1.2.)**

Box 1.2 Standard environmental economics assumptions (drawn from neoclassical economic axioms)

1. "Economic agents exist.
2. They have invariant, complete preferences over outcomes;
3. They optimise independently of one another in relation to constraints such as the availability of production factors, technological possibilities and disposable income
4. They have full, relevant knowledge of their decision problems
5. Their choices are made in fully integrated markets
6. Observable outcomes are fully co-ordinated and must therefore be discussed with respect to a general equilibrium"

Source: Weintraub, 1985 (cited by Neumayer and Dietz, 2009, p.272).

Through the valuation of ecosystem services (Turner, Georgiou and Fisher, 2008), environmental economics aims to make a contribution to assumption *five* (i.e. choices are made in fully integrated markets). Standard economics has been criticised for having to rely on assumptions such as those in **Box 1.2**, but as Herfindahl and Kneese persuasively state,

> "One can take specific account of factor after factor from which abstraction has been made —e.g., knowledge is not perfect, the same production function (defined shortly) is not known by all producers, prices are not uniform all over the country (allowing for locational differences), some goods cannot effectively enter into private exchange, and so on. But if one refuses ever to contemplate a system that is not complicated by these factors, he may miss understanding clearly that the real world —in market-type systems, at least— presents a set of economic phenomena which have the kind of coherence in their patterns over time which can be fruitfully characterized as constituting an economic system." (Herfindahl and Kneese, 1974, p.10).

A crucial feature of the standard economics model is that it foresees the need to justify institutional intervention to improve preference-related conditions:

> "The "basic theorem of welfare economics" seeks to legitimise rational behaviour as being socially desirable and also to justify some government intervention to improve the conditions under which individuals make choices. Intervention would be especially justified whenever so-called *market failure* exist, i.e. when it is clear that markets are not maximising collective welfare." (Pearce and Turner, 1990. p.11)

Few concepts perhaps seem to capture the claimed status of economics as an "expansive imperialist discipline" (Hirschleifer 1985, p.53)[8] as the concept of substitution; not so much because of a common understanding of it amongst various disciplines, but apparently because of a shared state of unawareness and ignorance about what economists really mean when they talk about substitution in conventional economic analysis away from environmental issues. Because substitution has been a key concept in the historical development of standard economic

[8] Cited in reference to Radnitzky and Bernholtz, (1987)

thought, it is hardly a surprise that it is now at the centre of sustainability analysis, inside and outside mainstream economics. Sustainability analysis in economics started with neoclassical growth models of economic growth with natural resources, particularly non-renewables. Seminal works such as Solow (1974) aimed to understand the rules and conditions for sustainability by assuming amongst other things perfect substitutability (Stern D. 2004; Pezzey and Toman, 2005)[9]. However, later developments to measure sustainability using the standard economics toolkit such as Pearce and Atkinson (1993) and Hamilton et al. (2007) did require an empirical appraisal of what true substitution possibilities are[10]. This topic is now considered further.

The meaning of "substitution" in sustainability analysis

Understanding the place of substitution in standard economics makes it much easier for us to follow its uses and meanings in sustainability assessment. The environmental and ecological economics literature has long been debating the extent to which man-made and natural capital can be substitutes in a sustainable economic scenario (Victor 1991). This is often associated with discussions about "weak" and "strong" sustainability (see Neumayer 2010 for a comprehensive overview). Out of these debates, it has been recognised that "true" sustainability conditions and indicators can only be derived from a model that adequately characterises the limits to long-run substitutability between man-made and natural capital." (Turner et al. 1996, p.8). The most frequent interpretation in the literature about this problem is that substitution possibilities straddle the abstract axiomatic world

[9] It is important to distinguish between unlimited und perfect: "Despite popular confusion, "unlimited" and "perfect" substitutability are not the same. If production is the multiple of powers of the stock of (human-made) capital and the flow of resource depletion, then capital is an unlimited substitute for resource flow: however small (but still positive) the latter, combining it with a large enough capital stock will produce a given output. But if production is a linear combination of capital and resources, then production can be sustained even with zero resources, so capital is then a perfect substitute for resources" (Pezzey and Toman, 2005, p.17)

[10] David I. Stern, 2011, Personal Communication August 2011

of economics and the material world of the natural sciences and engineering (Neumayer 2010; Ayres 2007). Historically speaking, modern economics was developed as a discipline to understand *choice,* as choices dramatically increased with fossil fuel dependence during the high industrialisation period (Wrigley 2010; Hicks, 1971, Pearce, 1993)[11]. No choice means no possibility —and no need, to make economic decisions, by definition.

> "Economics is the science which studies human behaviour as a relationship between ends and scarce means which have alternative uses" (Robbins, 1932. p.16)

Insofar as there is choice, there is also axiomatic *substitutability*; that is, the possibility, in principle, to substitute one scarce good or service for another. *Scarce* in this context does not mean absolutely scarce but *relatively scarce,* that is, carrying opportunity costs (Debreu 1959; Robbins, 1932). Things which are not relatively scarce are not economic problems in a modern economic sense. The absolute scarcity that worried classical economists in the eighteenth century (e.g. Malthus, Ricardo) and worries natural scientists today (Ehrlich 1998), is not very well captured in the language and concepts of modern economics (Norgaard, 1990; Cleveland, 1992; Baumgärtner et al. 2006). Economists such as Barnet and Morse (1963), Solow (1986), Dasgupta and Heal (1974), Stiglitz, 1974) tend to look at capital substitution as it is relevant to the study of *relative scarcities* which must be abstracted from the material world of *absolute scarcities* studied by natural scientists (e.g. Vitousek et al., 1986; Ehrlich, 1989, 1999) and ecological economists (Daly 1972; Costanza 1992; Cleveland 1992). Very importantly, such a divergence between relative and absolute scarcities is also very clear in discrepancies about the legitimate way to "value nature". While analysts such as Pearce et al. (2001) and Ayres

[11] Interestingly, this picture can be presented upside down too exposing a different angle: "if the Earth's resources were available in infinite quantities, and if they could be deployed at zero cost, the re would be not economic problem. Everyone could have everything they wanted without compromising each other's or later generations" wants and needs. It would not be necessary to choose. Choice becomes a necessity once it is recognised that resources are finite in terms of the absolute quantity, or in terms of the costs of extracting of using those resources". (Pearce, 1993, p.1)

(1997) favour marginal willingness to pay (WTP), others seem more inclined toward absolute WTP valuations (Costanza et al. 1997). As a result, the former group of authors is persuaded, for instance, that the WTP value of the world's ecosystems cannot exceed global GNP. The latter group's answer to this is that

> "This is not correct. GNP picks up only marketed goods and services. We argue clearly that ecosystems provide REAL income contributions to human welfare"(Costanza et al. 1998, p.69)

Disagreements such as the above have a place at the top of **Figure 1.2**, which presents a simplified picture of our topic of analysis. It provides a way to follow the substitution concept throughout some of its implied meanings in the sustainability analysis literature. At its core the figure highlights the two central interpretations of standard and ecological economics (explained in the following sections) and our appreciative approach to modelling under standard economics parameters. The conceptual gap between the material and abstract worlds manifested in conflicting types of scarcity is also associated with the absence of an *existence theorem* **(Figure 1.2b)** capable of articulating economic with ecological system equilibriums (Pearce and Turner 1990).

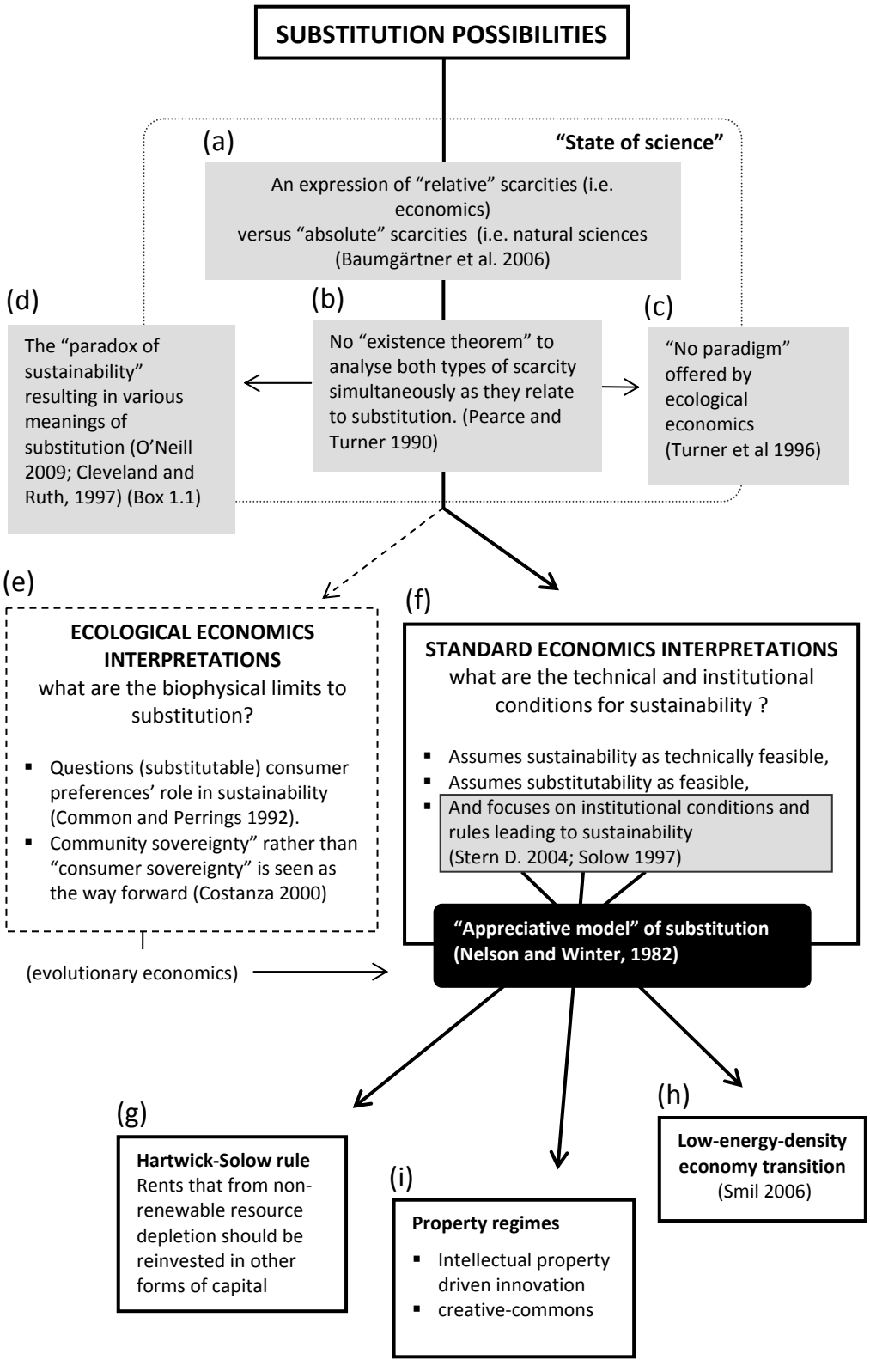

Figure 1.2 The topic of analysis: a standard economics approach to substitution complemented with an "appreciative" approach to modelling (Nelson and Winter 1982)

The need to find a suitable existence theorem from within standard environmental economics approaches has resulted in efforts to produce a working definition of sustainable development. While providing us with potential parameters for an "existence theorem", ecological economics perspectives are as yet not mature enough to deliver a consistent change paradigm with policy implications **(Figure 1.2c)** (Turner et al. 1996). The extent to which the artificial and the natural worlds can substitute for one another, has been taken to involve intangible services economics (Ayres and Kneese 1969) as well as the biophysical aspects of sustainability as a material aspiration (Cleveland 1998). Some authors have referred to this contradiction as the "paradox of sustainability" **(Figure 1.2d)** (O'Neill 2009, p.283). In this paradox, sustainability is seen as either the maintenance of specific goods such as fish stocks, rainforests and water sources (natural sciences literature); or as the maintenance of constant levels of welfare and preference satisfaction (economics literature). Thus, the paradox of sustainability, the lack of an existence theorem alongside the conflicting gap between relative and absolute scarcities and the relative immaturity of ecological economics to grapple with them all suggest to us what the "state of science" in sustainability analysis currently is (grey block, top of **Figure 1.2)**. The implications for an understanding of capital substitution are manifest in a variety of often incompatible approaches to derive consistent sustainability policy guidelines as suggested by Turner, Perrings and Folke (1996). We find analysts referring to substitution possibilities in the present (Hamilton et al. 2006), in the next 50 or 60 years (Solow 1997); in the next hundreds or perhaps thousands of years (Daly 1997); or as something "forthcoming in the always receding future" (Castle 1997 p.305). Following a diversity of research interests, analysts address substitution in sustainability indicators (Pearce and Atkinson, 1993); indicators of resource scarcity (Norgaard 1990); in mass balance production functions (Van den Bergh 1999); in growth theory (Solow, 1956), in the analysis of environmental values (O'Neill et al., 2008); of lexicographic preferences (Edwards, 1986; Edwards, 1992); in the analysis of "limits" to economic activity, such as material limits (Ayres,

2007, Cleveland, 1991; Cleveland and Ruth, 1997) thermodynamic limits (Ayres, 1998; Georgescu-Roegen, 1970) complementarity limits (Daly, 1997), physical-interdependence and macroeconomic limits (Stern, 2004), critical-natural-capital limits (Turner, Bateman, Pearce 1993; Ekins 2003). Many technical interpretations touching upon issues of time scale, spatial scale and marginal analysis have also been added to the set of parameters conditioning substitution (Box 1.3).

Box 1.3 A variety of technical interpretations in the literature on substitution

A) TYPE OF SUBSTITUTION

- **Direct:** when man made capital provides a **service equivalent** to that of natural capital. e.g. chemical pesticides for natural predators, photovoltaic cells for photosynthesis.
- **Indirect:** this substitution is **via efficiency** - increasing technical progress. This occurs when more efficient machines increase the productivity of natural capital. Cars that get more miles per gallon and light bulbs that give more lumens per watts. However technical change does not occur in a vacuum it requires investments in education human and natural capital, R and D, machines, equipment, factories and so forth.
- **Marginal:** substitution is greater the smaller the losses of natural capital (e.g. sun glasses and hats can protect against a decline in stratospheric ozone, dikes could protect against a rise in sea level because of global heating).
- **Non marginal**: previous measures would be ineffective against complete loss of stratospheric ozone and a dramatic rise in sea level.

B) WHERE THE BOUNDARIES ARE DRAWN
For instance, home insulation directly substitutes for heating fuel within the household sector. Substitution possibilities increase with the scaling up of individual processes to firms and entire industries

C) TIME SCALE: Long vs. short run. In general, longer time frames provide more potential for technological change and substitution.

D) SPATIAL SCALE: local vs. global. A society can increase its potential for substitution if it has access to regional and global supplies of natural capital.

Sources: (Cleveland and Ruth, 1997; van den Bergh, 1999; Stern, 1997)

Beyond economics but still within the boundaries of sustainability analysis, "substitution" is shown to relate to a rich variety of controversies raised by the idea of "humanising" nature, in the natural sciences (Vitousek and Ehrlich 1989; Norgaard 1985) but also in the social sciences (Giddens, 1999; Rose 1990; Turkle 2010). The good news is that all of these different aspects of the literature on substitution can be roughly

organised into two major groups or strands of analysis: the ecological economics **(Figure 1.2e)** and the standard economics approach to substitution **(Figure 1.2f)**. So far, we have suggested how each one of these two strands of analysis relates back to a particular view of scarcity. In what follows, we shall see how each strand of analysis further relates to particular sets of assumptions with regards to sustainability analysis.

Ecological economics interpretations

It is often suggested in the literature that the main difference between environmental and ecological economics is their respective views with regards to substitution possibilities in production between man-made capital and natural resources (Pearce 1994, Turner et al. 1996). Turner's classification ranging from *very weak, weak, strong* and *very strong sustainability* positions reflects some of the sophistication implied by those differences (Turner, 1993). The ecological economics approach to substitution **(Figure 1.2e)** generally stresses the biophysical limits to substitution (Daly 1972; Costanza 1998) complemented by what is sometimes known as the "materials balance" or "mass balance" approach to economics pioneered by Georgescu-Roegen (1970) and others (Ayres and Kneese, 1969). With a slightly more refined argument, ecological economists also argue that substitutable consumer preferences involving opportunity costs (economics) are most of the time weakened by the actual experience of the material world (biophysics). That is to say, consumer preferences and *consumer sovereignty* in general — fundamental tenets to welfare economics— are not seen as reliable parameters to safeguard ecosystem's resilience nor as offering any good guidance to move towards long term sustainable development. Common and Perrings (1992) have described this issue in the following manner,

> "An ecological economics of sustainability implies an approach that privileges the requirements of the system above those of the individual […] Consumer sovereignty in such an approach is an acceptable principle only in so far as consumer interests do not threaten the general system and through this, the welfare of future generations […] Since the valuation of resources deriving

> from ecologically unsustainable preferences is itself unsustainable, there is no advantage in giving special weight and special privilege to such valuations. What is important in the approach is the ability of the system to retain the resilience to cope with random shocks, and this is not served by operating as if the present structure of private preferences is the sole criterion against which to judge system performance." (Common and Perrings, 1992, p.32)

But to what extent is this argument really in conflict with standard economics axioms and assumptions? Is it true that individuals do not prefer sustainability? How reliable is the assertion that there is a "global deficit of care" about biodiversity (Pearce 2007, p.313)? It has been argued for many years that consumer culture is not designed to allow individuals to reveal "true" and freely expressed preferences (Coombs 2001, Jackson, 2005; Boulding 1965) in fact —so the argument goes— there is an entire industry (advertising) devoted to change and manipulate tastes and preferences (Costanza 2000). Ecological economists are not alone in this, environmental economists have wondered whether advertising should be subject to special taxes (Turner 1993, p.386) and political scientists have questioned the normative role of individualism and consumer sovereignty (Redclift, 1993). Underlying these ideas is the standard economics principle that conditions upon which individuals make decisions can be improved (Pearce and Turner 1990; Herfindahl and Kneese 1972). As pointed out earlier standard economics foresees the need to justify "institutional intervention" to improve preference-related conditions and sustainability is a good reason to do so. Unsurprisingly, the term "institution" entails a wide range of meanings, all unified by the idea of how society attempts to take charge and "manage" its own transformation over time.

> "The term "institution" is a broad one. It applies to organisations such as government departments that have a defined structure and resources, but also to less tangible customs, decision making procedures, laws and codes of practice. The "market" is an institution as it the network of international law. Institutions play a critical role because they influence human interaction, aid the resolution of disputes and

> help to determine what is, or is not, socially acceptable." (Pearce and CSERGE, 1993, p.187)

Standard economics interpretations

The way in which environmental considerations are to be embraced by the economic development agenda is something which has been debated since around the time of the release of *Our common future* (WCED, 1987)[12]. The most celebrated paragraph of the report contains two important statements,

> "Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development does imply limits —not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities." (WCED, 1987, p.14)

While the first statement is widely cited, the second is rarely commented upon. It announces for the first time in the report that absolute limits are not a priority in sustainable development. To most economists this second statement suggests the idea of relative limits or *relative scarcities* — carrying opportunity costs— idea which seems much closer to economic analysis, by definition (Robbins, 1932). One additional implication seems to be that absolute biophysical limits, or *absolute scarcities* —which are closer to the concerns of natural scientists — are not necessarily a priority. Furthermore, in terms of policy guidelines, to state that the limits to development are those imposed by "technology and social organisation" leads to two possible interpretations about what the conditions for sustainable development should be, according to Pearce, Markandya and Barbier (1989),

> "(i) That the next generation should inherit a stock of wealth comprising man-made assets and environmental assets, no less than the stock of inherited by the previous generation;

[12] Also known as the Brundland report

> (ii) That the next generation should inherit a stock of environmental assets no less than the stock inherited by the previous generation." (p.34)

While the first interpretation emphasizes the need to bequeath *all* forms of capital assets, natural and artificial[13], the second stresses natural assets only. This in turn leads to the first neoclassical economic definition of sustainable development as *non-declining wealth across generations* (Solow 1986). The implicit assumption in such a definition is that man-made and natural capital are *substitutes* for one another,

> "so long as the overall aggregate of natural and man-made capital does not decline between one generation and the next, the stock of natural assets can decline because the growth of man-made capital will compensate for it […] society as a whole can be better of through the depletion of natural resources and environmental assets so long as it uses the proceeds of that depletion to build up a stock of other assets." (Pearce, Markandya and Barbier, 1989, p.37)

The sustainability policy implication is that "we do not owe to the future any particular thing" (Solow 1993, p.181) insofar as the present generation leaves behind enough *productive capacity* to generate comparable well-being in the future (Solow 1986; 1994). Whilst it is true that Solow's approach to defining sustainable development was partly a natural outcome of applying standard economic principles to a new problem:

> "It is part of the folk wisdom of economics that everything can be traded-off against everything else; the idea that one choice might be regarded as infinitely more valuable than another is thought rather perverse" (Hargreaves-Heap et al. 1992, p.331).

It is also true that Solow's first definition of sustainable development was the result of his own investigation (Solow 1986) of a theorem made earlier by Hartwick (1977) which stated that a constant stream of consumption could be achieved by a society that invested all the competitive rents from non-

[13] For the purposes of this study "artificial", "man-made", "produced", "human-made" or "manufactured capital" are taken to mean the same thing.

renewable depletion[14] in productive capital. What Solow showed was that Hartwick's rule was equivalent to holding all capital stock constant over time so as to leave to the future at least the equivalent capacity to generate wellbeing we have today. Future generations —according to the "Hartwick-Solow rule" **(Figure 1.2g)**— can live off the interests yielded by that constant stock or patrimony of capital. Prices used to measure the total value of man-made and natural capital stocks are taken to reflect peoples preferences so market failures due to externalities are assumed to have been corrected or non-existent (Common and Stagl, 2005). The rule is a policy rule and investment cannot be left to markets, so government has to makes sure that it is satisfied (op. cit). When analysed outside the economic framework this rule alongside its key assumption about substitution has resulted in extensive debates between economics and other sciences. Ecological economists in particular and natural scientists in general —thinking in terms of absolute scarcities rather than relative scarcities— argue that biophysical reality necessarily imposes limits to the amount of man-made capital that can be substituted for natural resources (Daly 1972; Costanza 1991; Cleveland 1991)[15]. This is also known as *strong* in opposition to *weak* sustainability (Turner, 1993). As in many academic debates, "the discussion [about substitution] has been marked by both concealed agreement and exaggerated conflict (Holland, 1997)"[16]. Moreover, Stern suggests (2004) the whole debate between mainstream, environmental economists and ecological economists with regards to substitutability assumptions is characterised by much misunderstanding with regards to how scientific methodology is handled. A first aspect worth considering, according to Stern, is to see how neoclassical economists tend to organise the problem before they even try to investigate it,

> "The neoclassical literature on growth and resources centres on what conditions permit continuing growth, or at least non-

[14] Known as Hotelling's rule (Hotelling, 1931). "Rents" are the difference between the price obtained for the resource and its cost of extraction.

[15] The 1997 special issue of the journal *Ecological Economics* dedicated to Georgescu-Roegen's contribution to the field, is a good example of how disagreement involving high-profile analysts have unfolded over the years.

[16] Cited in O'Neill (2009 p.286)

> declining consumption or utility. Technical and institutional conditions determine whether such sustainability is possible. Technical conditions refer to things such as the mix of renewable and non-renewable resources, the initial endowments of capital and natural resources, and *the ease of substitution among inputs*. The institutional setting includes things such as market structure (competition versus central planning), the *system of property rights* (private versus common property), and the system of values regarding the welfare of future generations." (Stern D. 2004, p.40, Italics ours)

Stern also suggests —rather obliquely, that neoclassical economists such as Solow assume "perfect substitutability" between artificial and natural capital presumably as a way to keep them as variables under control and concentrate instead on the institutional rules and conditions for sustainability (having assumed sustainability as feasible). Thus, it is vain to insist that neoclassical economists unconditionally believe that all natural resources are fungible (O'Neill, 2009; Pearce 2007). This argument seems reasonable; as ecological economist Costanza stated in a famous article "it is a well-accepted method in science to make initial first approximations to complex problems and allow the results to determine whether it is worth investing the effort to do more elaborate studies" (Costanza 1998, p.68). This principle seems applicable to Solow's initial approximation to an economics of resource scarcity and sustainability. Stern explains this crucial idea as follows,

> "A common interpretation of [growth models with natural resources] is that […] degraded environmental services can be replaced by […] "equivalent" forms of human-made capital (people, machines, factories, etc.). But this is a misinterpretation. Neoclassical economists are primarily interested in what institutional arrangements, and not what technical [substitutability] arrangements, will lead to sustainability, so that they typically assume a priori that sustainability is technically feasible, and then investigate what institutional arrangements might lead to sustainability if it is technically feasible." (Stern D. 2004, p.40)

One of the "institutional arrangements" referred to in the above quote is the Hartwick-Solow rule mentioned earlier. Given the

many misinterpretations of the substitution assumption with regards to the Hartwick-Solow rule, Pearce (2007) has made an effort to clarify its meaning in practice,

> "The [Hartwick-Solow] rule states that it does not matter in which form capital is held – each is substitutable for the other. This feature of the asset-based approach to sustainability has generated much misunderstanding. No one suggests that one can dispense with all environmental assets provided the proceeds are invested in building other forms of asset […] It is about depleting, say, a forest here or there and investing the proceeds of the depletion in, say, schools or roads. That process actually defines human history. In economics jargon, substitution is always "at the margin". It is never about removing assets wholesale." (Pearce 2006, p.203)

Finally, Solow himself (1991) trying to persuade non-economists to see the rule in a more benign and practical spirit,

> "[The Hartwick rule is) "a very simple rule, and it is really true only for very simple economies" but it has the advantage, first of all, of sounding right, of sounding like justice, and secondly of being practical. It is a calculation that we don't make and I am going to suggest in a minute that we should be making it." (Solow 1991, p. 185)

To understand the practical implications of implementing the Hartwick-Solow rule it is also necessary to understand non-renewable resource depletion in terms that can relate to everyday consumption conditions (explained in our next section). We also need to have a better idea of the conditions that will determine substitution in the long run. At the moment substitution possibilities are assessed in the present by institutions such as the World Bank (see for instance Hamilton et al. 2006). An entirely different matter seems the long-run appraisal (i.e. the next 50 years). The problem can be described in the following terms: long-run substitutability conditions will depend on substitutable consumer preferences, which are subject to income effects (Hicks 1971). Future income effects on preferences rely largely on our ability to forecast long-term growth; and the basic model of economic growth we have today (Solow, 1956) does not include natural resources.

According to Solow's model, the only cause of continuing economic growth is technological progress. Half a century later it has been shown that useful work (or *exergy*) derived from hydrocarbons has been the true economic growth driver of modern industrialised societies (Ayres and Warr 2010; Stern D. 2011). Alongside the growth issue there is another one which has gone mostly unnoticed: the availability of hydrocarbons (i.e. fossil fuels) has solved for us not one but two problems, energy *generation* and energy *storage* (Smil 2006; Mackay 2009). A transition to alternative forms of energy (including nuclear fission) implies also a transition —almost necessarily—to low-energy-density carriers. In other words, a transition to a low-carbon economy could be more usefully characterised as a transition to a low-energy-density economy **(Figure 1.2h)** (Smil 2006, 2009; Reynolds 2007; MacKay 2009; Cleveland 1998).

The low-carbon transition as a low-energy density transition

One useful way to describe the evolution of a society is by looking at the energy density of the fuels that it burns at each historical stage. Also useful to note is what each society actually achieves in terms of human ends by burning those fuels, be it empire and slavery in ancient Rome or air travel, drug addiction and obesity epidemics in twenty-first century Detroit. The "organic economies" of the 18th century[17] characteristically relied on the low-energy densities yielded by firewood and phytomass (around 4.4 kWh/Kg). Modern-society lifestyles, in contrast, seem only explicable by the predominance of fuels with energy densities of 12 KW/ph and above. At the moment, there is a widespread concern with all things low-carbon: "low-carbon innovation", "low-carbon technologies", "low-carbon industries and markets", "low-carbon practices", services. The list continues to include low-carbon growth (Stern N. 2009) and low-carbon-economy transition plans (HM Government 2009). Notwithstanding the low-carbon spree, we

[17] This is the term used by Wrigley to describe those economies where "all the raw materials which entered into the production process were either of animal or vegetable origin, or, if mineral, could only be converted into a form of use to man by the expenditure of heat energy derived from wood." (Wrigley 2006, p.435)

can see there are some good reasons why the low-carbon economy transition will be first and foremost an energy density transition, most likely from *high* to *low* energy density carriers. In any case, the former is likely to prevail over the latter. This in turn, as we shall see, has useful implications in terms of what the Hartwick-Solow rule means in practical terms. Let us explain first the high-energy-density carrier consolidation period.

The high-energy-density carrier transition (1600 - 2010)

Since at least the Renaissance, we have been substituting modern energy carriers (starting with coal) for traditional ones, such as food, windmills and firewood, more or less like in **Figure 1.3.** Hydrocarbon predominance clearly coincides with both, the industrial age and the modern world as we know it. Even if climate change was not on the agenda, fossil fuels are finite and most modern societies still face two challenges. First, bringing renewable energy back into the mix (with a few technology updates); and two, doing so while considering the economic and lifestyle implications of phasing out hydrocarbons in our current modern age (as opposed to say, somewhere during the first half of **Figure 1.3.**

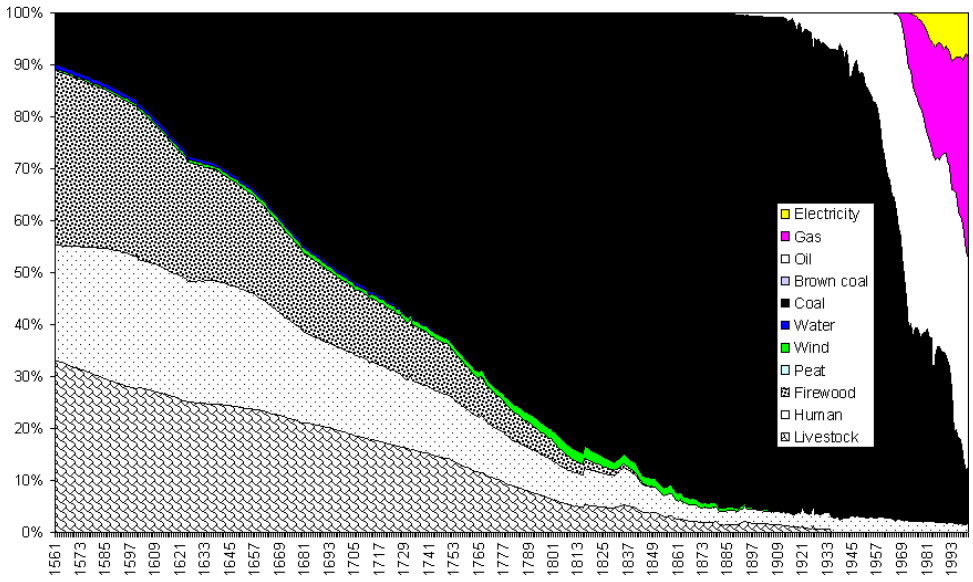

Figure 1.3. Energy consumption by carrier in England and Wales (1561-1993)
Source: Warde (2007).

Energy strategists and politicians are envisioning the challenge for the coming decades much like in **Figure 1.4.** This time, however, CO_2 emissions have been added to the picture arguably adding some dispensable aspects for a basic analysis. The key messages are that efficiency gains are to be coupled with widespread electrification in many sectors and with the increased use of renewable energy. At this point, a third issue, a rather critical one, must be considered if those key messages are to be put in the right operative mode. That is to say, the *energy density transition* implied by a switch to renewables as part of a low carbon transition strategy must be higher in the research, policy and public awareness agendas. Not least because models of economic growth based in historical records are unlikely to be of use in future (Ayres and Warr 2009). Let us explain why.

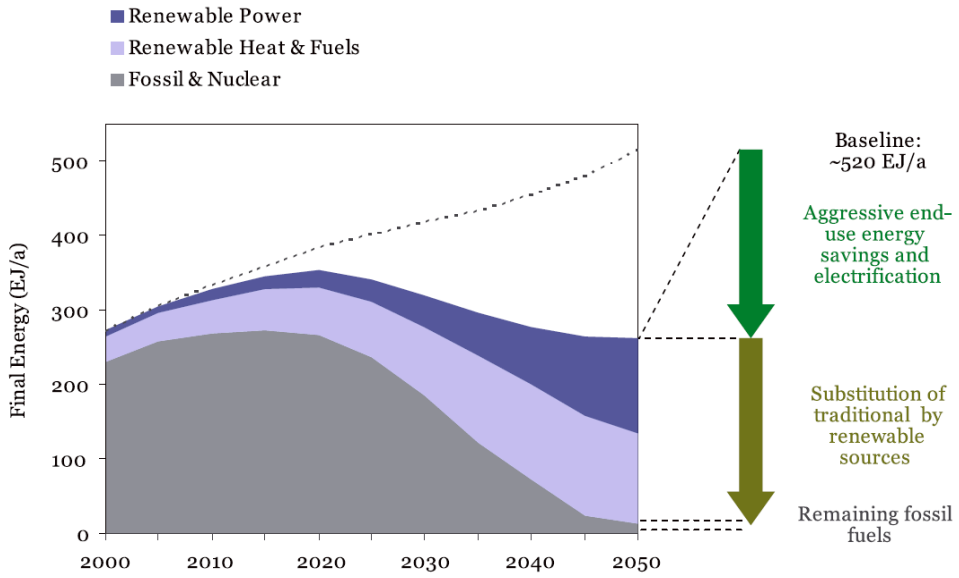

Figure 1.4 - Evolution of energy supply showing key developments (2000-2050) This is not a forecast, its use here is meant to be descriptive rather than analytical.
Source: WWF the energy report 2011 (Ecofys Energy Scenario).

The low-energy-density carrier transition (2010 – 2050)

Energy density is the amount of energy per unit weight (gravimetric energy density) or per unit volume (volumetric energy density) (Smil 2006, MacKay 2009). Hereafter we refer to high energy density (HED) and low energy density (LED) as

relative categories, to one another. An energy carrier is any means by which energy can be stored prior to consumption or prior to performing useful work (or *exergy*). Fuels, including hydrogen, are not "sources of energy" but energy carriers. Our true primary source of energy is the sun[18]. Some well-known HED carriers include petroleum, coal, natural gas and hydrogen. A second energy carrier group, often associated with a transition to renewable forms of energy, include electrical batteries, capacitors, springs, pressurized air, phytomass, wood, dammed water and flywheels. These are LED carriers because they have the ability to perform considerably less useful work than those in the first group.

As simple as it seems, there are many analytical advantages in looking at a low-carbon economy transition as an *energy density transition* too. When we pay attention to the technicalities, such a transition is not only about our plans to generate energy but also about our plans to store it prior to consumption while making sense of different energy densities[19]. Some additional criteria by which to assess the convenience of different energy carriers include: efficiency, lifetime, the maximum rate at which energy can be pumped into or out of the storage system; the duration for which energy stays stored in the system, cost and safety considerations (MacKay 2009).

To show how we can apply energy-density criteria to the way in which different energy worlds, past, present and future, are envisioned, **Figure 1.5** brings together a small but contrasting range of energy carriers in terms of associated densities. With this ranking order realistic comparisons between lifestyles choices and technical possibilities can be drawn. Note for a start how nuclear-fission electrification in the personal transport, agriculture and water sectors would radically change the way people live due to capacity constraints implied by hydrocarbon carrier replacement (e.g. pumped storage, electric batteries, sunlight-to-hydrogen).

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[18] Although geothermal is yet another source of primary energy our purpose is to make the useful distinction between what people often call *sources* when they actually mean *energy carriers*. The sun makes wind and waves and it is also transformed and stored into petroleum by biochemical and geophysical processes.

[19] Note the difference between *storing primary energy* (e.g. from sunlight-to-petrol) and storing an *energy carrier* (e.g. keeping petrol in a tank)

ENERGY CARRIER	CALORIFIC VALUE (kWh/kg)	
Propane	13.8	High
Petrol	13.0	
Diesel oil	12.7	
Kerosene	12.8	
Heating oil	12.8	
Tyres	8.9	
Ethanol	8.2	
Butter/Lard	8.0	
Coal	8.0	
Methanol	5.5	
Hardwood	5.0	
Newspaper	4.9	
Cardboard	4.5	
Firewood	4.4	
Straw	4.2	
White office paper	4.0	
Municipal waste	2.6	
Hydrogen*	*2.4	Low

BATTERY TYPE	ENERGY DENSITY (Wh/kg)	LIFETIME (cycles)
nickel-cadmium	45–80	1500
Nickel-metal hydride	60–120	300–500
lead-acid	30–50	200–300
lithium-ion	110–160	300–500
lithium-ion-polymer	100–130	300–500
reusable alkaline	80a	50

Figure 1.5 Some properties of storage systems and fuels (energy carriers) *These energy densities include the masses of the energy systems" containers. Taking into account the weight of a cryogenic tank for holding hydrogen, the energy density of hydrogen is reduced from 39 000Wh/kg to roughly 2400 Wh/kg. Something less dramatic happens with natural gas. Source: compiled from MacKay (2009)

Observe also —even before considering hydrogen-generation and fuel-cell costs[20] — how the benefits of employing hydrogen as an energy carrier are offset, almost entirely, by the inevitable use of cryogenic containers (from 39.4 down to 2.4 kWh/kg). For all its hype, one cannot help but to wonder, after some energy-density analysis, if achieving a "hydrogen economy" would not also entail considerable environmental and social costs, or indeed whether such an economy would bring about anything remotely resembling sustainability, however we define it. Fossil fuels spare us, not one, but *two* troubles, energy collection and energy storage. So whenever analysts refer to a "transition to renewables", not one, but two problems are to be addressed.

[20] Fuel cells are devices that convert chemical energy from hydrogen and other fuels into electricity.

The latter, storage, as we have seen is not an ancillary problem once we solve energy generation. Consider Denmark's wind power complex, which uses neighbouring countries" hydroelectric facilities to store its intermittently-generated wind energy (Nielsen, 2002). Solar, wave and tidal energy generation are not exempt from similar challenges. When the energy source is intermittent and located in an isolated area which cannot be connected to the distribution network, storage becomes crucial (Ibrahim et al., 2008). Hydrocarbon carriers, in contrast, present none of these problems: before human history sunlight was captured by vegetable photosynthesis; neatly stored and secured for us underground in vast quantities, sparing us at once the troubles of generation and storage. Consider the case of powering an electric car with electric batteries (i.e. LED carriers); So far it has been presented as a costly but not too radical a shift apart from current transportation habits; brand new EV will be relatively heavier and less roomy in the boot. In principle, subsidies will be phased out as economies of scale make electric vehicles more affordable and ubiquitous.

Now, consider the case of a society that has to run a whole industry sector or indeed a whole economy on LED carriers. That is the type of challenge we are facing in the future. What seems different about the prospect of a low-carbon transition — if it really is what societies want— is our very dependence on the high energy density of fossil fuels to run the whole economic system (Ayres, 1998; Ayres and Warr, 2009; Stern D. 2011) together with large-scale, country-wide migration to wholly new energy generation and storage infrastructures (Cleveland, 2008; MacKay, 2009; Reynolds, 2007). The most important problem with "economics of scale" in a transition to an economy run on anything other than hydrocarbons is this: long run consumer preferences for any sort of low carbon technology will be dependent upon personal incomes. Future income forecasts rely on our ability to forecast long-term growth; and the basic model of economic growth guiding policy today is the (1956) "Nobel prize winning work of Robert Solow that does not include natural resources at all" (Stern D. 2004 p. 38). As Ayres and Warr point out:

> "Most people nowadays believe in economic growth for much the same reason they believe in God or in the power of prayer: it is politically proper […] the easiest assumption about the future, *ceteris paribus,* is that it will be like the past. […] Given a 200-plus year history of steady economic growth, it is fairly natural to assume that the historical trend will continue. Governments, businesses and institutions are now, and have been for several decades, effectively addicted to the presumption of perpetual and inevitable economic growth" (Ayres and Warr, 2009, p.xvii)

Technically speaking, if a government were to shift to renewable energy overnight, the water system alone, bereft of the far superior exergy delivered by HED fuels, will most probably bring the whole economy to a halt followed by collapse (Smil, 2006) (Ayres Warr 2009). In a HED-to-LED transition, the possibility that the UK could keep importing 40% of its food while maintaining dietary habits would appear rather dim (Jones and Crane, 2009).

Notwithstanding the gravity and likelihood presented by these challenges, what a remarkable number of analysts, technology lobbyists and scientists seem to be, either too disingenuous or too dangerously optimistic about, is the extent to which society should trust in the inevitability of a commercially viable technological breakthrough —of nothing short of *magical* proportions— happening in the foreseeable future; particularly in energy storage systems and energy carrier manufacturing. For instance some scientists claim to have cracked the problem of producing hydrogen with photo-catalysis (Heyduk and Nocera, 2001; Nocera, 2009) or with green algae (Amos, 2004) for the purposes of micro-generation at home. Likewise, some LED technologies (e.g. solar thermal) are likely to play a role compensating for the loss of HED electricity availability. Yet, home micro-generation is unlikely to replace HED power supply.

The evidence about hydrogen-fuel cell household micro-energy systems replacing current centralised HED power supply infrastructure seems at the moment highly contradictory and highly politicised. It is true that some improvements in storage capacity are still possible, but the physical boundaries of energy density in materials and fluids shown in **Figure 1.5** are fairly

well known already and digits are unlikely to move much from where they are (Smil 2006, MacKay 2009). There are reasons to believe that if such a breakthrough does not come about soon enough, the global imperative of emission abatement will result most probably into a HED-to-LED type of transition.

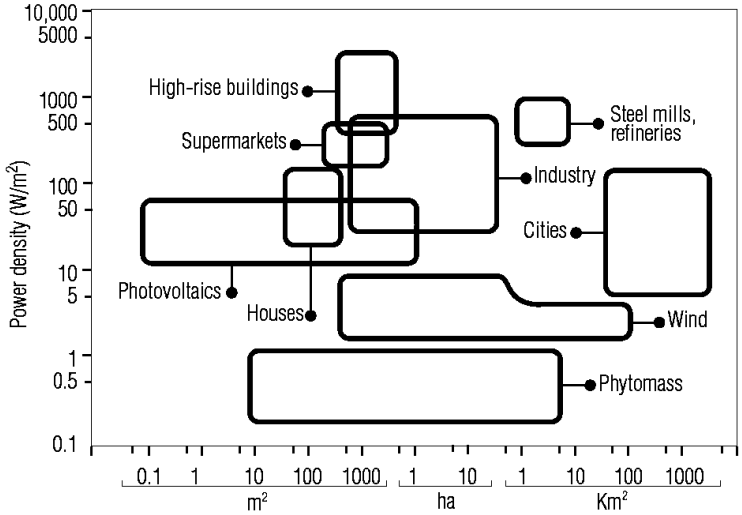

Figure 1.6 Power densities for fossil and renewable fuels. Source: Smil (2006)

Such a transition will be burdened by four additional factors we have not yet mentioned: the sheer scale of the shift; the intermittency of renewable source flows; the uneven distribution of renewable energy resources and last but not least, the substantially lower power density of renewable energy collection, that is to say the rate of production per unit of land area (Smil 2006).; **Figure 1.6** compares different land areas of production with "embedded energy" use in different building types.

In summary, the extent to which a country's energy mix includes a renewables energy portfolio will determine also the extent to which it will have to prepare itself to run economic activities, manage infrastructure systems, generate employment and reorganise the whole fabric of society around the energy that will become available —or not— as a result. Governments will probably have to regulate the use of particular energy carriers so that density allocation is done in accordance with whatever the social priorities will happen to be. In short,

important changes in behaviour and material ambitions are to be expected in all these adjustments. Eloquently put a few decades ago, societies will have to reverse those situations where "unsustainable development has resulted from technology outpacing changes in social organization" Norgaard 1984, p.16).[21] To finish our description of our topic of analysis in **Figure 1.2**, issues of technology and social organisation takes us to the question, what drives change? The literature suggests two trends, viz., intellectual property-driven innovation and open-source or creative-commons innovation (Hargreaves 2011). As we shall see in the sections which follow, these two categories will be useful to our methodology as they are key parameters to understand the nature of social and technological change.

Property regimes and innovation policy

Because the Hartwick-Solow rule implies a high level of substitutability, a key requirement implied by its implementation is the "increased efficiency in research and development, that is to say, new knowledge embodied in people technology and institutions" (Turner, 1996, p.20). Earlier in the "standard economic interpretations" section it was pointed out that the neoclassical literature considers sustainability as something which is determined by *1-technical* and *2-institutional* conditions (Stern D. 2004). Some technical conditions include the mix of natural resources and the ease of substitution among inputs. Institutional arrangements include market structure and the *system of property rights* (op. cit.).
This section introduces the latter **(Figure 1.2.i)** as a key variable in the future scenarios template that is explained in a later section. The emphasis is on intellectual property driven innovation and creative-commons (or "open-source") innovation as they affect innovation policy rules (presumably having a good degree of relevance to the hypothetical implementation of the Hartwick-Solow policy rule). For clarity,

[21] Challenging the idea that the limits to sustainable development are "imposed by the state of technology and social organisation" seen earlier (WCED, 1987) p.14)

the abbreviation "IP" rather than "IPR" is used hereafter to avoid confusing the terms "rights" and "regimes". The focus on IP is because "intangible" and "knowledge capital" have been influentially propounded by multilateral agencies and governments as the true global sources of wealth in the twenty first century (World Bank, 2006; Romer 1992; HM Treasury 2007).

Intellectual property rights can be more clearly understood as state-granted commercial monopolies over creation of the mind[22]. Some IP economists prefer the term intellectual monopoly (IM) (Boldrin and Levin; 2008). IP grants usually take the form of patents, copyrights, trademarks, brand names and industrial designs. Monopoly in intangibles has often led to monopoly in the tangibles domain (Boldrin and Levin 2008), it has also led to monopoly within the domains of culture and civil liberties (Boyle, 1997, Drahos and Braithwaite, 2002, Lessig, 2002). This has made IP-driven innovation regimes a matter of controversy.

Notwithstanding the controversies, because the economically relevant unit of analysis of IP is *the copy of an idea, rather than the abstract idea,* intellectual property is compatible with free markets and does not necessarily have to lead to intellectual monopoly (Boldrin and Levin, 2008). These concepts are explained further in **Box 1.4**. IP-driven innovation regimes are considered the principal type of innovation regimes in so-called knowledge-based economies (Gowers, 2006; Hargreaves, 2001; Romer 1990;1986). The right length of monopoly protection that is granted is currently a matter of debate not only in the UK but everywhere else in the world. More recently IP rights have come to include life forms, data bases and business practices (Hargreaves, 2011).

[22] Most official document and textbook definitions hide the word "monopoly" behind the word "rights". The Gowers Review's definition of Intellectual Property is one of many examples (2006) "Property is simply a bundle of rights to own, use and prevent others from using something, for example a plot of land, a car or a house. Intellectual Property (IP) is a bundle of rights that protects applications of ideas and information that have commercial value. IP rights give creators certain exclusive rights over the knowledge and information they create (e.g. the text of a book) to prevent others using it without permission." However it is necessary that our definition be clear on the fact that they are state-granted monopolies.

Box 1.4 Intellectual “property rights” do not necessarily imply “monopoly rights”

“Are we arguing that, while stealing potatoes is bad, stealing ideas is good? We are not. Economic efficiency and common sense argue that ideas should be protected and available for sale, just like any other commodity. But "intellectual property" has come to mean not only the right to own and sell ideas, but also the right to regulate their use. This creates a socially inefficient monopoly, and what is commonly called intellectual property might be better called "intellectual monopoly." When you buy a potato you can eat it, throw it away, plant it, or make it into a sculpture. Current law allows producers of CDs and books to take this, freedom away from you. When you buy a potato you can use the "idea" of a potato embodied in it to make better potatoes or to invent french fries. Current law allows producers of computer software or medical drugs to take this freedom away from you. It is against this distorted extension of intellectual property rights that we argue. It is a long jump from the assertion that inventors deserve the fruits of their efforts to the conclusion that current patent and copyright protection are the best way of providing such reward.” (Boldrin and Levin, 2002, p.209)

“Central to understanding the market for ideas and the incentives for the adoption of new ideas is understanding how ideas might be different from other goods. The starting point of the economic analysis of innovation is to recognize that the economically relevant unit [of analysis] is a copy of an idea. That is, typically, many copies of an idea exist in physical form, such as a book, a computer file or a piece of equipment, or in the form of knowledge embodied in people who know and understand the idea. When embodied in humans, copies of ideas are labelled with a variety of different names, which often obscure their common nature: skills, knowledge, human capital, norms, and so on. Careful inspection shows, though, that each and everyone of these apparently different entities is, at the end, nothing but the embodied copy of an idea, and that the latter was either discovered first by the person in whom it is currently embodied, or costly acquired (possibly via observation and imitation) from other humans, in whom it had been previously and similarly embodied. Economically valuable copies of ideas do not fall from the heavens, like manna, but are the product of intentional and costly human efforts. Only these copies matter, first, in the sense that if they were all to be erased, the idea would no longer have any economic value, and, second, in the sense that the copies are relatively good substitutes for each other: whether a copy of an idea is the original copy or the hundredth copy, it is equally economically useful. From the perspective of the functioning of markets, then, property rights in copies of ideas is assured by the ordinary laws against theft – what is ordinarily referred to as “intellectual property” protects not the ownership of copies of ideas, but rather a monopoly over how other people make use of their copies of an idea.” (Boldrin and Levin 2005, p.24)

The UK’s leading reports influencing national policy on the matter, the Hargreaves review (2011) and the Gowers review of Intellectual Property (2006), attribute to IP three important functions in society.

- To incentivise knowledge (and hence wealth) creation,
- to accumulate knowledge in a culture, and
- to protect distinctive identities.

Because the trend in institutions has been to identify “knowledge” with “innovation” and innovation is seen as a prerequisite for a transition to a low-carbon economy (Foxon

and Pearson, 2008, HM-Treasury, 2007, HM-Treasury, 2009, Stern N. 2007) the aforementioned statements have often been translated into similar principles,

- IP incentivises innovation for a transition to a low CO_2 economy
- IP allows for the accumulation of innovation, making the transition to a low CO_2 economy possible.
- IP protects the identities that innovators require during a transition to a low CO_2 economy

These principles are made evident in official as well as government-commissioned documents guiding policy (such as Gowers (2006) and the Stern review (2007); more importantly, they are formalised into policy instruments which harmonise and bind national government directives (e.g. the IP office in the UK) to those of multilateral organisations such as WTO, WIPO, and TRIPS[23]. The other trend in innovation is the one associated with open-source and so called "creative-commons". For practical purposes, we take "creative-commons" innovation (Lessig, 2001), to mean all forms of innovation that are legally shared in society. Its logo[24] is widely employed by individuals and organisations.

In practice, *creative-commons* is not very different from such things as open-source innovation (Weber, 2004; Raymond, 1999) or community and peer to patent (Noveck, 2006). In this study however and from an economics perspective, the more technically accurate term "creative-commons innovation" has been preferred to that of "open-source innovation". This is because, as environmental economists remind us, open-source and open access resources have no owner (Pearce and Turner, 1990); creative-commons in contrast do imply ownership with the added benefits of a culture of legal sharing (Lessig, 2001). Moreover, Garret Hardin's famous *Tragedy of the commons* (Hardin, 1968), is in reality a tragedy of open access where lack of ownership is rife (Pearce, 1995). In any case creative-

[23] Trade related aspects of Intellectual property rights

[24] www.creativecommons.org.uk

commons, open-source, and community innovation appear to share a common ethos:

> "We have come from a history of broad experimentation with different property regimes used to match different circumstances. Now we are entering a narrow, restricting bottleneck. Single-minded, one-size-fits-all definitions of ownership and control are being applied to all areas of life regardless of whether they equip us with the tools we need to solve global or local problems such as climate change, hunger, disease, homelessness and poverty."[25]

This ethos appears to involve a shared view about the future whereby knowledge property regimes follow an evolutionary path similar to the hourglass shape presented in **Figure 1.7**

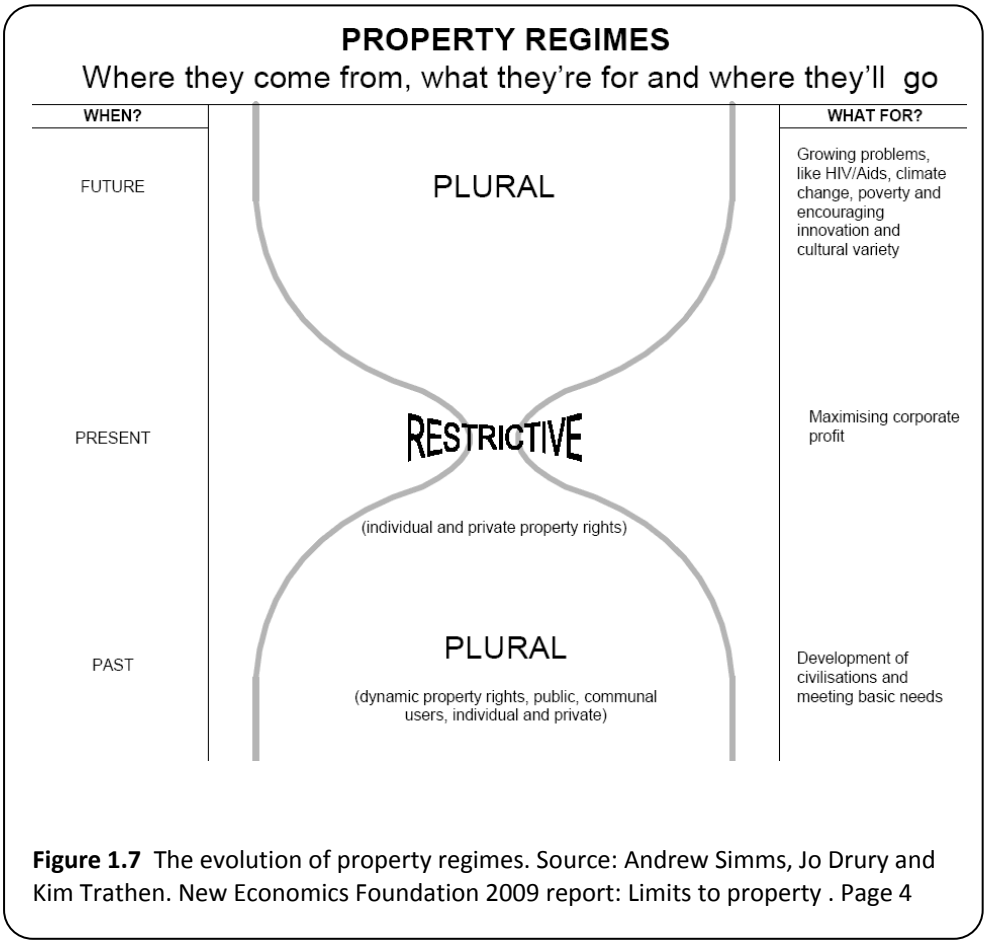

Figure 1.7 The evolution of property regimes. Source: Andrew Simms, Jo Drury and Kim Trathen. New Economics Foundation 2009 report: Limits to property . Page 4

[25] (www.creativecommons.org)

Here, we can see how what has become restrictive during the last few decades, will tend —according to those advocating such a view— to a more plural state, for a variety of reasons, all apparently to do with enabling people and institutions to tackle twenty first century problems such as new diseases and climate change. Unlike IP-driven innovation, the drivers of creative commons and open-source innovation are not as easy to pin down. This is because creative commons and open-source innovation take into account the existence of wider social processes.

For the purposes of understanding these issues for the UK case, at some point it became apparent that innovation policy was not being property addressed at the national level in the UK. The National Endowment for the promotion of Science, Technology and the Arts (NESTA) was therefore commissioned by the UK government in 2005 to undertake a major review of innovation within the country. As a result NESTA analysts developed the notions of "innovation gap" followed by "hidden innovation" as ways to redefine parameters of innovation traditionally overlook by conventional metrics based on such things as R and D investment and patent activity. NESTA's document *The Innovation Gap (2006)* explains the origins for the initiative,

> "Traditionally, any reference to an "innovation gap" with regard to the UK is assumed to mean the UK's deficit in innovation performance compared to other leading nations. However, traditional indicators of innovation performance are heavily biased toward investments in scientific and technological invention and so do not capture innovation in those sectors that represent the vast majority of the UK economy. Moreover, even within those sectors that they do represent, traditional indicators poorly reflect the true level of innovative activity. This gulf between practice and measurement is the real innovation gap. Understandably, policy built to remedy our historical poor performance on these indicators has focused on scientific and technological invention. This emphasis now needs to be balanced against a wider agenda around the skills and attributes required to create, absorb and exploit innovation in the rest of the economy." (NESTA, 2006 p.4)

Open or "hidden" innovation is important because it appears to be more representative of UK's innovative economy (NESTA 2003, 2006, 2009). It is currently being developed as a new innovation index. After reviewing the topic of analysis in some detail by describing **Figure 1.2**, we notice that we also need to —somewhat inevitably— describe it in terms of our position and value judgements with regards to methodology. We accept that: 1) "It matters a great deal that the search for the new should not involve dispensing with the value of the old" (Pearce and Turner 1990. p.xii); 2) that our understanding of the problem will determine the sort of model that is available in terms of methods; and 3) that at least some rough parameters for a model must be approachable from a standard economics viewpoint. Having said this, we are in a better position now to formulate the research questions guiding the rest of this thesis.

1.2 Research questions, academic and societal relevance

Given conventional economic theory assumptions (**Box 2.2**), in this study the following research questions are addressed:

Q1.- Since substitutability depends on society's relative valuations of man-made and natural capital in a changing world (technologically and culturally), under what conditions and institutional arrangements are long-run substitution possibilities likely to be higher?

Q2.- Are there particular mechanisms and patterns that are likely to be relevant to a characterisation of long-run substitution possibilities?

Academic relevance

Underlying this study is the recognition that a standard economics approach to long-run substitutability can yield interesting results provided assumptions and their place within the methods employed are made transparent. The latter has not always been a common practice. According to some

environmental economists, the lack of sufficiently explicit statements about the practical implications of substitutability assumptions used in models has resulted in years of misunderstanding between economists and non-economists (Pearce 1994; Stern D. 2004; 2011). Such misunderstanding can be easily avoided by exploring different exposition styles. Ease of exposition is one of the reasons for using an "appreciative" model rather than a formal one.

Given that "the search for the new should not involve dispensing with the value of the old" (Pearce and Turner, 1990, p.xii), this study looks at some institutional arrangements that might be essential to long-run substitution possibilities and presents them in the context of scenarios storylines. Such a "contextual" approach to understand long-run substitutability is academically relevant in that it recognises the opportunity to still capture those institutional arrangements and rules which the ecological economics literature appears to downplay or neglect together with the standard method (in a way perhaps reminding us of the baby being "thrown away with the water" metaphor).

We have mentioned three aspects of those institutional arrangements, the Hartwick-Solow rule of investment, the transition to a low energy density economy (as a determinant to investment decisions), and two styles of property regimes in innovation policy (IP-driven and creative-commons innovation). There are however further elements that are discussed in **Chapter 2** where the model is developed.

The topic of substitution appears to be moving in interesting directions within academia. For instance, some experts on the issue of substitution argue that theoretical discussions about major environmental problems (i.e. climate change), should start recognising some analytical priorities; particularly they highlight the overriding importance of substitution over the issue of discounting the future which absorbs the time of many economists (Neumayer 2010).

Experts are also recognising that the issue of the limits to substitution is more connected to the real concerns of people (op. cit.). Yet, as this study suggests, long-run substitution cannot be analysed "empirically" because the future is an ever

receding thing. In this regard, our exploratory exercise involving future scenarios (Foresight, 2002; Ogilvie, 2002) to contextualise long-run substitution possibilities seems at least methodologically feasible and intellectually motivating. There is a need for a less fragmented understanding of the economic and biophysical aspects of substitution and contextualising substitution through future scenarios seems to bring us closer to that possibility. Moreover, it suggests the possibility to capture practical aspects of substitution which cannot be captured via formal economic modelling, such as the difference between "productive investment" and "ephemeral consumption".

Societal relevance

The issue of long-run substitutability appears also to have important societal and policy implications. Many investment decisions are based on the assumption of substitution. Substitutability underlies the issue of discounting the future in official and academic reports about climate change policy; see Neumayer (2009) reviewing Nordhaus (2007). Additionally, substitutability has been said to be closer to the everyday reality and concerns of people than the issue of discounting the future,

> "I contend that those who believe that the current generation should take immediate and decisive action against climate change need to go beyond the issue of discounting […] the non-substitutability issue is much closer to the real concerns of people. By contrast, CBA studies of climate change and the debate on the discount rate are strangely out of touch with reality." (Neumayer 2003, p.41).

Our specific approach to the topic, the particular methodology that we employ and its proof of concept analysis based on future scenarios is very well suited to accommodate collective work —e.g. future scenario workshops (Ogilvie, 2002)— potentially turning economics into a more socialised activity. Many commentators outside academia have begun to worry about actual negative changes that they see in the world around

them. However, it rarely occurs to them to see those changes in terms of "capital swaps". More often than not, they see economic growth destroying the planetary environment, antisocial behaviour in the streets, obesity epidemics making people unhappy or family disintegration making people feel confused and alone. People often ignore that the problems they observe may well have a technical name in economics; they ignore that there is a formal debate about the true meaning of such technical terms and their conceptual underpinnings. Society at large ignores that often the problems they see are the result of economic decisions taken under substitutability assumptions. Finally, substitutability is implicit in many of the new worries people have about some of the directions that human societies are taking **(Box 1.5)**.

Box 1.5 Many public concerns are inadvertently linked to our topic

"FOOD PRODUCTION"

"Present-day farming fails to feed the world for the irreducibly simple reason that it is not designed to feed people. It is designed to generate the greatest possible amount of cash in the shortest possible time. To do this, modern agribusiness does precisely the opposite of what biology, and common sense, suggest are necessary."

Colin Tudge
Biologist and writer
Source: colintudge.com

"PLANETARY FUTURE"

"Broadly speaking, there are two types of people on this planet. There are those who believe that the future of humanity lies here on earth, and there are those who believe it lies out in space. Stephen Hawking is one of the latter. One of the world's most celebrated scientists is certain that we have no alternative but to ship out. Life on earth, says Hawking, is at ever greater risk of being wiped out by threats like nuclear war or a genetically engineered virus."

Natasha Loder
Science and technology correspondent
Source: The Economist 2008

"THE USE OF SCIENCE"

"The most recent quick-fix, genetic engineering, is being championed not as a means of increasing homeostasis and yields in stable agricultural systems but as a means of producing crops that will grow in degenerating agricultural ecosystems."

Dr. Tewolde Berhan
Source: The Soil Association 2008

1.3 Research strategy and future scenario outline

Up to this point the chapter provides the concepts and tools for a basic understanding of the key theoretical issues from which to derive answers to our research questions. To address them properly however, a suitable framework is needed **(Figure 1.8).**

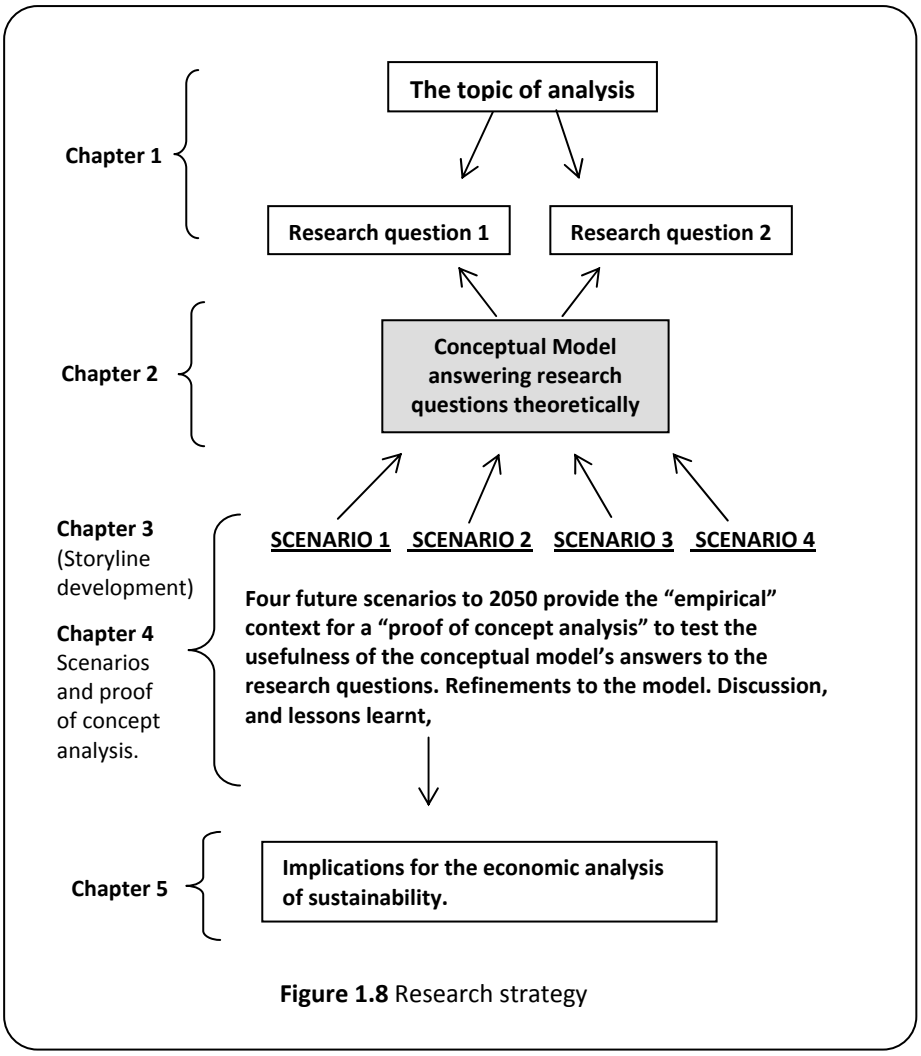

Figure 1.8 Research strategy

The research strategy consists first, of a model that answers our research questions theoretically **(Chapter 2)**; secondly, of a proof of concept analysis: an independently derived tool designed to "empirically" test the virtues of the model through future scenario narratives **(Chapter 4)**. Therefore, while **(Chapter 3)** explains how storylines were built, **Chapter 4** lays down the storylines alongside the corresponding substitution patterns that were yielded in each through the "running" of the

model (see scenario protocol at the end of **Chapter 2**). At the end of **Chapter 4** a "proof of concept analysis" is presented followed by refinements to the model and a discussion about the lessons learnt from the whole exercise. Finally, **Chapter 5** discusses the wider implications of the study for the economic analysis of sustainability.

The use of scenarios in scientific research

As an analytical tool, future scenarios (Foresight, 2002; Ogilvie, 2002) offer the opportunity to understand substitution, if not "empirically" at least "contextually." Scenarios are useful tools to move away from simplified descriptions and incomplete assessments of solutions, identify critical uncertainties, explore different logically consistent pathways and to frame better questions about the future (Foresight 2007).

> "[Scenarios] are not ideologies or matters of faith. They are simply ways of exploring possibilities. Scenarios provide a way of having a more imaginative and coherent conversation about the future and since there are more that one plausible scenario, scenario planning enables a conversation that does not end with one side winning and the other losing. Indeed the differences among us are among the most important tools for creating a diversity of possible futures, giving real meaning to human freedom" (Ogilvy, 2009, p.ix)

Future scenarios have been used extensively in environmental sciences and sustainability analysis. They have been used for instance in economic analysis for ecosystem assessments (Bateman et al. 2010), in marine ecosystem assessments (Pinnegar et al., 2006), tackling obesities (Foresight et al. 2007), global ecosystems (MEA 2005), land use change (Shearer, 2005), climate change scenarios (IPCC 2007), and "decarbonising the economy" scenarios (Anderson, 2005). From a methods perspective, scenarios allow for the processing of large amounts of information that often needs to be captured and retrieved in a random diversity of circumstances and formats (our "multi-source data collection" carried out in **Chapter 3** being a good case in point). Scenario development often challenges more lineal forms of appraisal (including econometric and statistical

analysis) which understandably need to restrict their scope to operation domains where variables are expressed in compatible measurement units (e.g. Kilowatt-hours, US Dollars per capita).

> "Scenarios are neither predictions nor forecasts, nor comprehensive critiques. They are informed narratives, developed to support a systematic exploration of possible futures with the aim of helping to make current policies robust and resilient to future change." (Foresight 2008, p.11)

Scenarios have the additional advantage of being very suitable for collective analysis, learning and decision making. That is to say, the usefulness of scenarios as tools to perform complex operations, where analysis can be done and shared collectively is consistent with the increasing need in science to communicate with lay audiences (Royal Society 2002). This seems particularly the case when discussing sustainability issues.

Future scenario outline

Most future scenarios consist of a scenario template and a set of storylines (e.g. Foresight, 2001). In our case the template was developed theoretically and the storylines empirically through a variety of data sourcing techniques.

A) Scenario template: the scenario template that was used to generate all scenarios was constructed around two key uncertainties: values and behaviour driving innovation (horizontal axis) and the nature of response regarding the high-energy-density bonus (vertical axis), see **Figure 1.9**

Uncertainty one: w*hat innovation style will receive social priority?*

The "values and behaviour driving innovation" (horizontal axis) shows behaviours that tend to prioritise either individualistic "**do it for me"** approaches associated with intellectual property (IP-driven innovation); or community

based "**do it yourself"** (creative-commons) approaches to innovation. IP-driven innovation can also be associated with the exploitation of existing technologies and infrastructures and creative-commons innovation with disruptive technologies and new business models (DEMOS, 2008)[26].

The extent to which these associations are immune to exceptions is not fundamentally important. What is important is the type of innovation style that will tend to predominate in each scenario given such things as the evolution of technology or consumer preferences. Will, for instance, organic farming be always considered fundamentally in conflict with genetic modification? Will IP-driven innovation still contribute to shaping the car industry in the year 2050? Will the technology in the car sector be disrupted by cultural change, or by e-communications and business models innovating under creative-commons? These questions are moot.

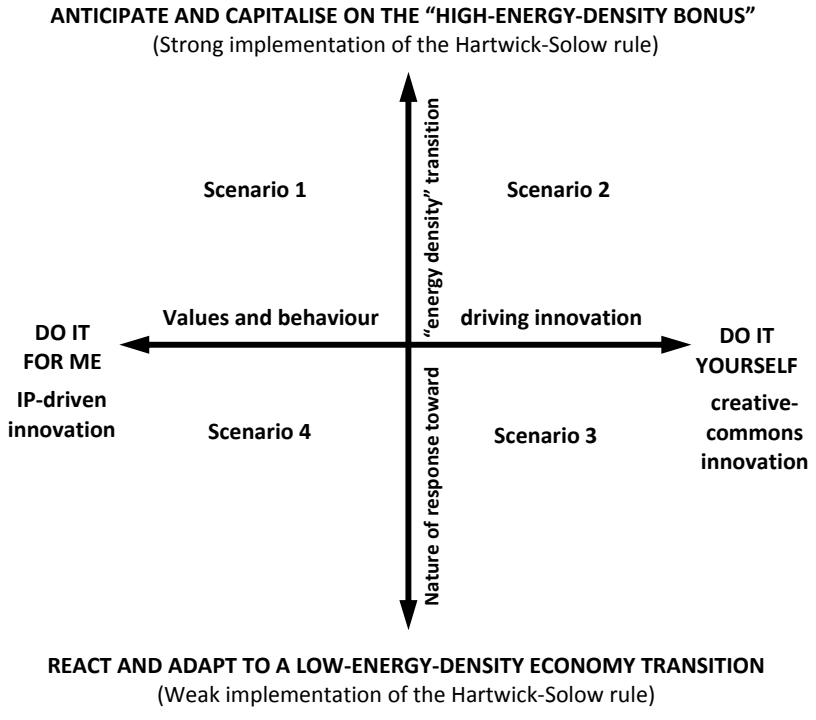

Figure 1.9 Scenario template

[26] See also for example the mission statement of www.opensourceinnovation.org/: *"To live in a world with more humane technologies, where human rights are respected"* [www.tinyurl.com/383poqd]. **NOTE**: long internet addresses are abbreviated in this way: [383poqd]. To access them add prefix, e.g. [www.tinyurl.com/383poqd].

Uncertainty two: will society invest the rents from the "high high-energy-density bonus" in forms of productive capital? (Hartwick-Solow rule)

This second key uncertainty (vertical axis) can be seen in terms of degrees of policy implementation of the Hartwick-Solow rule from "strong" (scenarios 1,2) to "weak" implementation (scenarios 3,4). As explained in an earlier section, the rule lays down that the competitive rents from non-renewable depletion[27] should be reinvested in other forms of productive capital. The result will be sustainability defined as constant consumption (Solow, 1974). Those rents are measured in prices which in a market economy are taken to reflect people's preferences. For this to make sense market failure due to externalities is assumed to have been corrected or considered unimportant, which has been the case for a long time (Simpson, Toman and Ayres, 2005). For the rule to deliver, its policy dimension must be recognised,

> "Always saving and investing the rents arising in the extraction of resources is not what is guaranteed to happen if the determination of savings and investment is left entirely to markets. The [Hartwick-Solow] rule is a policy rule —government needs to see that it is satisfied" (Common and Stagl, 2005, p.395).

The Hartwick-Solow rule makes sense in that "most environmental protection can be regarded as an act of investment" (Solow 1991, p.185). At present, many authoritative studies addressing the low-carbon transition[28], appear to be paying insufficient attention to the finer technical, political and lifestyles implications of a HED-to-LED transition. That is to say, a large scale shift from high-energy-density carriers —e.g. fossil fuels— to those alternative carriers implied by a low-carbon society transition (e.g. electric batteries, pumped storage, ethanol, hydrogen[29]) which typically, store energy at significantly lower densities. For the purposes of framing our

[27] Known as Hotelling's rule (Hotelling, 1931)

[28] The Low Carbon Transition Plan HM Treasury 2009, or Powering Our Lives (Foresight 2009) or HM Treasury low carbon transition plan.

[29] Hydrogen being the most inefficient energy carrier of them all.

scenarios, it was important to address this whole issue in terms of society's ability and foresight to either anticipate or react to the high-energy-density bonus or "grace period" —manifested in the form of fossil fuel endowments— in order to facilitate a smooth transition to sustainability in energy use.

Of interest is the fact that we could only ignore such a "high-energy-density bonus" by taking as given the imminent arrival of a few "game-changing" technological breakthroughs[30]. The physics and chemistry of materials suggests, however, that if such breakthroughs ever come about are unlikely to be technically or commercially feasible in the near and mid-term future (Smil 2006; MacKay 2009).

There is, however, another instance which would render our assumption about a HED-to-LED transition irrelevant to our framework: the fact that a transition to non-fossil energy generation is presented as desirable —or even as inevitable— by institutions, does not mean it will happen by 2050. Replacing the high energy densities of hydrocarbons may well prove too difficult not to postpone (Smil, 2006; Fouquet, 2010). Adopting such a view, however, would have been the matter of a different study.

B) Scenario storylines: these were developed through a multi-source data collection exercise organised by stakeholder type (**Chapter 3** explains in detail the storyline making process). Data were sourced in a variety of ways: a research seminar, the use official statistics on consumer preferences, document reviews, direct observation, naturally occurring conversations, public events, semi structured interviews, TV, press, website and radio coverage monitoring, personal communications. Cars, food and homes were used as topical entry points to our scenario narratives. Additionally, a wide range of institutional reports involving the use of prospective scenarios were used as supplemental material to make storyline contents as robust as possible. These included:

[30] Such as finding a low-entropy way to produce hydrogen or a *"magic"* battery pack capable to bend the known chemistry of battery technology.

- *Alternative Marine Futures* (Pinnegar, 2007)
- *Foresight Futures 2020, scenarios and guidance*. (Foresight 2002).[31]
- *Foresight programme's Tackling Obesities* (Foresight 2007)
- *Forum for the Future's Climate Futures* (FFF, 2008)
- *Intergovernmental Panel of Climate Change Report* (IPPC 2007)
- *Powering our Lives* (Foresight 2008)
- *Retail Futures* (FFF, 2007)
- *Shell's Energy Scenarios to 2050* (Shell 2008)
- *Sustainable Transport Visions: Hydrogen-fuel Cell Vehicles*.[32] (Whitmarsh, 2008)
- *The Chatham House Food Supply Scenarios* (Chatham House 2008)
- *The Mental Wealth of Nations: Mental Capital And Wellbeing* (Foresight, 2008)
- *The Millennium Ecosystem Assessment* (MEA 2007)
- *The State of the Countryside 2020* (CA-DEFRA 2003)

Having looked at the fundamentals of the topic of analysis, the research strategy and the basic aspects of scenario construction, **Chapter 2** introduces a conceptual model of long-run substitution alongside the proof of concept protocol to test it.

[31] This document "was developed, reviewed and revised over the last 3 years by a team of researchers at SPRU-Science and Technology Policy Research, University of Sussex, in consultation with stakeholders from business, government and academia" (p.2)

[32]

2. Model and proof of concept protocol

2.1 Introduction

This chapter develops an "appreciative model" (Nelson and Winter, 1982) of long-run substitutability (as opposed to a formal one). Although this is an appreciative model and as such it is meant to be non-technical, the aim is to understand the relationship between four different "scenario versions" of sustainability and the substitution possibilities that each one is consistent with. It incorporates conventional standard economic assumptions (cf. **Box 1.2)**.

It assumes market failure due to environmental externalities has been corrected producing both, allocative efficiency and a "level playing field" between environment and economic development (Pearce, 1993, p.3). Sustainability is understood in its "weak" (Pearce and Atkinson, 1993) or even "very weak" (Turner, 1993) definition. That is to say, roughly, limits to substitution are not a problem so long as wealth is kept constant over time (Solow, 1986; Hartwick 1978; Pearce, Markandya and Barbier, 1989).

The model is "intertemporal" in that each generation "looks after the next" hence presenting no problem to analysing scenarios to the year 2050[33]. To develop the model we look at the neoclassical definition of capital as *any controllable source of services*. Since not everything that counts as "capital" today may count as capital tomorrow (Pearce, 1991), some additions are made to the neoclassical view of capital in **Section 2.4** (notably the introduction of the "runaway capital" notion).

The model addresses the first and second research questions theoretically. In **Section 2.6** three general substitution mechanisms are delineated: *sustainable substitution*, *runaway substitution*, and *intra-domain substitution*. Final **Section 2.7**

[33] As Pearce and colleagues remind us: "Indeed one of the advantages of understanding sustainability in terms of leaving an inheritance of wealth no less than we inherited is that so long as each single generation does this, no single generation has to worry about generations far into the future. Each generation "looks after" the one that follows. On the face of it, this solves one otherwise intractable problem of deciding how far into the future one needs to look in order to decide how "sustainable" current development activity is". (Pearce, Markandya and Barbier, p.35-36).

contains the proof of concept protocol guiding the analysis carried out in **Chapter 4.**

2.2 An "appreciative" and "contextual" approach to modelling

Our approach to modelling seeks to simulate (and stimulate) our understanding of how different dimensions of capital substitution might be shaped by real world conditions. This will be better appreciated in the future-scenario proof of concept analysis developed in **Chapters 3 and 4**. In producing this model we faced the challenge of having to accommodate complex analysis in a stylised, easy to understand heuristic manner. Our task began by accepting some teaching advice:

> "In making things simple many caveats and complications are glossed over. But everyone has to start somewhere and it is best to get the message across first and make things complicated later on, rather that create a sea of confusion at the outset and hope that some people will swim through it." (Turner, Pearce and Bateman 1994)

Using the above as a guiding principle, this chapter develops a "contextual appreciative model" of long-run substitutability between three categories of capital, physical, human and natural as denoted by Pearce and Barbier (2000). The model is "contextual" in that it seeks to provide a basis from which to understand how different dimensions of analysis —as they appear in the literature on substitution— might interact to deliver logical, self contained "empirical" realities[34]. It is implied that such realities involve economic, cultural, political and technological aspects.

The model put forward is "appreciative" —as opposed to "formal"— in that theoretical ideas, variables and modes of explanation are used flexibly and more as a means of organising analysis. This form of analysis may in turn be shared, supplemented and discussed by people in audiences without an economics background (Nelson and Winter, 1982). **Box 1.1** in the previous chapter captures the differences and

[34] The word "empirical" is used as a metaphor and insofar as the future scenarios we shall use can be said to contain "experiential" or "observable" material.

advantages offered by appreciative approaches to theory. Appreciative modelling is particularly suitable when our purpose is to understand theory and empirical reality together. This form of modelling is considered useful, for instance, by the technological transitions and systems innovation research community (Geels 2005); where formal economic analysis has been insufficient given the multidisciplinary character of both, the topic and the community of people investigating it.

Our appreciative model is also "contextual" in that it is designed to translate any narrative (including the scenario storylines used in this study) into a corresponding capital substitution pattern faithful to the storyline.

Although our model is not a formal economic one, it nevertheless keeps a close distance and builds upon conventional economic concepts and axioms with regards to substitution (i.e. welfare economics). It also builds upon the environmental and ecological economics literature on the various limits to substitution (reviewed in **Chapter 1**).

Our model starts with the neoclassical conception of *capital*, which at least since the late nineteenth century has been revolutionising the way economists understand human activity in relation with the natural resource base.

2.3 The neoclassical definition of capital

The neoclassical definition of capital is: *all controllable sources of services.* In more detail:

> "[capital is] anything which yields a flow of productive services over time and which is subject to control in production processes" (Herfindahl and Kneese 1974, p.68)

There are three important ideas to emphasize from this definition, particularly from a historical perspective:

- It introduces and links the idea of *control* to that of capital.
- It *expands* the domain of what qualifies as capital,
- It implies a higher degree of *substitutability* between "capitals"

Firstly, under the above definition, capital has a meaning insofar as it can be *controlled* for productive purposes. As we shall see, this has important implications for substitutability and also for our model which introduces the notion of uncontrolled capital or "runaway capital". This has the purpose of allowing our model to address *intended* as well *unintended* aspects of sustainability, which have long been mentioned in the literature by many authors (Stern D. 2004; Shove and Walker, 2007; Neumayer 2009, Norgaard 1985, O'Riordan, 2004). Worth noting is that the problem of control in economics is not a new one, it was raised by Hamilton (1919) early in the twentieth century as control pertains to *institutions*[35].

The **second** aspect to note about the above neoclassical definition of capital is that it expands the domain of what can be considered as capital. Because it leaves behind the distinctions between capital, land and labour typically made by classical economists, just about anything can be turned into capital provided it can be controlled to yield services people want. It is perhaps worth reviewing in more detail how Herfindahl and Kneese explain such a conceptual "jump" in economic history,

> "At one time, [classical] economic theory divided the sources of productive services into three parts —labour, capital, and land. Part of the justification for this division lay in the belief that the supply conditions were quite different […] with the coming of marginal productivity theory, economists realized that these distinctions were artificial, and that instead of thinking of three sources of productive services, it was more useful to think of many different kinds of productive services, each of them homogeneous and having its own marginal productivity […] these considerations lead to the general definition of capital." (Herfindahl and Kneese, 1974. p.67-68. Emphasis in the original).

The reason why this conceptual jump is important is because with the "marginalist revolution" the labour theory of value was abandoned and a commodity's price was seen not as a measure of its embedded labour cost but of its relative scarcity[36]

[35] Hence the label "institutional economics". A perspective which although it has influenced this study, has not be employed as a conceptual footing.

[36] As opposed to its *absolute scarcity.*

(Pearce and Turner 1990). Such an abstract understanding of what constitutes capital has led economists to justify axioms with regards to a wide range of capital types, such as "human capital" "social capital" (Pearce et al 1989) "intangible capital" (Hamilton et al. 2004) but also some seemingly strange varieties probably never imagined by classical economists, such as "euphoric capital", "success capital" or "music appreciation capital" (Stigler and Becker, 1977).

There is an important link to be noticed between these extensions to the idea of capital and the axiom of consumer preferences underpinning welfare economics[37]. The latter extensions to capital have been used by economists such as Stigler and Becker in the 70's to further strengthen the axiom of consumer preferences as something fixed and stable (op. cit.), an axiom which has been much criticized by ecological economists (Common and Perrings 1996) some of whom have argued for community sovereignty in place of consumer sovereignty (Costanza 2004).

As we shall see, this debate is taken into account —at least partially— and some concepts integrated into our model.

Thirdly, Victor (1991) has crucially suggested that the neoclassical definition of capital not only implies more substitutability, it also brings nature into question, for the first time in history, to provide for human needs and development.

> "[The neoclassical idea of capital] implies a high degree of substitution not only between different types of manufactured capital goods, but also between these capital goods and resources. This is important since the easier it is to substitute manufactured capital for depleting resources or a degraded environment, the less concern there need be about the capacity of the environment to sustain development." (Victor, 1991 p.194)

The (intertemporal) model seeks to contextualise long-run capital substitutability by using a set of future scenarios to the year 2050, in order to do this, our model does not go as far as to include notions of "euphoric capital" or "success capital", it nevertheless draws instead on Pearce's (2000) classification of

[37] Hence environmental economics and its treatment of the idea of wellbeing (as in Bateman et al 2010)

capital as: physical capital (machinery and infrastructure), human capital (knowledge, education, innovation and skills) and natural capital (natural resources and sinks).
While these categories of capital are comprehensive enough to take an analysis of substitution forward, they also fall short analytically because the subcategories they involve (e.g. education) are not homogeneous. That is to say, investing in education per se will not lead inevitably to the attainment of sustainability goals, as is commonly assumed by institutions (World Bank 2003).
The finer public discussion of what type of education is consistent with a sustainable society is not yet a significant debate within the economic analysis of sustainability. Notwithstanding this apparent shortcoming in economic science, if our appreciative model is to capture long-run substitution possibilities it must be able to capture the duality between what has been indentified in the literature as intended and unintended aspects of sustainability (O'Riordan 2004; Stern 1995) and how they affect our analysis about substitution.

2.4 Additions to the neoclassical view of capital

Sustainability as intended plus unintended actions and events

In what follows we introduce some distinctions to the neoclassical notion of capital. We explain how they are useful to our model and how they can assist us to characterise both *intended* and *unintended* aspects of a sustainability transition in ways that might be relevant to economic analysis and theory. Certain aspects of un-sustainable development can be usefully characterised in terms of capital which appears to be no longer under control (e.g. non-optimal pollution), or has never been but we sometimes would like to have under control (e.g. biodiversity, pests, the global climate).
In strict terms and according to our neoclassical definition, capital that is not under control — in a sense "runaway capital"— cannot qualify as capital. To be considered as such in our model capital needs to fulfil the requirement of being

subject to human control for the purposes of yielding sustainable services. The apparent significance of this is that, strictly speaking, large amounts of "wealth" no longer qualify as capital in the context of the economic analysis of wellbeing as they often lead to some sort of "production failure".
For the purpose of modelling long-run substitutability, we are labelling this ambiguity in capital as "uncontrolled capital" or "runaway capital". The introduction of these exploratory concepts requires some explication.

Some capital inputs might be more sustainable than others

Production processes in modern economies have become very complex and, technically speaking, the range of things that qualify as "capital" has been widening, perhaps faster than we can understand the changes they bring about, *natural capital* being an exemplary case (Victor 1991). Adam Smith most likely never imagined a world economy where "intangible capital" would eventually be accorded the status of the main wealth of nations (World Bank 2006). Smith thought instead, that

> "The sovereign, for example, with all the officers both of justice and of war who serve under him, the whole army and navy, are unproductive labourers […] In the same class must be ranked, some both of the gravest and most important, and some of the most frivolous professions: churchmen, lawyers, physicians, men of letters of all kinds; players, buffoons, musicians, opera-singers, opera-dancers" (Smith 1971 [1776], p.314)

The economic conceptualisation of wealth has evolved from this seemingly extreme view from the father of economics, to another seemingly extreme view, where knowledge as wealth reaches the status of "light",

> "Knowledge is like light, weightless and intangible, it can easily travel the world, enlightening the lives of people everywhere" (World Bank, 1999 p.1)

These two polarised conceptions of capital and wealth suggest at least the need for a less homogenous treatment of certain categories of capital. For instance, categories such as "knowledge capital" and "human capital" are used today to "pigeonhole" under a single label the wider notion of "culture". There are many types of knowledge, and some seem better than others for certain purposes. The need for a less homogeneous treatment of knowledge capital is supported by a large body of literature on the role of knowledge and education in sustainable development (Murdoch and Clark 1995); it is also supported by ecologists who question the idea that knowledge in society *per se* will contribute to benign environmental outcomes (Ehrlich 1999); economists themselves often hint at the necessity to recognise the heterogeneous nature of knowledge capital, Stern (1995), and human capital, Pearce (1997),

> "Sustainable development is as likely to be threatened by the collapse of social norms as by environmental problems —i.e. some social capital is also "critical". (Pearce 1997, p.296)

The need for a more heterogeneous view of knowledge capital is also made apparent in the literature on the role scientific knowledge for sustainability (Stirling 2009). In the broader context of the social appraisal **Table 2.1** exemplifies the many different routes by which scientific knowledge is an *essential* but not a *sufficient* condition for the governance of knowledge. It illustrates how knowledge capital cannot be seen as an isolated, self-contained domain, it needs to be understood in the context of institutions and their legitimate use and power.

The same need for a heterogeneous view of capital might be seen for the case of physical and natural capital. Not all physical capital assets are in themselves "good" to attain sustainability. That is to say, not all capital goods in the form of infrastructure, for instance, can be said to be under human control for the purpose of producing services which enhance human wellbeing —as our definition of capital lays down.

Table 2.1 Key linkages between sustainability, science, precaution and participation. The implications of power in processes of governance and social appraisal

GOVERNANCE CONCEPT	Emphasis in social appraisal (ways in which sustainability can be understood)		
	Substantive imperatives driven by outcomes	**Normative principles relating to process**	**Instrumental pressures exerted by power**
Sustainability	Evaluates outcomes according to publicly deliberated, reasoned social goals: human wellbeing, social equity and environmental quality	Attention is directed at the institutional and procedural aspects of sustainable governance such as equity, transparency, accessibility, agency, and representativeness	A legitimation discourse substitutes publicly reasoned goals of Sustainability with the aim to simply sustaining privately favoured features of the status quo
Science	Strives to maximise theoretical robustness and empirical reliability, thus minimising error and contingency in associated decision outcomes	Aspires to Mertonian and Popperian norms such as universalism, disinterest, scepticism, communism, peer review, falsification, experiment, transparency, collegiality and learning	The language of sound science and evidence-based or science-based decisions denies the crucial roles of subjective interests and values in framing appraisal
Precaution	Prompts appropriate consideration (rather than neglect) of more intractable aspects of incertitude over outcomes: uncertainty, ambiguity and ignorance, as well as risk	Broadening out of appraisal addresses a diversity of pros (as well as cons); effects ; options (at earliest stages) and perspectives; with an emphasis on monitoring, flexibility and reversibility	Treated simply as a decision rule, conceals latitude for interpretation in appraisal of key concepts such as threat, seriousness, reversibility or scientific certainty
Participation	Allows systematic rigour in validating the "framing" of evidence and analysis and exploring the implications for outcomes (just as science validates the data and methods themselves)	Opening up of appraisal fosters greater accountability in policy making by presenting information and advice in plural and conditional, rather than unitary prescriptive fashion	Provides a means to weak justification aiming at consent, trust, credibility, blame management, and strong justification aiming to secure specific desired outcomes
Governance	Aims at reflectiveness in that a broad range of inputs to appraisal build a complete picture of the full range of possible governance interventions and their respective broad consequences	Aspires to reflexivity in that appraisal outputs convey the ways in which results are conditioned by (and co-constructed with) the different governance interventions they supposedly inform	Displays an unreflective stance, in that there is little effective deliberation or "public reasoning" in appraisal over normative aims or wider substantive consequences associated with governance actions

Source: Adapted from Stirling (2009)

If indeed there was control over all physical infrastructures and the vast amounts of energy they depend on, no global calls for sustainable development would have been made in the first place (WCED, 1987). In a similar analogy, not all "natural capital" can be subject to control to produce services for a market. As pointed out by Victor (1991), the category of

"capital" implies an origin in human action, and this in itself is a highly problematic attribution when applied to the natural environment:

> "In referring to the environment as capital, there is the implicit assumption that it can be substituted by other forms of capital, that it is reproducible and that it is there to be managed in much the same way as manufactured capital" (Victor 1991, p. 210)

Victor's observations are also extendable to issues of control. That is, what is conventionally known as "natural capital" in environmental and resource economics can hardly be said to be subject to control in the same way as man-made capital is; and in those few instances when natural capital is indeed assumed to be subject to control (e.g. natural parks, farmland) important market failures for many ecosystem services such as clean air or insect pollination, are almost inevitable (Sedjo and Simpson, 1995). In other words, a substantial part, if not most, of what we want to call natural capital today —because of the implicit contributions that it makes to human wellbeing— is unlikely to meet the requirements of a neoclassical definition of capital. Therefore, there is a need to adopt into our model of long-run substitutability a less homogeneous view of capital attributes.

A focus on capital inputs

Modern economic analysis partially captures issues of control over the environment in terms of market failure, negative and positive externalities or spillovers. The focus is almost inevitably on the *output* side because the economy itself is seen as a lineal process with clearly identifiable inputs and outputs. That is to say, the capital inputs to production processes in general —whether we are talking about raw materials, education, or infrastructure— appear to be treated mostly as having neutral attributes and effects over the environment and sustainability in general.

The environmental problem is seen rather as a question of negative output management (pollution abatement), the

correction of market failure (valuing nature) and the implementation of green taxes and other market-based instruments (Pearce and Barbier 2000).

In a certain sense, the economic analysis of clean sustainable production still bears a strong bias towards the "end of pipe" approach. What our exploratory notion of uncontrolled "runaway capital" seeks to characterise is the *input* "production failure" side of the problem, where some "runaway capital goods and services" often appear as if they had an inbuilt capacity to yield "services" which are commonly associated with unsustainability. Examples abound depending on whether we refer to physical, natural or human capital.

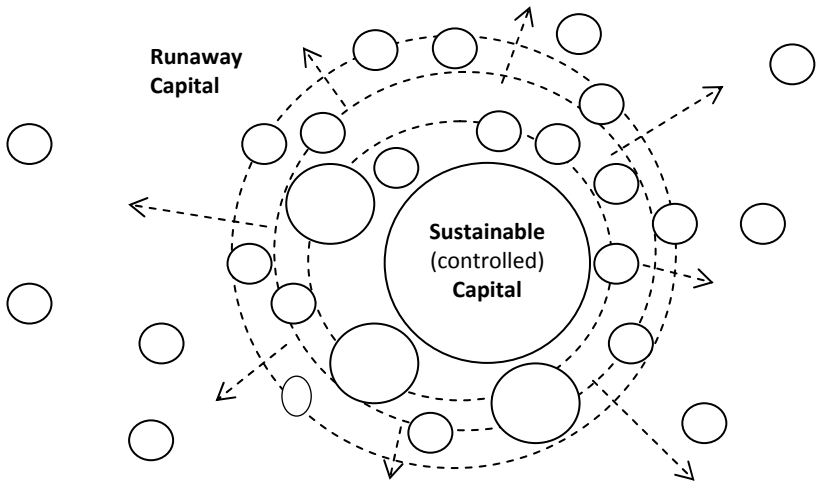

Figure 2.1 "Sustainable capital" and "runaway capital", not all capital inputs might yield "sustainable" services

How to identify such forms of capital is discussed below; the point so far however, is that a distinction between "controlled capital" and uncontrolled or "runaway capital" appears at least worth exploring through our model both in terms of capital means and capital ends. For the sake of conceptual clarity, we shall take the notions of "controlled capital" and "sustainable capital" to mean the same hereafter **(Figure 2.1)**.

The idea of "runaway capital" as a cause of unsustainability on the input side builds upon parts of the environmental and ecological economics literature which have sought to represent

the economy as a circular rather than lineal process and where clear distinctions between capital inputs and service outputs, or between productive investment and wasteful consumption are not seen as necessary as they are in formal conventional approaches (Pearce and Turner 1990; Ayres and Warr 2009; Georgescu-Roegen 1970).

When it comes to the environment, we do not know what we do not know (Ehrlich et al., 1997) and insofar as that continues to be the case, controlling nature in evolution seems difficult, unlikely, and as some economists and philosophers would argue, perhaps undesirable (Norgaard 1985; O'Neill 2009). Analysts studying the economics of managing biotechnologies and biological resistance understand the difficulties of human control over nature with exemplary sophistication (Regev, 2002; Swanson, 2002).

Welfare loss as "runaway capital" or capital depreciation

It is at least arguable that looking at aspects of capital control is a useful way to characterise intended and unintended aspects of sustainability. Taking these ideas into account, our model introduces the notion of *controllable capital* (K) —or just *capital*— in contrast with that of *runaway capital* (R); the latter being a generic label we shall use to identify capital which results in some sort of "production failure", *welfare loss,* and ultimately unsustainable development.

The idea of "runaway capital" is comparable to the idea of *capital depreciation* put forward by Pearce (1993), however, whilst all capital that depreciates could be seen as runaway capital, not all runaway capital necessarily implies "depreciation". In any case it does not seem an accurate a term to describe the dimension we are trying to capture. This might be better appreciated in the hypothetical examples which we are about to give. **Figure 2.2** shows *runaway human capital***,** —e.g. influential ideas and knowledge that go undebated in society; *runaway natural capital* of which "obesogenic environments" might be a good example (Foresight 2007).

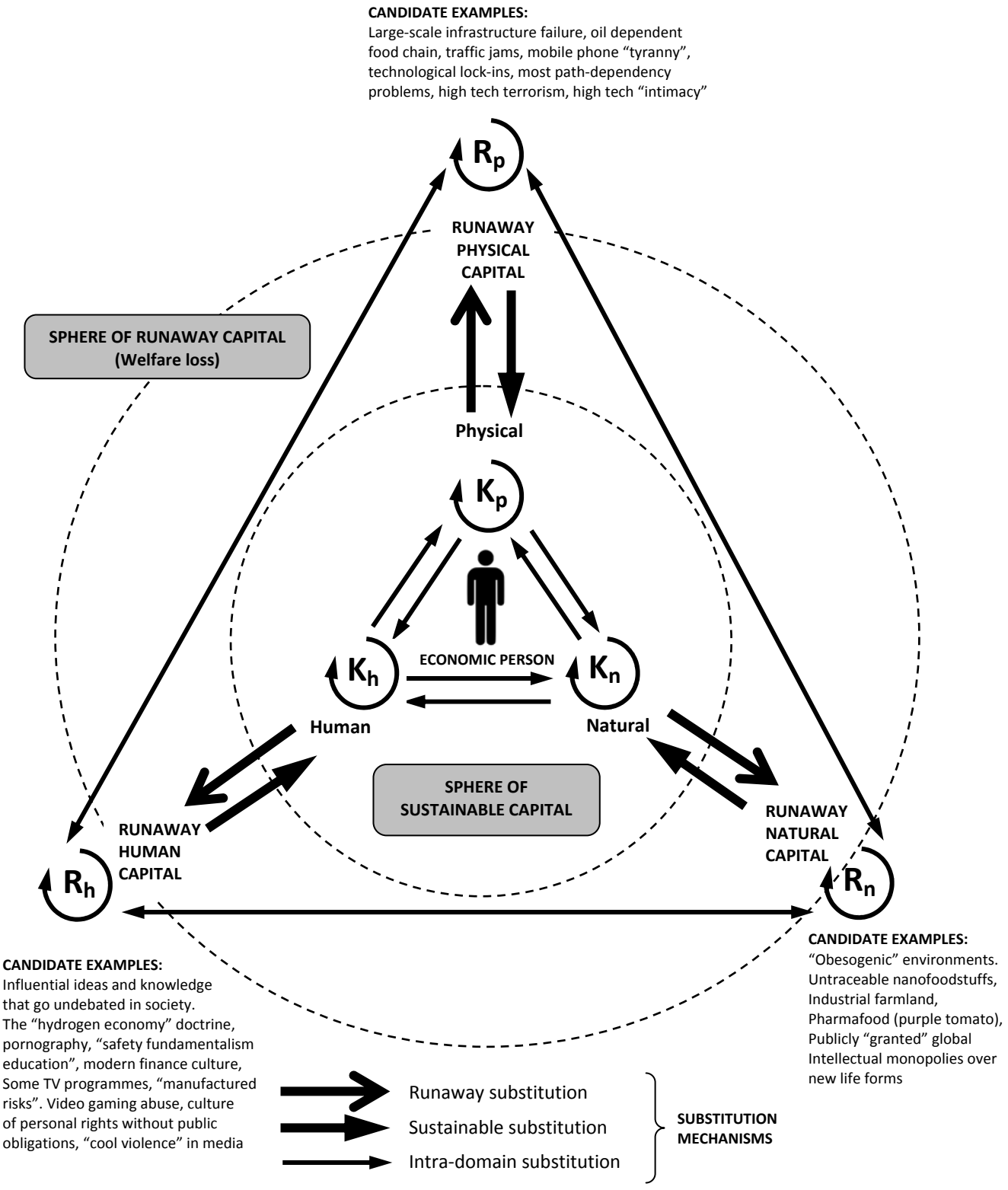

Figure 2.2 – The substitution triangle: substitution takes place between the spheres of "sustainable capital" and "runaway capital". People can freely express their preferences about services yielded by capital but not about those yielded by runaway capital. In this way, the figure is meant to capture intended and unintended aspects of sustainability. The first two substitution mechanism (e.g. controlled and runaway capital substitution), are the focus of this model. This is because said mechanisms arguably represent critical transitions at the human-nature interphase.

It also shows *runaway physical capital* comprising such things as large infrastructure failure and many technological path-dependency problems. Meanwhile, technology can be considered the added result of human and natural capital together. Alongside our three-tier classification of capital, **Figure 2.2** includes the three principal substitution mechanisms represented by different arrow shapes (and explained in a following section).

At the centre of the substitution triangle is economic person who is both a producer and consumer with individual preferences but without necessarily neglecting the possibility of accommodating other analytical perspectives such as "public preference" analysis (Georgiou et al. 2001) or "community sovereignty"[38] (Costanza 2000) in a modern economy. Many environmental problems, consumer dissatisfaction and welfare loss, can be usefully characterised as the result of large amounts of physical capital goods initially meant to yield services for beneficial human ends which go partially or thoroughly "out of control" in subsequent stages.

Out of control is meant to imply in this case, no longer yielding the wellbeing-related services they were supposed to yield, and yet delivering outcomes for which there are incomplete, erratic or questionable consumer preferences (Costanza 2000; 2004). As we can see in the **Figure 2.2**, these "runaway capital goods" can be seen tangibly in the form of non-optimal pollution (Pearce and Turner 1990), traffic jams, eroded agricultural land, and generally speaking all those man-made infrastructures in the built and natural environments whose contribution to the wellbeing of people has become questionable or sometimes clearly unsustainable, as in the case of hydrocarbon-dependent industrial agriculture.

The corollary in reviewing the foregoing issues is that people can freely express their preferences about services yielded by capital but not about those yielded by runaway capital. For exemplary real-world case of how different substitution interactions between sustainable and runaway capital often result in systemic welfare loss (i.e. outer circle in **Figure 2.2**), let us refer to *obesity epidemics,* a truly complex phenomena whose

[38] As opposed to consumer sovereignty

causality and consequences cannot be studied comprehensively by any academic discipline alone. See **Figure 2.3**

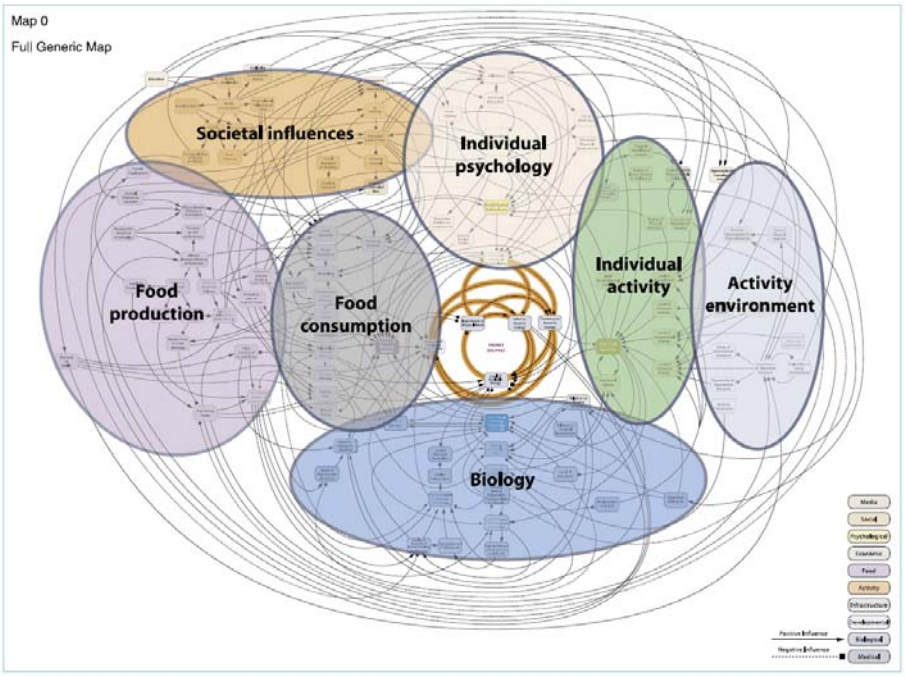

Figure 2.3 – The complex causality of obesogenic environments as an example of systemic welfare loss or "runaway capital" Source: Foresight (2007)

In terms of capital substitution however, it is possible to translate obesity epidemics into its various overlapping tangible and intangible "runaway substitutions". For instance, it is arguably the case that many people become obese when the substitution of motor cars (Rp) and mechanised food production and retail (Rn) for human physical activity (Kn) and for certain values and social norms (Kh) takes place on a regular basis. These can be translated into a hypothetical pattern:

(Cars substitute for physical activity)	**Rp > Kn**	Substitution pattern for obesity (hypothetical)
(Cars substitute for values and norms)	**Rp > Kh**	
(Industrialised food chain substitutes for physical activity)	**Rn > Kn**	
(Industrialised food chain substitutes for values/social norms)	**Rn > Kh**	

The Foresight report *Tackling obesities* (2007) suggests that a sustainable pathway for modern society will necessarily involve policies aimed to:

> "Creating an environment that better suits our biology" (op. cit. p.1).[39]

It is not clear that consumer preferences will be a solution to the problem of obesogenic environments. Research suggests quite the opposite in fact. An *obesogenic environment* is a place where people appear to have little control over what they eat, how they work and commute to work, what technology they use, how they use it, how they interact socially, how many hours they sleep, what media messages they receive or how to process them (Foresight 2007). In other words, obesogenic environments offer obese individuals almost no opportunities to control their own lives. And what could be said about the "obesogenic society" in general?

At a wider level, it has been argued that the aggregated effect of technological production across societies overtime often produces unintentional effects and patterns which are not always subject to human control (Schmidt, 2008; Foresight, 2007). Some technology patterns — e.g. computer network disruption, large scale infrastructure failure,— seem to fit that description.

Notwithstanding the fact that technological innovation is frequently "portrayed without qualification as self-evidently good" by institutions (Stirling, 2008, p.264), some aspects in the way technology and certain infrastructures are evolving seem no longer aligned to human biological evolution. Consider page 5 of UK's Foresight final governmental report *Tackling Obesities*, which contains a rather intriguing statement:

> "The pace of the technological revolution is outstripping human evolution" (Foresight 2007 p.5).

Furthermore, obesity should be seen, according to the report, as one of the penalties of the modern world,

> "We evolved in a world of relative food scarcity and hard physical work – obesity is one of the penalties of the modern

[39] The full reference is as follows "Creating an environment that better suits our biology and supports us in developing and sustaining healthy eating and activity habits is a challenge for society and for policy makers. It's not simply a health issue, nor a matter of individual choice". (op. cit. p.1)

> world, where energy-dense food is abundant and labour-saving technologies abound". (op. cit p.1)

The Foresight programme ran for several years and it involved the work of hundreds of scientists. Its 2007 report is rich in insights containing what seem far reaching implications for almost any discipline or area of intervention we happen to be looking from. This is not an accident, judging the situation from **Figure 2.3** it is possible to see how obesity epidemics sits right across numerous converging phenomena for which vast theoretical lacunae still exist. Its rise as a worldwide epidemic seems to reassert our species' position of sheer ignorance about how we interact, not only with our natural, but also with our technological, built and cultural surroundings.

Welfare loss associated with obesogenic environments has a complex chain of causality always resembling the "chicken and egg" parable. Consider many of the "neutral" contents in commercial television or in public education which often end up perpetuating "cowboy economy" lifestyles and ambitions, at once delaying efforts to steer a course towards sustainable consumption patterns in society (Coombs 2001, Jackson 2005, Boulding 1965). The famous "hidden persuaders" thesis in advertising was one of the first studies in a long tradition in academic research committed to understand and often question the role of advertising in a free society (Packard, 1954-1991). It is not a coincidence that some environmental economists too, have wondered "whether taxes on advertising are required" (Turner 1993, p.386).

Whether educational institutions and other "human capital developers" are doing their part to educate free individuals who prefer more sustainable lifestyles is something which can be at least compared against some official statistics: people in the UK throw away as much as 30% of the food they buy (UK-Cabinet-Office, 2008) and yet as many as three quarters of them will become obese by 2050 if current trends continue (Foresight 2007).

Meanwhile, statistics also suggest that American energy companies invest less in research and development than the pet-food industry (Friedman 2010). Are these indicators evidence that societies are in full control over their human

capital for the purpose of delivering wellbeing? The room for scepticism seems plentiful. It appears that rather than one type of human capital there are various types of human capital; some of which seem to contravene the goals of sustainability. As Robert Solow has commented in a recent interview,

> "We, by we I mean economists who talk about this sort of thing tend to think of education as "a thing", whereas there are lots of kinds of education, we tend to measure education by input not output, […] instead of worrying so much about quantities of education we ought to be thinking about the content of education, what is it that students need to know […] Our natural measure of our success in generating an educated population is the fraction of the age group that is in college, I would be very interested in other kinds of post secondary education that are skill-based, vocational education that will equip people for the jobs that are likely to be available. That's going to require that employers be involved in the planning of that sort of education, for this country and perhaps for much of the world, that's a whole new idea."[40]

People in general are constantly exposed to media messages and conversations "in plain English" containing what appear to be lay insights about the state of consumer preferences with respect to wellbeing and environmental protection; a topic which is not new in the ecological economics literature (Costanza 2004; Stern 1995; Common and Perrings 1995). Some of these insights—one has to admit— often challenge established scientific observation and methods: "cars and screens are making people fat and lazy", "mobiles have made people less punctual and less formal", "I am no longer going out with her but with her and her mobile" "household dogs are substituting the need for children", "for some people club-cards and brand loyalty are like having friends and family", "online relationships have replaced real face-to-face interaction", "shopping has defeated politics". The list goes on and on, and each one of these examples at least partially reflects a world which different authors have attempted to characterise. Two of such attempts include Dubos' "man adapting" concept back in the 1960s (Herfindahl and Kneese, 1974) where people's tastes

[40] www.tinyurl.com/3j6a9e6

may often adapt at the expense of their own best interest or even survival, and Beck (1992) and Giddens' (1999) idea of a "risk society".

> "A world which lives after nature and after the end of tradition is one marked by a transition from external to what I call manufactured risk. Manufactured risk is risk created by the very progression of human development, especially by the progression of science and technology. Manufactured risk refers to new risk environments for which history provides us with very little previous experience. We often don't really know what the risks are; let alone how to calculate them accurately in terms of probability tables." (Giddens, 1999, p.4)

Out of the risk society literature emerges the concept of *reflexivity* (Beck, 1992). This concept, alongside that of public dialogue (Costanza 2000), are key to establishing a first conceptual difference between controllable and runaway capital. **Table 2.2** shows some speculative examples of sustainable and runaway capital. Sustainable capital is shaped by a social process of public dialogue and reflexive governance (Stirling 2009). Quite in contrast, runaway capital is characterised by the absence of such process. We now turn to a second criterion to differentiate between sustainable and runaway capital, the economic one.

Table 2.2 Speculative examples of *sustainable* and *runaway* capital where the role of social process is key. The purpose of this table is to illustrate schematically the wide ranging potential for analysis, rather than the particular discussion implied by each of the examples chosen.

	SUSTAINABLE CAPITAL (Speculative examples)	**RUNAWAY CAPITAL** (Speculative examples)
Shaped by	Shaped by social process of public dialogue and reflexive governance	Shaped by processes outside social dialogue and reflexive governance
Human (Kh)	• Medical knowledge • The sciences, natural and social • Cooking with and for dignity • Cultivation • Sports, arts, music, spirituality • Social relations and organisation • Reverence, love, forgiveness • Community patenting /brands • Agriculture, brewing, curing	• "Safety fundamentalism" culture • State-granted intellectual monopolies • The "hydrogen economy" doctrine • Modern finance culture • Controversial bioscience research • "Want-to-have-one"s-own-cake-and-eat-it" fads and purchasing culture • Culture of personal rights without public obligations
Natural (Kn)	• Non-obesogenic workplaces • Un-bottled safe drinking water • Penicillin • Kinship • creative-commons tomato seeds • Perennial seeds and plants • Some farmland	• Obesogenic environments • GMO pollution • Critical natural capital • Evolutionary resistance of pests • Industrial farmland, • Nanofoodstuff, • Pharmafood (purple tomato) • Intellectual monopolies over life forms
Physical (Ki + Kn)	• The internet (some aspects of) • Electricity generation • Bio char • Quality of life improving internal combustion engines • creative-commons wind turbines • Bicycles • Mobile communication	• Wind-farm infrastructure failure • Oil dependent food supply systems • Car use and dependence • Obesity epidemics (aspects of) • Dirt cheap mobile phone tyranny • Computer viruses (a business) • Technological lock-ins • Other path-dependency problems • High-tec terrorism • High-tec "intimacy" • Mobile phone "tyranny"

A "level playing field" for asset valuation

Although it is true that "the most desirable feature of the price mechanism is that it signals to consumers what the cost of producing a particular product is, and to producers what consumer's relative valuations are." (Pearce, Markandya, Barbier, 1989, p.154); it is arguable that such a mechanism may be disrupted by monopoly pricing (Boldrin and Levin, 2008) whereby the pricing mechanisms that are used to value man-made and natural capital may be inconsistent and incompatible. Underlying some arguments made in the literature is the idea that if consumer preferences are to remain substitutable in the long run, scarcity-related relative-price increases for environmental goods and services need to be taken into account (Sterner and Persson, 2008; Hoel and Sterner, 2007). Amidst discussions about "weak" and "strong" sustainability (Neumayer 2009), some critics suggest, for instance, that the difficulty with understanding future substitutability across capital types boils down to changes in relative prices over time (Mäler, 2007). Prices are relevant to substitutability because they play a central role in conveying information about scarcity (Pezzey and Toman, 2005), however, since sustainability relevant prices are very difficult to anticipate for the long run case (Stern, 1995) prices may indicate some scarcity only to the extent that a level playing field of compatible pricing mechanisms at the micro level is ensured so that at least some relative and absolute scarcities are captured by consumer preferences (Baumgärtner et al. 2006).

To make sense with the assumption that sustainable development is feasible, future substitution possibilities, — understood as society's relative valuation of man-made and natural capital (Pearce, Markandya, Barbier, 1989)— are likely to require a level playing field between nature and the economy, at least at a macro level:

> "[…] there is no level playing field between environment and economic development. Until the economic value of environmental quality is an everyday feature of the way we compute progress and, more importantly, the way we make

> economic decisions, then this imbalance will not be corrected and the environment will not be given a fair chance. That is why economic valuation is important." (Pearce, 1993, p.3).

Thus, at a macro level "a level playing field" means valuing nature, (i.e. people's preferences about changes in the environment). However, at the micro level, a level playing field could mean various things. It could mean that pricing errors and distortions be avoided and that relative and absolute scarcities be equally considered. Fisher and colleagues (2008) argue, for instance, that in valuing ecosystem services double counting errors should be avoided. This suggests that valuation is likely to increase in sophistication and rigour in the future. If this is true, a "level playing field" at the micro level may also imply paying better attention to property rights. Environmental economists have observed for a long time that:

> "Due to a lack of inadequate (or absent) property rights regimes which ensure that resource values can be practicably appropriated, ecosystem services are assigned to little or zero value and weight in policy decisions." (Turner, Adger and Brower, 1997, p.61)

Environmental assets tend to be undervalued in the absence of effective ownership (Barbier 2001). Such an *undervaluation* may often go hand in hand with the relative *overvaluation* of man-made assets via monopoly pricing (Boldrin and Levin, 2008). Such an interaction of assets where "the worst of both worlds" comes together, presumably damages those conditions under which individuals should be making free choices. This suggests that a "level playing field" at the micro level could also be characterised in our model as follows. Since the pricing mechanisms employed to impute values to man made and natural capital are often inconsistent, a sustainable society where individuals freely-express their preferences requires that pricing mechanisms meet at least some minimum standard of consistency if they are to reflect some of the *relative* and *absolute* scarcities of environmental goods and services that individuals need to perceive when making choices (Baumgärtner et al. 2006). Some authors have long stressed the importance of considering valuation in terms of the efficiency gains and the

relative rates of return that environmental assets can yield under "normal" yet often disadvantageous market conditions.

> "Any decision to "hang on" to natural capital therefore implies an opportunity cost in terms of forgoing the chance to invest in alternative income-yielding assets, such as […} factory plants, machinery buildings […] education, job training […] art treasures, financial assets or even wine, which could also be considered alternative economic assets to natural resources. [But] if natural resources are to be an "efficient" form of holding on to wealth, then they must yield a rate of return that is comparable to or greater than that of other forms of wealth. In other words, natural resource depletion is justified up to the point where the comparative returns to "holding on" to the remaining natural capital stock equal the returns to alternative investments in the economy. If the latter always exceeds the former, then in the long run even complete depletion of natural capital is economically "optimal" (Barbier, 1994, p.54)

With the above elements in mind, **Figure 2.4** identifies nine potential "playing fields" or asset valuation scenarios between natural and man-made capital and where some scenarios are more level than others.

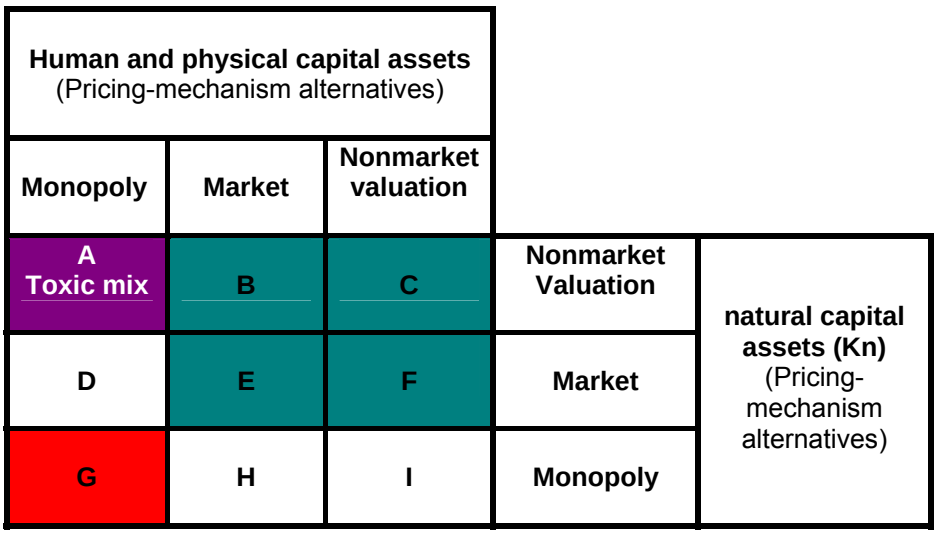

Figure 2.4 Pricing mechanism scenarios; where some assets are overvalued by the market due to monopoly pricing and others undervalued due to absence of effective ownership (i.e. environmental).

In this simplified picture of reality, two groups are distinguished, natural capital on one side and man-made

capital on the other (i.e. physical and human capital). Capital assets in general can be valued according to three principal types of pricing mechanism alternatives: monopoly pricing, markets, or non-market mechanisms (e.g. contingent valuation). Green cells (B,C,E,F) represent scenarios where pricing mechanisms are consistent in relation to one another whilst the rest represent scenarios where pricing mechanisms lead to "pricing distortions" away from the market mechanism (therefore "not compatible" with sustainability).

In our model pricing distortions occur when some assets are overvalued by monopoly while other assets are undervalued due to the absence of effective ownership. In both cases, "pricing distortions" away from the market mechanism make it harder for (future) individuals to express their preferences freely, for instance, they may be forced by law to pay monopoly prices. G,E and C are scenarios where valuation mechanisms across capital types are —in principle— fully compatible, yet presumably most economists would argue that scenario "G" (in red) is to be avoided because an economy where all capital assets are monopoly priced is not a scenario people or economists would prefer.

Although a scenario such as "G" may not seem plausible today, it may become so in the future, —e.g. technical means to "monopolise" man-made or natural assets via TPM or TPS[41] already exist (Oppenheim, 2008), and patents applications over life forms are already a reality (Smith et al. 2003)[42]. Many people would oppose a scenario such as "A" (the "toxic mix") arguing perhaps that it would imply unprecedented undervaluation of nature alongside unprecedented overvaluation of man-made capital (and in passing undermining the possibility of any level playing field for preference formation). In contrast with the previous two scenarios, C,B,E and F (in green) would be regarded by many as consistent with sustainable development goals. The relevant issue for the model is that pricing mechanisms need to be compatible in the long run for preference satisfaction to be a measurement of wellbeing rather

[41] Technical protection systems (TPS) and technical protection measures (TPM). Tangible or intangible monopoly is achieved making it hard for consumers to be aware of it.

[42] US Pat. App 11635355 - Filed 6 Dec 2006. http://tinyurl.com/6fqdn6m

than an indicator of "runaway capital". As we shall see later on, these are aspects which will be integrated as part of a systematic way to differentiate between sustainable and runaway capital in real life (scenario) settings. To round up the argument, although it is true that the price mechanism ideally tells consumers what the cost of producing a particular product is, and to producers how consumers value products, such mechanism is likely to be disrupted in scenarios A,D,G,H,I leading to "runaway capital". Sustainability prices and market prices, even in the absence of monopoly, have long been seen as problematic as suggested earlier in the introduction[43]. There are reasons to argue that monopoly valuation of some assets combined with non-market valuation of others is likely to produce great uncertainty if the resulting pricing interactions are left unchecked. It has been already mentioned that:

> "One limitation on the use of market prices is that they may suggest that any one nation can largely deplete its natural resources now, become a "knowledge nation" reliant on human capital, import most of its resources in the far future, and perhaps remain sustainable. However, this is not an option for the global economy, since not every nation can be a resource importer (Brekke 1997, p.72; Pezzey 1998), and if they all tried to be, resource prices would rise dramatically."(Pezzey 2005, p.132)

It is difficult to anticipate what society's substitutable preferences about environmental goods and services will be like in a sustainability transition. However, we have argued that **Figure 2.4** assists our model to identify those scenarios where a "level playing field" is more likely to be found in the absence of information about future relative prices. As said earlier, the relevant issue for the model is that pricing mechanisms employed to value man-made and natural capital are compatible for preference satisfaction to be a measurement of wellbeing in the long run (rather than an indication of "runaway capital").

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[43] "Prices that would induce and economy to achieve a present-value optimal allocation of resources are normally referred to as *efficient prices*. By analogy, we refer to prices that induce a sustainable time path of utility as *sustainability prices.* Sustainability prices figure prominently in what economics can and cannot say about the measurement of sustainability (Pezzey and Toman, 2005, p.126)

2.5 A "sustainability test" for capital

Seeking to make operational some of the ideas mentioned so far, a simple "sustainability test" is shown in **Table 2.3**.

Table 2.3 A sustainability test for capital: telling the difference between "sustainable capital" and "runaway capital" in the "sustainable society" model

ISSUE-FRAMING TEST	ASSET-VALUATION TEST	SOCIAL LEGITIMACY TEST
*Who **FRAMES** and defines both, the challenge at hand (e.g. problem) and the capital means to implement a policy response?*	*What asset **VALUATION** scenario best describes the capital means used to implement policy response?*	*Who sets the standards and **LEGITIMISES** both, the definition of the challenge and the solution which paves the way for policy implementation?*
Examples: • ***To feed the world*** *(challenge) GM crops (capital means)* • ***Carbon storage*** *(challenge) bio-char (capital means)* • ***Low-CO2 mobility*** *(challenge) hybrid vehicle(capital means)* • ***Energy saving*** *(challenge) Loft insulation(capital means)*	Examples: *A,B,C,D,E,F,G,H,I* *(See Figure 2.4, Pricing mechanism scenarios)*	Examples: • *Jeremy Clarkson* • *Long open social process* • *George Monbiot* • *James Lovelock* • *Policy maker* • *Richard Branson*
This test refers to the use of science, the assumptions used to frame the challenge or situation at hand. It refers consequently, to the capital means to address the situation or implementing a response	This test refers to compatibility of pricing mechanisms between natural and man-made capital (physical and human), and the likelihood that they be consistent with consumer preferences	Legitimacy matters as it leads to real life implementation. This test refers to the governance of knowledge (scientific, lay and commercial knowledge) in regards to the challenge and the framed policy solution.
Challenge is framed by a process of social trial and error involving a variety of actors including but not exclusively formal scientists	Challenge is defined by stakeholders with narrow particular agendas often in a relatively short period of time	Scenarios B,C,E,F No apparent or significant Inconsistency. Not necessarily in conflict with consumer preferences	Scenarios A,D,H,I considerable inconsistency potential conflict with consumer preferences (with technology often increasing such a possibility)	Legitimacy is the result of a long, social process of trial and error, public dialogue including but not restricted to commercial Interme-diaries and knowledge managers	Legitimacy is greatly /swiftly influenced by few profit-maximising individuals often enjoying public grants. This increases the risk of weak public support after implementa-tion particularly if things go wrong.

Sustainable capital Runaway capital

The test is meant to be a minimum, easy to apply criteria by which to find out whether in our sustainable society model a given capital asset qualifies as either "sustainable capital" or as "runaway capital" in a "real life" scenario situation. It consists of three components or "tests": *issue-framing test*, *asset-valuation test* and *social-legitimacy test*. The table explains the specific contents of each test.

Up to this point we have deliberately avoided mentioning the social theory literature which deals with the idea of a "runaway world". This is because an attempt was made to show how it manifests itself in practice first —e.g. obesity epidemics— before looking briefly into the literature. Leach (1967) and later on Guiddens (1999) have referred to a "runaway world" as a place where traditions recede and people no longer control the outcomes of science, technology or culture in general. For Leach writing in the sixties, there was no point in having "faith in the limitless powers of human rationality" (Leach, 1968, p.78-79). Later in 1999, Giddens produced his Reith lectures for the BBC on the "runaway world" theme. Ever since, critics have reflected upon the relevance of the concept in the following way,

> "It suggests a world wholly out-of-control which had formerly been under control —both of which are exaggerations — but it also correctly implies that science, social science, and technology no longer offer the promise of any overall control. Indeed, some technologies —such as industrial processes which pollute, nuclear technology, and genetic engineering— are now as much constituents of a world out-of-control as means of controlling it; they are as much part of the problem, adding to manufactured uncertainty, as part of any solution" (Bryant and Jary, 2000, p.263)

Our view on the "runaway world" concept as it applies to "uncontrolled capital" is comparatively more cheerful in that it seeks to understand how reality would change in our sustainable society model. That is to say, the use of the term "runaway capital" in our model is more technical than philosophical. In summary, it seeks to reformulate the

increasingly questioned status of consumer preferences and consumer sovereignty as indicators of wellbeing, environmental value and sustainability in future (Common and Perrings, 1995). Despite the lack of a workable "existence theorem" in environmental economics (Pearce and Turner 1990) together with the many criticisms from ecological economists to a preference satisfaction theory of wellbeing, ours is a model where substitutable consumer preferences remain analytically relevant. Delineating sustainable capital from runaway capital seems to be at least a step in that direction. The foregoing concepts put us in a better position to delineate the substitution mechanisms as part of the model.

2.6 Substitution mechanisms

There are three general substitution mechanisms (shown graphically in **Figure 2.2**) and thirty six specific ones (shown in **Table 2.4**). The three general mechanisms types are,

- **Runaway substitution:** when any type of runaway capital substitutes for any type of sustainable capital (e.g. Rp>Kn)

- **Sustainable substitution:** when any type of sustainable capital substitutes for any type of runaway capital (Kh>Rn)

- **Intra-domain substitution**: when substitutions do not breach their own sphere of capital (e.g. Rn>Rp; Km>Km)

Table 2.4 Specific mechanisms (36): our model focuses on the runaway and sustainable substitution types only as they are indicative of big transformations in society (white cells).

	Rp	**Rn**	**Rh**	**Km**	**Kn**	**Kh**
Rp	Rp>Rp	Rp>Rn	Rp>Rh	Rp>Km	Rp>Kn	Rp>Kh
Rn	Rn>Rp	Rn>Rn	Rn>Rh	Rn>Km	Rn>Kn	Rn>Kh
Rh	Rh>Rp	Rh>Rn	Rh>Rh	Rh>Km	Rh>Kn	Rh>Kh
Km	Km>Rp	Km>Rn	Km>Rh	Km>Km	Km>Kn	Km>Kh
Kn	Kn>Rp	Kn>Rn	Kn>Rh	Kn>Km	Kn>Kn	Kn>Kh
Kh	Kh>Rp	Kh>Rn	Kh>Rh	Kh>Km	Kh>Kn	Kh>Kh

Any narrative can be translated into its equivalent substitution mechanism so as to configure patterns. This was illustrated with a short example for the case of obesity epidemics **(Section 2.5, p.67).** For methodological reasons we shall focus in this analysis on the first two general mechanisms to configure patterns leaving the intra-domain mechanism out (i.e. grey cells, **Table 2.4**).

The reason for focusing on analysing only the first two types of substitution (i.e. runaway substitution and sustainable substitution) is because the transitions between runaway to sustainable substitution and vice versa seem indicative of big transformations in society at a qualitative level. That is to say, they seem to indicate impacts on human society and nature for which no easy interpretations are readily available. To put it another way, we focus on runaway and sustainable substitution mechanisms because they seem to entail more *enigmatic* transformations —e.g. the combined use of nanotechnology and biotechnology in agriculture (The Royal Society, 2004), than those of the intra-domain type —e.g. from petroleum to gas; to substitute rapeseed oil in the food industry for other types of oil.

On the other hand, our scenario template **(Figure 1.8)** already incorporates a large-scale HED-to-LED transition which implies a transition from, say petroleum to gas. It can be argued that the HED-to-LED transition will involve to a great extent many substitutions of the intradomain type where different energy density carriers substitute for one another. When energy use is substituted for say, better urban design, then we can talk about sustainable substitution. If, on the contrary, more cars are produced as a result of industry lobbying, one could argue that social change is being delayed and therefore "runaway substitution" is taking place (where there should have been "sustainable substitution").

2.7 Proof of concept protocol and model terms of reference

This final section lays down the proof of concept **protocol** (outlined in **Table 2.5**) that guides the proof of concept **analysis** to be conducted in **Chapter 4** (following the scenarios). The purpose of the proof of concept analysis is to test the usefulness of the model developed in this chapter, and if necessary make the necessary refinements.

The model suggests already a basic answer to the first research question: long-run substitutability (understood as the result of society's relative valuation of man-made and natural capital in a changing world) is likely to require institutional arrangements that improve the conditions upon which processes of social legitimation and governance allow capital inputs to yield services that are compatible with sustainability. "Processes of social legitimation and governance of capital inputs" relate to the "sustainability test to capital" **(Table 2.3)**.

The assumption of "feasible sustainability" holds to the extent that, in the long run, individuals find the right conditions to freely express their substitutable preferences. Careful consideration of the neoclassical definition of capital as "any controllable source of services" (Herfindahl and Kneese, 1974) suggests these conditions are met if and only if capital inputs are subject to some form of "control" by society, that is to say, social legitimation and governance of capital inputs.

The correct way to derive more meaningful results from the above claims is not by inspecting the technical aspects of substitution itself (cf. Ayres, 2007), but rather by analysing how scenario *conditions* surrounding substitution lead to *scenario-specific "sustainabilities"*. The model provides a proxy systematic way to distinguish controlled from runaway capital (sustainability test to capital). Having such a tool in place is important to understand what "control" and social ownership mean and in doing so to identify substitution mechanisms by particular type. The second research question was also answered in the previous section; however a more precise description as to how those mechanisms are used to generate patterns is offered later in this section.

Table 2.5 proof of concept protocol

CONCEPTUAL MODEL	
Research questions (Chapter 1)	1. Since substitutability depends on society's relative valuations of man-made and natural capital in a changing world (technologically and culturally), under what conditions and institutional arrangements are long-run substitution possibilities likely to be higher? 2. Are there particular mechanisms and patterns that are likely to be relevant to a characterisation of long-run substitution possibilities?
Theoretical answers to research questions yielded by the model (Chapter 2)	1. Long-run substitutability (understood as the result of society's relative valuation of man-made and natural capital in a changing world) is likely to require institutional arrangements that improve the conditions upon which processes of social legitimation and governance allow capital inputs to yield services that are compatible with sustainability. "Processes of social legitimation and governance of capital inputs" relate to the "sustainability test to capital" **(Table 2.3)**. 2. The model shows 3 general and 36 particular, substitution mechanisms; together they form patterns that can be used to characterise long-run substitution in context-specific situations (such as future scenario pathways)
PROOF OF CONCEPT PROTOCOL	
Scenario protocol (followed as a structuring devise) (Chapter 4)	i) All scenarios begin with a summary covering cars, food and green homes as topical entry points. ii) All narratives unfold according to a fixed set of 21 questions **(Box 4.1)** iii) The conceptual model **(Chapter 2)** is employed to translate each scenario storyline into a corresponding pattern of substitution. Each scenario pattern is shown in preliminary form in the grey column of each narrative. Subsequently, substitution instances are processed and analysed graphically in a separate section at the end of the chapter. This is done through "pattern matching" (Yin, 2009; Campbell, 1966). Discussing each substitution occurrence in the grey column was beyond the scope of the exercise. iv) To allow for comparison, a fixed quota of substitution instances was assigned equally to each scenario storyline (up to 200, no less than 190). v) Storylines exhibit contrasting degrees of social and policy implementation of the Hartwick-Solow rule of investment with regards to a transition to lower-energy-density carriers.
To test the theoretical answers given by the model, the following "empirical" analysis is carried out (Chapter 4)	**Testing the model's answer to QUESTION 1** Implementing the Hartwick-Solow rule brings society closer to sustainability. If it is true that long-run substitutability requires a process of social legitimation and governance of capital inputs to production, then it is reasonable to expect: **i)** A clear overlap between those **observed** patterns where sustainable-substitution predominates (the K>R type) and those **expected** patterns where the implementation of the Hartwick-Solow rule is the strongest, (Scenarios 1 and 2) **ii)** A clear overlap between those **observed** patterns where runaway-substitution predominates (the R>K type) and those **expected** patterns where the implementation of the Hartwick-Solow rule is the weakest (Scenarios 3 and 4). In both cases the degree of pattern overlap would evidence the degree to which substitution is possible. It would also indicate some of the influence that values and behaviour driving innovation would have in shaping sustainability. **Testing the model's answer to QUESTION 2** Did the 36 substitution mechanisms register occurrences in all scenarios? To what measure can it be claimed that the intended taxonomy of substitution mechanisms "covers" the reality of the scenario? Did they yield patterns?

Although many "proofs of concept" are conducted outside scientific research[44] for a variety of purposes—e.g. engineering, business development — the notion of proof of concept employed here is not markedly different from any other test or demonstration procedure where scientific thinking is involved. It is ultimately the arrangement of the various elements of investigation which is the challenging aspect of a scientific analysis. Hicks' own version of that challenge is clear enough,

> "The method of modern economic investigation is the same as the method of all science. Economics studies facts, and seeks to arrange the facts in such ways as to make it possible to draw conclusions from them. As always, it is the arrangement which is the delicate operation. Facts, arranged in the right way, speak for themselves; unarranged, they are as dead as mutton." (Hicks 1971, p.3)

In the Hicksian sense, it is not the output of the model but the underlying assumptions that deserve careful consideration and analysis. This is particularly true when it comes to modelling the future (O'Riordan, 2000). In order to understand what can and cannot be expected from the proof of concept analysis underpinning this study, a few conditions and terms of reference are worth revisiting.

A standard economics footing

As suggested in **Chapter 2,** both, the proof of concept analysis and the appreciative model being "proved" or demonstrated, aimed to be consistent with "very weak" or "Solow sustainability" hence the Hartwick-Solow rule (Turner, 1993) outlined in **Chapter 1**. Since this version of sustainability looks at the maintenance of an overall stock of capital without having to pay special attention to the environment, it conveniently allowed the model to focus on humans, rules and institutions rather than on nature and all the requirements to maintain its integrity at satisfactory levels. This does not meant the environment is not important, it only means the model assumes

[44] "A proof of concept (POC) or a proof of principle is a realisation of a certain method or idea to demonstrate its feasibility, or a demonstration in principle, whose purpose is to verify that some concept or theory that has the potential of being used. A proof-of-concept is usually small and may or may not be complete." Source: www.tinyurl.com/6kavrmj

humans to be the problem and as such, a lot can be done by looking at human society rather than nature. Although the model was framed around the "clean but extreme assumptions that give formal general equilibrium theory its artificial vanilla flavour" (Solow, 1997. p.8), the purpose of the study as a whole, was to tease out some aspects of the problem of substitution which presumably cannot be captured by formal economic modelling. The use of an "appreciative" model meant that such things as "marginal" willingness to pay values, discounting the future and the like were far beyond the purpose of the model. Moreover, it also meant that an important feature be added to the model: the distinction between "controlled capital" and uncontrolled or "runaway capital".

It should be noted that such a distinction is not to be seen as an attempt to introduce preference formation and modification into the model. To "filter" sustainable from runaway capital is only meant as a proxy criterion to understand the nature of capital inputs in a sustainable society once "weak" or "very weak" sustainability[45] are assumed as feasible. Our model considers the institutional and "social appraisal" arrangements that make the filtering between the two forms of capital practicable in the real world (Stirling, 2009).

Self-interested economic person remains at the centre of the model **(Figure 2.2)**, yet institutional and other forms of intervention are justified when they improve the conditions upon which economic person makes choices (Pearce and Turner 1990); this includes "supplying better information" (Pearce, 1995, p.50). The model sees the regulation around runaway capital as another of such interventions. We take a "weakly sustainable society" to mean no other thing than a society where substitution possibilities *tend to be* smooth or large or in formal terminology "perfect" (as represented in the Appendix). At issue here is neither questioning the basic assumption in welfare economics of exogenously given preferences nor the need to correct market failure where there is one (this is assumed away in the model). At issue are the

[45] Although Turner (1993) made the distinction between "very weak" and "weak" in the early 1990s, the literature has unfolded over the years focusing more on the latter and almost omitting the former. See for instance Neumayer's (2010) account.

necessary attributes that capital inputs must have in order to yield the "sustainable services" for the "sustainable society" represented by the model. It was argued in **Chapter 2** that some capital attributes yield services that seem to be closer to sustainability goals than others, thus deserving to be represented as such in the model. Presumably, since the economy is assumed to be sustainable, those "runaway capital" assets whose attributes seem further away from sustainability should be depicted outside the sustainable economic process (i.e. the inner circle in **Figure 2.2**).

Underlying the model is the presumption that, if capital is by conventional definition "any controllable source of services" (Herfindahl and Kneese, 1974), it seems reasonable to assume economic person normally expresses preferences with regards to services that are yielded by capital but not by "runaway capital" **(Section 2.4).** As said earlier, underlying the model are also the assumptions of sustainable development made feasible by a homogeneous capital stock, that is to say, by "perfect substitution possibilities" as implied in neoclassical economic analysis of Solow type sustainability[46] (see also **Appendix**). After a number of authors (Stern D. 2011; Solow 1997, 1986; Hartwick, 1977) the foregoing assumptions allow us to investigate the rules, institutional arrangements and conditions that would be consistent with a sustainable society. Such an interest is justified by the consideration that sustainable development is more easily defined than deployed (Turner, 1993), thus presenting us with the class of analytical problem that studies such as this, seek to address,

> "Defining sustainable development is not the only, and probably not the most important, problem. If the sustainability goal is accepted, then a fundamental requirement is a set of sustainability principles that can give some concrete form to a sustainable development strategy. This strategy will necessarily have to encompass multiple and interrelated goals (reflecting the several dimensions of the sustainability concept) — social/cultural, economic, political, environmental and moral—

[46] In this study, assuming "perfect substitutability" (i.e. keeping the variable under control) is not the same as "perfect substitution", (i.e. assuming that something has already been "successfully" substituted in the hypothetical reality of a future scenario).

> and will have to deploy a package of enabling policy instruments." (Turner, 1993, p.3,4)

Assuming sustainability as "feasible" presumably allows us to treat our model as a positive rather than as a normative model. In this sense, the model "describes" how things are and "what people think" for each scenario "version" of sustainability. More particularly, the scenario narratives were developed to intentionally exhibit contrasting degrees of implementation of the Hartwick-Solow rule of investment[47]. Whilst scenarios 1 and 2 exhibit two different versions of "strong implementation" of the rule, scenarios 3 and 4 are meant to exhibit two different versions of "weak implementation". These features were propounded in the scenario template in **Section 1.3**.

Future scenarios as "empirical" basis for analysis and social appraisal

The proof of concept is based on the premise that although empirical analysis about the future can only be an imperfect speculative activity, future scenarios will at least allow us to contextualise substitution possibilities as they would happen in real life situations given two important assumptions.

(ii) It is being assumed that there are two key innovation styles shaping future technological and social/behavioural change: IP-driven and creative-commons innovation[48].

(ii) That society is faced with the challenge to either anticipate or react to a low-energy-density carrier transition.

Future scenarios are being employed to test an *intertemporal* model of long-run substitution possibilities between man made (human and physical) and natural capital. Scenarios are also being employed as an alternative to case study analysis of historical trajectories and events (e.g. Geels 2005). Such a proof

[47] As explained elsewhere in Chapter 1 the Hartwick rule shows that "if sustainability is technically feasible, a constant level of consumption can be achieved by reinvesting the resource rents in other forms of capital, which in turn can substitute for resources" (Stern D. 2011, p.29)

[48] Associated with the open-source concept. The reasons for refraining from using the open source concept in economics are stated at the end of Section 1.1

of concept necessarily relies on the degree of robustness that can be assigned to future scenarios in place of historical case studies. This is important because:

> "Where there is a historical record, the model can be calibrated against measured output to test for its robustness and accuracy. Where there is no historical record, or where the model is essentially designed to depict the future, then the only test for reliability is peer group criticism of the model's assumptions, interactions and sensitivities to relationships between cause and outcome, which are uncertain or simply not known". (O'Riordan, 2000)

Likewise, we mentioned earlier in this chapter the importance of social appraisal (in the sense implied by Stirling, 2009). Scenarios, seen as communication tools (e.g. scenario workshops) are assumed to deliver the possibility for social appraisal. It is important to recognise that the time and resource constraints of a PhD level exercise deemed the prospect of submitting our scenarios to peer group criticisms unrealistic. The exercise was therefore only extended to a level where further work could improve results, both for the credibility of the scenarios themselves and for the robustness of the proof of concept based on them.

Likewise, the proof of concept is not meant to be judged against the ability of the appreciative model to provide "results" with any degree of forecasting-value. Given the plausibility of its premises, the exercise should be judged instead against the ability of the exercise as a whole to organise analysis with regards to future substitution possibilities and conditions.

At issue are the sustainability scenario conditions for sustainable substitution, as represented by the model, to be at its highest.

The proof of concept analysis is not about the ability of the model to forecast a particular lineal version of substitutability, it is about assessing various degrees of sustainable substitutability against four scenario versions of sustainability. Scenarios represent "rival" versions of sustainability and means of implementation (this is where the Hartwick-Solow rule enters the scene). Each scenario version of sustainability

represents a different society where the social appraisal (Stirling, 2009) of science, technology and capital inputs varies.

> "Instead of using aggregative procedures in analysis, normative rules in precautionary appraisal, or deliberative procedures oriented towards consensus or common ground, [social] appraisal instead conveys its results as series of plural and conditional recommendations [...] This involves the systematically revealing how alternative courses of action appear preferable under different framing conditions and showing how these dependencies relate to the real world of divergent contexts, public values, disciplinary perspectives and stakeholder interests" (Stirling, 2009,p.210-211)

The issue therefore is not whether the model is proven right or wrong to forecast substitution events in the year 2050, at issue are the "weak-sustainability" scenario conditions under which the model can be "right", or to put it another way, under which sustainable substitutability can be at its highest. The proof of concept analysis involves the use of four future scenario "answers" as to what *right* could mean in terms of social appraisal. So for instance, sustainable substitutability may only be consistent with scenarios where particular requirements are met (e.g. that certain values, forms of social and institutional organisation predominate over others, that preferences favour the reproduction of sustainable capital inputs, that society is able to manage the HED-to-LED transition wisely and so on). In the end a scenario is judged on the basis of internal consistency rather than rosiness or number of "good" things happening in it

The appreciative model can be tested via "pattern matching analysis"

The proof of concept protocol in **Table 2.5** contains a test formulated as proxy to assess the usefulness of the model. The test involves the use of pattern matching analysis as the most desirable analytic strategy in case study research (Yin, 2009; Campbell, 1966) —although we apply such a strategy to future scenarios. A pattern is a non-random arrangement of things emphasising holistic (the whole) rather than atomistic (the constituents) values in qualitative analysis (Campbell, 1966; Hak and Dul, 2009). Models often "predict" patterns of values;

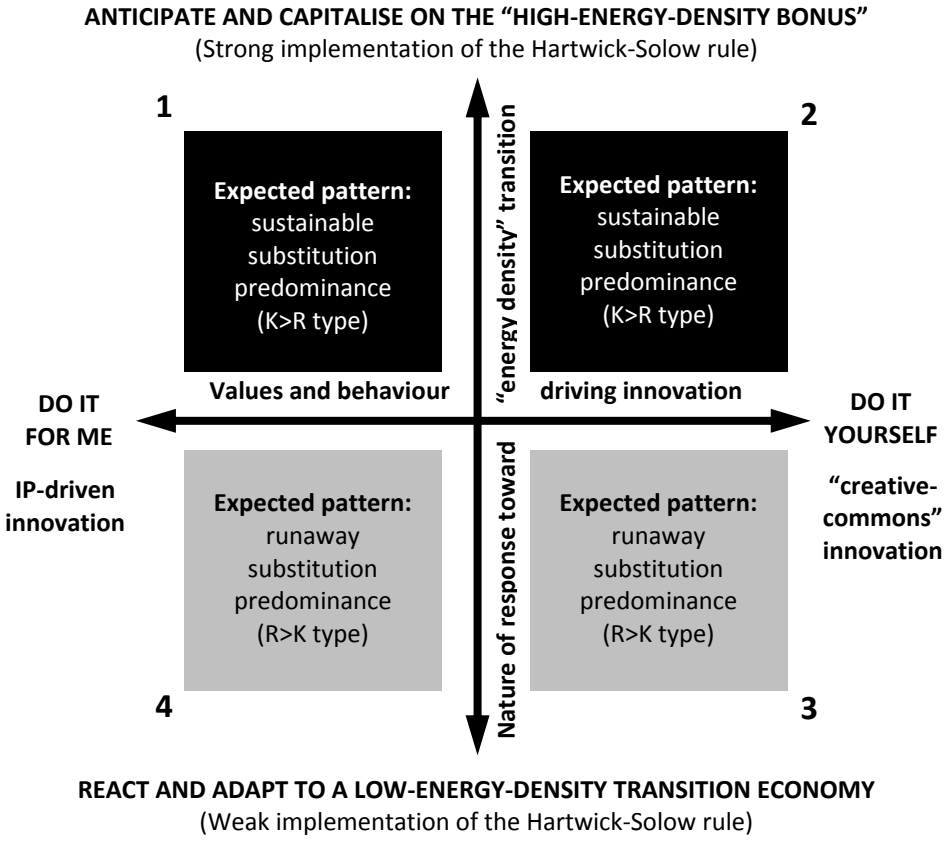
these can be seen in terms hypothetical "expected patterns" (op. cit.). Our testing procedure compares the *observed pattern* generated by the model with the *expected pattern* generated by the scenario template.[49]

Yin (2009) makes reference to two general types of pattern matching in theory-testing: (a) the pattern in a non-equivalent *dependent variables design* where a predicted value must be found for each element of a pattern of dependent variables; and (b) the pattern in a non-equivalent *independent variables design*. An example of the latter is a pattern derived from a typological or configurational model (Hak and Dul, 2009) such as the one developed previously in this chapter**,** where substitution mechanisms configure higher-order patterns. Pattern matching in the *dependent* variables design, according to Yin, should be as rigorous as to disconfirm a hypothesis even if only one variable of the pattern does not behave as predicted. However, the *independent* variables design —the approach we adopt—implies a different array: various expected patterns of independent variables are formulated, each based on a different and mutually exclusive "rival" theory. For the case of our analysis, This is done through the quadrants of the same scenario template shown previously in **Figure 1.9**.

There are various ways in which our expected pattern could be configured. In what follows we explain how our expected pattern template was configured and why. To better explain its virtues, we contrast our pattern template with a competing alternative that was actually rejected. **Figure 2.5a** shows the expected pattern template configuration we adopted. Here, the vertical dimension (i.e. nature of response towards energy density transition) is dominant. Hence, the scenario template exhibits four expected patterns based on "rival" strategies: whilst Scenarios 1 and 2 represent scenarios of *strong implementation* of the Hartwick-Solow rule, Scenarios 3 and 4 represent *weak implementation* scenarios.

[49] "Pattern matching is the core procedure of theory-testing with cases. Testing consists of matching an "observed pattern" (a pattern of measured values) with an "expected pattern" (a hypothesis), and deciding whether these patterns match (resulting in a confirmation of the hypothesis) or do not match (resulting in a disconfirmation). Essential to pattern matching (as opposed to pattern recognition, which is a procedure by which theory is built) is that the expected pattern is specified before the matching takes place." (Hak and Dul, 2009, p.663)

(a) Expected patterns (generated by scenario template)



(b) Observed patterns (generated by the model through scenario storyline)

17- Where do products come from, who makes them?

Most cars on UK roads today are **not just manufactured** in China but indeed Chinese™ in hardware and software. ***Formal* direct employment in the car sector is non-existent.** ***Informal* employment in the *Flexi EV* sector, though not in government statistics, is suspected to be quite high.** Some *formal* **indirect employment** can be found in the service and commercial strands.

Rp>Kp
Rh>Kh
Kp>Rp
Kn>Rn
Kn>Rn

(Excerpt from Scenario 4)

Figure 2.5 The "expected pattern" (a) and an example of an "observed pattern" (b)

Of relevance to the proof of concept is to determine which one of the expected "rival" scenario patterns in **Figure 2.5a** has the largest overlap with the "observed patterns" yielded by the model. **Figure 2.5b** shows a short excerpt from one of our storylines exemplifying how observed patterns can be derived from them. **Section 2.4** explained for the case of obesity epidemics, how a short storyline can be translated into a corresponding substitution pattern, at least in a preliminary

fashion[50]. As mentioned earlier, the vertical dimension dominates the expected pattern configuration. This bears the question: what if axes are not orthogonally independent and the horizontal causes, say, a sub-optimal implementation of the Hartwick-Solow rule in Scenario 1 and an unexpected configuration in Scenario 3? In such a case, might it not be useful to adjust for the weight that the horizontal axis could have on the expected pattern template? **Figure 2.6** shows one out of many possible configurations that might result from adjusting for such influences. Doing this prematurely however, may not only be an endless task, it may defeat the very purpose of conducting pattern matching analysis. Why? Because at this

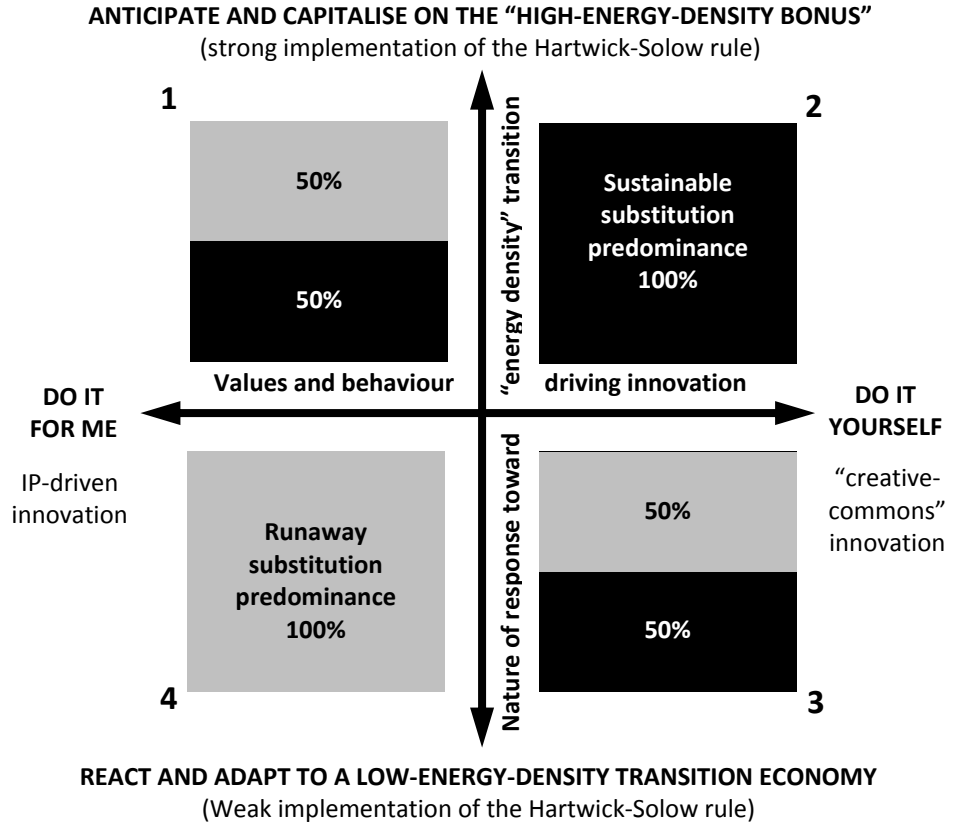


Figure 2.6 A rejected alternative: expected pattern template adjusted for the influence of the horizontal dimension. Arguably not as good as Figure 2.5 as it downplays the potential contribution of IP-driven innovation to the successful implementation of the Hartwick-Solow rule.

[50] These are indeed early days and only a sketch of how this could be done can be offered. To provide a more sophisticated way to "translate" storyline content into substitution patterns will require further work. Having said that, we suggest the method put forward here takes us already a long way and there is no point in "biting more than can be chewed".

stage there are advantages in assuming a preliminary proof of concept analysis, as a *pattern recognition* exercise (Campbell, 1966). This is particularly the case in the first stages of design of a new model such as ours. Therefore, one possible answer to the above question may be *no*. It may not be as useful as it seems to adjust the expected pattern template to accommodate for the possible influence of the horizontal axis on the implementation of the Hartwick-Solow rule. This answer is complemented by a further question: what if IP contributes positively to the implementation of the Hartwick-Solow rule? Therefore, it is possible that in trying to make it more sophisticated than it needs to be the second template may present us with two unnecessary complications: first, unlike the first template, it may downplay *a priori* the contribution of IP-driven innovation to the successful implementation of the Hartwick-Solow rule. In other words, the second pattern is not *neutral enough* to constitute the "straw man" required by our proof of concept analysis. Secondly, not having our designated "straw man" means, in practical terms, not realising the methodological value of "the opposite case" in theory testing:

> "The more important task for theory is to try to understand what happens or can happen in the opposite case." (Solow, 1974, p.11)

There is no way of knowing, prior to our scenario development and proof of concept analysis what the effect of the horizontal axis on substitution patterns will be. All we know at this time is that IP-driven innovation only triggers runaway substitution mechanisms when it results in intellectual monopoly, yet monopoly is no longer the defining characteristic of IP (Boldrin and Levin, 2008). Therefore, the preliminary nature of the proof of concept underlying this study suggests that the template in **(Figure 2.5)** is more suitable than its counterpart example in **(Figure 2.6)**. Our next chapter describes how scenario storylines were developed. Subsequently in **Chapter 4**, scenario storylines are "translated" into their corresponding substitution patterns (see **Figure 2.5b**"**.** Following the proof of concept protocol and the terms of reference outlined earlier, the usefulness of the model is tested at the second part of **Chapter 4.**

3. Scenario storyline development

3.1 Introduction:

A good scenario storyline is the result of a rigorous, calculated, arduous and messy process all at once. Artistic elements are also part of the endeavour. A scenario that is elegant, inspiring and presented with craftsmanship is universally appreciated. Imagined futures need to be inspiring but also consistent and realistic across a wide range of issues and actors. Although most scenarios are framed to a predesigned template (in our case **Figure 3.1**), developing contents that will render each scenario unique is not an easy task.

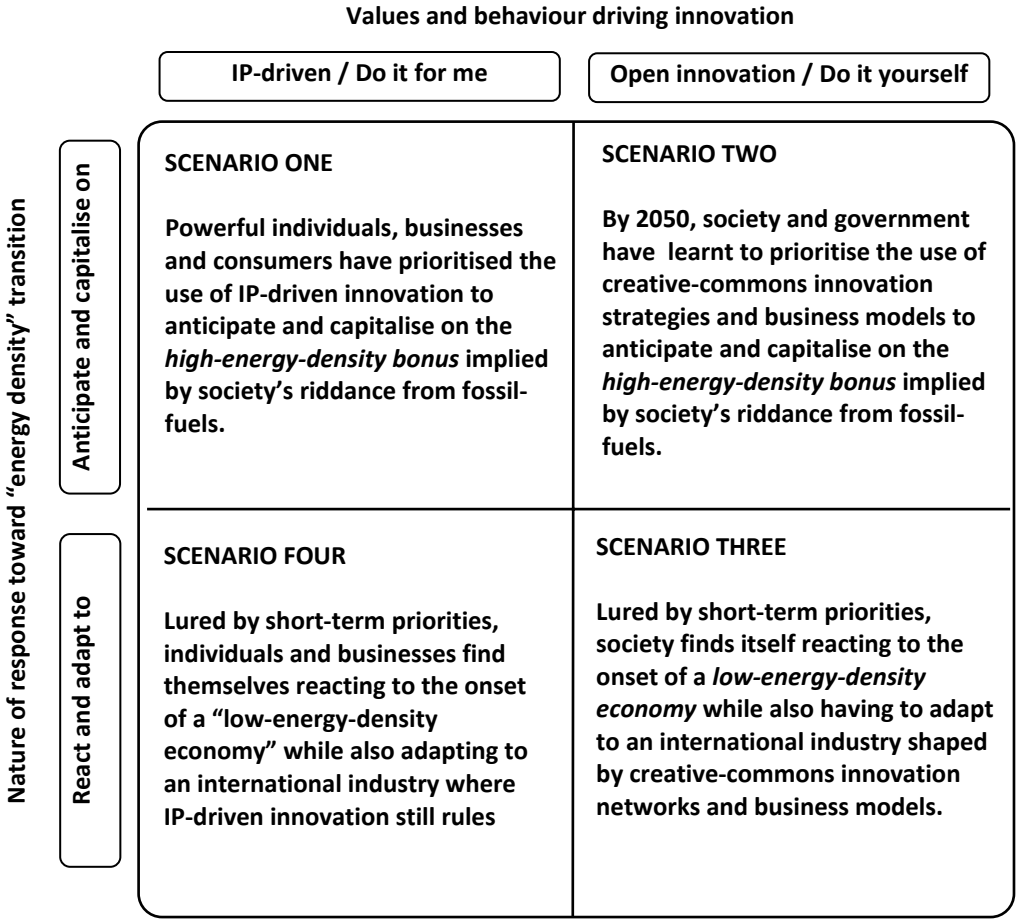


Figure 3.1 The scenario template with a few sneak previews from the year 2050

All foregoing issues become more challenging when storylines are meant to assist a proof of concept analysis such as ours. Storylines need to be done, redone and recalibrated several times until a balance between two conflicting objectives is achieved: plausibility (complex enough) and focus (simple enough); only in this way are the factors that matter delineated (Foresight, 2009). This chapter explains the principal aspects that preceded the writing of our storylines to the year 2050.

- Cars food and homes as topical entry points
- Multisource data collection
- A list of key findings influencing all scenarios

The fact that the present chapter is developed as a technical one does not imply that the challenge of constructing the storylines was purely technical. We hope that the scenarios themselves convey some of the less mechanical aspects and flavour behind their making.

3.2 Topical entry points: cars, food and homes

Future scenarios often focus on a specific area of interest (e.g. energy, ecosystems). Because our purpose was to contextualise the variety of substitution possibilities in real life settings, the thematic focus of our scenario was made deliberately more diffuse than conventional scenarios. That is, we needed a few topical entry points as opposed to an overarching theme, so we,

A) … looked at basic human needs **(Figure 3.2)** …

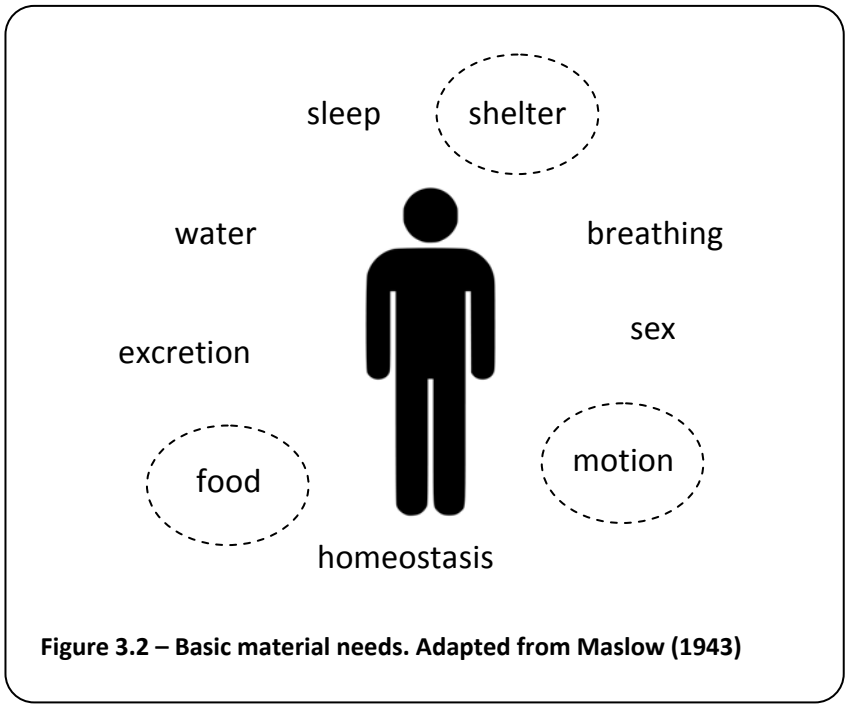


Figure 3.2 – Basic material needs. Adapted from Maslow (1943)

B) … we accepted as useful the view that "unsustainable development has resulted from technology outpacing changes in social organization" (Norgaard 1985, p.16) …

C) … and we chose three topics that would offer opportunities of exploring the satisfaction of human needs and wants from a *technological* and *social* innovation perspectives (WCED, 1987).

- **Passenger cars and sustainable mobility,**
- **Food production and supply**
- **Green homes: technologies and behaviours.**

3.3 Multisource data collection

We have described our scenario outline and scenario template in **Section 2.6.** In this section we explain the process behind storyline construction. Our data collection started by recognising that, to be useful, scenarios need to feed from a variety of sources and formats in ways that are often neither static nor predictable. Most narrative scenarios refer to *early indicators* or *forerunners* of a certain future as if looking back from that future to the world of today (see for instance, Foresight 2007, 2010). Following that rationale, we organised our data collection activities around three basic questions. From each question three category stacks were derived, all shown in **Table 3.1** The rest of this section explains each in more detail.

Table 3.1 – The multisource data collection: a roadmap

Whose view was to be included?	*About what key themes or issues?*	*How should data be obtained?*
STAKEHOLDER SELECTION	**GENERIC ELEMENTS OF ENQUIRY**	**SCENARIO-FRIENDLY DATA COLLECTION (in no chronological order except for the research seminar which was used as a pilot method from the start)**
***IP-driven innovator** ***Hidden innovator** ***Government representative** ***Commercial intermediary** ***Impartial truth-seeking analyst**	***Innovation** ***Incentives** ***Identity** **Disaggregated into questions:** ***Table 2.3** ***Table 2.4** ***Table 2.5**	**1-Research seminar** **2-Statistical data** **3-Direct observation** **4-Documental information** **5-Revealed preferences** **6-Naturally occurring discussions** **7- Interviews** **8-Monitoring media** **9-Personal communications**

Stakeholder selection

Our principal criteria of selection was *people's outward motivation.* We deliberately avoided typifying stakeholders as collectives of people representing uniform well-demarcated sectors. More in tune with times of change perhaps, two general issues were used as criteria. First, it became apparent that the nature of stakeholder's advocacy and values in relation to innovation had become difficult to pin down, —even for stakeholders themselves—, a sort of "identity crisis" seemed to define the character of organisations and our stakeholder mix had to reflect people's perceived place within that crisis. One of the research seminars conducted at the beginning of this study[51] warned us about the cons of presuming sectoral affiliation as reliable indicators of stakeholder's true degree of advocacy and values. Along with many institutional readjustments taking place today, some stakeholders in business, for instance, appeared to behave, hold views and perform tasks, traditionally associated to the ethos of other sectors, such as local government (O'Riordan, 2004). Customary divisions between public and private are increasingly reshaped by trends in regulation, subsidies, decentralisation, privatisation, participation, devolution, public-private partnerships and industry practice (Sikor, 2008)[52]. Likewise, some stakeholders in academia seem to have adopted business-like views and values traditionally considered little short of *taboo* in the realm of academia. Additionally, some stakeholders inside government

[51] "Public and private in natural resource governance" Thomas Sikor, Tim O'Riordan, Friday 2nd May 2008, (see Table 2.3)

[52] On this point Sikor elaborates further in the book presented at the seminar: "Practice in resource governance has gone ahead of our thinking. The state, civil society and various kinds of communities establish diverse forms of *publics* […} Alternatively, private actors and actions display different forms of autonomy, indicating the existence of many different kinds of *privates*. Just compare the numerous restrictions imposed on landowners in the European Union (EU) for the sake of broader interests with the relative autonomy enjoyed by the food processing industry. Publics and privates demonstrate that it is not useful to think of public and private as singular entities. There are multiple publics and numerous privates, thus blurring their respective definitions. […] We are witnessing the emergence of various kinds of hybrid institutions running through the public/private divide. Throughout the world, for example, governments have promoted associations in agricultural water management, endowing groups of private actors with public powers. Likewise, we see so-called public–private partnerships mushroom all around us. […] We have also come to recognize that the dichotomy between state and market is no longer present, if it ever was". (Sikor, 2008, p.1)

or in publicly funded organisations[53] seemed to hold the type of values attributable to academia or even to business. An indicator of the latter is perhaps the increasing use of terms such as "client", "added value" and the like in government practice. Secondly, the criterion for selection was not just a matter of stakeholder's advocacy or values, it had also to be sensitive to the increasingly blurred boundaries between institutions and sectors themselves (for reasons beyond the scope of this research to unravel). These two issues suggested the need for a more critical view on clear-cut sectoral classifications. The key point is that our stakeholder categories were devised to force our information gathering to reflect the values and nature of advocacy of people beyond their obvious sectoral affiliation. Observing individual motivations in the context of institutional transformation seemed the only way to ensure our assessment of innovation was based on a truly balanced and comprehensive set of views. Methodologically speaking, the following categories should be seen as organising tags —of collated information— rather than fixed boundaries of analysis.

IP-driven innovator: this refers to the individual or organisational innovator who innovates only if intellectual property of the innovation in question can be secured and enforced. In economic terms, the IP innovator can be recognised as the one who will reject the idea that the process of innovation could often be a sunk cost[54]; instead she believes innovation is *always* a fixed cost (business expenses) which needs to be recouped via state-granted human monopoly rents charged to customers (Boldrin and Levin 2002). More recently the IP-innovator wants to recoup her investments via technical means

[53] Such as so-called "Quangos", a semi-public administrative body outside the civil service but receiving financial support from the government, which makes senior appointments to it. ORIGIN 1970s (originally US): acronym from quasi (or quasi-autonomous) non-government(al) organization. Oxford Concise Dictionary of English 11th edition.

[54] If a brand new car is bough from a car dealer and then sold the next day, its market value would be considerably less. If a company pays its employees one month and then goes into administration the next month, it cannot ask its employees for a refund of their salaries. These are examples of sunk costs. Costs that are intrinsic to almost any enterprise. In a knowledge economy one would expect a lot of the innovation process undergone by the knowledge –intensive industries to be sunk costs.

such as TPM or TPS[55] (Oppenheim, 2008). She also believes ideas are expensive to produce but cheap to access and distribute (Romer 1990). Many "R and D innovators" are becoming IP-driven innovators (Hunt and Bessen, 2004; Bessen and Hunt, 2007)

Hidden (creative-commons) innovator: initially a result of the work on "hidden innovation" (NESTA 2006) this category comprises open access or open innovation; it also comprises social and behavioural innovation. Social innovation implies "broader application not just high tech, manufactured or private sector's innovation. It can apply to low tech, services, public and private. It implies a broader sense of motivation, not just motivation by profit but also by public goals. It implies a broader account of where innovation comes from and how it develops. Innovation is often about developing, adapting, blending, remixing existing ideas rather than developing entirely new ones". (Leadbeater, 2008)[56] Translating the ethos of the hidden innovator into economic terms[57] the hidden innovator sees the process of creation as a sunk cost and for the most part sees creation as a cultural process whereby ideas are both consumption goods but also capital goods. In other words, this means the hidden innovator would not readily accept that ideas are expensive to produce while cheap to copy and distribute.

Government representative: taking into account new notions of governance (Rhodes, 2002) this category sought to encapsulate actors often performing activities or expressing views associated with government practice. This includes not only government officials but other type of actors. It seemed appropriate for instance, to allocate the views of some academic groups or individuals commissioned by government under this category. Because some government-funded or government-commissioned stakeholders often perform roles that do not

[55] Technical protection measures or systems, such as *digital rights management* (DRM)

[56] Understanding Social Innovation, Centre for Social Impact, Melbourne, Sept 16th 2010 (Conference paper available on [3kp7ge]

[57] Meaning the hidden innovator is not necessarily aware of it

seem to fall inside traditional government roles, they were allocated elsewhere.

Commercial intermediary: comprising consultants, intellectual property lawyers, retailers, commercial association representatives and other intermediaries. Without it being necessarily a good or a bad thing, in certain circumstances and for a period of time, academics and government officials often find themselves playing a role in a seemingly commercial intermediary capacity. In those cases they were included under this classification.

Impartial "truth-seeking" analyst: whether they find the truth or not is not so much the point. What counts under this category is how the stakeholder comes across in our various ways of capturing her values and behaviours regarding the process of innovation. Impartial truth seeking analysts are found in many sectors. Commercial intermediaries for instance cannot be said to be moved by pecuniary interests alone. For that reason some had to be included under this category. It was mostly the quality and rigour of their opinions which determined whether a particular stakeholder should be considered within this grouping.

Generic themes of the enquiry: it seemed useful to assume at this stage that although innovation appeared to be a normal occurrence in our three case studies, much empirical ignorance as to what innovation was and how it actually happened prevailed; the literature nonetheless, in all its variety and purpose, seemed unambiguous in relation to two recurring features: technology and human behaviour. Additionally, the literature seemed polarised between two broad types of innovation styles: IP-driven innovation and open hidden innovation.

Taking these two references as starting point we needed then to get a clearer idea of the type of information we hoped to elicit from stakeholders. **Box 3.1** maps out the thinking behind the selection of three broad generic themes of enquiry. It also connects each theme to a corresponding question and to further

refinements, that is, each issue addressed by each question was disaggregated into finer aspects of enquiry as listed in **Tables 3.2, 3.3** and **3.4**. While our purpose was to capture some of the complexity of the innovation / green job interplay, we were also wary at this stage of the risks of over-theorising (Silverman 2006). In any case, the purpose of these elements, imperfect as they were, was to take us into the subject matter with a minimum of theoretical framing.

Box 3.1 – Three generic themes of enquiry

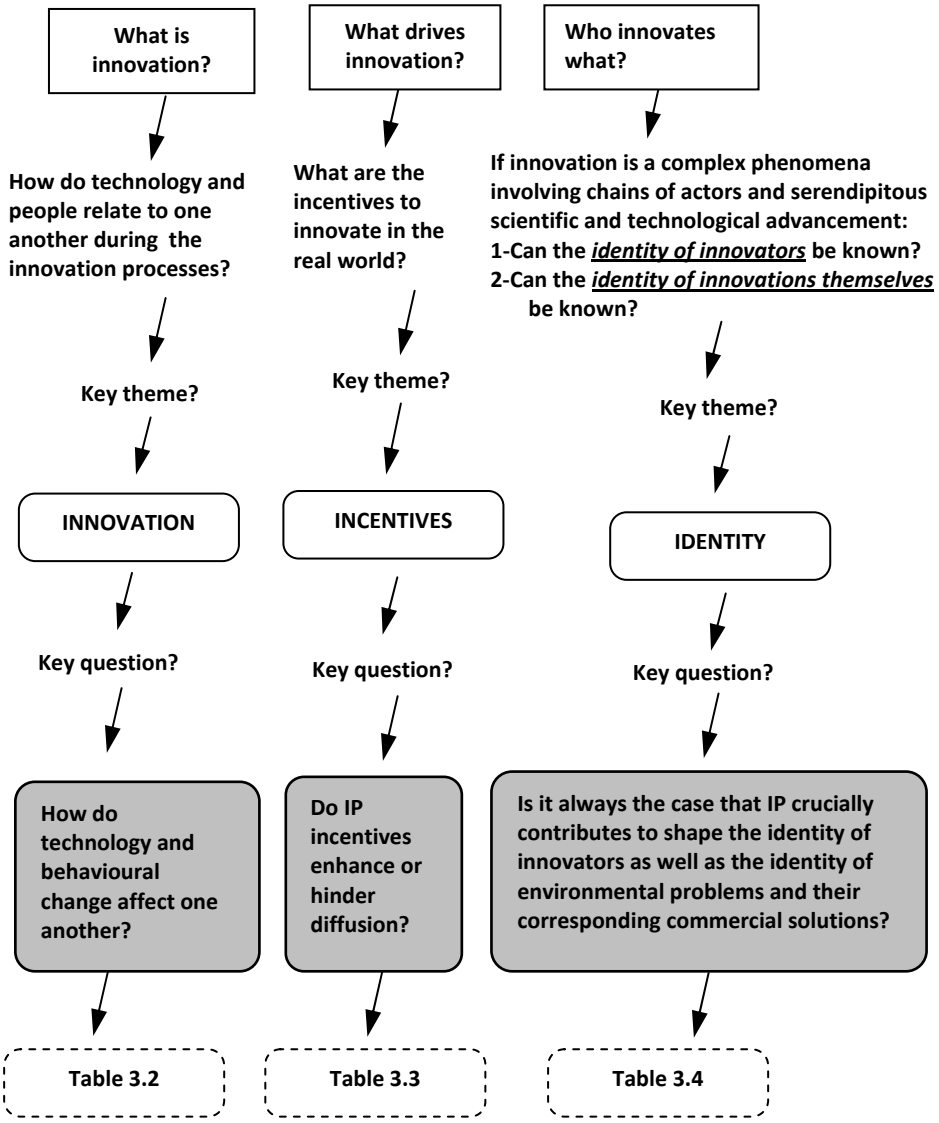


Table 3.2 – INNOVATION (questionnaire)

INNOVATION – Key underlying question:
How do technology and behaviour change affect one another?
(Column on the right synthesizes the other two into a question)

	SUPPLY-LED MODEL (Mostly technological) R and D based, IP-driven	FULL-CIRCLE MODEL (Includes behaviour and creative-commons Innovation)	GUIDING QUESTIONS
1	Innovation is the result of IP incentives	IP incentives are the result of innovation	**How would you describe the innovation process of …**
2	Innovation is the result of a resource-centralised top down process	Innovation is the result of a resource-dispersed bottom- up process	**How many people/organisations were involved in the innovation process, for how long, in what ways? What where the financial circumstances of it?**
3	Ideas and knowledge are expensive to produce	knowledge generation is a processes whereby ideas are shared	**How would you describe the IP mix of this innovation (proprietary/ licensed/ public domain)?**
4	Ideas and Knowledge are cheap to reproduce/imitate/copy	Reproducing copying requires expensive education, infrastructure ultimately a whole cultural apparatus to value and make sense of what is being copied	**Could you point at some of the aspects that could potentially make the innovation process more cost-efficient in the future?**
5	A LCE transition requires a major techno fix	Requires a combination of techno and social innovation, behaviour, business models, organisational change	**Has the innovation process changed the organisation itself in any way or even consumer's behaviour? What do you put it down to? Was it intentional or unintentional?**
6	New problems need brand new to the world solutions	New problems can be solved with old technological solutions and adaptations too	**(If relevant) tell us a bit please about your particular alternative to other innovations in the sector**
7	Only producers produce	Consumer and users produce too	**Is the consumer giving inputs to the innovation process of … and how is it rewarded (if at all)?**
8	No incentives, no innovation	Innovation itself is sometimes its own incentive when it increases wellbeing	**Is this innovation inevitably attached to IP incentives or have there been successful alternatives in the past?**

Table 3.3 - INCENTIVES (questionnaire)

INCENTIVES - Key underlying question:
Do intellectual property incentives enhance or hinder diffusion?

(Column on the right synthesizes the other two into a question)

	SUPPLY-LED MODEL (Mostly technological) R and D based, IP-driven	**FULL-CIRCLE MODEL (Includes behaviour and creative-commons Innovation)**	**GUIDING QUESTIONS**
9	IP grants rights to creators	IP takes away rights and cash from creators	**Could you please describe a bit the relationship between so called "raw innovation" process and the commercialisation of it? How would you describe the roles of the people involved as well as their benefits?**
10	First mover advantage is not enough	First mover advantage can frequently be a real advantage under the right business model and fair play	**Would you regard the "first mover advantage" as a sound business strategy?**
11	IP promotes better accumulation of knowledge and diffusion of what would otherwise vanish	IP slows down diffusion of innovation	**Has IP made the diffusion of the product faster? What has been your experience on this so far? Is the IP value-added of the product compatible with the need for affordability for the green consumer during the whole life cycle of the product/innovation?**
12	Innovation policy and incentives lead inevitably to environmental solutions	IP policy and innovation policy are frequently not aligned	**Do you find innovation policies to be aligned with the environmental problems and solutions of your particular sector? Have you taken part in that policy making process?**

Table 3.4 – IDENTITY (questionnaire)

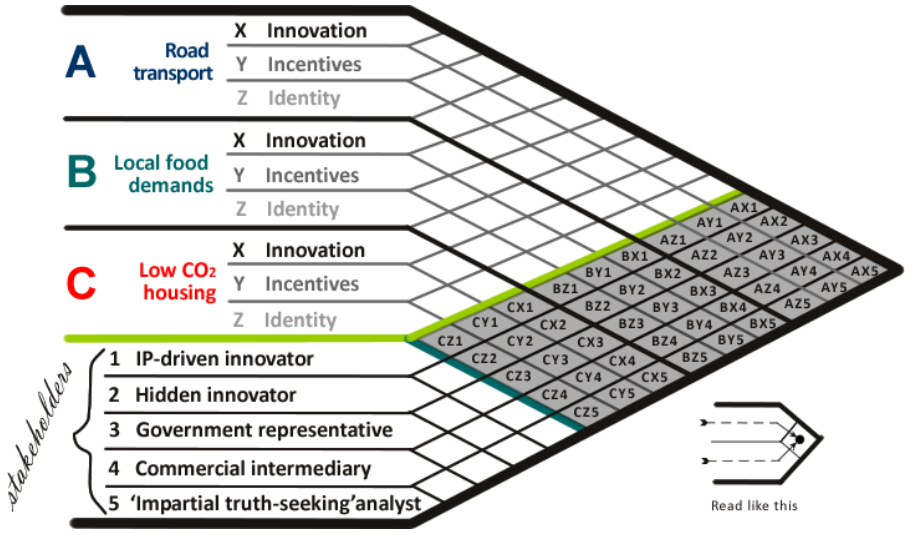
IDENTITY - Key underlying question: is it always the case that IP crucially contributes to shape the identity of innovators as well as the identity of environmental problems and their corresponding commercial solutions?

(Column on the right synthesizes the other two into a question)

	SUPPLY-LED MODEL (Mostly technological) R and D based, IP-driven	**FULL-CIRCLE MODEL (Includes behaviour and creative-commons Innovation)**	**GUIDING QUESTIONS**
13	IP protects product's identity	IP shapes people's identity	**How do you regard the brand identity of this product as it relates to people's decision to buy it and use it? From your point of view, how relevant is this brand identity in tackling our carbon footprint?**
14	Without protection product identity cannot survive	Without protection product identity can survive so long as is not monopolistic	**How important is legal protection expenditure in keeping the identity of your brand or IP?**
15	Product identity enhances novelty value (eco-chic)	Non-monopoly product identity can enhance self identity and group identity	**What's the IP commercial value of this product and how often do you have to renew the product to keep it profitable?**
16	It is a good idea that IP contributes to shape the identity of a problem and its solution	It is not a good idea that IP contributes to shape the identity of a problem and its solution	**Has any aspect of your IP mix been particularly effective in meeting consumer's wants and diffusing better and cleaner technology and innovation?**

The comparative table shown in **Figure 3.3** contains two types of cells. The grey coded ones were used to plot our data collection requirements in three levels: by **case study** (A,B,C) by **generic themes of enquiry** (X,YZ) and by **stakeholder type** (1,2,3,4,5). The white cells were an ensuing reminder that our study would have to show at some point how the three case studies influenced one another.

Figure 3.3 Data needs (grey cells), case study interactions (white ones)



We knew from the start that scenarios would be used to process data. We also knew that good scenarios would rather grapple with varying qualities of data and collection techniques so long as a wide range of themes, early indicators and stakeholders were covered. The strength of scenario appraisal as a methodology is that it must handle, uneven, discrete, complex, often messy information, so long as is comprehensive too. Unlike other forms of analysis such as statistical and econometric analysis, or ethnographic research, it does not matter much that we show too much deference to numbers, or that we go to great lengths capturing longitudinal details about a specific trend or that we monitor the behaviour of a specific actor with implacable rigour and technique. Rigour in scenario

making can be verified in the plausibility and usefulness scenarios themselves are able to deliver via a multilayered outcome, typically in the form of scenario storylines (for the case of narrative scenarios such as ours). For all these reasons, it was ensured that methods were adapted to analytical needs rather than analytical needs to available methods.

Research seminar (October 2007 – October 2008)

An exploratory research seminar was organised (23 weekly sessions) under the theme: *people, nature and technology interactions*. The purpose of the seminar was to bring practitioners, and all members of the academic community together to discuss a variety of themes around the issues relevant to this study addressing also issues of interest to the wider community of students and Norwich residents (see **Box 3.2** and **Table 3.5**).

Box 3.2 Open Seminar:

From: Andres Bucio [A.Bucio@uea.ac.uk]
Sent: 04 November 2008 14:59
To: "ug-env-all@uea.ac.uk"; "pg-env-all@uea.ac.uk"
Subject: Open Seminar - Needs FACILITATORS

Dear everyone,

The Open seminar www.ueaopenseminar.co.uk which is a student-run interdisciplinary seminar from ENV to the rest of UEA is looking for a NEW FACILITATOR or FACILITATING TEAM. The OS was launched in the autumn of 2007 and so far has attracted more than 440 attendants to over 23 weekly events. Its website has received hundreds of downloads (documents and podcasts) and has been a popular one to the wider community in Norwich. The seminar has had two formats:
1- Talks/conferences (someone gives a talk) and 2- Paper discussions (people get together to discuss a mind-bending text or a problem). This is your opportunity no less, to organise your dream-seminars while you do your (under/postgrad) degree at ENV. The Open Seminar is an excellent excuse to do many things you wouldn't normally do, such as asking high-calibre people to do a talk for you and your mates. In doing so you will benefit everyone, develop many skills, learn a lot, meet lots of interesting people and contacts in and out the uni, some of whom may become crucial for your own research. The seminar has been held in the Queens building (a staff friendly brand-new, hassle-free, fully equipped facility, which you can explore anytime http://www.mx-d.com/seminar/pages/map.htm. It's all set up already (open to your own creativity) and IT IS NOT TIME-CONSUMING as you might think, not if you use the toolbox created for this purpose. Feel free to ask any questions … above all, feel free to take the lead

Regards,

Andrés Bucio
Postgraduate Researcher (PhD)

The seminar was also a way of testing ideas with the multiplying effect of its participants. It proved beneficial in that it helped to clarify many aspects of the original research design and proposal. It also provided a good opportunity to capture the opinion of many stakeholders in business, politics (green party) and academia.

Table 3.5 open seminar's website: diary of events (continued overleaf)

Table 3.5 open seminar's website: diary of events (continued)

when	where	what	Ref
2007 / Autumn			Σ issues
18 Oct 4:00-5:00	The Queen's Building (Room 0.17) map	SHORT PRESENTATION AND DOCUMENTARY FILM Case in point: How Cuba Survived Peak Oil? The surprise team	
1 Nov 4:00-5:00	The Queen's Building (Room 0.17) map	PAPER-DISCUSSION (Attendants encouraged to read reference documents) 'Technological optimists vs. technological pessimists: two competing measurements of sustainability'. Andrés Bucio - CER (Moderator)	
8 Nov 4:00-5:00	The Queen's Building (Room 0.17) map	DOCUMENTARY FILM Introducing the Biofuel Series 'Lost in palm oil' (a documentary film about the experience with biofuels in Indonesia)	
15 Nov 4:00-5:00	The Queen's Building (Room 0.17) map	CONFERENCE 'Biofuels and their impacts on global climate, people and forests' Dr. Andrew Boswell, www.biofuelwatch.org.uk	
22 Nov 4:00-5:00	The Queen's Building (Room 0.13) map	AUDIO CONFERENCE REVIEW 'The politics and economics of climate change' Michael Jacobs- Former Economic Adviser HM Treasury Ecological Economist	
29 Nov 4:00-5:00	The Queen's Building (Room 0.17) map	PAPER DISCUSSION Attendants encouraged to read paper ahead of session **The limits of consensus (Kerkhof-2006)** Moderator: Dr. Lorraine Whitmarsh - Tyndall Centre	
Thursday 6 Dec 4:00-5:00	The Queen's Building (Room 0.09) map	PAPER DISCUSSION Attendants encouraged to read paper ahead of session **Sustainable Knowledge (Murdoch - Clark 1994)** Moderator: Niki Ward - ENV	
2008 / Spring			
Friday 11 Jan 4:00-5:00	The Queen's Building (Room 0.13) map	PAPER DISCUSSION **Planet engineering: lessons from the Biosphere 2 project** Ex-Biosphere 2 Ecosystem Manager Adrian Southern - ENV (Attendants encouraged to read one page article ahead of session)	
Friday 18 Jan 4:00-5:00	The Queen's Building (Room 0.09) map	CONFERENCE **Climate change activism: the experience of getting involved, the practice of involving** Alexandra Woodsworth (PhD postgraduate researcher) - CER	
Friday 25 Jan 4:00-5:00	The Queen's Building (LT 1.03) map	CONFERENCE **Whither Biofuels?** - Bruce Tofield, Richard Parker - see profiles	
Friday 1 Feb 4:00-5:00	The Queen's Building (Room 0.09) map	CONFERENCE **Agriculture: can we feed the world in a manner that is environmentally and socially sustainable?** Professor Bob Watson (CSA)-DEFRA ENV	
Friday 8 Feb 4:00-5:00	The Queen's Building (Room 0.09) map	BOOK-EXCERPTS DISCUSSION Attendants encouraged to read material ahead of session - **Lateral thinking in scientific research: does it always work?** Moderator: Richard Cornes (PhD postgraduate researcher)- CRU	
Friday 15 Feb 4:00-5:00	The Queen's Building (Room 0.09) map	CONFERENCE **Astrobiology: Looking for life elsewhere in the universe** Colin Goldblatt (PhD postgraduate researcher)-Earth System Modelling Group	
Friday 22 Feb 4:00-5:00	The Queen's Building (Room 0.13) map	PAPER DISCUSSION (Attendants encouraged to read paper ahead of session) **Three Persistent Myths in the Environmental Debate** Discussion leader/moderator Dr. Brendan Fisher - SCERGE	
Friday 29 Feb 4:00-5:00	The Queen's Building (Room 0.09) map	DOCUMENTARY FILM AND DISCUSSION **Intellectual Property: the oil of the twenty-first century**	
Friday 7 Mar 4:00-5:00	The Queen's Building (Room 0.09) map	VIRTUAL CONFERENCE AND DISCUSSION **Choice-editing, product roadmapping and the three-planet economy: can shopping change the world?** (We will watch a presentation given by Dr. Alan Knight from the Sustainable Development Commission and discuss the implications)	
EASTER BREAK - (15 March 2008 - 13 April 2008)			
Friday 18 Apr 4:00-5:00	The Queen's Building (Room 0.08) map	CONFERENCE **Environmental implications of constitutional change: the EU Reform Treaty** Dr. David Benson -CSERGE	
Friday 25 Apr 4:00-5:00	The Queen's Building (Room 0.09) map	CONFERENCE **Linking environmental science research and business development: the case of CRed** Dr. Simon Gerrard (CRed)	
2008 / Summer			
Friday 2 May 4:00-5:00	The Queen's Building (Room 0.09) map	BOOK PRESENTATION **Public and private in natural resource governance** (Earthscan) Dr. Thomas Sikor (Editor) School of Development Studies - Professor Tim O'Riordan School of Environmental Sciences	
Friday 9 May 4:00-5:00	The Queen's Building (Room 0.17) map	CONFERENCE **Our ideological vulnerability to nature: the right climate for change?** Dr. Nick Brooks Visiting Research Fellow Tyndall Centre for Climate Change Research School of Environmental Sciences	
Friday 16 May 4:00-5:00	The Queen's Building (Room 0.09) map	REVIEW OF ONLINE CONFERENCE **Responsible Growth 2050: Integrating Society, Ecology and the Economy (The World Bank)** (We will watch and discuss an online panel with Kirk Hamilton, Ian Johnson, Jahmal Sahir, Richard Newfarmer)	
Friday 23 May 4:00-5:00	The Queen's Building (Room 0.09) map	CONFERENCE Postfeminist lifestyling: environmental implications Professor Diane Negra - School of Film and Television Studies	
Friday 30 May 4:00-5:00	The Queen's Building (Room 0.09) map	CONFERENCE: POSTPONED **Energy-carrier transitions and path dependencies: historical and evolutionary approaches** Dr. Paul Warde, Reader in Early Modern History School of History - UEA	

Official statistics

The first approach that was used to understand the state of play of innovation and employment was certainly the statistical one. Although it may not be possible, or practical, or relevant to enumerate all the sources and types of statistics that were retrieved at different stages of the investigation, it is at least worth mentioning that official statistics are as good as the methods used to analyse the data they throw up. They also provide first hand evidence about the way "science" is seen and done by different institutions. Some of the organisations from which statistical information was retrieved in a variety of formats and at different stages of this study include: The Office of National Statistics (UK), The Department of Trade and Industry (DTI), Intellectual Property Office (IPO) Department for Transport (DT), Department of Environment, Food and Rural Affairs (DEFRA) World Resources Institute (WRI), World Bank online database, The Global Footprint Network (GFN), OECD's online database. University of Sheffield's Worldmapper database. This list does not include all those pieces of statistical information that were drawn upon from non statistical documents. It is also worth mentioning perhaps that the rejection of large amounts of information and often knowledge was also an integral part of this study even when such information does not figure in its final outcome.

"Revealed" and "stated" preferences implied by a variety of studies

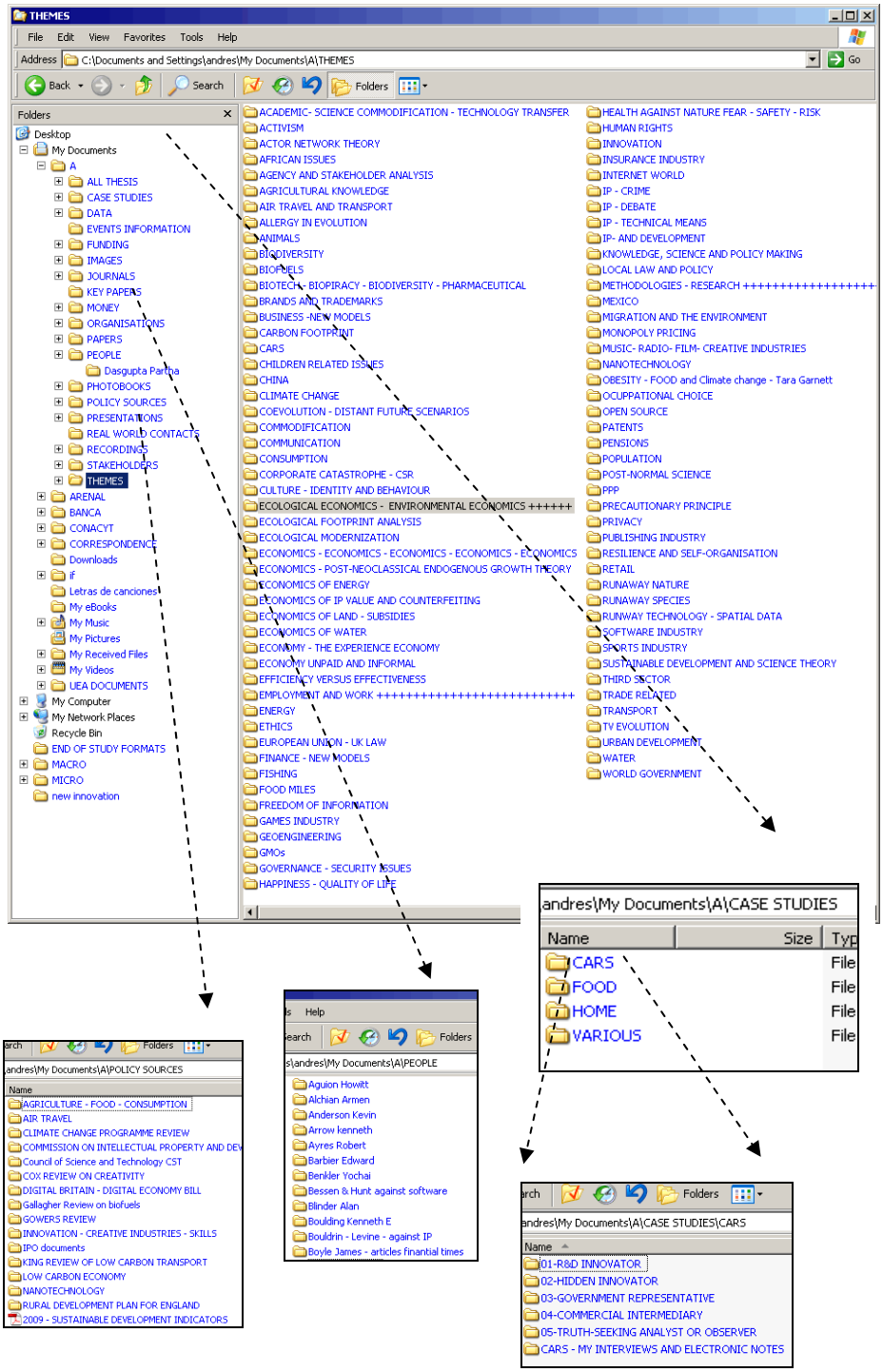
Stakeholders and the wider society attach value to human and environmental assets in a variety of ways (e.g. purchasing decisions). However negative purchasing decisions can also constitute a revealed preference. The last decade or so has witnessed an explosion of reports grappling with the issue of stated preferences regarding not only the value of environmental assets, but also the value of a variety of goods and services for which there might or there might not be a consolidated market. Many of these reports bear titles such as "Intellectual property infringement" and "The economic cost of copyright infringement". However, notwithstanding the negative overtones of such titles the subject matter of those reports is the revealed preferences of important sectors of the

population. This has happened in a range of industries including the car industry, the agricultural and building and construction sectors as well. It would have been a mistake to set aside such records as they appeared to announce important social change with regards to willingness to pay and consumer preferences, as well as new directions in business models in some sectors.

Documents

Of at least two types: academic papers and policy documents. A systematic monitoring of official websites for the purpose of upgrading the documentation was carried out at least once a week throughout the whole duration of the research. Additionally an archive of 94 themes comprising 743 subcategories was constantly enriched with new entries. Many of the key themes were also organised by subcategories of stakeholders (5 types). See **Box 3.3**

Box 3.3 – A look inside the document archive and its organising features



Direct observation, (what stakeholders actually do)
There were a multitude of opportunities to observe what stakeholders actually do when they work or even when they are innovating. Electronic note taking was frequent during interaction with stakeholders.

Naturally occurring conversation, public events
Many of the circumstances of encounter with stakeholders were at public meetings, seminars, workshops and exhibitions. They were also visited in their workplaces, where abundant exchanges of opinions with the author or with other people took place. The fact that a lot of the conversation was rather serendipitous did not diminish but increased its informative value.

Semi-structured interviews (what stakeholders want us to know)
This includes interviews conducted by the author as well as interviews conducted by others, often peers scientists or experienced journalists (and accessed via radio programmes, podcasts or webcasts). The latter were made available either by personal request or via institutional websites. Between 30 and 40 semi-structured interviews were carried out by the author between September 2007 and October 2009, many of them with high level stakeholders, including some scientific advisers to government and top corporate officers. Though listing their names might seem useful we are also aware that people change, opinions change, and for the specific context of this study collecting information was not more important than what we did with it analytically.

Monitoring the media and institutions (in the 21st century)
This category comprised the systematic monitoring of selected materials in various formats: film documentaries, newspapers, newspaper supplements, podcasts, webcasts, weblogs, magazines, visual materials, advertisements, online vox-pops, online forums and consultations (e.g. NESTA's innovation index public consultation, and government consultation on future skills, BIS). Box 3.4 shows the level of efficiency attainable these days through an adequate use of internet tools.

Box 3.4 Online monitoring the media and institutions (new contents in bold)

Personal communications

Several people where consulted directly for very specific questions throughout this study, including:

Dr. Bruce Tofield, (Low Carbon Innovation Centre, UEA)
Professor Charles Oppenheim, (Loughborough University)
Professor David I. Stern, (University of Canberra)
Professor David Levine, (Washington University, St Louis)
Professor Eric Neumayer, (London School of Economics)
Professor Frank Geels, (University of Sussex)
Professor Giles Atkinson, (London School of Economics)
Professor Kerry Turner (University of East Anglia)
Professor Laurence Lessig, (Harvard Law School)
Professor Michel Boldrin, (Washington University, St Louis)
Paul Kingsnorth, (Writer)
Dr. Paul Warde, (University of East Anglia)
Professor Peter Fleissner, (University of Technology, Austria)
Professor Robert Ayres, (INSEAD – France)
Professor Sir David King (Smith School - University of Oxford)
Professor Terence Kealey, (University of Buckingham)
Professor Thomas Sikor, (University of East Anglia)
Professor Thomas Sterner, (University of Goteborg)
Professor Tim O'Riordan, (University of East Anglia)
Professor William Rees, (University of British Columbia)
Professor Wouter de Groot (Leiden University)

3.4 Key findings influencing all scenarios

This section looks at the key findings within five categories:

- *General themes affecting all scenarios*
- *Energy sector*
- *Passenger cars*
- *Food supply*
- *Housing sector*

First qualification: what follows is not a list of all key issues according to specific stakeholders or all those issues contained in government reports. Each stakeholder has a set of priorities and a specific agenda. Organisations undertaking research in nanofoodstuff have a different agenda from those looking to stress the qualities of different diets. This happens in every sector and not all stakeholders have equal access to the media. The following section focuses only on those key findings in each category that seemed likely to have a long term impact upon the way current trajectories of innovation and energy density transitions are envisioned and debated by all stakeholders simultaneously. **Second qualification**: after reading this chapter, it may appear to the reader that the car sector was presented in a less succinct and more detailed way than the housing and food supply sectors. This is because, as the car sector heads towards increased technological *simplification* (i.e. electrification)[58] we had to review a past trajectory involving considerable technical detail; quite in contrast, as the technology and sociology of food and housing are heading towards increased *complexity*, we had to take a less historically-charged perspective and focus on the issues more generally and prospectively. With the conventional limitations of PhD-level survey, what follows is the compressed result of our own data sourcing exercise combined with an updated review of the literature on the three case study areas as of summer 2011. The purpose of this section is to inform narratives for concept testing. It is not meant to be exhaustive.

[58] And as we shall see, this applies to electric-motor-using "hydrogen" and "hybrid" cars too.

General themes affecting all scenarios

1. **The low-carbon economy transition will be first and foremost an energy density transition, most likely from *high* to *low* energy density carriers.** Although improvements are still possible, the physical boundaries of energy density in materials is well known (Ayres and Warr 2009, MacKay 2009, Smil 2006)
2. **All scenarios assume the imminent arrival of competing allocations for fossil high energy density carriers.** They also assume that —politically speaking— some allocations will be more critical than others to avoid the worst economic and social effects of a transition to a low-energy-density-economy (LEDE transition)
3. All scenarios accommodate the possibility of a major technological breakthrough, particularly in energy storage; they differ however on the degree of adoption according to technical and commercial viability (e.g. availability of materials, price) **At any rate, such a breakthrough was assumed likely to accentuate rather than remove the system-wide problem of how sustainable the status quo is on the whole, with or without the breakthrough.**
4. **Innovation in the three sectors considered is, and will continue to be, a borderless phenomenon**. It seemed neither realistic nor useful, for all scenarios, to assume innovation as a predominantly localised activity; either at its early formation stage or in subsequent deployments; neither innovations that enable the upgrading of existing systems or infrastructure, nor for those innovations that lead to the implementation of novel practices, or ways to organise responses. They are all assumed as dependent on wider effects. For a majority of instances in the UK context, even the need to innovate locally is, in the main, triggered or at least partly driven by wider-scale phenomena, whether technological in nature (e.g. e-communications) or those innovations that come about in response to an specific local need (e.g. the idea to build with local materials, in local vernacular styles in a sort of communal spirit). Instead, all scenarios recognise that across all sectors of the economy and

indeed in transport, the food chain as well as housing, innovation needs to be seen as a process that integrates and is affected by regional and global forces and dynamics.

5. **All scenarios assume that the magnitude and nature of the energy transition is likely to force an economic slowdown upon society.** Scenarios also assume politicians and governmental reports cannot be expected to be explicit about it, now or in the future.
6. **It was assumed for all scenarios that employment would become at least partially decoupled from personal income earnings well before the year 2050**. This would presumably come about by many means: time banks, LETS schemes, a shorter working week and so forth (NEF 2009, 2008)
7. **All scenarios reflect the fact that for many years the use of economic vocabulary has disguised the fact that modern economic growth —and every success story built upon it— has been the result of a large-scale *subsidy*.** This subsidy has always come from the natural world in the form of two billion years of accumulated energy reserves (Ayres and van den Bergh, 2005, Ayres and Warr, 2009). Business managers often talk about how profitable and competitive their organisations are, however, this may turn out to be type of vocabulary which potentially brings much confusion and ignorance to any scientific assessment of where these stakeholders stand in terms of being part of the problem or part of a solution.[59] There are some of the reasons why

[59] "Economists in the late 1950s were surprised to find that they could not adequately explain economic growth per capita in terms of changes in the two factors, capital and labour. Most of the growth in GDP had to be attributed to a residual, namely a time dependent multiplier A(t) of the production function as a whole, or of one or more of its factors. That multiplier was labelled "technical progress". But no independent definition of technical progress has ever been offered. In fact, for economists, technical progress has essentially been identified with increasing *factor productivity* or (more usually) just labour productivity. Nobody has worried much about the circularity of this definition. But, it is clear from many sorts of evidence that a large part — probably by far the largest part — of the historical increase of "labour productivity" that apparently drives economic growth is, in fact, attributable to the vast increase in the exergy flux, per unit of human labour, supplied from outside the system. In effect, exergy (in combination with machines, i.e. capital) has been a substitute for human labour in many sectors. (Machines alone cannot replace human labour.) If one adds exergy to the production function, then economic output — and growth — must be reallocated among three factors, labour, capital and exergy. This allocation would surely explain a much larger fraction of total historical growth, leaving correspondingly less to be explained by exogenous multipliers" (Ayres 1998, p.206)

economic concepts cannot be uncritically relied upon to explain the economics of a low-carbon society transition, their analytical value is eroding rapidly and therefore our scenarios to 2050 needed to draw upon less conventional criteria. Figure 3.1 shows the *fossil fuel economic growth engine* that a transition to sustainability is now forcing us to reconsider and perhaps to a great extent abandon long before the year 2050. Because the energy growth engine has treated fossil fuels for the most part as exogenous to the economy (even by so called "endogenous growth" theorists), they have remained as undervalued variables in most economic models. To the extent that a transition to a low carbon economy means that society has to start generating its own energy as well as its own means of storage we can be *certain* that **by the year 2050 some of the most widely used concepts emanating from Figure 3.4 will have lost most of the meaning and weight** they carry today.

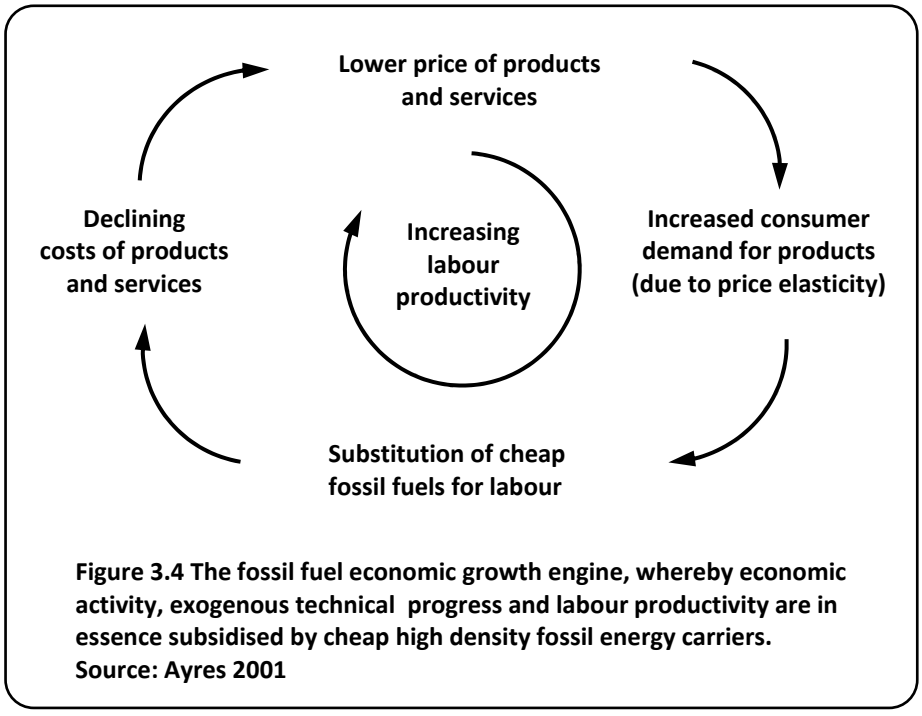


Figure 3.4 The fossil fuel economic growth engine, whereby economic activity, exogenous technical progress and labour productivity are in essence subsidised by cheap high density fossil energy carriers. Source: Ayres 2001

8. **All scenarios reflect the fact that the analytical value of a range of other economic concepts and terminology which society often takes for granted, such as *economics of scale "profitability", "productivity", "net costs", "discount rates"***

and so forth, is likely to erode hence misguiding a lot of intelligent people once key economic activities can no longer be subsidised by the cheap availability of hydrocarbons with high energy densities. There are reasons to suspect current economic judgement is obscured by the fact that we simply have never experienced what living in a low-energy-density economy (LEDE) will be like. Consider Dr. MacKay's example: "sometimes people focus too much on economic feasibility and they miss the big picture. For example, people discuss "is wind cheaper than nuclear?" and forget to ask "how much wind is available?" or "how much uranium is left?" (MacKay 2009, p.23) Another example is a new way to calculate the price of carbon emission cost. Slightly unnoticed, the approach to carbon valuation in the UK went through a major review in 2009. The new approach moves away from a valuation based on the damages associated with impacts (the "damage-cost-avoided" approach) and instead uses cost of abatement and mitigation estimates to put a price on carbon (HM Treasury 2010). Which method is more robust than the other for the long run case is something which necessarily relies on sustainability relevant value and prices which are extraordinarily difficult to determine with current market data (Stern, 1997,1995; Sterner et al. 2008; Pezzey and Toman, 2005). Therefore the cost of carbon seems yet another problem which remains for the most part subject to the indeterminacy of economic concepts and analyses as they relate to a low carbon sustainability transition. Paraphrasing Pezzey and Toman (2005) "we refer to prices that induce a sustainable time path of utility as *sustainability prices.* Sustainability prices figure prominently in what economics can and cannot say about the measurement of sustainability (p.126)

9. **UK's future energy mix is likely to include coal, nuclear fission and energy imports. It is not yet clear how the country will pay for them.** With high costs, nuclear fission will probably provide an airbag to people's lifestyles during the low carbon transition, along with coal and CCS (carbon capture and storage) which are likely to be in the UK's future

energy mix. As pointed out, future expansion of wind and solar energy is likely to meet public opposition. Today each person consumes about 125 kWh per day, the realistic estimate for renewables is in the order of 18kWh per day per person (as shown in **Figure 3.5**).While priority may be given to food-security oriented agriculture, biodiversity and recreation, the UK may well end up relying on energy imports from abroad to supply its (EU, African) based power facilities the question of how it will pay for it has not an obvious answer.

10. **The transition to renewable sources of energy in the UK is likely to encounter formidable public opposition in forthcoming years and decades. MacKay (2009).** The latter author argues that there is a difference between what is technically possible in terms of renewable energy production and what is likely to be socially acceptable *after a public consultation* (see **Figure 3.5**)

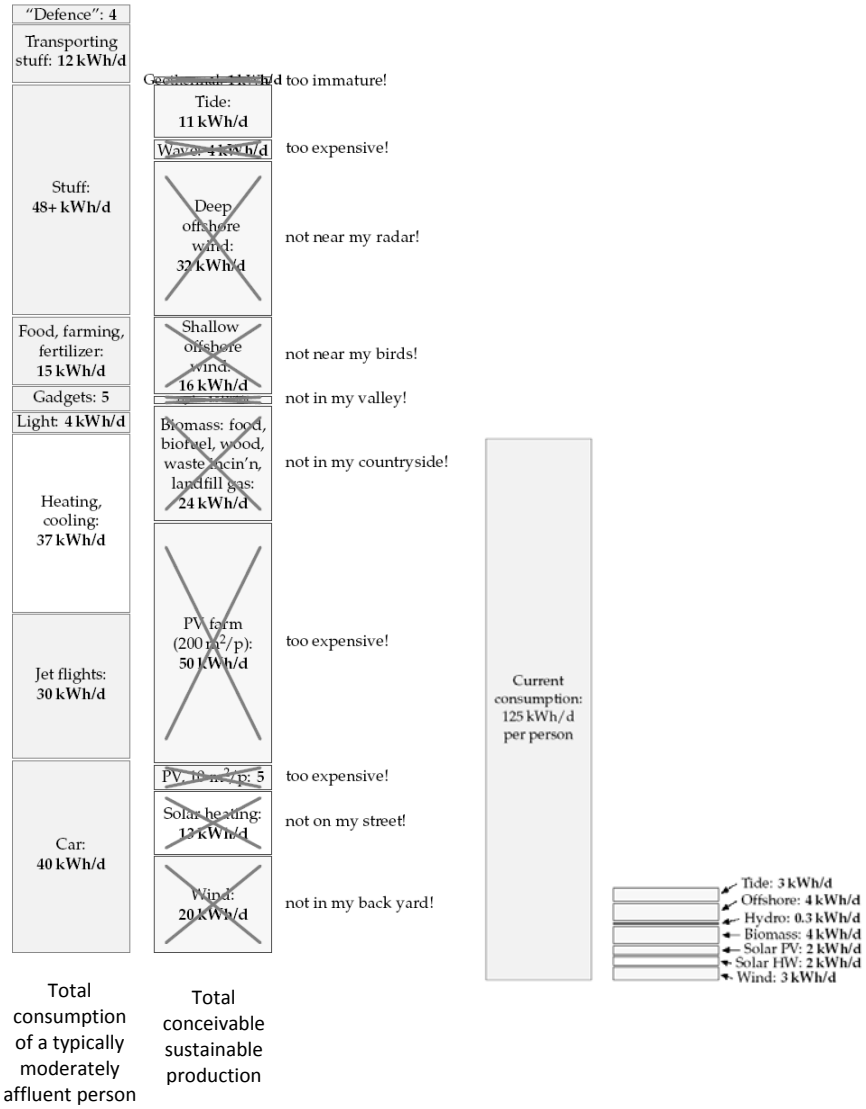


Figure 3.5 The social costs of a transition to sustainable energy production. According to MacKay, this is the state of play after we add up all the traditional renewables, *and then have a public consultation*. After the *public consultation* the maximum the country would ever get from renewables is 18 kWh/d per person. The left-hand consumption number,125 kWh/d per person, is the average consumption, excluding imports, and ignoring solar energy acquired through food production. Source MacKay 2009 p.109)

Energy sector

1. **Fuels, including hydrogen, are not "sources of energy" but *energy carriers*, means of storage. Our primary source of energy is the sun[60]. This is why it is useful to think of the low-carbon economy transition as an *energy density transition*.** Put in a different way, the transition is not only about our plans to generate energy but also about our plans to store it for consumption while making sense of different energy densities[61].
2. Whatever the calculations, it must taken into account that five factors will make the transition to a non-fossil world far more difficult than is commonly realised: the **scale of the shift**; the **lower energy density** of the replacement fuels (relative to weight); the substantially **lower power density** of renewable energy extraction (rate of production per unit of land area); **intermittency** of renewable flows; and **uneven distribution** of renewable energy resources (Smil 2006) Furthermore, "on these points at least, there is no urgency for an accelerated shift to a non-fossil world: *fossil fuel supplies are adequate for generations to come, new energies are not qualitatively superior, and their production will not be substantially cheaper.* Arguments for an accelerated transition to a non-fossil world are predicated almost entirely on concerns about climate change. Even then, because of the enormity of requisite technical and infrastructural requirements, many decades will be needed to capture substantial market shares on continental or global scales. *A non-fossil world may be highly desirable, but getting there will demand great determination, cost and patience*. [Italics ours] (Smil 2006, p.22,23). The disparities in required land areas suggest the implied impacts of a transition to renewables: either importing a lot of energy or formidable changes in current lifestyles.

[60] True: geothermal is yet another source of primary energy, we are only trying to make a useful distinction between *sources* and energy *carriers*. The sun makes wind and waves and it is also transformed and stored into oil by biochemical and geophysical processes.

[61] Note the difference between *storing primary energy* (e.g. from sunlight-to-petrol) and storing an energy carrier (e.g. keeping petrol in a tank)

3. **An interesting picture of a future society can be drawn solely on the energy density of the fuels that it burns. The heavy cars that we drive and the type of foodstuff we eat today are only explicable via calorific values of above 12 kWh/kg, typically contained in fossil fuels, principally oil.** As shown in **Table 1.5** oil derivatives have high energy densities compared to other energy carriers, such as firewood (4,400 Wh/kg) lithium-ion batteries (140 Wh/kg) and so on. Unless a major technological breakthrough happens soon enough —an unlikely event— the low CO_2 transition will most probably have to be from *high* to *low* energy density fuels and other means of storing energy, such as electric batteries, biomass, pumped storage in hydroelectric complexes.
4. **Energy storage is likely to be equally or perhaps even more challenging to the status quo than energy generation.** Energy storage, more than generation, is more likely to question current consumption patterns and ultimately the status quo. Paying equal attention to power generation and energy storage[62] is not only a key to understanding the present but also to understanding possible futures for our food, homes and cars. Storage considerations are likely to question the weight of cars the use of synthetic fertilisers in agriculture, human and animal feed as well as diets. Homes will probably have to be built with energy saving criteria including building for the very long term rather than say, the next 30 years. From an energy storage perspective the low-carbon economy transition may cost more money to everyone, impacting lifestyles significantly, in all scenarios (BBC 4 "you and yours" panel). To understand the type of challenges in energy storage systems we considered examples such as Denmark's celebrated wind power complex, which uses neighbouring countries" hydroelectric facilities to store their intermittently-generated energy. Solar, wave and tidal energy generation present similar problems. Hydrocarbons in contrast present none of these problems: the sunlight has already been captured by vegetable photosynthesis and elegantly stored underground in vast amounts, sparing us the

[62] Power is a flow or rate, energy is a volume measure, often used indistinctly

troubles of *generation* and *storage* that precede *consumption*. Two billion years later we are cruising for burgers in our cars while business managers boast about how much wealth they produce.

5. **At the moment, there are better reasons to think the "hydrogen economy" is more about politics than about science and technology.** Though some scientists claimed to have cracked the problem of producing hydrogen with photo-catalysis (Heyduk and Nocera, 2001; Nocera, 2009) or with green algae (Amos, 2004). We assumed the whole "hydrogen economy" rhetoric to be more about politics (e.g. big oil politics, science politics) than about tackling the energy storage problem faced by all industries. **Box 3.5** synthesizes one of many scientific views informing this assumption.
6. **The battle to harmonise standards in energy storage is likely to be harsher unless governments intervene at a supranational level.** The lobbying and politics of energy storage and the battle for harmonising technology standards —hence monopolising whole sector technologies— are already a battleground and will continue to be perhaps for the rest of the transition. Consider the battle in road transport between those stakeholders who lobby for nation-wide use of hydrogen and those who support electrification. In cases like this agreements may never be reached and different technologies may have to coexist via government intervention.
7. **Alternative electricity generation is less capable of adjusting to demand peaks.** This includes solar, wave, tidal and nuclear. The first three have the additional problem of being intermittent, they produce energy when they can rather than when people need it.

Box 3.5 Why hydrogen is the energy carrier of the future (and perhaps will always be).

"I think hydrogen is a hyped-up bandwagon. I'll be delighted to be proved wrong, but I don't see how hydrogen is going to help us with our energy problems. Hydrogen is not a miraculous *source* of energy; it's just an energy *carrier*, like a rechargeable battery. And it is a rather inefficient energy carrier, with a whole bunch of practical defects. The 'hydrogen economy' received support from *Nature* magazine in a column praising California Governor Arnold Schwarzenegger for filling up a hydrogen-powered Hummer (see Arnold below)

The 'Governator'

Nature's article lauded Arnold's vision of hydrogen-powered cars replacing 'polluting models' with the quote 'the governor is a real-life climate action hero.' But the critical question that needs to be asked when such hydrogen heroism is on display is 'where is the *energy* to come from to *make* the hydrogen?' Moreover, converting energy to and from hydrogen can only be done inefficiently – at least, with today's technology. Here are some numbers:

- In the CUTE (Clean Urban Transport for Europe) project, which was intended to demonstrate the feasibility and reliability of fuel-cell buses and hydrogen technology, fuelling the hydrogen buses required between 80% and 200% *more* energy than the baseline diesel bus.
- Fuelling the Hydrogen 7, the hydrogen-powered car made by BMW, Figure 20.26. BMW Hydrogen 7. Energy consumption: **254 kWh per 100 km**. Photo from BMW. requires **254 kWh per 100 km** – *220% more* energy than an average European car.

If our task were 'please stop using fossil fuels for transport, allowing yourself the assumption that *infinite* quantities of green electricity are available for free,' then of course an energy-profligate transport solution like hydrogen might be a contender (though hydrogen faces other problems). But *green electricity is not free*. Indeed, getting green electricity on the scale of our current consumption is going to be very challenging. The fossil fuel challenge is an energy challenge. The climate-change problem is an energy problem. We need to focus on solutions that use less energy, not 'solutions' that use more! *I know of no form of land transport whose energy consumption is worse than this hydrogen car*. Here are some other problems with hydrogen. Hydrogen is a less convenient energy storage medium than most liquid fuels, because of its bulk, whether stored as a high pressure gas or as a liquid (which requires a temperature of −253 ◦C). Even at a pressure of 700 bar (which requires a hefty pressure vessel) its energy density (energy per unit volume) is 22% of gasoline's. The cryogenic tank of the BMW Hydrogen 7 weighs 120 kg and stores 8 kg of hydrogen. Furthermore, hydrogen gradually leaks out of any practical container. If you park your hydrogen car at the railway station with a full tank and come back a week later, you should expect to find most of the hydrogen has gone."

Source: MacKay 2009, p.129-130

8. **Future electricity mix in the UK is expected to include, coal, nuclear power and renewable sources (the latter at least 20% by 2020)**. Nuclear is less able than coal fired power stations to adjust production to meet demand peaks. Likewise, wind, solar and wave power may produce a lot of electricity in a stormy night not when people want it. This electricity must either be used, stored or it will be lost. Under EU regulation, by 2020, 20% of UK's energy mix will have to come from renewable sources. Additionally, a turning point for the country's energy sector is due in 2015 when a considerable number of large power plants will have to be

decommissioned under EU's large combustion plans directive. Last but not least, by the year 2050 the UK will need to reduce its energy consumption per capita of a projected population of 77 million (ONS 2008) so as to meet emission reduction targets of 80% to 1990 levels. By the year 2050 the country's remaining net energy demand would have to be met by a mix of renewable sources of energy, coal and nuclear fission, all of which are already in the government's energy portfolio plan.

9. **Access to "rare earth metals" is likely to become a problem in the future across all green and low carbon industries. "Beijing officials are already forcing global manufacturers to move factories to China by limiting the availability of rare earths outside China" (NYT 2009/10/01)**. Energy generating equipment and other hi-tech industries are now an international industry with China and India quickly becoming big players. Many analysts appear to underestimate the fact that China has also become world's first supplier of rare earth minerals, which happen to have crucial applications across the whole renewable energy sector[63] (**Figure 3.6**).

[63] The world's first supplier of lithium however (for electric batteries) will soon be Bolivia.

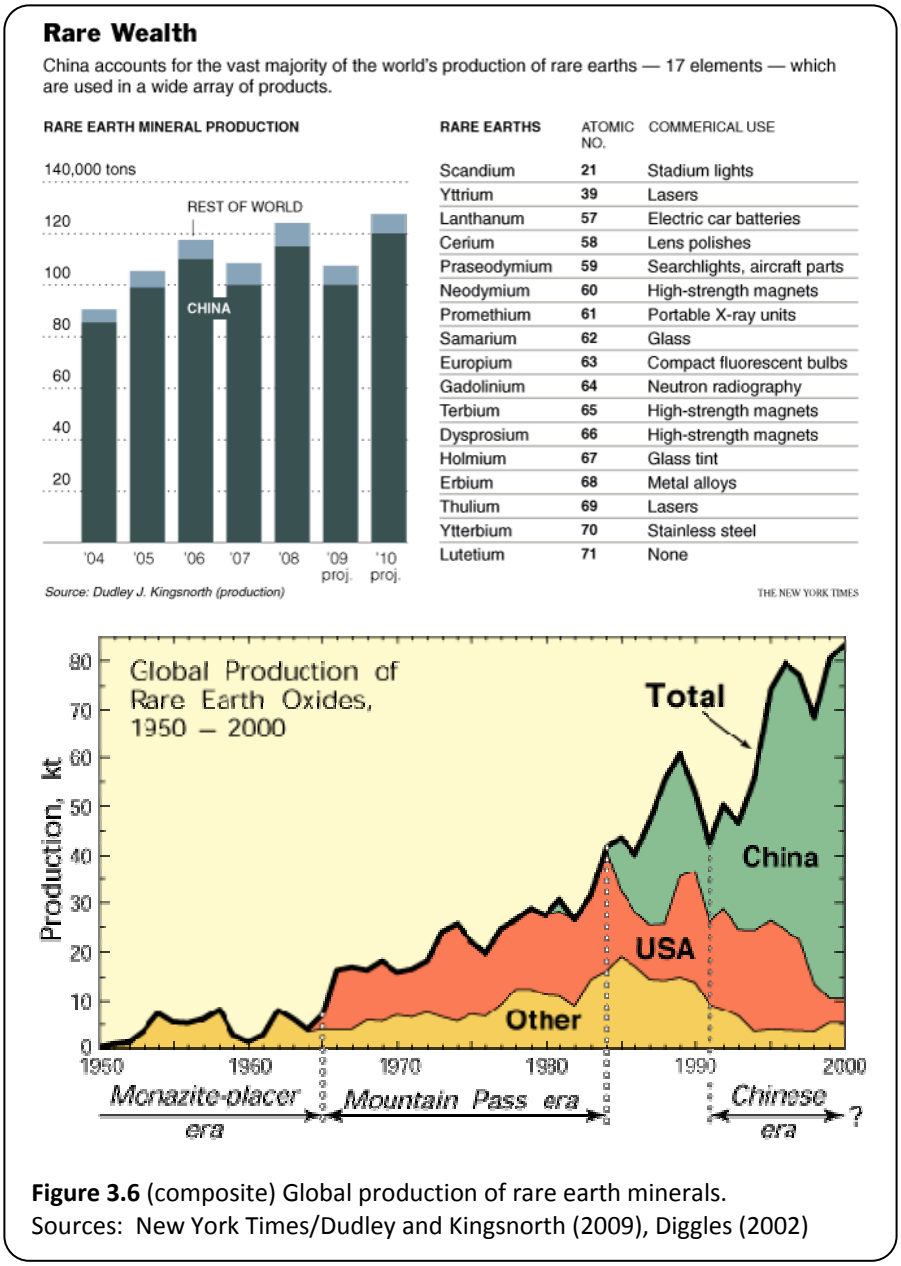


Figure 3.6 (composite) Global production of rare earth minerals.
Sources: New York Times/Dudley and Kingsnorth (2009), Diggles (2002)

10. **No evidence suggests that the UK —or any country in Europe or the US for that matter— is on track to spearhead a profitable, green, technological revolution (Lucas and Hines 2006) as many people have been suggesting over the past few years** including president of the Royal Society, Martin Rees[64] Rolls Royce's chief executive John Rose[65] a few secretaries of state or indeed the last three prime ministers.

[64] Conference "The world in 2050" Royal Society, 2008
[65] Conference "Creating a High-Value Economy" at the RSA 2009 (Royal Society for the encouragement of Arts, Manufactures and Commerce)

Passenger car sector

1. **The energy density of fuels and indeed all other forms of energy storage, is one of the most if not *the* most important technical factor shaping transport policy today and within the next 40 years.** A transition to low carbon transport is likely to be also a transition from *high* energy densities (e.g. petrol and diesel oil) to *low* energy densities (e.g. electric batteries, biofuels, hydrogen[66]). This means any form of road transport will have to grapple with the increasing costs of carbon and the need for lighter vehicles. Motoring costs may soon become a lot more sensitive to costs per unit of vehicle weight. The global car industry in 2010 appears distant from the aforementioned signals. And so appear government standards (see **Figure 3.7**)
2. **If electric vehicles (EV's) are those who use an electric motor, it would help the technical and political debate once and for all to see all hydrogen fuel-cell cars as what they are: electric cars too.** Ultimately, an electric motor is used to move the "fuel cell hydrogen car", hydrogen is the chosen means to store energy (instead of a battery) and electrochemical fuel-cell devices are used to convert hydrogen into electricity. Remarkably no stakeholder ever mentions this, apparently because of the politics of fuel cell technology (which by the way may be transformed by creative-commons fuel cell technology) All the extra-steps to convert energy into motion explain why the much-hyped "hydrogen car" is hyper-inefficient too. Meanwhile Nissan-Renault's CEO Carlos Ghosn, has described the hybrids like this: "hybrids are like mermaids when you want a fish you get a woman and when you need a woman you get a fish."

[66] The commercial use of hydrogen still depends on the arrival of a major technological breakthrough, at present is one of the most inefficient and impractical energy carriers.

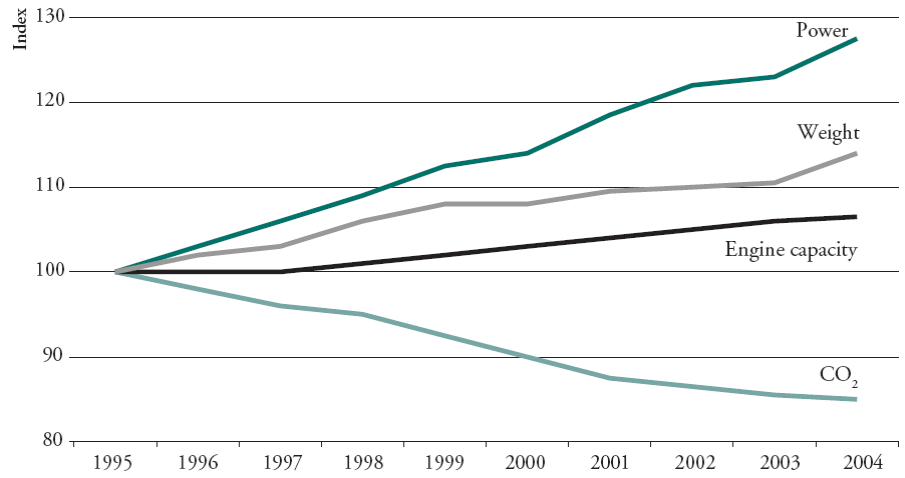


Figure 3.7 Recent trends towards heavier and "safer" vehicles have offset improvements in reductions in CO2 emissions. Changes in average vehicle CO2 emissions, power, engine capacity and weight. Original source: ACEA (in the King review of low carbon cars 2008).

3. **Private road transport is likely to become more expensive and public transport will play a greater role in the run-up to 2050. Figure 3.8** suggests the type of energy requirements transport policy will have to grapple with in terms of costs and CO_2 emissions.
4. A transition to a lower-energy-density economy (LED economy) will imply in the medium term (next 20 years or so) **transport policies toward differentiated high-density fuel use, prioritising strategic areas** such as road freight, public transport, domestic and international shipping in general as well as farm equipment and agricultural machinery.
5. **If the UK as a nation had a fleet of electric battery cars being charged overnight (wind, wave power) or when the sun is bright (solar), then the power industry's income from drivers would come on top of the income it currently gets from homes and companies.** Electric motoring would in fact improve the economics of both nuclear power and alternative energy, playing a central part of the government's desire to push for a low carbon economy[67]

[67] BBC News, John Madslien, 2009/04/16 [2w4sq2c]

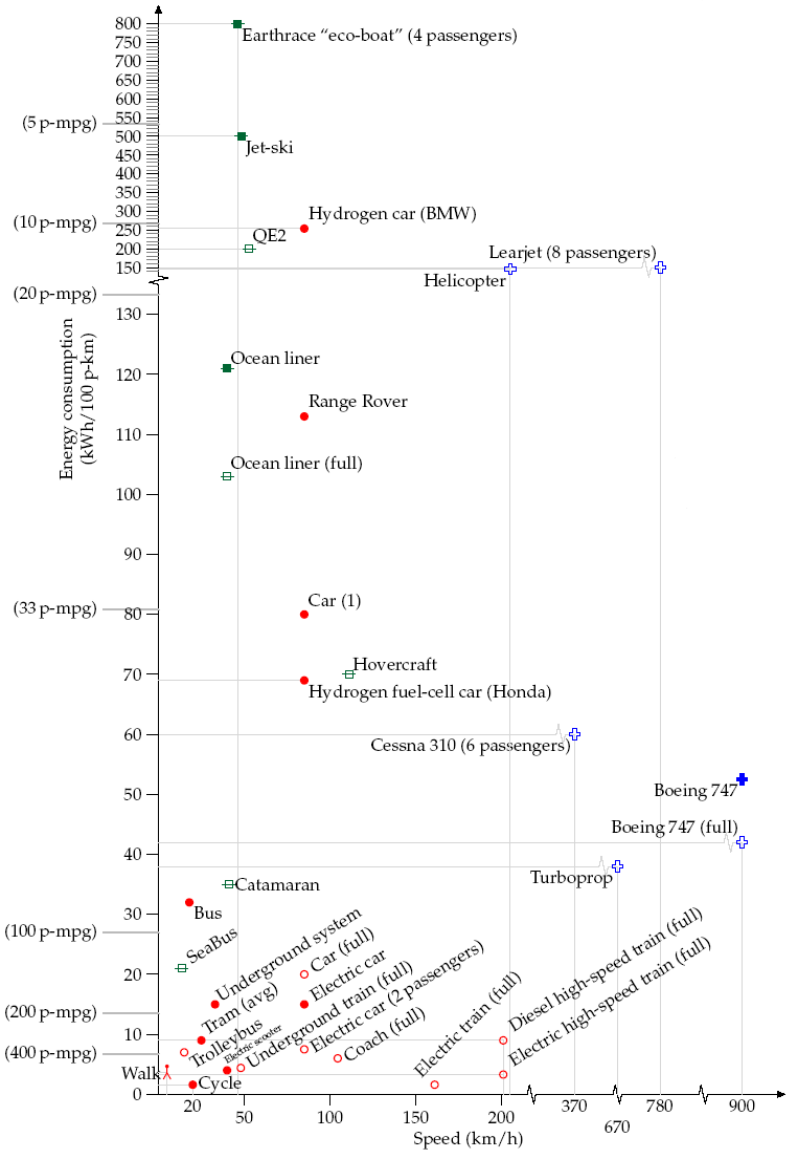


Figure 3.8 Energy requirements of different forms of passenger transport. The vertical coordinate shows the energy consumption in kWh per 100 passenger-km. The horizontal coordinate indicates the speed of the transport. The "Car (1)" is an average UK car doing 33 miles per gallon with a single occupant. The "Bus" is the average performance of all London buses. The "Underground system" shows the performance of the whole London Underground system. The catamaran is a diesel-powered vessel. On the left, equivalent fuel efficiencies in passenger-miles per imperial gallon (p-mpg). Hollow point-styles show best-practice performance, assuming all seats are in use. Filled point-styles indicate actual performance of a vehicle in typical use.

Source: MacKay 2009

6. **Moving away from fossil fuels will mean sharp reductions in government income from petrol and diesel. Perhaps government would want to tax electric motoring and**

making it more expensive. This might in turn persuade companies to provide more flexible and lucrative *pay as you go* type of services (see next point)

7. **The idea of moving from "manufacturing cars" to offering "transport solutions", may not prove to be a sustainable business model in the longer term.** This includes "pay as you drive services" and "car-kilometre packages" much like the mobile phone industry does today. Variants of this new model are already being tested by new players in the industry such as *Riversimple* and *Better Place*[68] Some generic features for such models to work are listed below **(Box 3.6)**. The missing feature however, that would render these models unworkable is explained further below. **The "transport as service" model outlined in Box 3.6 seeks to square the circle of the energy transition by concealing what appears to be one of the most challenging issues the industry will be facing: *the seemingly imminent switch to lower-energy-density carriers* not just in the car industry but across the whole economy.** Marketing sexy "car kilometres" and turning automobiles into the "new mobile devices" where people only pay service providers "for what they really need"[69] would almost certainly boost profits for any car company adopting the model. It would do so however, only for a while and by having to rely on the consumer incomes yielded by an economy still running on high energy density hydrocarbons. The "transport services" business proposal obscures the fact that, in a transition to a low-carbon transport system, *the whole economy too,* would be running on low-energy-density carriers yielding less —not more— disposable incomes for drivers. If this all is true, a business model like this would not add up. It would simply be an attempt to plug the energy density gap by transitorily inflating the price of a service that, left to the market, would necessarily be a lot cheaper for what it delivers: lower torque

[68] The first one is a UK-based company which promotes the "creative-commons hydrogen car" [majeub] while the second is an Israel-based which promotes swapping station infrastructure and integrated services for electric cars [59rw6r]. See also INDEGO-consulting [32lfbzw]

[69] Shai Agassi's TED talk 2009 [dg9euj]

per energy unit. This would happen with current electric or hydrogen car technologies.

Box 3.6 A new business model for the car industry? Somewhat questionable.

- The car industry currently works by massive investments in factories which produce large numbers of vehicles to push through dealers as news sales, with the second-hand market left to itself. A new hypothetical model in contrast, would import most of the car in flatpack form from countries such as China or India and assemble it closer to where customers are.
- Plastic panels would replace paint (which account for much of the pollution in car assembly lines today)
- Increase flexibility would enable companies to sell "trendy transport solutions" rather than cars.
- Vehicles would become more updatable and marketing would persuade drivers to upgrade constantly
- Vehicles could be leased in a "pay as you drive" scheme (more or less like mobile phones) so when one driver returns a car, it can be renovated and released as a second-hand model. Servicing and repairs would be included in the lease, locking in profits not captured by current manufacturers.
- Leasing would widen up the business of financial services and insurance (which already accounts for the biggest proportion of profits for companies like Ford)
- Because there is no second hand market, there would be little incentive for car theft, so insurance could be cheap and profitable.
- Cutting costs would be possible, just like cheap airlines do. There would be a focus on "good enough" products rather than "the best".

Sources: Financial Times. April 22, 2004 [2whjf6b] , INDEGO-consulting

8. **For the aforementioned reasons, the "transport services" model might turn out to be the "make profits while you can" model** or perhaps the "innovative way of business as usual" model. It is still at least questionable that the car industry will ever move successfully and more profitably than it currently does by switching to a "transport as service" model and to lower energy density carriers simultaneously.
9. **The car industry worldwide is currently facing several crises: financial crisis, human resource, technological crisis[70]. It remains uncertain whether its business model is either secure, sustainable or even necessary in the twenty first century. There are three major trends shaping the future of the global as well as the UK car industry: regionalisation, market fragmentation and overcapacity**

[70] including Toyota's "sticky pedal" ordeal

(Holweg et al. 2009). The most preoccupying is the latter one: with or without recessions, bailouts and emergency loans, the global car industry in 2010 has a appalling **overcapacity** which turns into an oversupply of about 20 million cars. This is similar to all the installed capacity of Western Europe. To boost employment and dynamism in the economy, governments have been encouraging and *subsidising* —most probably by burning fossil fuels or by causing others to burn them— the growth of new assembly plants, new car inventories, sales incentives, discounts, car credits, whole financial infrastructures. A story resembling many aspects of the recent crisis in the UK and US housing sector. In other words, the car industry in the UK, insofar as it is "global" appears to be a bubble that sucks up energy and public finances in order not to explode, but only for the moment. The other two trends are **regionalisation** —which refers to how global manufacturing is being replaced by more local manufacturing— and **fragmentation of markets**, meaning the increase in model range and the shortening of the average car life cycle (e.g. a car used to be 7 years on the road in 1970, today only 5). **Offshoring is a very real threat to the whole UK car industry.** A consensus is emerging that "essentially all employment in vehicle assembly, component manufacturing and R and D is under threat of off-shoring, while the employment in motor vehicle retail and services is not. Thus, of the 384,000 directly employed by the automotive sector, we estimate that potentially 330,000 jobs could be lost in the future" (NAIGT 2009)[71]. Composite **Figure 3.9** compares car sector employment trends as well as R and D expenditure. According to some analysts it is attractive to invest in the UK because the labour force is flexible, yet that flexibility makes it easier to close plants in the UK than anywhere else in the diagram. (Holweg et al.

[71] An Independent Report on the Future of the Automotive Industry in the UK. The New Automotive Innovation and Growth Team (NAIGT) was launched in April 2008 to facilitate the development of a collective strategic view from the automotive industry on the innovation and growth challenges that it faces in the period to 2025. It was an industry-led project facilitated by the Automotive Unit (AU) within the Department for Business, Enterprise and Regulatory Reform (BERR). [6zpmcvo]

2009). As for R and D expenditure, **Figure 3.9** suggests that unlike France or Germany, the UK is competing as an assembly location only with the rest of the world.

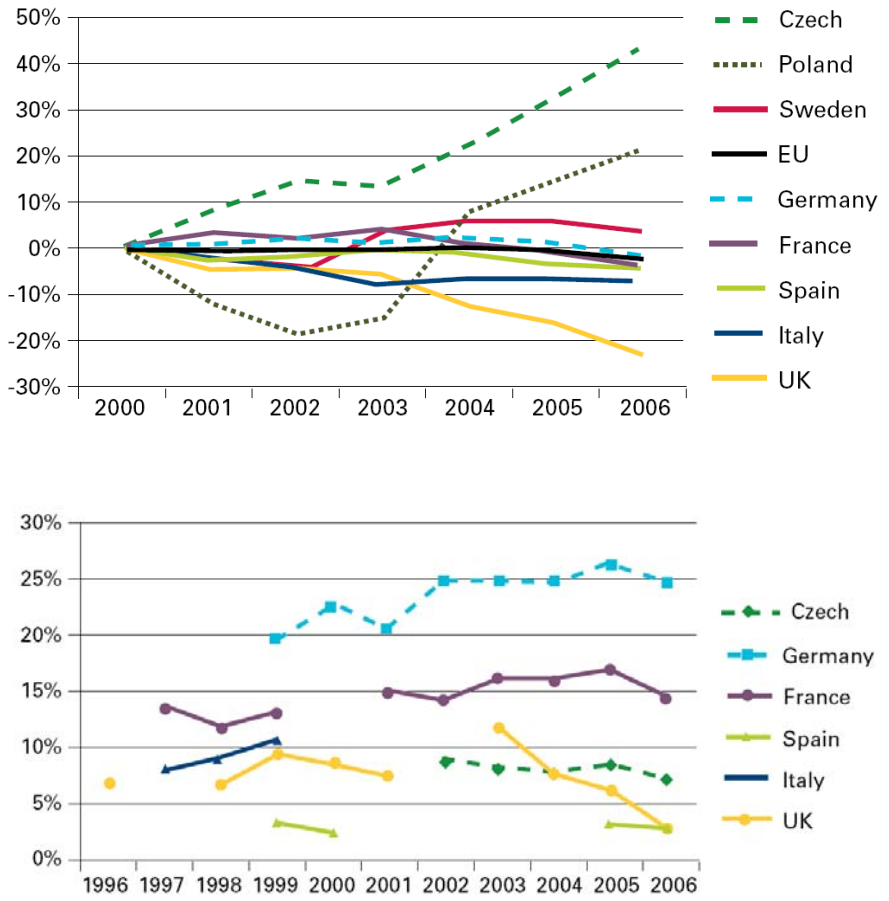


Figure 3.9 (Composite) Car industry trends in the EU: employment (figure above) R&D expenditure (figure below). Source: NAIGT 2009, (with EuroSTAT data)

10. **Under current trends, open-source and creative-commons technology is likely to revolutionise the technology and economics of the whole automotive industry.** It is hard not to associate car technology development with "big investments", "big infrastructures", "big manufacturers" and even "big oil". To just mention the possibility that similar business models to those that have brought other big industries to their knees —such as the pharmaceutical or the music industries—might be well in the process of "infecting"

and transforming the entire car industry as we know it, still sounds a bit far-fetched or even absurd. **Yet, there is some evidence suggesting this is exactly what may soon be occurring. The first signal one is the historical resurgence of the electric car as a *political* —not just technological — alternative to the conventional petrol car[72].** While the internal combustion engine has more than 350 moving parts requiring high maintenance, the electric motor has only one moving part requiring little maintenance (the rotor). It is at least worth arguing that much like *generic formulas* as well as *digital sound recording* in the pharmaceutical and music industries respectively, electric vehicle technology has potentially a democratising effect in the way people consume, learn, share and develop automobile technology by themselves. **The second signal is the incipient popularity of online DIY car clubs whereby people appear to be using e-communications to access high quality car parts and building know-how**[73] Our scenario template, as applied to UK's road transport industry sought to accommodate questions such as how people in 2050 might be able to use technology to tackle mobility needs and how such needs might be spatially transformed by energy supply systems in the first place. Equally important, the template allowed us to contrast different futures about what people might want to do individually or collectively should they have in their hands a hypothetical *high-energy-density bonus* with a "use-by date" in it.

[72] It suffices to say that on both sides of the Atlantic, car electrification is already part of a political agenda to move forward the car industry into the 21st century.

[73] A basic Google search such as *build your own car* throws up as many as 211 million results (2010/08/23). The figure goes down to 36,600 when inverted commas are used, this however is not yet indicative of a less important phenomenon. Equally important are "creative-commons ecology" developers [3hb3mzw]

Food sector

1. **We are likely to see a convergence between organic production and creative-commons genetic modification within the foreseeable future. Creative-commons genetic modification will very likely be the litmus test for the GM science and industry,** which at the moment remains controversial because of 1-substantial equivalence issues[74], 2-ownership. That is to say, resembling what has happened in other industries —notably the pharmaceutical, and software industries where disruptive technologies have made business models irrelevant— the long controversial issue of ownership of genetic material may no longer stand in the way of developing and propagating the genetic modification technology commercially via "creative-commons trials". This is likely to include organic farming. One early indicator of this is the EU funded John Innes Centre's research programme which delivered an "anti-cancer purple tomato' in October 2008[75]. To note is 1-how the food industry is moving into the pharma industry, and 2-how a supranational body is funding the production of first trials. There are reasons to believe that moving into creative-commons and into organic GM production is simply a matter of time.
2. **The UK is going to face real constraints on fertility inputs, particularly nitrogen, potassium (manufactured with natural gas) and phosphates which are crucial to yields increases in industrial agriculture.** Without phosphates the country would have yields today about the level in the 1900s. China, the US and Europe, import mineral phosphates from Morocco. 20 or 30 years ago the worldwide estimate is that we had 600 years woth of of phosphates left. Current optimistic estimates are 60 years. A more realistic estimate

[74] The "substantial equivalence" principle was first used in the 90s by FAO and WHO. It is basically a nutritional value "checklist" that allows comparison between GM and non-GM food. If a GM food is "substantially equivalent" to its conventional counterpart, then it is assumed as safe as conventional food. The controversy originated by such a "checklist" mentality is that it measures things we already know and expect. The science of substantial equivalence however, tells us nothing about unforeseen dynamic changes in the organic structure of food at the genetic level and as a result of modification.

[75] BBC News 2008/10/23 [5r5myvf]

might be 30 years of supply left (Chatham House 2008, Soil Association 2008)

3. Modern agriculture is truly the "use of land to convert petroleum into food"[76] This is the one sector where a shift to **renewables or alternative energy is very unlikely to provide a technically equivalent replacement for oil** that modern agrosystems use to produce food. **We use apporximately 10 times more calories in the production of food than we get out as food.** And for every kilogram of food travelling around the world, it is emitting 10 kilograms of carbon dioxide. So we are wasting a 10-fold amount in production and then generating another 10-fold amount of carbon dioxide in distribution, most of it totally avoidable (Soil Association 2008).**If oil reached $200 US dollars a barrel, it would be cheaper to produce organic food per ton kilogram of output** than it would be to grow food non-organically (Jones and Crane, 2009). The UK is around 60% self-sufficient in food. **Less energy will imply not only less inputs but also less ability to subsidise agriculture and maintain such things as the water supply system.**
4. **Organic agriculture would cut greenhouse gas emissions and water pollution dramatically. Hydrocarbon related inputs to farming would drop by 95% and sprays by 98%, farm employment would increase by 73%.** Water use would fall, and farmland's capacity to act as a buffer to reduce flooding would increase. Soil health would increase and there would be about 50% more wildlife. "As organic fruit and vegetable yields compare favourably with conventional agriculture, organic farming could, with some adjustment, supply similar volumes as at present, or even increase output if necessary."[77] Due to the need to abolish intensive pig and poultry systems in organic agriculture, chicken, egg and pig meat production would fall to roughly a quarter of current levels, making large quantities of grain available for human consumption. Dairy production would fall by around 30%-40%, unless herds were to be re-established and dairies were to reopen in parts of the country which have lost them.

[76] Albert Bartlett, Cited in MacKay (2009)
[77] ibid

While the amount of wheat and barley produced would drop by around 30% due to lower yields, there could be as much wheat and barley available for human consumption under an organic system because far less grain would be fed to animals. A wholly organic agriculture could actually produce more beef and lamb than at present, with beef production rising by 68% and lamb by 55%"[78]

5. **There is a hight risk that genetic engineering might not be championed as a means to increase homeostasis and yields in stable agricultural systems but as a means of producing crops that will grow in degenerating agricultural ecosystem**s (Berhan 2008). American courts are beginning to ban GM crops, apparently for the same reasons as the European courts: GM technology tends to remove choice (by contamination of other crops) and technological options. While genetic engineering should be an option for the future it should be seen within a wide balanced socioeconomic context: "UK department for Business, Innovation and Skills should review relevant intellectual property systems to ensure that patenting or varietal protection of new seed varieties does not work against poverty alleviation, farmer-led innovation or publicly funded research efforts" (The-Royal-Society, 2009. p.x)
6. **Tackling obesity epidemics as well as diets, are likely to be part of a comprehensive strategy in regard to food production and security** (Foresight 2008). Around 10 billion pounds a year are spent on diet related ill health. Existing patterns of consumption are not fit for a resource constrained future (UK-Cabinet-Office, 2008)
7. **Britain is not far from "losing ground" in the "biotech revolution" against more powerful competitors and "brain drainers". The UK is unlikely to spearhead that or any other revolution involving green high-tech** where China and India are becoming very powerful[79]. Furthermore we may soon see the extensive application of converging

[78] Peter Melchett, RSA conference "Food in a world without oil" Sep 2009 [65zamdw]
[79] BBC 4 Peter Day "In business" (various programmes throught 2008-2009)

NBITC[80] technologies in agriculture. Such converging technologies are unlikely to be British.

8. **Of the two billion tons of grain grown around the world, less than half is eaten directly by people. "**We know we can feed 10 billion people, because we are already growing enough — if they have a vegetarian diet" The real threat is consumption patterns, not overpopulation[81]. **Around a third of all the food people buy in the UK we buy ends up being thrown away, half of it could have been eaten**[82].

[80] Nanotechnology, Biotechnology, Information technology and Cognitive sciences
[81] Joel Cohen [34phjqx]
[82] DEFRA [32gehrv]

Housing sector

1. **Existing homes are responsible for 27% of the total CO2 emissions of the UK. Yet, more than technology, the "low hanging fruit" issue in housing is universal high quality insulation,** which will require skills which aren't there yet (and are likely to employ a lot of people at some point). Meanwhile, a lot of vested interests over intellectual property appear to contaminate the debate on the importance of new technologies enabling home owners to generate electricity to achieve so called "zero-carbon housing" (Code for Sustainable Homes, Level 3)[83]. **The introduction of the Feed-in-Tariffs Scheme in April 2010, appears to have complicated this debate even more.**
2. **Home energy efficiency is achievable mostly by implementing three universal measures:** 1) really thick insulation in floors, walls, and roofs, 2) making sure the building is sealed airtight and with an active ventilation system to retain heat. 3) design the house so as to exploit as much sunshine as possible (MacKay 2009) **(Figure 3.10)**

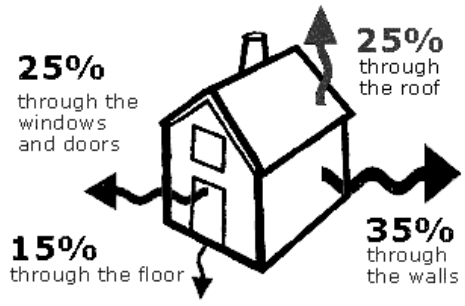


Figure 3.10 Typical home heat loss

3. **Technology-wise, low-grade energy technologies (e.g. solar or thermal) are likely to play a role compensating for some of high grade electricity savings. However, home micro-generation is unlikely to replace high grade current electricity power supply.** The evidence about hydrogen-fuel cell household micro-energy systems replacing current

[83] [2j362d]

centralised power supply infrastructure is at the moment highly contradictory and politicised.

4. **Between 75 to 80 percent of the houses in 2050 have already been built.** This means, even if all homes built from today were zero carbon, in 40 years time it still would not affect ¾ of UK's homes. In other words: "it's the existing stock stupid". **Consequently, government's Code for Sustainable Homes level 3 appears to be addressing the 1% of new homes and may distract attention from the other 99% of existing homes.**[84]
5. **It is possible that creative-commons technologies for the home may end up being funded by hypothecated taxes well before 2030.** With existing green-home technology monopoly prices and under the current Feed-in Tariffs Scheme, the cost of opportunity of micro generation of energy may well turn out to be too high to be sustainable within, say the next two decades or perhaps much less than that. This means that for a few years middle class home owners will be able to mess about with expensive patented technologies with a low energy return on investment (for the taxpayer but not for them). This might create a technological lock-in as well as a fuel poverty gap[85]. It could well be the case that at some point in the future, well before 2020 or 2030, government decides to finance low cost creative-commons technologies to give micro generation a boost. This may well be done, as some have been proposing already, by introducing a dedicated, hypothecated tax to finance new creative-commons technologies. (Prins, 2010).[86]
6. **There is an enormous shortage of skills in the UK on high-quality green construction techniques.** Drastic cultural

[84] Michael Meacher is Labour MP for Oldham West, John Gummer MP, Suffolk Coastal. BBC 4 Costing the Earth

[85] George Monbiot interview: Costing the earth BBC4 2008/05/01

[86] "It is wrong to assume that a price on carbon can induce the generality of firms to undertake the requisite R and D. This is for a simple and powerful reason. Generally, basic research, development and demonstration cannot be easily patented. So the market has no incentive to fund it. The endless business battles in the pharmaceutical industry tend to revolve around the control and release of intellectual property and illustrate this point" (Prins 2010, p.33)

changes in training, from apprenticeships through to experienced workmen are much needed.[87]

7. **The UK does not produce green technologies for the home (except for smart meters, related software and the like). The market is mostly dominated by other European and Japanese companies. Opportunities to create employment in the sector are relatively low.**
8. **"The number of people living alone in Britain more than doubled between 1971 and 2005.** This was driven by, amongst other things, increasing numbers of working age people opting to live alone, rising divorce and separation rates, and increasing numbers of old people living alone (following death of a partner). This trend is predicted to continue" (Sustainable Development Commission 2008).
9. **More people living alone and more people working from home could mean increases in energy consumption** not just because of heating space requirements, in the winter, but because of companion pets: a dog consumes 9kWh worth of food a day (a human consumes 12 kWh). **It could also mean drastic changes in the social fabric, are bound to happen as a result of unsustainable health, both physical and mental[88].**
10. **The energy embedded in houses is barely ever taken into account, this is likely to change in the future as energy becomes more expensive.** This means shifts to longer-term construction practices as well as shifts in materials use may occur by 2050.[89]

[87] Phil Jones, Lofters construction building contractors. BBC 4 Costing the earth 2008/05/01
[88] The mental wealth of nations: mental capital and wellbeing. Report, (Foresight 2008)
[89] Patrick Dickinson Conference (2007) [6l96a6g]

3.5 Conclusions

This chapter explained the various technical elements behind the construction of the scenario storylines. Very importantly, the scenarios narratives in **Chapter 4** can be "backcast" into the empirical material described in the previous section. This is why the collection of data had to accommodate a great variety of stakeholder sources. With the conventional limitations of a PhD-level survey, rigour was rendered by the fact that no stakeholder's "truth" was left unquestioned and scrutinised in the light of other stakeholders "truths". The claimed "science" of many of the issues dealt with was genuinely put to the test and no stakeholder turned out to be immune to oversight. One salient finding in the car sector was that technological possibilities[90] are for the most part "mature"[91], the tendency in the sector being towards greater simplicity (e.g. electric motoring). In contrast, food production and green housing may soon be touched, if not revolutionised, by the technological convergence between NBIC technologies —i.e. nanotechnology, biotechnology, information technology and cognitive sciences— (Schmidt, 2008; Royal Society 2010). Perhaps one of the most interesting issues to investigate was stakeholder's perception about the physics of energy storage in general and about the role played by hydrogen in particular. It was interesting to see how a majority of stakeholders perceived hydrogen as a "source of energy" rather than a storage device. Many stakeholders failed to perceive hydrogen fuel cell vehicles as another type of *electric vehicle* (i.e. using hydrogen instead of batteries as means to store energy, plus a fuel cell to covert it into electricity). Issues are being debated publicly at the time of writing and weighing the relative importance of the key findings was perhaps the most difficult part of the survey. We did our best in trying to capture those root elements which seemed likely to have a long term impact. Our next chapter **(4)** turns the various elements presented here into four scenarios to the year 2050. This is follows by a proof of concept analysis to test the model introduced in **Chapter 2.**

[90] Not to be confounded with the commercial availability of those possibilities.
[91] Onboard gadgets aside

4. Scenarios 2050: a proof of concept analysis

4.1 Scenario presentation

This chapter contains four sustainability scenarios through to the year 2050 followed by a proof of concept analysis section. The underlying premise is that scenario building is not about trying to predict the future, but rather about identifying a range of possible futures that might unfold under contrasting, but plausible assumptions. Given the time-bound nature of the exercise, plausibility and comprehensiveness were prioritised over the development of detailed timelines, and the scenarios were considered in terms of final outcomes in the year 2050 only. We have done our best to develop the scenarios up to a stage where collective discussions could be stimulated and further improvements explored. These scenarios are not forecasts and none is meant to be better or worse than others. We deliberately avoided —contrary to common practice— the use of headline descriptions expressing value judgements, (e.g. "green markets, "the techno-garden"). Hopefully, what follows will provide us with slightly dramatised yet plausible, self-contained, imagined futures about **intended** and **unintended** aspects of a transition to a low-energy-density economy. Scenario narratives can be "backcast" into the empirical material described in the key findings section of the previous chapter. Following the proof of concept protocol, scenarios were developed according to some common parameters:

- All scenarios begin with a summary covering cars, food and green homes as entry points.
- To improve analytical usefulness, all scenario narratives unfold according to a fixed set of questions **(Box 4.1)**
- By applying the conceptual model it has been possible to "translate" each storyline into its many particular substitution mechanisms or instances, which together form a substitution pattern. Each scenario pattern is shown in preliminary form in the grey column on the right of each narrative. Following the scenario section, the observed patterns are analysed graphically in a separate section at the end of the chapter.

This is done through pattern matching analysis (Campbell, 1966; Yin, 2009;). Discussing each substitution instance in the grey column was beyond the scope of the exercise.

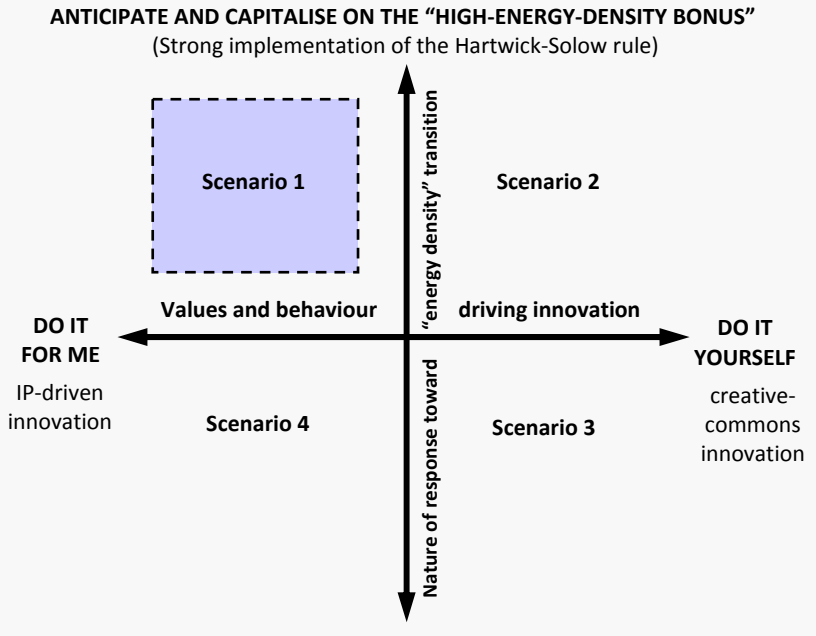
Box 4.1 A fixed narrative structure. Storylines unfold to a fixed set of questions.

1- What types of cars, food and homes are there?
2- What is the state of the economy?
3- How are people being employed?
4- What is the role of government?
5- How has society changed?
6- What are some examples of things consumers ask for?
7- What is the state of international relations?
8- What is the role of each sector in society?
9- What are some examples of the role played by the media?
10- What are some examples of changes in the energy infrastructure?
11- How have working and travelling patterns changed?
12- What are the big political battlegrounds?
13- Examples of what NGOs and opinion leaders are campaigning on
14- How have sectoral structures changed?
15- What is regulation like for government?
16 Who are the new key players in the economy?
17 Where do products come from, who makes them?
18 What are some examples of the role of the internet?
19- What are some examples of big changes in a supply chain?
20- Examples of how new technology is being used
21- How are consumers, including children, being engaged?

- To allow for comparison, a fixed quota of substitution occurrences was assigned equally to each scenario storyline (up to 200, no less than 190). The analysis that is done afterwards however, is based on corresponding percentages.
- Last but not least, storylines exhibit contrasting degrees of social and policy implementation of the Hartwick-Solow rule of investment with regards to a transition to lower-energy-density carriers as explained in **Section 1.3**

SCENARIO ONE

SUMMARY: By 2050, powerful individuals, businesses and consumers have learnt to prioritise the use of **IP-driven** innovation to **anticipate** and capitalise on the *high-energy-density bonus* implied by society's riddance from fossil-fuels. Ruthless competition, patent wars against the UK and other countries plus a global monopoly over *rare earth metals,* have strengthened China's place as a superpower in most green industries. This is a market-led, individualistic, highly unequal democracy where people often internalise personal failure uncritically while winner-takes-all values are transmitted by the media and inelegant public figures. Conflict-prevention, strategic subsidies and the rule of law are government priorities. **CARS:** a government-sponsored UK car industry has focused on the production of few 'heritage' and luxury concept vehicles for the super-affluent global consumer. Somewhat paradoxically, central government also subsidises hundreds of creative-commons electric car SMEs across the country which in turn rely on semi-formal and unregulated global networks of suppliers. The average citizen's dream is to one day afford the Super-Dorkon EV-4000™. **FOOD:** A lot of people grow their own food communally or individually, often with creative-commons GM inputs subsidised by local authorities. Those who can, sometimes complement their diets with special brands of added-value food. The pharma-food industry is focused on life prolonging Food™. A subsidised agricultural sector is focused on exports 'to feed the world' though the country is not seeking to be self-sufficient. Trade, politicians insist, continues to solve the food security problem. **HOMES:** The housing industry is led by standards and by those who bypass them. Big emphasis is given to the zero carbon home and more particularly on the 20% to 30% efficiency gains from new technologies. Meanwhile, community building organisations claim their rights to longer term construction practices as well as creative-commons technologies for the home. Some employment is generated in retrofitting until the 2020s. The subsidised "green home appliances" industry employs only a few.



1- What types of cars, food and homes are there?

Posh people today like to describe the range of car choices circulating on British soil as "truly pathetic" compared to the 2010-2030 "second car boom" period. In 2050, most passenger cars in the UK are **all-electric luxury concept units**, only for those who can afford them, which is less than a quarter of the working population. The transport alternatives include **Black Cabs™** (also electric), **First Bus Network™, Telepresence™**, or ***Flexi EVs*: low cost, low maintenance, no frills, electric cars built by local SME and** self-employed entrepreneurs across the country. Heavy vehicle brands such as **Massey-Zhuan-Ferguson™** running mostly on **hydro-kerosene™**. *Flexi EV's* are partly the result of semi-regulated networks of global suppliers. **Generic modular parts and refurbished materials** are often **bought over the internet** and shipped into the UK by various means including **airfreight**. People commuting to and from suburbs and the countryside rely on additional transport alternatives, such as so-called the ***Flexi POO*** — two-stroke internal combustion engine cars running on **methane generated from human and animal waste**. Commuters can also opt for ***Flexi VOVs*, "vegetable oil vehicles"** typically running on rape seed oil compounds. Likewise, **motorcycles**, **scooters** and mopeds have boomed all over the country, noise, pollution, warts and all. **Energy patents (patented forms of energy)** are now vital assets in the IP asset portfolio of many **Local Corporate Authorities (LCAs)**. A comparable product polarisation can be appreciated in the way people access their food: people who can afford expensive EVs tend to shop for food in **supermarkets** and drink "safe water" out of **Nano-H_2O-Bottles™**. These people focus on health prevention and are prepared to pay higher prices for their favourite brands of **Neutraceuticals**, **intelligent nano-foodstuffs** and other branded products: **anti-cancer cherry tomatoes, the zero calorie chocolate cake, the Scottish banana** and so on. All across the country on the other hand, the less affluent majorities now **earn an income by selling their surplus produce** via retail exchanges or local co-operatives. **Vegetable box schemes** outsell supermarkets in fact. The high-tech portion of the food industry is seen by government as a source of income exports "to feed the world" though **the country is not food self sufficient**. Trade, politicians insist, has solved the food security problem. The housing industry is heavily influenced by **standards set up by government via a closed consultation process**. Standards in turn determine markets for **branded low-carbon appliances and equipment.** In this way, great emphasis is still made in the zero-carbon home target and more particularly on the 20% to 30% efficiency gains from new technologies. **Much less emphasis is**

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given to longer term construction and good building practices through **better training**, which is what many community building organisations have advocated for during the last few decades. The **"green home appliances"** industry has received substantial support from government, it however, **employs a small proportion** of the workforce inside the country, **which has mostly moved abroad.**

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2- What is the state of the economy?

Global brands of electric vehicles, and above all, grid electricity, have become prohibitively expensive for the majority of UK consumers. **Income distribution and mobility has never been so low** in a western democracy. Only 17% of the working population in Britain can afford the global brand vehicle, the **all-electric concept car** complete with **gizmos** and on-board intelligent service platforms. None of this precludes us halfway through the twenty first century —and halfway through **a global climate crises** too— to still see **heritage brands** such as **VW-Rolls Royce™** running through the countryside on eighth-cylinder internal combustion engines (and bullet proof windscreens). Heritage cars such as these are typically owned by power company officers and **energy patent lawyers,** 73% of which, according to *The economist*, are affluent **single women**.

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3- How are people being employed?

It is estimated that the *Flexi V* industry and all other forms of **unregulated motoring employ as much as 12.6%** of the workforce in the UK. **Agriculture and community-based food production accounts for 16%** of UK's workforce, while construction 14%. **The global car industry employs a meagre 0.7%**.The **bike industry** generates service jobs for 2.2% of the working population and in some areas such as London and Birmingham up to 4%. These **percentages could be higher if only most bicycles weren't manufactured in East Africa** by **Chinese brand names such as Raleigh, Benotto and Dawes.** Some employment is generated in the **housing retrofitting** sector but only up until the 2020s. Although the **branded "green home appliances" industry has received substantial support from government,** it employs a small proportion of the workforce inside the country, **which has mostly moved abroad.**

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4- What is the role of government?

This is **an unequal democracy kept alive by the knowledge economy ideology**. Although the current *New Green Party* government often finds it hard to enforce regulations, by 2050 **politics in general has learnt to accommodate inequalities "sustainably"** and in an orderly manner. In this highly

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individualistic scenario some people have learnt to anticipate IP-driven innovation profitably while **many have learnt to internalise personal failure uncritically. Market ideology and individualism have kept democracy alive.** Government has played a role in making sure the **educational system self-perpetuates**. Rh>Kh Rh>Kh

5- How has society changed?

This is a society where **a great deal of ideology dressed up as formal education for the creative economy shapes the character** of individuals. Individualism is widespread and **people are constantly reminded from early childhood that knowledge and ideas are the most noble and honest way** to produce wealth. Particularly if those ideas can be used "to save the world". In fact **wealth originated in material tangible activities, such as manufacturing or the exercise of practical skills are often frowned upon and looked at with slight contempt.** Rh>Kh Rh>Kh Rh>Kh Rh>Kh Rp>Kp Rn>Kn

6- What are some examples of things consumers ask for?

In an **economically polarised society**, the average citizen's dream is to one day afford the **Super-Dorkon-EV-4000™.** Other people, think of themselves more realistically and opt for the **Flexi V** or **public transport.** Usually these are the people who also participate in **community food security initiatives** as well as community house construction and retrofitting. The **production and supply of local vernacular materials** has become an industry of its own thanks to demand, which under **regulatory pressure** has been able to coexist with **the green housing standards set by LCAs**. Affluent consumers, often demand such things as nano-insulating materials such as **Hyper-hemp™**, others go for the cheaper **Modcell™** (prefabricated straw bale) **which costs between 5 to 8 times** more than the conventional straw bale cubic metre. Food buyers are divided between those who want —and can afford— either **branded-food therapeutic added value and convenience** or home-grown **nutritious affordable food.** Water has become also an **expensive service**, typically ranging from rain water for the poor majority down to **Nano-H_2O-Bottles™** which provide **nano-food metabolizing capacity** as well as "tailored body water solutions" to **improve human performance. Nano-capsules delivering active ingredients** are one of the biggest markets nowadays. Rh>Kh Rh>Kp Rp>Kp Kn>Rn Kn>Rn Kh>Rh Rh>Kh Rh>Kn Rh>Kn Rh>Kn Kn>Rh Rn>Kn Rh>Kp Rh>Kn Rh>Kn

7- What is the state of international relations?

Converging NBIC technologies (Nanotechnology, Biotechnology, Information Technology and Cognitive Sciences) have resulted in **less dependence on a few raw materials** such Kh>Rn

as cotton from African providers. Yet **the benefits of such technologies have not been well captured by the UK business community**. Intense competition from the East **has made very difficult** for UK businesses to reap the benefits of IP-driven innovation. **Patent wars** against the US, Germany, Japan the UK and other countries have strengthened **China's place in the world as a green technology super power** (France being China's biggest EU partner in the car industry). Yet, up to the present day, **Prime Minister Beckham still describes Britain as "a world-class knowledge-based economy"**. **Minority groups are beginning to abhor the Beckham dynasty.**

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8- What is the role of each sector in society?

Sustainable transport, nutritional health and zero-carbon housing are perceived as issues to be tackled by global high tech manufacturers and suppliers who are also happen to lobby and promote **through the media** particular definitions of sustainable transport, nutritional health and green housing zero-carbon standards. Affluent consumer's concerns about the state of the environment are evidenced by their **willingness to pay a premium for greener cars**, expensive foodstuffs and green **home appliances and materials**. This despite the fact that most people can't afford all these products and services. **Successful businesses have learnt to cash in on individual's hopes.** This includes **not only car manufacturers but also oil companies**, **power suppliers** and a number of **niche service provider**s of foodstuffs and materials.

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9- What are some examples of the role played by the media?

Thanks to the media, export markets, particularly the Chinese, are still **firmly believed to be dependent upon the ability of LCAs to enforce IP rights inside the UK for products and services coming from abroad**. This is **a notion that has been promoted by media institutions** for decades. Even well-informed intelligent citizens still expect innovation to be an IP-driven endeavour in any wealth creating activity. **The humble *Flexi V* industry is not really seen as an innovative industry**. For those who drive them, *Flexi Vs* are **not seen as "real automobiles"** in fact, they are **seen as appliances** or equipment, part of people's daily working lives. Likewise, **home-grown food is seen as a second sub-optimal alternative** to Neutraceuticals and intelligent nano-foodstuffs, which **are said to increase longevity** and prevent chronic disease.

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10- What are some examples of changes in the energy infrastructure?

Since 2025 the country is (controversially) **divided into energy-**

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autonomous regions. Energy is priced according to each region's contribution into the Afro-European supergrid and according to **ISO's clean energy standard™.** Energy-wise, the country is 60% self sufficient, but its per capita **energy consumption has decreased** from 125 kWh/day, at the beginning of the century to 53 kWh/day, in 2050. Most of the electricity generated in the UK comes from nuclear reactors and clean fired coal (where **Canadian and Chinese CCS patented technology standards dominate**). Only **17%** of current energy mix comes from indigenous renewable sources.

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11- How have working and travelling patterns changed?

Although **working patterns and income structures have been adjusted dramatically since the PEWR years (Pensions, employment and welfare reform (PEWR)** pronounced *pure* by public officials) in the 2030"s, nearly 43% of British citizens still find themselves travelling more than 20 miles three days a week (two in the winter). There are three transport alternatives available to them: **Virtual Travelling™, First Bus Network™** or get themselves hold of a *Flexi EV*: low cost, low maintenance, no frills, electric cars. **Time banks, and LETS schemes widespread all over the country** have meant a drastic **reduction of people's travelled distances and an increase in perceived available space (indeed the country has began to look several times bigger)**. These reforms have also meant that **people no longer see money** as the inevitable **outcome** of their working hours: except for the affluent portions of society, **access to different forms of social organisation and productive environmental space are now seen as alternatives to financial capital.** Indeed, according to a recent survey, twenty-century **terms such as "wages" and 35-hour working week are no longer recognised by a majority of the people under 50.**

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12- What are the big political battlegrounds?

Pensions, employment and welfare reform (PEWR) has been perhaps the biggest political battleground of the last decades. **The responsibility and capacity to provide many former public services has now been passed on to individuals.** This has taken much effort from government **harnessing the media** to make the PEWR appear "cooler than it is".

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13- Examples of what NGOs and opinion leaders are campaigning on

Although for many practical reasons **cutting the "creativity" income slice** of the "knowledge economy cake" **has not always been possible** during the first half of the century. **Many people, taking heed of TV presenter Jenny Clarkson's advice, *patent it*,**

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get rich and retire, **remain hopeful that circumstances will change during the second half.** Not everyone shares this opinion however, financial journalist Oucohaabi Paxman has drawn for us a slightly different picture. For her, the first half of the twenty-first century will be remembered as **"the beginning of the end of the private car era and of women's empowerment through it"**. Meanwhile, **online campaigns** supporting community **organisation** have been common during the last 30 years at least. These campaigns are characterised by their **lack of celebrity figures** and instead evidence **the presence of local leaders and strong community networks.**

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14- How have sectoral structures changed?

All three sectors have seen important changes at the level of markets which are now pretty much **polarised** between haves and have-not consumers. **High end technology products and services are seen as the optimal solution to all sector's challenges even if people can't afford them**. The most affluent individuals purchase their cars, food and homes from global markets. Most people, however have come to rely on themselves and partly on their communities to provide for **food** security and home construction and materials. **Government has helped this transition —in a sort of airbag strategy— by redistributing resources and knowledge in the form of informal and unregulated subsidies**. Today China is not only a high technology leader, it also happens to enjoy monopoly control over most *rare-earth minerals*, as well as **human monopoly control** over their processing, both essential across the whole low-carbon and green industry sectors. Although stakeholders in the Chinese mining business include Australia, Japan, Russia, Saudi Arabia, South Korea the US and Britain, **patent thickets over ore processing** are still Chinese. The real message to the green manufacturing industry though, was sent in 2019, just before the Burma crisis, when the **Chinese government decided to tighten up its grip on dysprosium exports by 98%, followed by cuts in all other rare-earth exports by 2023; effe**ctively granting themselves **monopoly control over most of the electric motor market worldwide**. Such monopoly was particularly corrosive in those countries such as the UK, where four decades ago, **governments saw the opportunity to electrify their car fleets as part of their national energy strategy**. Along with India, China has also become a **biotech powerhouse.**

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15- What is regulation like for government?

The legal battle has been truly about standard setting and about **what is publicised as acceptable to the affluent global consumer** in terms of safety, convenience and glamour. **The car**

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industry has been lobbying for decades against lighter cheaper cars. Likewise the **food and housing industries have long lobbied for tougher safety standards**. Industry lobbyists want standards that favour **heavier cars** with more **on-board value added services** for which they can charge, even if the global market for these cars contracts as a result. **Industry lobbyists also want more valued added foodstuffs and more efficient materials and appliances that aim to "zero carbon". Pushing regulation** in a direction so that ever wealthier *but fewer* global consumers would pay *more* for motoring has meant that **large subsidies at different points during the time period —starting with the 2008 car industry crises and bailout— were channelled to feed UK's global entrepreneurial ambitions to spearhead "a green car technological revolution". This proved to be a costly and misguided strategy.** Although current *New Green Party* government often finds it hard to enforce, **society still finds refuge in the idea that the rule of law still prevails**. It is a well known fact that the Flexi V industry is **by no means economically self-sustaining**. **Neither are local markets of food** supply, which receive many **inputs and subsidies in the form of GM products**. Much like agriculture for a long time, **the *Flexi V* industry is an unregulated yet heavily subsidised sector**. **Also subsidised is the bicycle industry.** Since the 2020's in the run-up to the PEWR, **bicycles have been made available for free** —but only in England and Wales— by most LCAs.

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16- Who are the new key players in the economy?

Although worldwide car manufacturing peaked in 2035 — and has been declining ever since— last year, in 2049, six out of ten passenger cars in the world were designed and manufactured in China. **Eight out of ten electric vehicles were manufactured with vital Chinese parts including the motor.** The days when cheap labour made Chinese exports soar are long gone. Heavy vehicle brands such as **Massey-Zhuan-Ferguson™ running on hydro-kerosene™** are usually bought by LCAs and used for tough jobs in construction, agriculture, and other labour-intensive industries. The **food industry is more than ever a global industry** where **high value added patented formulas and services have replaced what once were goods and commodities.** New players in the industry are China, Vietnam and Russia. The latter one is the **biggest patent right holders in the "particle farming" business globally.**

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17- Where do products come from, who makes them?

Although more than half of the luxury concept cars are designed and manufactured in China, **industry holdings, human resources and management are best described as a truly global**

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phenomenon. Black Cabs™ are also electric and manufacturer Manganese Bronze™ is also Chinese, since 2010. A lot of the **nano-foodstuff products are manufactured in the US as well as China, India, Brazil and Russia.** Finland has become an important provider of **Nano-board™** as well as many of` its ancillary products and services for the high-tech construction industry. **For the less affluent, construction materials as well as standard quality food are produced locally** in most regions across the UK.

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18- What are some examples of the role of the internet?

***Flexi EV's* are partly the result of semi-regulated networks of global suppliers both online and offline**. The electrification of the car industry has also meant that **anybody with some cash and a broadband connection can build an efficient electric car by buying parts online** out of unregulated markets operating globally. E-communications have become crucial for community interaction across all industries, but most importantly in local food production as well as community buildings.

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19- What are some examples of big changes in a supply chain?

Supply chains in all three sectors have become increasingly localised as well as increasingly globalised. **The links between the two are semi-regulated by local and central governments for reasons of political governance.** This is done via subsidies and other types of incentives not pecuniary in nature, such as **regulatory tolerance** to certain practices in the supply chain. This is made evident in all industries, where **informal markets provide a social "airbag"** or safety net to citizens.

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20- Examples of how new technology is being used

Today, organic agriculture receives informal subsidies from government in the form of such things as nano-inputs for agriculture as well as GM seeds and bio-pesticides. For a long time creative-commons GM supplied the organic farming market nationwide, but since the 2030s, **once GM became widespread, patented rights over** goods and services —not just in agriculture but in all industries— **became again enforced** as a result of international pressure, above all from China, India and to a minor extent the US. **This is why "governance subsidies" have to be provided via informal channels to the majority of the population in the form of patented, yet informally commercialised products and services**. The recipient population ironically, still holds true the rule of law. **In 2050 hydrogen is still the energy source of the future (and will always be)**. Electric battery technology **has not changed** in the last 40 years and it is unlikely to change in the next 40. In contrast, **Shell's**

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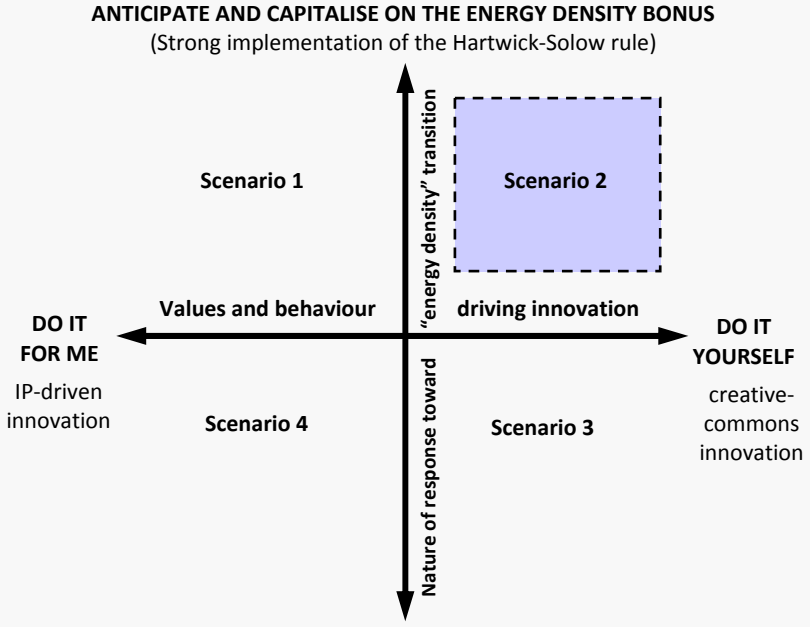
hydro-kerosene™ is used in many costly applications, and patented battery pack designs and systems **have continuously changed so patent thickets and clusters can self-perpetuate for the benefit of IP holders**. Following a two-decade oligopoly, electric **battery swapping stations** were phased out by 2034 and replaced by **Ultralav Charging Systems™ (leased by LCAs to UK businesses but on top of Chinese-Israeli patented technology).** **Rh>Kn** **Rh>Kp** **Rp>Kp** **Rh>Kp**

21- How are consumers, including children, being engaged?

Pop stars and celebrities are paid big money to write songs against piracy and to make television spots where copyright crime is associated with such things as human trafficking and terrorism. IP rights have always been promoted and via awareness campaigns, in schools such as the "IP day" every year. This has taken time out from other activities, such as **edible gardening.** **Rh>Kh** **Rp>Kp** **Rh>Kn**

SCENARIO TWO

SUMMARY: By 2050, businesses, individuals and government have learnt to prioritise the use of **creative-commons** innovation strategies and business models to **anticipate** and capitalise on the *high-energy-density bonus* implied by society's partial riddance from fossil-fuels. The UK has gained politically useful international green credentials as a result of government strategy. **CARS**: Electric batteries have become cheaper thanks to government's 2027 *creative-commons EV strategy*. China monopolises rare-earth metals. UK has managed to spearhead an industry from recycling these materials. Grid electricity has become an expensive resource. Flexi EV's are simple, frugal, people drive them with a sense of social and environmental responsibility; they also provide a sense of local identity as each region has their own version. Creative-commons *Flexi EV's* are made in the UK and during the last decade employment in that industry has soared. Only a few people can afford the Dorkon EV™ model. **FOOD:** Agriculture now employs 17% of the workforce and organic farming for food security has been a government top strategy since the 2020s. The arrival of creative-commons GM in that decade enticed most organic farmers to test its benefits. Dietary habits have changed dramatically. Hypothecated taxes have made funding available for public research on agriculture. Research priorities however, are the result of negotiated socialised processes. UK diplomacy has sought to reposition food security as a matter of inter-dependence with other nations. **HOMES:** Personal carbon allowances have put pressure on the construction industry to focus on the low hanging fruit of green housing: hot air and hot water efficiency savings. After regulatory pressure building contractors minimise the energy spent in the life cycle of the UK housing stock: from construction, labour and materials down to its demolition which is usually planed with time horizons of no less than 150 years. Government sponsored innovation have made creative-commons energy generation technologies more equitable for taxpayers and more accessible to homeowners. Alternative materials and local techniques have been dug out from vernacular tradition. Global exchanges of best practice in the industry via the "sister municipalities" programme has been a success.



1- What types of cars, food and homes are there?

Private vehicles today are truly "not made like they used to be". Although most automobiles today are powered by electricity, **there are indeed as many models as people driving them**. **Kp>Rp**
While it is true that the enormity of car types currently seen on UK roads is a natural consequence of evolving **creative-commons manufacturing technologies** since at least the 2020s, it **Kh>Rh**
is also true that such a variety is the result of **people's evolving needs**, possibilities and choices to **assemble their own electric vehicles (EVs)** themselves. What used to be seen with slight **Kh>Rh,**
contempt as "garden shed creativity" turned out to be one of the **Kp>Rp,**
most important assets in **rejuvenating the national transport and mobility industries.** The UK electric vehicle industry is **Kp>Rh**
highly competitive. SMMT's business expert Mustafa-Oost[92] has estimated that **brand new car registrations accounted for only 7% of the national fleet** (over 33 million cars). Most "car sales" **Kp>Rn,**
are in effect, **"second-hand CUTs (car-upgrade transactions)**. **Kp>Rn**
This is why hardly any **Flexi-EV** on the road is totally old or totally new. Meanwhile, food security and **self-sufficiency** have **Kn>Rn,**
been high in the agenda. The country has switched to organic farming and as much as 85% of the food supply is met via farmers markets. Creative-commons **organic GM has been** **Rh>Kh**
deployed. However, this has taken long years of a still **ongoing** **Kh>Rh,**
shared process with society. Increased food self-sufficiency and security has been made possible only because **dietary habits** **Kh>Rn,**
have dramatically shifted to **reduce animal protein and food waste**. Meat and dairy products constitute a much lesser proportion in people's diets than in the past. **Most people now** **Kn>Rh,**
complement their incomes by selling their surplus produce via retail exchanges or local co-operatives. **Vegetable box exchange is one of the backbones of food security at the local level**. The **Kh>Rh**
high-tech R and D in the food industry has been absorbed by **Kp>Rh**
creative-commons initiatives across universities and publicly run research establishments. Food **standards have been set up by** **Kh>Rh**
government via an open consultation process. **Standards in turn determine markets for creative-commons low-carbon** **Kh>Rp**
appliances and equipment at home. Emphasis on the zero-carbon target for homes **has not been a target for the last 25** **Kh>Rh**
years. Much more emphasis is given to **longer term high quality** **Kp>Rp**
construction practices. Personal carbon allowances have put pressure on home owners as well as the industry to focus on

[92] Society of Motor Manufacturers and Traders (SMMT)

[93] CT stands for Community Trademark

[94] The prefix *Flexi* is reminiscent of the first Flexi VNA truck scrapyard battery packs[94] which were used in some of the first *Flexi EV* prototypes (apparently by some college and community projects —e.g.Lowestoft where used battery packs were not in short supply).

household cooling, heating and hot water efficiency savings. Government **sponsored innovation** has made **creative-commons energy generation technologies** more equitable for taxpayers and more accessible to homeowners. Good affordable practices such as straw bale and limestone construction **techniques have been relearned** and updated from **local vernacular traditions**. Local authority codes of practice based on "choice editing" principles have given building contractors and community builders no option but to focus on **prolonging the life cycle of the UK housing stock** so as to minimise the embedded CO_2 of the housing stock as well as the energy spent in construction: new houses are now built to last, and are usually planed with **time frames of no less than 150 year**s. The only way to make these houses affordable to owners however has been via so-called **Community Construction Partnerships** which have been running by law since 2019.

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2- What is the state of the economy?

This is a **low-energy density, low-carbon economy** and overall **levels of wellbeing are decent yet frugal.** It has been an evolving difficult process for everyone. That is to say, at the micro level, this is an economy which has to deal with **so-called HIS-and-HER-problems:** the *household income substitution* problem (HIS problem), and the *household energy replacement* problem (HER problem). At the macro level, rarely talked about by the newer generation, **energy and water access were the key historical factors bringing the old economic model down to its knees** during the 2020-2035 historical period. Two crucial mistakes were made by most energy economists early on in the century. First, they **blindly assumed the inevitable arrival of a game-changing technological breakthrough**, notably in clean hydrogen generation and storage. Second, industry **projections sidestepped the hugely problematic** system-wide effects implied by an economy running on low-energy densities. Eventually the whole government **tax revenue structure would be transformed, alongside** subsidies, employment, inflation, disposable incomes, labour productivity, economies of scale and so forth. **Fortunately, government projections were careful not to sidestep these issues and took provisions to manage society's *high-energy-density bonus* (EDB)**. From 125 kWh at the beginning of the century, **the whole economy has shifted to an overall energy consumption regime of 62 KWh per day per person** in the UK. **Artificially inflated prices in food, cars and home appliances** became a salient issue in all sectors during the financial meltdown of 2008-2009. During the 2010s, for instance, **electric cars were made deliberately expensive by manufacturers,** notwithstanding the fact that EVs have always

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been simpler and cheaper to build, even without economics of scale (e.g. drive train and motor) requiring far less energy, water and infrastructure than the most efficient petrol car plant. **Manufacturers made EVs more expensive by adding unnecessary patented parts and systems in them** (notably panel gizmos and battery packs, whose generic equivalents were three to four times cheaper and often even more efficient). **Car manufacturers felt in those days they had to make a profit up front** because EV technology in general was many times more reliable compared to petrol car technology and to make things worst for them, **they would require less servicing and replacement** parts. Finally, **manufacturers made the first commercial EVs artificially expensive simply *because they could* under regulatory framework.** Still enjoying two billion years of energy reserves, government was able to encourage people to **buy luxury EV through subsidies,** at least up until 2014 when a reality check fell upon budgetary projections. Soon after long distances and heavy loads became a transport luxury and the Low-Energy-Density Economy Act (LEDE Act) came into force in 2020 , policies were directed to optimise the use of the *high-energy-density bonus* (EDB) and **local food community suppliers began to innovate in new forms of organisation and local enterprise**. Under the **LEDE Act** all industries focused on producing creative-commons technology that were compatible with wider social innovation targets in mobility and accessibility. **Farming and construction followed the same trajectory as the car industry, ending unemployment in the process. Obesity levels have dropped since the 2030's and the NHS is on target to fulfil its promises to deliver services by 2050.** Additionally in 2021, dedicated carbon taxes allowed central government to **channel funds to assists the provision of infrastructure and use of e-communications to accelerate the emergence of all kinds of localised** enterprises across the country. Farming and **urban farming** community networks and local building enterprises were a priority in those days.

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3- How are people being employed?

Nationwide **training programmes in all sorts of practical skills including interpersonal skills, international face to face negotiation for export markets; also apprenticeships in such things as green building techniques and urban farming** have been deployed since the 2020s. As a result, today as much as **21% of the workforce in the UK intermittently combine construction, farming** and commerce as a way of earning a living. Earning a living for citizens means a different thing than in the past. According to the *2032 UK Employment Act* it means "**accessing different forms of capital, including social**

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organisation as well as creative-commons technology and knowledge on how to do things well, effectively and in accordance with material and spiritual necessities irrespective of age or gender"-. On example of employment generated in this way can be found in the **"green home appliances"** industry, under the **creative-commons Green Housing Initiative (CCGHI).** Highly skilled employment in the green home appliances industry has been generated by **open R and D thanks to hypothecated** (dedicated) taxes. To "afford" a car **in 2050 means to count on a variety of "capitals" and "incomes" which are not necessarily pecuniary in nature**. The term "disposable income" still causes many people to either frown or smile. **Citizens can no longer rely on disposable incomes alone to afford food, a car or indeed the homes where they live;** more often than not they also have to rely on their ability to interact and **negotiate a number of occupational trade-offs with local enterprises, local government, and community organisations**. They also have to rely on **their own inputs in the form of knowledge, skills, time and labour**. Household incomes come not only from diversified sources but also in **differentiated currencies,** which can be local, regional and for some people often global. Many people often **exchange transport services for other goods and services in other sectors, such as food provision and construction.** While government's *creative-commons industrial strategy* has resulted on **higher levels of employment in the car industry**, China still enjoys monopoly control over *rare earth metals*. For this reason indirect employment in the *Flexi EV* industry has become highly popular over the years and new **regional enterprises have mushroomed in the recycling and recovery of key vehicle parts and components** (e.g. those containing dysprosium). Brand new car parts and materials —quite in contrast— are more expensive than ever. **Since 2030's about 12% of UK's population has moved to other countries (including China and India) looking for better paid jobs in highly skilled industries.** One third of the people that leave every year make a return within the following five years according to the ONS. **Employment in the air travel industry has not been affected in the way other commercial transport industries have,** fuel prices have skyrocketed, yet, demand has increased exponentially too. Despite ICT ubiquitousness today, in the creative-commons knowledge economy, **people will still do anything to physically reach other parts of the globe and interact face to face with others.**

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4- What is the role of government?

Land use in the UK has gone through **unprecedented change —**

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to make land available to all— during the last 30 years. Three decades ago most farms used to be 500 acres or so, **today the average size of a farm** does not exceed 45 acres. **The EU's single payment scheme became unsustainable towards the mid 2020s.** All this transition, intended as **well as unintended**, demanded great political ability, devolution of power to municipalities **novel governance mechanisms,** and a vigorous industrial strategy. Since its inception, **the creative-commons Industrial Strategy (CCIS)** has been pivotal to UK's sustainable development policy in all aspects of public administration. **Transport policy is built into interlocking aspects of the CCIS such as environment, employment, urban planning, food production and supply as well as housing**. However, public resources are stretched so the focus has been on such things as **multimodal** public transport, mobility, accessibility, sustainable communities. Public resources also focus on supporting **edible gardens and green gyms, —a colloquial expression for community farms—** (this last one complementary to obesity epidemics policy). **Walking, cycling, Flexi V sharing** and resource-saving e-communications have also been part of the policy pack for decades. **Hypothecated taxes have made funding available for public research in all industries,** notably **sustainable agriculture,** transport, home appliances and materials.

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5- How has society changed?

After a series of **social, financial and environmental shocks** society has **developed over the last few decades,** a sense of social cohesion where **people have turned to each other for help.** There has been **a shift away** from the **individualistic, market-led approach** to wealth creation and prosperity. Such shift has become apparent by just looking at the landscape in the countryside. **Still a knowledge economy, access to land policies (Chapter 4 of the creative-commons Industrial Strategy) have greatly transformed the way society is organised.** The willingness and **need for people to support each other in the face of** the energy transition has proven to be the most important asset people themselves can rely upon. **Devolution of power to local authorities has been crucial to society's ability to accommodate change culturally and politically.** Meanwhile, central government has sought to reposition the country internationally **regaining green credentials as a social innovator and sustainability laboratory**. Despite all this, **a lot of people have left the country**, lured by riches of the East. This includes many highly skilled workers who have seen their lifestyles significantly diminished when compared to those they see in Chinese and **Bollywood romcom heroes**. Influential media

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figures often describe today's society's transformation as *a necessary evil*. Comparisons are often made with other countries" trajectories where, unlike the UK today, social polarisation has destroyed democratic values. **The curtailment of some of the liberties —and imprisonments— made possible by the oil economy,** such as materialistic lifestyles **have not hindered overall increases in quality** of life for a majority of the population as a result of a **better organised society** where **older and younger generations have equal but different roles in solidarity.**

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6- What are some examples of things consumers ask for?

Business models such as the company **Better Place™ failed to embrace the creative-commons transition** people were asking for. *Pay as you drive/* ***battery swap*** **schemes** and related "transport solutions" were the first "business innovations" to go down during the 2020s (though they had some extended success in the E-Black Cab fleet which was subsidised by government). **Companies offering *pay-as-you drive* schemes, —which were often granted monopoly rights over network infrastructure— eventually failed to deliver what they promised because such deployment of "profitable business sense" could not be accommodated effectively within an economic system already being run on low-energy-density carriers.** These events marked the beginning of a trend where transport services" "brand value" eventually became in the best of cases controversial and unsustainable in an industry which ultimately **produced less than 230 thousand jobs** altogether and which was **importing cars from China and India** by the millions.

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7- What is the state of international relations?

UK diplomacy has sought to **reposition food security** as a matter of interdependence with other nations rather than **competitiveness alone. Fairer terms of trade have been set and the oil-dependent single payment scheme has been phased out following the lead of New Zealand** early in the century. **Pre-empting international patent wars and foreign technological dominance in the car industry, the government's *Creative-Commons Industrial Strategy* launched twenty years ago (2025)** was successful at revitalising a sector which was believed to be almost dead. **It also impacted agriculture and food security favourably**. It has created many jobs in construction, agriculture and transport while **realising the longer term benefits of social innovation.** After the **Car Industry Recovery Act** followed by the *creative-commons EV Strategy*, global manufacturers entered the creative-commons bandwagon early on in the time period, becoming manufacturers of modular parts. Competitors such as

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China and India were able to compete with price and quality but not in the **current economy which aims to protect the local employment spurred by battery technology**. The international dimension of food security is seen more comprehensively and seriously. Global exchanges of best practice in the industry via the **"sister municipalities" programme have been a success**.

8- What is the role of each sector in society?

Agriculture is no longer seen as a cash producing activity but as a food and **livelihood sustaining activity**. The housing industry which has also **now become an integral part of the local fabric of society** has now become the second most important employment generator in the country (after food production and supply). Private EV's are **simple and frugal** but people **often appear to take pride on them and share them with a sense of social and environmental responsibility**; Flexi EVs are also said to provide a sen**se of local identity** for those who make them.

9- What are some examples of the role played by the media?

The media has **been very active promoting social cohesion values.** It has also been harnessed at the local level to transmit educative messages about how to **connect resilient communities locally** to the wider global sphere thus promoting international solidarity. In a BBC Today programme survey **people voted the Flexi EV as the all time favourite technological invention after the bike.** TV commentator and sports car collector Fred Dimbleby highlighted back in 2033: "*car electrification has meant* ***no "new product development",*** *it has instead marked the end of an old industry format and with it the end of an era.* ***The new format, the EV format, has already done for the car industry what digital recording did in the noughties for the recording industry: a full dismantling from the bottom up****. Let us not be surprised to witness in the years ahead, some similarities between creative-commons modular part design and manufacturing in the UK and P2P file sharing; this time though, the business model revolution will not only be legal but also* ***instrumental to employment policy*** *and the industry's survival".* Today, 17 years later, we know Fred was right, not just for the case of cars, the message can be also applied to such things as **nano-bio agricultural technology as well as green appliances for the home.**

10- What are some examples of changes in the energy infrastructure?

Millions of EV Batteries **provide storage capacity** to the Smart Grid[CT] which represents another **source of income** for the

individual or community owner[93]. In other words, car ownership, either is seen by those directly involved as a part-time activity which generates various types of incomes and benefits. By 2030 most forms of private transport ran on electricity. **Battery technology was made available via government regulation in the form of compulsory patent licensing, community trademarks(CT) and community patenting(CP).** All these reforms were part of the *creative-commons EV strategy* deployed in 2029 by the Technology Strategy Board which followed from the *EU Directive on Battery Technology and Rare-Earth Metal Recovery (2019)*. Analogous transformations have occurred in the agricultural sector, as well as the construction industries, —both sectors covered in Chapters 4 and 5 of the Creative-Commons Industrial Strategy— where different power generating technologies have been encouraged over the years via **apprenticeships programmes** and made available to all who want to use them and improve them.

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11- How have working and travelling patterns changed?

Using **greener transport, being a responsible commuter** and in general travelling less is seen as a civic duty. Those who go over their personal transport allowances (PTA) are expected to pay penalty fees and taxes. In 2050 only **3.7 million people in the UK** have never been actively involved in some form **of time banking, a community of local exchange trading or complementary currencies.**

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12- What are the big political battlegrounds?

The biggest political battleground has been for society as a whole —the government taking the lead— **the transformation of deeply ingrained cultural values which were reliant on cheap oil consumption**. After the Pensions, Employment and Welfare Reform (PEWR), during the 2020's families or "households" with **two full-time incomes** were severely **penalised by the tax system**, as a result, married women stopped working and **women in general stopped marrying**, that's why the 2020 is known as the *fatherless decade*. **Today very few people have what used to be known as a full time job, and "convenience marriage" rates have increased since the 2030s.** Without such thorough transformation the country would never have recovered its green credentials in any international arena of negotiations. There has been in fact a shift away from the individualistic, market-led approach to all three sectors, agriculture, construction and car manufacturing. There has also been a **shift away from CO2 emissions targets** to favour strategies which advocate "energy security and benefits for all". **The second most important battleground has been the removal**

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of some former "rights" over patented technologies as well as the ensuing replacement by government sponsored creative-commons **employment-generating business models.** Such tasks have been made politically easier by the fact that technology's evolution had been following that same path for a long time and government intervention was only pivotal to accelerate the trend to the best advantage of society. **Road transport for instance, was seen as part of a comprehensive set of rules governing sustainable transport and mobility targets,** following a series of car industry bail outs, **inflation and personal debt reshaping the economy** as a whole.

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13- Examples of what NGOs and opinion leaders are campaigning on

Well known journalists such as Tom Page have argued that just because some industry players wish to **influence industry standards so they can reap the monopoly benefits of future transport solutions for the masses** does not mean rival technology developers should not be allowed to coexist in the market. "*Consider hydrogen storage versus electric batteries*—says Page—, *only creative-commons innovation standards deliver the level playing field for technological co-existence and SME sustainability*". Along with other variables, notably energy price increases, there appears to be some correlation between today's transport patterns and lower divorce rates. Cambridge Professor Brutus Carpenter and colleagues report that for a majority of women since at least the 2040s, **a hubby —even more than a *partner*— has been the practical way for them to secure a functioning EV** at the front door. *Women First!* campaigners and lobbyists have been quick to disagree, advocating for **equal access to individualised private** transport particularly for women who return home after dark.

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14- How have sectoral structures changed?

The 2020s was the decade when, after a series of well-known **economic** and **environmental crises,** drastic changes started to occur in every sector. The general trend was towards **localised production in all industries and devolving powers to local government.** With a few exceptions. The European Automotive Consortium initiated a regional restructuration process that would make the entire UK car industry *"less recognisable than a Top Gear episode without me"* said Jeremy Clarkson in his speech during Formula 1's historic *Farewell Race 2022*. While it is true that many commentators were asking —as early as 2008— whether the end of the motor industry was near, who would have thought that just halfway through the century the majority of passenger cars in the UK would be all-electric, locally

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produced *Flexi EVs*[94], assembled by hundreds of local, often community owned SMEs utilising creative-commons fully compatible modular platforms distributed in flat-pack form by a new automobile industry? Those who were born before 2010 still remember the average petrol car as a finished product people would buy with their "disposable incomes" —though in practice this meant *on credit*. Consumers could even choose their car colour online. Likewise, **who would have thought creative-commons GM would be the acid test of not just for GM but also for organic agriculture? Who would have thought houses would be made of stone?** Kh>Rh

15- What is regulation like for government?

Once UK's car fleet was becoming fully electrified and after years of lobbing, 2024 saw the enactment of the ***Community Patenting, Copyright and Trademark Statute*, today known simply as "LIPS"** (The Low-carbon IP statute) managed at first by the Technology Strategy Board. The early LIPS statute effectively democratised the patenting and trademark process across the whole car industry. **Devolutionary powers in 2025 eventually transferred the community trademark and patenting granting process to local authorities.** While devolving powers to local authorities, central government also had to act as a tough regulator setting **creative-commons innovation standards that inevitably drove most industries away from top down "IP granting black boxes"**. Resilience policies (economic, technological, social) are recognised to contradict those industry officials who argue that eventually sector standardisation would follow a natural course. Kh>Rh Kh>Rp Kh>Rh

16- Who are the new key players in the economy?

Rather than trying to outcompete China, India and other big players by spearheading a "green high-tech revolution" government has sought to reposition the **country's sustainability standing and international image so as to regain some of its green credentials as a social innovator and creative-commons technology adopter and developer.** Such strategy has been particularly effective at unleashing the potential of **hundreds of creative-commons business models** for new players in the transport, food and housing sectors. Kh>Rh Kh>Rh Kn>Rh

17- Where do products come from, who makes them?

Over 95% of *Flexi EVs* today are made in the UK. **In any case, the industry's business model is highly localised and articulated into multimodal public transport logistics and infrastructure across the whole country**. To get the most out of a *Flexi V* people not only invest in modular parts and materials they also have to Kp>Rp

apply their own labour and "sweat equity". Yet, *labour productivity* is a term rarely applied to vehicle assembly , this is because vehicle assembly is an activity which car companies under creative-commons business models have managed to *client-source.* **Client-sourcing started back in the 1990s with such things as self-check-out tills in supermarkets whereby clients would get cheaper goods by partaking with their free labour.** Today self-service has been substituted to a great extent by **community-based food production and house building and retrofitting**. Creative-commons high-technology has also meant that products designed anywhere in the world can be made and improved locally. **This is the case with the creative-commons home appliances industry in the UK. Meanwhile, Creative-Commons biotechnology has also meant a big boost for local agricultural industries, who went through very difficult times between 2020s and 2030s.**

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18- What are some examples of the role of the internet?

In general **e-communications have been instrumental in creating a sense of community and awareness of the need for more collective approaches to transport, mobility, food supply and construction.** The impact, however, has been a more far reaching one. In 2004 the Cabinet Office published the "Creative-Commons, Open Standards and Reuse: Government Action Plan". Updated in 2009 it stated: *creative-commons has been one of the most significant cultural developments in IT and beyond over the last two decades: it has shown that individuals, working together over the Internet, can create products that rival and sometimes beat those of giant corporations;* ***it has shown how giant corporations themselves, and Governments, can become more innovative, more agile and more cost-effective by building on the fruits of community work*** *[…] While we have always respected the long-held beliefs of those who think that governments should favour creative-commons on principle, we have always taken the view that the main test should be what is best value for the taxpayer […] Where there is no significant overall cost difference between open and non-creative-commons products, creative-commons will be selected on the basis of its additional inherent flexibility."* This trend in public service provision was eventually passed on to other sectors such as the car, food and home building sectors. ***Flexi EV*** **owners shop online for their car-upgrade transactions (CUTs)** and use professionalised online workshops that are popular nationwide. It is in the interest of car owners —whether individual or community owners—to add some value to their cars. They do so for various reasons. **An estimated of 72% of car users complement their weekly transport needs with alternative means, including public transport, walking and cycling.** For

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someone to rely entirely on private transport means either having membership of an online *Flexi-club* or **acquiring the vehicle themselves offline**. Over two thirds of those who own a car also lease it to other people over the internet (**20% of owners never use their cars themselves**). *Flexi Vs* can be community owned, shared, leased, sold up front, some are used as part of a range of seasonal online "club" services. **Kh>Rh** **Kh>Rh** **Kh>Rp**

19- What are some examples of big changes in a supply chain?

Although there are still **significant labour cost differences** across countries, it is a well known fact that **assembly costs eventually became insignificant in the automotive industry worldwide and in the UK**. At the beginning of the century, direct assembly costs would only account for **4% of total value in a new vehicle**. Most of the costs and added value came from components, services such as product development and brand value. **Car electrification made all this complex cost structure obsolete.** EVs were in principle simple to build (e.g. a motor has 1 moving part, the rotor, against 250 moving parts in an internal combustion engine). **By 2030 assembling costs were client-sourced (transferred to customers),** who were enabled to buy the required parts of the car in modular flat-packs. **Since at least 2040 hardly anyone can afford a fully assembled EV** or to buy the entire car from a single supplier. The typical would-be EV owner gets different parts separately from different suppliers to optimise costs. **The market for refurbished parts is enormous, and government policy has made sure creative-commons standards are in place, overriding any earlier standards promoted by old monopolies, typically from the 2010-2020 period** (e.g. battery swap station standards). This would guarantee flexibility and inter-operability between region car brands and infrastructure. **Rh>Kh** **Rh>Kh** **Rp>Kp** **Kp>Rh** **Kp>Rh** **Kp>Rp** **Kh>Rh** **Kh>Rp**

20- Examples of how new technology is being used

Notwithstanding **the damaging brain-drain** on tax-office revenues, in his maiden speech in the House of Commons on 6 July 2049 New Green Labour Prime Minister Barnaby Lucas stated: *the politically vital recovery of our international green credentials has been far from easy or gratuitous. Investments in Scientific Commons and creative-commons green technologies coupled with social innovation in* ***localised and democratic community trademarks, copyright and patenting, have become widespread in our nation's transport, mobility, food security and home energy supply and storage industries****. It is thanks to the imagination, energy and sense of solidarity of the people driving this country forward into the future that the successful deployment of a previous administration's creative-commons Industrial Strategy has* **Kh>Rh** **Kp>Rh** **Kh>Rp**

finally crystallised in the form of an unprecedented generation of revitalised ***income-generating, quality of life enhancing green jobs.*** **Kn>Rp**

21- How are consumers, including children, being engaged?

"Consumers" as understood half a century ago do not exist in 2050, everyone produces something for someone else. Most people of all ages are fully engaged with institutions with their communities and with the environment, online and offline, globally and locally. **Child work is not seen as a bad thing** but as complementary to formal education (children see it as a way to combat tedium). It is done integrally within local communities and exchanges exist with other communities regionally and as a vital componenet of the *Health and Age Solidarity Programme* (from which **NHS's budget has** substantially benefited).

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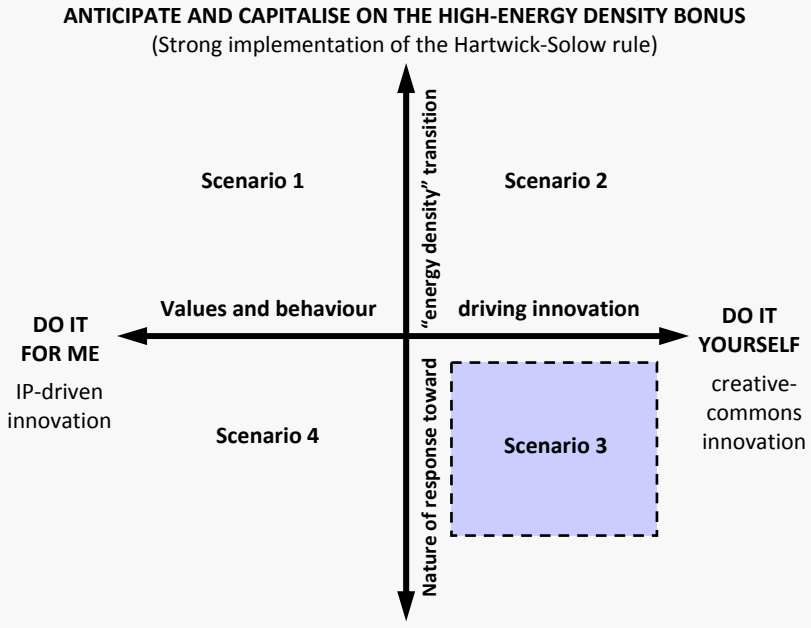
SCENARIO THREE

SUMMARY: Lured by short-term priorities after a deep financial crisis, by 2050 the UK finds itself reacting to the onset of a *low-energy-density economy* while also having to adapt to global industries shaped by creative-commons innovation networks and business models. The missed opportunity in taking advantage of the high-energy-density bonus is partly due to wrong ambitions and partly due to lack of early government intervention in every sector. **CARS:** China has inundated the country with cheap 5-year-disposable electric cars. Many are bought just for their batteries and materials. Semi-formal employment is generated in hundreds of SMEs who recover, redesign and remanufacture the cars. Poor anticipation is also reflected in technological lock-ins for the established heritage car industry where technology became outmoded by 2026. What was left from companies was put on sale. **FOOD:** enormous earlier investments in biotechnology are lost to creative-commons biotechnology. To "feed the world" was suddenly not profitable enough for biotech companies in an creative-commons-based industry. So indeed no useful research is done on the true opportunities technology has to offer. Ultimately, expensive energy would mean consumers could not afford to pay premiums for GM organics. **HOMES:** when the sector eventually moves into creative-commons mode, not only are previous investments in technology no recouped, technology itself becomes outmoded. Early retrofitting when fossil fuels were cheap would have been also cheaper, now it is more expensive. The "energy density" bonus of the first half of this century was wasted. Meanwhile, technological lock-ins are ubiquitous in low carbon technologies, solar collectors, photovoltaics, gas boilers. Not bailing out the car industry early in the century in 2008, would have saved government enough resources to retrofit the whole country's housing stock and more.



1- What types of cars, food and homes are there?

There is widespread "technological lock-in" in all kinds of obsolete low-carbon home technologies, such as solar collectors, photovoltaic panels, wind turbines, gas boilers and so on, which **25 years ago claimed to be the best investment under government dedicated subsidies**. Today people know they were not. Letting the car industry go down early in the century in 2008, **would have saved government enough resources** to retrofit the whole **country's housing stock** and more. Instead all that money went into **subsidising European, American and Japanese** green appliances for the zero-carbon home. Today all these products can be made cheaply with creative-commons technology. Creative-commons **GM-blue-algae based hydrogen production as well as creative-commons fuel cells have become cheaper;** however, they have **experienced relative (i.e. subsidised)**, success because their use only makes sense in places where access to grid-energy is intermittent. **Enormous earlier investments in the biotech food industry have been lost. To "feed the world" was suddenly neither profitable enough nor making business sense at all in an creative-commons-led world.** So indeed **no useful research is done on the true opportunities** technology has to offer. Ultimately, **less energy has also meant the world cannot afford to pay premiums on GM organics.** When the sector eventually moves into creative-commons mode, not only are previous investments in technology not recouped, **technology itself becomes outmoded.** Early retrofitting in the housing sector when fossil fuels were cheap would have been also cheaper, now it is more expensive. **The "high-energy-density bonus" of the first half of this century was to a considerable extent wasted.** Meanwhile, social innovation in the car, food and housing sectors has been stifled by the ubiquitousness of **cheap creative-commons technology imports**. Two decades later in 2031, a Daily Telegraph's headline announced that "*Chinese firms: bound to inundate the country with efficient disposable electric cars, cheap agricultural products and cheap gadgets for the British home*. Today we know such a bleak prognosis was not so far from reality. **Most people now call electric cars made in China BBQ-EV's (bound-for-the-bin-quality electric vehicles)**.These cars tend to work well for the first five years after which they become disposable. **Another industry has emerged where some people buy them only for their batteries and make all kinds of business with them.** On the market side of things, car imports have been coupled with **car package deals where**, for instance, urban electric car buyers get a number of weekends away in

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[95] EVs are those which use an electric motor, this includes today's creative-commons fuel-

conventional petrol or biofuel load lugging cars. **Two out of ten electric vehicles in the UK use expensive subsidised hydrogen instead of electric batteries to store energy.** While the EV design and manufacturing **industry is dominated by the East**, US dominance in hydrogen EVs comes from the manufacture of electrolysers rather than cars (which are assembled mostly in India). **By today's creative-commons standards (ISO-OS21,000) electric vehicles (EVs) use either electric batteries or hydrogen as means of storage[95].** Rh>Rn Rh>Kp Rh>Kh

2- What is the state of the economy?

We live in an economy of post-crisis trying to adapt to international trends in **creative-commons manufacturing, where physical investments —rather than intellectual property investments— deliver power to corporations**. This is particularly true given the fact that the global market of rare earth metals is dominated by China and which affects all industries. Many analysts impute the **long missed opportunity** in the car sector for instance to wrong ambitions and also a lack of early and more strategically informed governmental intervention. **In general terms, society has found itself reacting to creative-commons innovation while failing to realise the longer term capacity to tap into social change and social innovation**. Ex-secretary of Business and Industry Toby Pollock, stated five years ago: *at this stage we need to recognise **past miscalculations** so we can move the sector forward: **misplaced hopes on patented technologies have resulted in considerable losses for the UK car industry for more years than any Minister of Transport can remember.** As a result ours is an industry practically **invisible to our economy**, to our employment and our own markets, thought it still bears our symbols globally. Readily available individualised transport imported from abroad and a relatively stable balance of payments, have reinforced a private-passenger-car approach to challenges **where more social grassroots** enterprise development and lifestyle redefinition would have achieved longer term sustainability in our transport system. **One thing that we've learnt, is that we the people of this country are still reluctant to get out of our cars.** Even if they are Chinese or Russian, our **infatuation** as ever **is with individual mobility**. Steering course back to where we **were once as a manufacturing nation**, will not be an easy job even if it was the straightforward answer to the problem many would like it to be. If the future is to be any brighter in* Kp>Rp Rh>Kh Rp>Kp Rh>Kh Rh>Kh Rh>Kp Rh>Kh Rn>Kn Rp>Kh Rp>Kp Rp>Kp Rp>Kp

cell hydrogen vehicles, where an electric motor is used to move the car, hydrogen is a means of energy storage (instead of a battery) and electrochemical fuel-cell devises are used to convert hydrogen into electricity

[96] Brazil, Russia, India and China

*terms of our **car dependence** and well as our car industry independence, drastically intense measures will eventually have to be **pondered by society**.* After the 2020s and some have argued that long before the 2008 car industry **bailout**, the model of highly centralised investment in high end technology proved to be unsustainable for the mass market of passenger cars. **The creative-commons business model has always been by definition reliant on global knowledge and innovation**, however it was the Chinese electric cars which began to mushroom in all five continents since the 2020 (because of **monopoly over materials**). Social innovation in the transport sector has **been stifled** by the wide availability of **techno-fix imports**.

3- How are people being employed?

In our three sectors employment has been uncertain but it is slowly beginning to recover. At the moment there is **massive employment** outside the formal economy. **People have self-organised for the last few years to rebuild livelihoods and communities**. This however, has not been easy without **strong institutions** of government where resources are already stretched. Most people live between paid and unpaid activities and occupations thanks to people's **self organising capacity**. Full-time jobs are rare indeed and only in certain privileged areas such as, health, the civil service, the police and **football clubs**. E-communication has played a key part in **rebuilding** the agricultural and food supply chain as well as community housing initiatives. **In many areas of the country former big retailers have seen the opportunity to act as community building catalysers by providing people with market incentives and apprenticeships for all types of jobs in agriculture and construction.** The difficulties associated with basing important decisions on past trends after a time of crisis has caused central government in general to become more reactive and short-termist in its employment policy delivery and implementation. **Devolution of power to local authorities,** has for the most part been a success though tax revenue has dropped considerably, weakening the position of central government. **The UK car industry started loosing competitiveness early in the century, when most of the industry started moving to either eastern Europe or the far East (China and India).** Today in 2050, employment generated in the **UK car sector is limited** to service employment in well known **franchise companies (American as well as German) who specialise in electric battery, assorted parts and materials recovery, renovation and recycling.** By 2020, the country abandoned hopes to play a role in the international car industry.

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4- What is the role of government?

With local governments **taking the lead as far as public services** such as transport is concerned, not much has been advanced in relation to achieving consistent transport solutions across the UK. **The devolution of power to local authorities without a longer term plan and regulatory scheme has meant the implementation of costly and very unequal and fragmented regional programmes, based on creative-commons technologies that are not harmonised by a central authority.** This has made multimodal forms of transportation, regional markets of local food and the good performance of the housing sector **costly and technically difficult to implement.**

5- How has society changed?

People have become more religious and yet they seem to perceive technology as an **inevitable** aspect of life. **The educational environment has thrown up newer generations of people assuming all technological developments around them are part of destiny. As a result they are uncritical about the role that technology plays in shaping their everyday lives and value systems**. Yet, society still struggles to understand why "technological fixes" in key areas such as biotechnology, transport and energy provision have not been able to replace social change and social innovation. **One of the consequences of such seemingly techno-fix oriented society —further accelerated by creative-commons innovation— is the overdependence on technological systems as if they were nothing short of *magic***. Also the is overdependence on efficiency measures in the transport sector, (such as the adoption of EVs) **often at the expense** of longer term **mobility and accessibility objectives,** which by their own nature are only achievable through an improved and more deliberative public planning of urban spaces and multimodal public transport systems. **Those between 18 and 35 —the "creative-commons generation"— have often been criticized for being distracted and uncritical, "asleep at the wheel" regarding the long-term consequences of certain creative-commons technological convergences between nanotechnology, biotechnology and information technology and the cognitive sciences (NBIC).** Identities and social cohesion have become seriously **disrupted** by an excessive trend towards **moral relativism** and poor levels of human freedom. **Some scientist have feared the widespread use of controversial creative-commons NBIC, which have begun to favour the decline of the biosphere while overestimating the hypothetical benefits of what some scientists have called for a long time the *technodom*.** Events have unfolded, in such a way that **once people believe** in certain

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techno-fix pathways, not much can be changed throughout the scenario time period to alter those perceptions. **The result is that the inertia of short-term solutions undermine the possibility to anticipate the type of social innovation that is required.** Rp>Kp Rh>Kh

6- What are some examples of things consumers ask for?

Consumers in general —the younger generations— want things that are cheap and fulfil some of their expectations, **often irrespective of health** standards or how these standards are arrived at by companies themselves. Creative-commons **technology has indeed become just like magic. People want such things as the 100-year purple potato chips, the ultra-omega 3 blue salmon, and extra-strong GM cider** containing tissue reconstructing active ingredients. The British car industry trend of mass production of expensive units embracing hybrid and electric cars —which began in 2010— **failed to attract enough** consumer demand despite **government subsidies**. By the year 2020 the car industry hit its all time low. **Better internal combustion engine technology was developed under creative-commons with relative success, but only by European, Chinese and Japanese car companies.** These adjustments where **not promoted by consumers** but by big corporations, government and **the onset of a low energy density** economy. Rp>Kh Rn>Kn Rp>Kp Rh>Kn Rn>Kn Rh>Kp Rp>Kp Rp>Kh

7- What is the state of international relations?

There have been several financial crises in the last few decades leading to some international conflicts. **On the commercial side of these conflicts, after a series of Intellectual Property rows during the 2020s** between some of the BRICs[96] and the rest of the world in many "knowledge intensive industries" including biotechnology and nanotechnology, China in particular, emerged as a stronghold for creative-commons technologies of all types. **As a result, the world has become more dependent than before on physical communications and air travel has received a boost amongst the business community, despite fuel costs.** Rh>Kn Kh>Rh Kp>Rh

8- What is the role of each sector in society?

Export markets in creative-commons technologies rely greatly on face to face interactions (rather than, say, licensing). Although UK has a long tradition of **"adventure business entrepreneurs"** and more recently some **employment** has been generated in such things as rapid response mechanisms for emergencies (e.g. flooding), **this same ability to export know-how has hardly ever been experienced in the case of creative-commons technologies biotechnology, housing or transport.** Anticipation in technology-driven sectors such as the car sector Kh>Rh Kn>Rn Rh>Kh Rp>Kh

simply failed to follow the creative-commons trend, this is manifest in **a shortage of all sorts of practical skills in manufacturing as well as international face to face negotiation.** Additionally, the inability to speak languages other than English —for a long time an advantage—has proved to be a disadvantage in today's new international business environment where many deals and business links often have to be made face to face and in languages other than English, such as Mandarin. **The UK car, food and housing industries depicts a "things did not go as planned" type of scenario, the "knowledge economy ideology" and too much trust in illegitimate business claims backed up by inflexible political stances advocating the false benefits of patented technology** have caused society to abandon long term resilience strategies and investments in the car, food and housing sector.

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9- What are some examples of the role played by the media?

The media is dominated by a fragmented internet. Public media's influence in society has declined as a result of bad corporate **decisions inside the BBC to implement the licensing scheme "pay as you watch". Creative-commons** media has in fact **replaced many of the functions of the BBC** but without all the benefits of a unified national network.

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10- What are some examples of changes in the energy infrastructure?

A number of system-wide technological lock-ins have resulted in a lack of flexibility to accommodate what many other countries adopting creative-commons platforms early on have. **For instance millions of EV Batteries provide storage capacity to the Smart Grid**[CT] yet the grid is not equipped to **get the balance right** between cars plugged in at night and the energy required because of old switching technology that is costly to replace nationwide. Unlike other countries such as France, many old infrastructures have been maintained and simple technologies such as **EV Battery technology were not made readily available via compulsory licensing when it was necessary to do it for the EV national industry to grow. Similarly, the lack of community trademarks**[(CT)] **and community patenting**[(CP)] **in home appliances have also put the whole energy system back for at least a decade in relation to other counties.** The *creative-commons EV strategy* was postponed in 2029 by the Technology Strategy Board after years of **industry lobbying**. Analogous set backs have occurred in the agricultural sector, as well as the construction industries whereby **energy storage technologies were kept under licensing schemes until 2037 when the schemes finally lapsed, just a little to late.**

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11- How have working and travelling patterns changed?

Contrary to some of the forecasts made four decades ago, **only 18% of today's population relies entirely on public transport.** Rp>Kp
Unlike other countries, such small increase for the case of the UK is correlated with several facts: people are older, they travel smaller distances than before, the cheap availability of creative-commons EVs. The agricultural and housing sector generate **less employment than th**eir counterparts in mainland Europe. Rn>Kn

12- What are the big political battlegrounds?

To take full advantage of creative-commons business models, **government has to come to grips** with the fact that the country must develop an entirely different —**less "remote"— business culture** and that institutions play an important part of such transformation. **One surprising element of today's business environment is that creative-commons technology markets rely more on face to face interactions than ever** (as opposed to say, licensing business models which would be done remotely), **many business opportunities have been missed partly because of the lack of interpersonal negotiating skills in an international context where English is not the only language spoken**. Kh>Rh Kn>Rn Kh>Rh Kn>Rn Rh>Kh

13- Examples of what NGOs and opinion leaders are campaigning on

Earlier this year (17 of August 2050) social entrepreneur and peace Nobel laureate Jean-Psualomi Druker Malaboutu made an appearance on BBC 1's Sunday chat show "Take it or leave it" where he touched upon the current use of technology. One of his statements was particularly telling: "*well, for more than half a century successful green* ***creative-commons innovation has indeed received the back-up of many governments around the world though certainly not so much here in Britain.*** *It suffices to look at the Chinese and Russian cars you guys drive and the type of EV and public transport infrastructure that is in place. Now, we need to be honest about this, the wider worry for social entrepreneurs like myself —not just in little Timmins, Ontario where I come from, but perhaps more acutely in places like the UK —is that, over the last 30 years, for all the hype of creative-commons,* ***the truth is, every new generation has been unwillingly educated to relate to technology in terms that are —one might say—indistinguishable from magic, if you catch my meaning*** *[laughs]. You can't run a country like that!* ***nobody knows how anything works,*** *whether we are talking about synthesised milk production, the smart grid, or a second hand nano-boiler.* ***Yet, we readily trade*** *atomic submarines, financial services, hospitality and the like for millions of electric cars and all types of ubiquitous technologies by the millions every year.* ***The more we*** Rh>Kh Rp>Kp Rh>Kh Rh>Kh Rn>Kn Rp>Kp Rh>Kp

depend on these technologies the less we know how they work *[laughs]. Like all those million* ***"Navi-skullplant" users****. Does anyone know how they work? Christ alone knows how those things work once you get the plastic implant under your skin! Mine never worked anyway, so I am forced to cycle every day to work [laughs]. Now, correct me if I am wrong, but most people here have also learnt to deride those few who know how technology works as "nerds" [more laughs].* ***The problem with mass imports of "magical" techno-goods even if, or perhaps because, they have been the result of ubiquitous creative-commons innovation, is that they wind up —in the case of cars— delaying the deeper cultural transformation that, say, a truly intermodal transport system takes*** *[boos] and let's not talk about delaying the renaissance of the whole British car industry which, for those who know about history, has seen better days let me tell you [boos then laughs]."*

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14- How have sectoral structures changed?

Creative-commons innovation in the electric car industry— roughly 82% of all the passenger car market worldwide and 95% of the UK market— has made car design and car final assembly costs insignificant compared to part **manufacturing and materials** (particularly rare earth metals in magnets). This is no longer the "knowledge intensive" sector it was only five decades ago this year. **Aided by the widespread use of e-communications over the last few decades, the "electric car business model" has done today to the car industry what digital sound recording did to the music industry at the beginning of the century: *de-commodify* what was previously regarded as "high value added" in the car production chain.** Things are back to basics in many respects. **Yet exactly the opposite has been occurring in the agricultural sectors where biological products (plants and crops) have now been commodified and turned into creative-commons technology.** Overall the effect is being a complete transformation of the agricultural landscape whereby **we can no longer say it's a natural landscape but a commodified, more value added technological one.**

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15- What is regulation like for government?

Problem definition and standard setting were at some point strong aspects describing what the government thought as duty in regulating the private sector. **However, strong government intervention to privilege IP-driven innovation strategies meant less opportunities for big traditional players in an industry where creative-commons based business models and innovation has come to dominate** green technological development, infrastructures and standards. **Such immense**

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turn of events within the industry, amongst other things, have resulted in international big players no longer British based, dominating different sectors.

16- Who are the new key players in the economy?

Most of the new players in all three industries are global in nature. They have got into the creative-commons bandwagon and **have learnt to provide high value added goods and services on the side of creative-commons platforms.** For instance. **UK company Riversimple** initiated the creative-commons innovation trend in England (together with the Swiss OSCAR prototype). **Riversimple first trialled its creative-commons hydrogen fuel cell car back in 2009, however it did not received much attention at the time. This was because "creative-commons" did not represent an attractive business model in the eyes of most people in the industry.** In a knowledge economy, it was said at the time, **patented technology was the only one** which made business sense and business sustainability.

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17- Where do products come from, who makes them?

Today, electric vehicle manufacturing worldwide is dominated by China, India and to a lesser extent East African subcontractors. China enjoys **monopoly control of key materials** since the 2020s. The UK is at the moment 72% food self-sufficient (though **dietary habits have changed radically since the 2030s)**. Many **materials used in construction** come from EU countries, many wood materials come from Finland.

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18- What are some examples of the role of the internet?

The ubiquitousness of the internet has undermined the growth of many of the so-called creative industries and a lot of them have had to adopt the face to face business model. More government support via training earlier in the time period **would have widened** business opportunities considerably. For certain standards, it is true that there is a case of **authority without responsibility**, that is to say, **government and corporations set the standards and define environmental problems but then e-communication technologies and creative-commons innovation soon have a disruptive effect on those standards, ultimately weakening the power of many patented products and services**, this has been the case with many so called **intelligen**t food labels.

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19- What are some examples of big changes in a supply chain?

Poor anticipation from government and industries is also reflected in technological lock-ins for the established heritage

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car industry and its supply chain. Similarly, the food chain has **not received enough support** at a time when patented brands and technology —**not being able to compete with creative-commons technologies**— become outmoded in a matter of years. Patents and brands have to be put on sale in either local or international niche markets. **The most important problem caused by short-term thinking was that regulation of technology was disjointed, with no focus on long-term issues and could not cope with creative-commons associated business models. Vehicle efficiency for instance and food safety were prioritised over wider mobility accessibility targets** and over nutritional value and long term dietary habits respectively. **A focus in IP-innovation at an earlier stage, also put supply chains in a less favourable position to accommodate the constraints of a lower-energy-density storage systems** in their operations.

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20- Examples of how new technology is being used

Organic producers have come to depend on GM seeds which have been developed internationally under creative-commons forms of innovation. Yet seed prices have become more affordable and adaptable to local farming conditions. Biotech companies have seen this as a race to the bottom in terms of recouping investments, yet society overall as benefited from these new technologies. **There are huge business opportunities in the provision of added services which can only be provided by means of face to face interaction and social networks** (much in the same way pop bands had to do gigs instead of selling records to make a living at the beginning of the century). **Institutions have failed to hop on such a bandwagon during the last 20 years because it has meant less profits in a cultural transformation** not everyone has been prepared to join in. **The knowledge economy has meant not particularly more new technology development, but more reliance on financial instruments and brand names for a diversity of services which are in decline as the economy has contracted.** Such logic has proved to be dysfunctional to creative-commons innovation as a whole which has become the predominant employment generator for other countries.

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21- How are consumers, including children, being engaged?

People engage with technology via e-communications and pretty much outside the sphere and influence of institutions which haven't been prepared to compete with trends that are not in line with what they consider the standards should be. **Although to some extent people have turned to each other building a stronger sense of community** in the face of economic

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environmental and social instability, this is a scenario where **events have outpaced actions at the level of institutions and businesses in most sectors of an economy which has contracted.**

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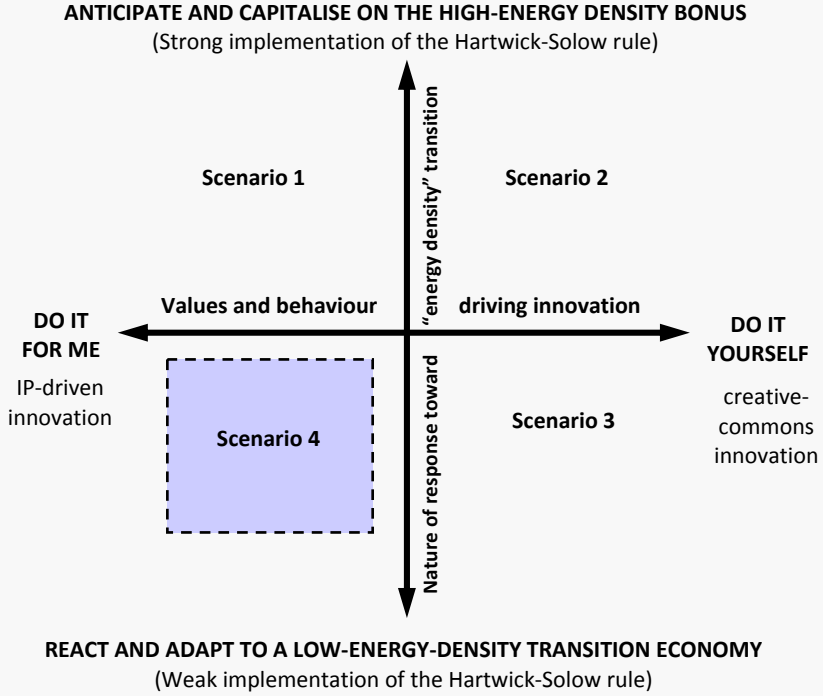
SCENARIO FOUR

SUMMARY: Lured by short-term priorities after a deep political crisis, by 2050 individuals, government and businesses find themselves **reacting** to the onset of a "low-energy-density economy" while also making efforts to adapt to industries where **IP-driven** innovation is prioritised globally. Governments tax revenue is at an all time low in a polarised society between the super affluent and those who live outside the economy. **CARS:** By now most cars are made abroad, principally China and India. An important proportion of the highly skilled workforce has moved abroad. Some people drive expensive Dorkon EVs while 50% uses public transport and other alternatives. Thanks to people's "garden shed" creativity, a new semi-regulated industry of home-made cars has mushroomed across the country. No subsidies for the Flexi V industry mean local authorities have to tolerate informality within the sector. Some SMEs buy the low quality cars just for batteries and motor containing rare earth metals often sold in unregulated markets. **FOOD:** Institutions did not foresee the possibility of people and skills being lost to other countries, mostly eastern Europe and the Far East. Investment in short term profitable ventures in the food industry has resulted in a less competitive food industry. Focus has been put on energy drinks and spirits. The country is neither food self-sufficient nor able to feed the world. **HOMES:** Focus on selling green home appliances has forestalled the country's ability to build and retrofit greener homes. Ironically, no employment was created in the green home gadget industry that was commercially viable or attractive to costumers after the 2021 crisis. Twenty years ago gadgets were made in China. Meanwhile, attention was divested from building strong buildings, strong communities, and saving some hot air at home.



1- What types of cars, food and homes are there?

Just before the 2040s —ten years ago—, **to speak of the UK car industry was to speak of ever more efficient, sophisticated expensive petrol and diesel cars**. This surely included plug-in hybrid vehicles which have never truly got rid of their "mermaid alternative" stigma[97]. In contrast, thanks to **people's garden shed creativity**, an unregulated industry of DIY Flexi EV cars has emerged across the country, authorities have had no option but to be tolerant. These cars use generic batteries shipped from China, India, North Korea and Vietnam. The country imports all its **Black Cabs™** and **Zhuan-Ferguson™ vehicles used in agriculture**. **Generic modular parts and refurbished materials** are often **bought over the internet** and shipped into the UK **under no regulation** at all. This also happens with all Flexi vehicles also such as the ***Flexi POO*** — running on **methane generated from human and animal waste**, the ***Flexi VOVs*, "vegetable oil vehicles"** running on **seed oil** compounds, **motorcycles**, **scooters** and **mopeds** are all imported from abroad. **Local Corporate Authorities (LCAs)** have used Flexi VOVs for a long time. In the food industry there is a similar polarisation: **supermarkets sell "safe water" in Nano-filtering devices™ and all types of intelligent nano-foodstuffs**. Meanwhile, **people sell their surplus produce** via informal markets in communities all over the country. **Vegetable box schemes** paying no taxes have also become common in cities. Projects "to feed the world" have been abandoned as the country has **increasingly become self-sufficient** but at the same time **less able to generate biotechnology** in a highly competitive food industry. Amongst those biotechnology companies that haven't moved abroad targets are **seldom agreed.** The housing industry also **divided between highly standardised projects** and those which are under no regulation at all. **Standards set up by government via consultation process that are typically inefficient and underfunded by local authorities** have no leverage in many regions of the country. **Informal markets for low-carbon appliances and equipment have also become common all over the country.** Those local communities which are **not under regulatory pressure** have focused **on longer term construction** practices advocated by community building association for the last couple of decades. **The government's "Best brands for the green home" initiative employs a very small proportion of the workforce inside the country**, mostly in servicing equipment.

Rp>Kp
Rh>Rn
Rn>Kn
Rp>Kp
Kp>Rh
Kn>Rp
Rh>Kp
Rp>Kh
Kp>Rp
Rh>Kh
Rp>Kp
Rp>Kp
Kn>Rn
Rh>Kh
Rh>Kn
Rn>Kn
Kh>Rh
Kh>Rh
Kn>Rn
Rn>Kp
Rh>Kh
Rn>Kn
Rp>Kp
Rh>Kh
Kh>Rh
Kp>Rh
Kh>Rh
Kp>Rh
Kp>Rp
Rh>Kp
Rp>Kp
Rh>Rn

[97] It is often recalled that back in the 2000s when asked about hybrid cars Nissan-Renault's CEO Carlos Ghosn, said that hybrid cars were like mermaids: *"when you want a fish you get a woman and when you need a woman you get a fish"*

2- What is the state of the economy?

The private car status quo is maintained for an elite market of powerful consumers. **Monopoly grants over key green infrastructures to few global players have delivered some exciting but short lived results.** Innovative ways of prolonging "business as usual" have led to some green dysfunctional targets being met at a huge social and environmental cost. **Global brands of electric vehicles**, are within the reach of only a few consumers. **Income distribution and mobility is at an all time low**. Only 5% of the working population in Britain can afford the global brand vehicle, **the all-electric concept car. Heritage cars such as VW-Rolls Royce™ are only for the super rich to drive in secluded areas of the country.** Many people argue the economy only survives because **defence exports have increased as well as financial service**s and a prominent position in the global trade of carbon.

Rh>Kh
Rp>Rn
Rh>Kp
Rh>Kn
Rh>Kp
Rh>Kh
Rh>Kp
Rp>Kp
Rn>Kn
Rp>Kp
Rh>Kn

3- How are people being employed?

Two thirds of UK's **highly skilled workforce in the transport industries has emigrated to other countries, Virgin-Rolls-Royce™** being the only exception, though marketing people inform us they are no longer neither in the "car" nor in the "business" sector. **The informal EV industry employs 18% of the workforce** in that sector in the UK. **Agriculture and community based food production accounts for 26 %** of UK's workforce, while construction 21%. **The global car industry often flies service personal into the country to service the few cars that still run.** The informal bike industry generates **manufacturing jobs for 4 % of the workforce in the sector**. **These proportions are higher thanks to informality within the sector. Employment** generated in home retrofitting declined right after 2031. The **green home appliance SMEs operate too in informality and have received support only from some local authorities,** they employ an important part of the workforce within the sector, but this is **thanks to lack of regulation**. **Another part of the this industry has just moved abroad.**

Rh>Kh
Rp>Kn
Kp>Rh
Kn>Rn
Kn>Rn
Rh>Kh
Rn>Kn
Kp>Rh
Rh>Kh
Rp>Kn
Kp>Rh
Kn>Rh
Rh>Kp

4- What is the role of government?

The idea of "profits first, sustainability second" has led to government policies aimed at economic growth at a time of transition to low-energy density carriers. The green low carbon industries as well as carbon markets **were promoted** as the industries of the future. **However, lack of systemic foresight combined with what was then called green growth, have forestalled government plans to promote real growth as well as green jobs**. Central government as well as local authorities have had no option but to **turn a blind eye to an enormous number or**

Rh>Kh
Rn>Kn
Rh>Kp
Rh>Kh
Rh>Kn
Kh>Rh

activities which go unregulated for two principal reasons, lack of institutional capacity, and lack of a regulatory framework able to accommodate conflicting targets, on the one hand intellectual property rights and on the other environmental sustainability, social justice and wellbeing; what some analysts have called for a long tim**e knowledge governance.**

Kh>Rn
Kn>Rp
Kn>Rh
Kh>Rh

5- How has society changed?

This is a **divided society** that has gone through numerous crisis, all of them **international in nature,** out of which no consistent or durable lessons have been drawn. **Society at the grassroots has faced the prospect of a government subjected to global forces which cannot control except by protectionism,** a route the country has not taken for fear of even worse outcomes. **People have increasingly become self reliant** but at the same time distrust in central government has led to **fragmented development** across regions. Many regions are substantially better off than others, **energy provision is unfair** and **the tax system struggles to connect a globalised reality of law enforcement with a localised reality often characterised by informality.** People in general are more individualistic than ever and **creativity to solve immediate local problems** has **not been adequately supported** by central institutions.

Rh>Kh
Rh>Kh
Kp>Rh
Kp>Rp
Rp>Kp
Rn>Kn
Rh>Kh
Kh>Rp
Kp>Rh
Rh>Kp

6- What are some examples of things consumers ask for?

Although car electrification **arrived much later than everybody** thought it would, transport service providers, have played the role of meeting consumer demand which has been typically focused on **immediate necessities rather than anticipating** times of higher energy prices and lower density carriers such as electric batteries. **Many needs are satisfied via informal markets in all sectors and industries so there is an obvious lack of market intelligence as to what the majority of people are asking for.**

Kp>Rp
Rp>Kp
Rp>Kp
Kn>Rh
Kh>Rh
Rh>Kp

7- What is the state of international relations?

The world has gone through several **financial, political and environmental crises**. The need for a world government has been voiced since the second world war, this time however things are different, and will always be, according to OECD analysts.

Rh>Kp
Rh>Kn
Rh>Kh

8- What is the role of each sector in society?

Informal economic activities are widespread and politicians and lawyers see regulation as the solution. Many retailers have tried to work together with unregulated farms, to no avail. **Most communities have created their own food supply network where they feel they are better off than having any dealings**

Kh>Rh
Kp>Rh
Kn>Rh

with supermarkets. Something similar has happened in transport and construction. People **profoundly distrust old formal organisations and prefer to do things their own way**. After the deep crisis, there is **not much statistical information** about how the informal economy is doing. Government resources are stretched and it has been **very difficult to build institutional capacity** and an effective system of governance.

9- What are some examples of the role played by the media?

The **market has been volatile** and EV service providers such as Better Place™ have claimed to be guided by consumer demand. **Car industry executives however, have always admitted driving EV technology upwards to new heights every year has always been dependent upon the injection of huge amounts of advertising cash.** For instance, the long running advertising **campaign announcing hydrogen and hybrid** vehicles as the "vehicles of the future" —which commenced with California's **"Governator Schwarzenegger" early on in the century**— lasted well into the 2030s. In hindsight, the shared opinion today is that both were used as **decoy technologies to buy extra time for the oil industry.** This opinion has been reinforced by a few **media scandals such as the 2042 Shell e-mail hack,** featuring **Ekaterina Pekarkovinsky, apprentice secretary and former lover** to Shell's chief executive Henk de Vors.

10- What are some examples of changes in the energy infrastructure?

Carbon Capture and Storage (CCS) technology in the power sector, **currently dominated by the likes of Chinese-German Oi™** and Canadian-Japanese Bombardier-Mitsubishi™ **has turned out to be more cost inefficient than projected.** CCS systems have been implemented successfully in only one out of three power plants. Since 2025 the country is divided (after a long and controversial political process) into energy-autonomous regions. The country is 40% energy self-sufficient and its **per capita energy consumption has decreased from 125 kWh/day, at the beginning of the century to 117 kWh/day, for the affluent and 46kWh/ day for the poor.** Most of the electricity generated in the UK comes from nuclear reactors and fired coal. Only 10% of current energy mix comes from indigenous renewable sources.

11- How have working and travelling patterns changed?

Although many people **dream of driving a brand new** Dorkon EV™, this can **only be done by 16% of the population** who commutes to work at least 3 days a week. **Another 60% uses** First Services Public Transport™— the only transport company that was rescued (from the French and the Swedish who

dominate 70% of public services solutions in the EU region). The other **24% of commuters have access to a *Flexi EV*.** **Kp>Rh**

12- What are the big political battlegrounds?

Social innovation has proven to be a driver for change in inter and intra city mobility, however **local governments have not been able implement sufficiently flexible governance mechanisms in the EV sector because Intellectual Property granting policy —particularly battery technology patents— is still in the hands of central government and at the EU level.** As a result, localised **innovation and employment** in electric vehicles has been occurring in a **disarticulated manner,** always negotiating positions between public and private services and always **at the fringes of legality.** The long delayed **Pensions, Employment and Welfare Reform (PEWR)** has been perhaps the biggest political battleground of the last two decades. **The responsibility to provide many former public services has now been officially passed on to individuals years after this became common in an informal way in each municipality.** This has taken much effort from government **harnessing the media** in order to make the PEWR appear **"cooler than it is".**

Kp>Rp
Rp>Kp
Rh>Kh
Rh>Kp
Rp>Rn
Rh>Kp
Kh>Rh
Rh>Kh
Kh>Rh
Kh>Rh
Rh>Kh

13- Examples of what NGOs and opinion leaders are campaigning on

A former niche market for taxi fleets —and **a profitable monopoly** too—electric cars **battery-swap service providers** have recently been in the headlines, though for the wrong reasons. In his *Guardian* editorial of today —10th July 2050— Tim Carroll addresses **last week's emergency loan**, the second this year, to **Better Place™, UK's EV battery swap-station giant**. In passing, he bluntly describes what goes on in the car sector as "*the outcome of an 80/20 bad old salad mix of big oil interests (80%) and **big EV state-granted battery-swap station oligopolies** (20%), so the answer to our children at the breakfast table is no … there is not such a thing as a UK car industry even though we could certainly talk about a lavish car market of Rolls-Royce for the filthy rich, …that's not us by the way, we're just locals"*. Often criticised for his family breakfast rants, Carroll's snapshot of the situation doesn't seem so far fetched this time: ours has indeed been a highly competitive, market-led and at times market troubled half a century where the transport sector has been experiencing a long "hidden crisis". Many —including **Archbishop Odin Macgregor**— have imputed this to "*an endemic condition in the sector because of oil and nothing but big fat oil, we'll never get over it, not even come the day when we run out of it* ".

Kp>Rh
Rp>Kp
Rh>Kh
Rh>Kp
Rh>Kp
Kh>Rh
Kh>Rh
Rp>Kp

14- How have sectoral structures changed?

Informality is the name of the game for most sectors. The rule of law is lagging behind about 20 years and society at the grassroots has moved on. **The rule of law is in fact utterly unfit to meet today's conditions of environmental and economic vulnerability in many regions.** Many people today still wonder why the full electrification of the car industry in the UK **was delayed** until the mid 2030s. The truth is that under economic efficiency and **profitability targets emphasis was made on the standard setting for big patented infrastructures.** In the food sector something similar has happened although perhaps worst during the 2030s where **severe droughts** in some parts of the country as well as **floods transformed local agricultural practices.** Housing has also been another adaptation story, alongside floods and economic downturns.

Kp>Rp
Rh>Kh
Rn>Kn
Rh>Kh
Rh>Kp
Rh>Kh
Rh>Kp
Rn>Kn
Rn>Kn
Rn>Kp

15- What is regulation like for government?

A grassroots **informal industry of *Flexi EVs* has emerged** across the country **using generic batteries** shipped principally from Asia, authorities have no **option but to be tolerant** in regards of the legal status of many actors. Informality is everywhere, **the food and housing sectors are highly organised at the community and interregional level, but central government and local authorities have less to do with it than people's need to self-organise after the 2034 and 2045 crises.**

Kp>Rh
Kh>Rp
Kh>Rh
Kp>Rp
Kh>Rh
Kp>Rp

16- Who are the new key players in the economy?

The car industry is dominated by **risk averse state supported IP-driven** businesses and individuals, 50% of which are either Chinese or Indian. The other 50% are Japanese, German and French. Worldwide car manufacturing peaked in 2035, and has been declining ever since. I**n 2049, six out of ten passenger cars in the world were designed and manufactured in China.**

Rh>Kh
Rp>Kp
Rp>Kp

17- Where do products come from, who makes them?

Most cars on UK roads today are **not just manufactured** in China but indeed Chinese™ in hardware and software. ***Formal* direct employment in the car sector is non-existent.** ***Informal* employment in the *Flexi EV* sector, though not in government statistics, is suspected to be quite high**. Some *formal* **indirect employment** can be found in the service and commercial strands.

Rp>Kp
Rh>Kh
Kp>Rp
Kn>Rn
Kn>Rn

18- What are some examples of the role of the internet?

The internet has been crucial to community wellbeing, however ICT communications infrastructure is one of the few **subsidised industries** in the country. **Based on past experiences, there are in fact several overlapping internet infrastructures**

Kp>Rp
Rh>Kp
Kp>Rp
Kh>Rh

which have made communications robust in times of crisis. This however, far from being a result of any national initiative has been the result of **partnerships between a global civil society and organisations such as the Electronic Frontier Foundation and Interworld.** **Kh>Rh** **Kp>Rp**

19- What are some examples of big changes in a supply chain?

Housing supply for the less affluent under-regulated regions has been transformed to local standards. **Since the 2030s crises, houses have been built with vernacular materials** such as stone and straw bale. This has mean a new supply chain within communities whereby **government standards play in fact no role**. **Houses are built with the best practice available and according to tradition.** The food supply chain, has experienced a similar return, although inputs to agriculture are often from unregulated sources shipped into the UK. **To regulate agriculture would represent for government expensive investments which at the moment are not available**. State granted **monopolies over green car infrastructures** have been seen as a solution to harmonising green car technology. **Both petrol infrastructure as well as electric car technology holders were at some point granted licence to operate.** This was seen by government as an easy way out of the problem of **conflicting standards**. "Fast-tracking" standard setting in this way has nevertheless **compromised** SMEs **ability to generate employment p**articularly in **the low-tech electric vehicle industry,** where they would have had to align themselves to those standards. This of course, did not happen. In the end few companies dominate a market where private road transport options alongside **energy prices skyrocketed after 2020.** **Kh>Rh** **Kp>Rp** **Kh>Rh** **Kp>Rp** **Kn>Rp** **Rh>Kh** **Rp>Kp** **Rh>Kp** **Rh>Kh** **Rh>Kn** **Rp>Kh** **Kp>Rh** **Rh>Kn**

20- Examples of how new technology is being used

Today, the housing sector receives **some informal subsidies** from government in the form of such things as nano-materials. **For a long time creative-commons nano technologies were very cheap but since the 2030s, once they had an important market share patented rights over these materials became again enforced as a result of international pressure,** above all from the US and China. For this reason so called "sectoral governance subsidies" have to be provided **via informal channels.** **Rh>Kh** **Rh>Kh** **Kh>Rh** **Kh>Rp** **Kh>Rn** **Rh>Kh** **Kh>Rp**

21- How are consumers, including children, being engaged?

Companies in general have always **had "outreach programmes" which have aimed to promote IP rights by means of awareness campaigns**, such as the "IP day" every year and the schools programme on copyright crime and awareness. **Children are invited to exhibition**s where new technologies are demonstrated so they can learn about future employment opportunities for them in the knowledge economy. **Rh>Kh** **Rh>Kp** **Rh>Kh** **Rh>Kh** **Rh>Rn**

4.2 Proof of concept analysis

This section follows the proof of concept protocol **(Table 2.5)** as a means to test the usefulness of the model via pattern matching analysis (Yin, 2009; Campbell, 1966) and refine it accordingly. Before we can "match" anything it would be useful to first identify both *expected* and the *observed* patterns separately. For convenience Figure **4.1** repeats **Figure 2.5a** containing the *expected pattern template*. The template exhibits contrasting degrees of implementation of the Hartwick-Solow rule. As we will see later in this section, if it is true that long run substitutability requires a process of social legitimation and governance of capital inputs to production, then Scenario 1 and 2 of strong implementation (in black) should overlap with those observed substitution patterns where *sustainable substitution* is predominant. The opposite is expected of Scenarios 3 and 4, where weak implementation (in grey) should overlap with observed patterns where *runaway substitution* "predominates".

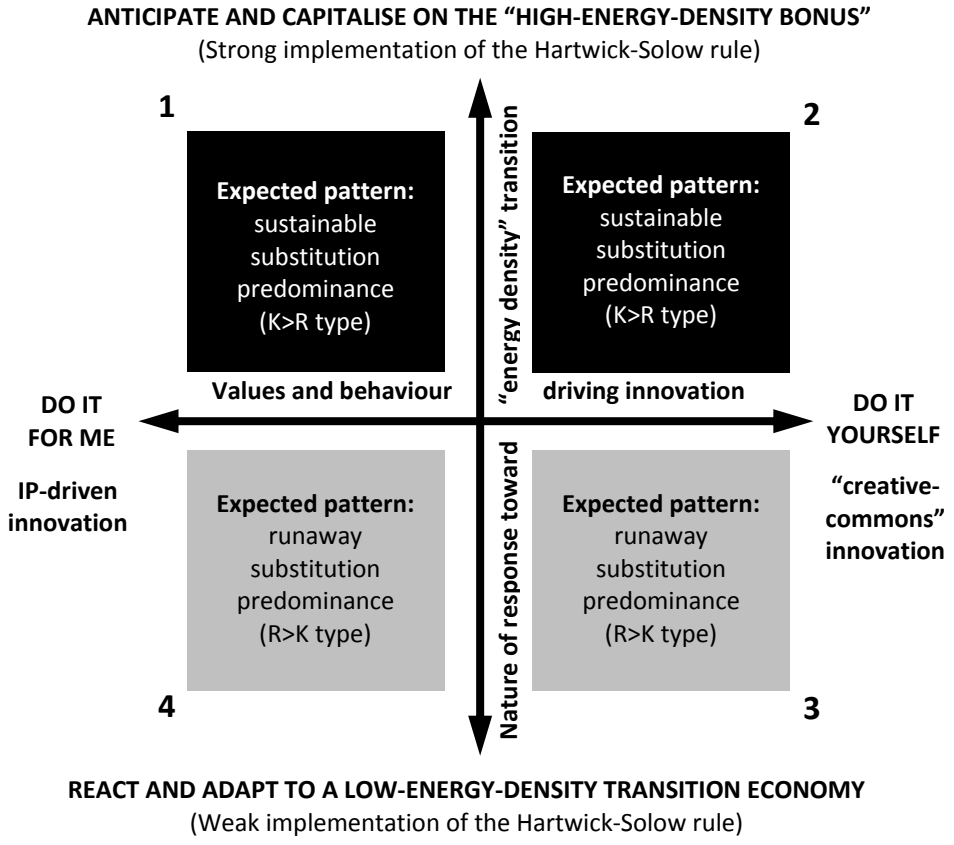


Figure 4.1 Expected pattern template

To better understand what the word "predominates" means in this context, we need to look at the actual patterns. Typically, patterns are generated through data. In our model we generated that data by counting up the number of substitution occurrences in the grey column of our scenario narratives. That grey column is a "translation" of each scenario narrative into a substitution "code" comprised by its various substitution mechanisms (refer to **Figure 2.5b**). Our *observed patterns* are therefore the result of putting all those substitution mechanisms together in a spatial array. Typically, patterns are best appreciated visually. **Figure 4.2a** shows the basic distributions of *observed patterns* across all four scenarios. It features *runaway* and *sustainable* substitution patterns shown in separate blocks. Specific counts and subtotals have been included (in percentages) so as to expose quantitative differences. A scale of colours has been added to highlight the status of each cell coordinate, where substitution counts can range from high (red) to low (yellow). White coloured cells indicate no occurrences at all (these cases will be discussed later).

Already we can see that Scenario 2 is distinct from the rest in that it presents us with by far, the strongest pattern of sustainable substitution. It is also possible to note quite clearly how runaway substitution predominates in Scenarios 1,3 and 4. After comparing all the red and orange coloured cells in all scenarios, it seems evident that the role of human capital is the salient form of substitution of every general and specific type. The latter might be seen as the natural outcome of a "knowledge economy" style of economic development manifest in all four scenarios. The unique situation of Scenario 2 is made all the more apparent in **Figure 4.2b**, where sustainable versus runaway substitution averages are compared across all scenarios. Scenario 4, occupies the second place in terms of sustainable substitution predominance, although still by less than half the proportion (36.3%) of Scenario 2 (almost 80%). (Interpretations as to what this means are the subject of our next section, where we test the model). Our observed patterns can be rearranged in a variety of ways and formats so as to emphasise different aspects of analysis. In what follows we use these possibilities to assist the testing of our model.

(a) Observed patterns, basic distributions across scenarios(%)

	ONE	TWO	THREE	FOUR
Rp>Kp	10.5	2.1	15.3	11.6
Rp>Kn	0.5	0.5	2.1	2.6
Rp>Kh	2.6	2.1	5.3	3.7
Rn>Kp	0.0	0.5	1.1	1.1
Rn>Kn	6.3	2.1	7.4	6.3
Rn>Kh	0.5	0.5	0.0	0.0
Rh>Kp	16.8	3.1	10.1	12.1
Rh>Kn	7.9	0.5	4.2	6.0
Rh>Kh	22.5	8.9	29.1	20.5
Subtotal	**67.5**	**20.4**	**74.6**	**63.7**
Kp>Rp	7.9	15.7	3.7	7.9
Kp>Rn	1.6	3.7	1.1	0.0
Kp>Rh	4.2	7.3	4.8	6.8
Kn>Rp	1.0	3.1	0.5	1.6
Kn>Rn	5.2	6.3	5.3	3.2
Kn>Rh	1.6	6.3	1.1	2.1
Kh>Rp	2.6	8.4	1.1	2.1
Kh>Rn	0.5	3.1	0.5	1.1
Kh>Rh	7.9	25.7	7.4	11.6
Subtotal	32.5	79.6	25.4	36.3
Total	100%	100%	100%	100%

Runaway substitution

Sustainable substitution

0	
≤3 %	
≤6 %	
≤8 %	
≤12 %	
≤30 %	

(b) Observed patterns: sustainable versus runaway substitution averages (%)

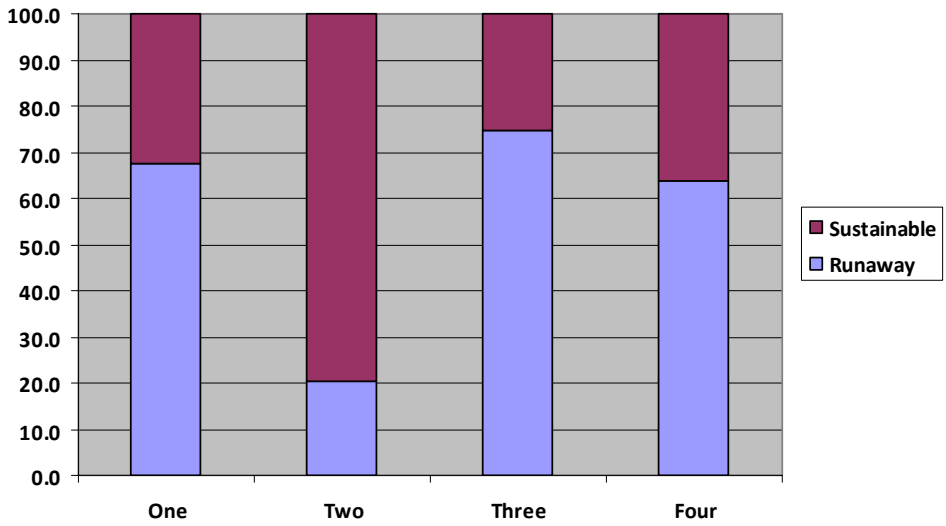


Figure 4.2 (Composite) Observed patterns

Testing the model: the answer to the first research question

In our first research question we asked the following: *since substitutability depends on society's relative valuations of man-made and natural capital in a changing world (technologically and culturally), under what conditions and institutional arrangements are long-run substitution possibilities likely to be higher?* The principal claim of the model is that long-run substitutability (understood as the result of society's relative valuation of man-made and natural capital in a changing world) is likely to require institutional arrangements that improve the conditions upon which processes of social legitimation and governance allow capital inputs to yield services that are compatible with sustainability. The notion of "processes of social legitimation and governance of capital inputs" relates to the *sustainability test to capital* in **Table 2.3**.

In brief, the assumptions of "feasible sustainability" and "perfect substitutability" hold to the extent that, in the long run, individuals find the right conditions to freely express their substitutable preferences. In our sustainable society model these conditions depend on the existence of processes of social legitimation and governance of the capital inputs to production. A basic way to test the above claim (following our protocol) runs as follows: implementing the Hartwick-Solow rule brings society closer to sustainability (expected pattern). If it is true that long-run substitutability depends on individual consumers finding the right conditions to freely express their preferences (observed pattern) and if it is true also that this requires a process of social legitimation and governance of the capital inputs to production, it would be reasonable to at least expect:

(i) An overlap between those observed patterns where *sustainable-substitution* predominates (the K>R type) and those expected patterns where the implementation of the Hartwick-Solow-rule *is the strongest* (Scenarios 1 and 2).
(ii) An overlap between those observed patterns where *runaway-substitution* predominates (the R>K type) and those expected patterns where the implementation of the Hartwick-Solow-rule *is the weakest* (Scenarios 3 and 4)

ONE

	Kp	Kn	Kh	Rp	Rn	Rh
Kp	Kp>Kp	Kp>Kn	Kp>Kh	Kp>Rp	Kp>Rn	Kp>Rh
Kn	Kn>Kp	Kn>Kn	Kn>Kh	Kn>Rp	Kn>Rn	Kn>Rh
Kh	Kh>Kp	Kh>Kn	Kh>Kh	Kh>Rp	Kh>Rn	Kh>Rh
Rp	Rp>Kp	Rp>Kn	Rp>Kh	Rp>Rp	Rp>Rn	Rp>Rh
Rn	Rn>Kp	Rn>Kn	Rn>Kh	Rn>Rp	Rn>Rn	Rn>Rh
Rh	Rh>Kp	Rh>Kn	Rh>Kh	Rh>Rp	Rh>Rn	Rh>Rh

1

Expected pattern: sustainable substitution predominance (K>R type)

TWO

	Kp	Kn	Kh	Rp	Rn	Rh
Kp	Kp>Kp	Kp>Kn	Kp>Kh	Kp>Rp	Kp>Rn	Kp>Rh
Kn	Kn>Kp	Kn>Kn	Kn>Kh	Kn>Rp	Kn>Rn	Kn>Rh
Kh	Kh>Kp	Kh>Kn	Kh>Kh	Kh>Rp	Kh>Rn	Kh>Rh
Rp	Rp>Kp	Rp>Kn	Rp>Kh	Rp>Rp	Rp>Rn	Rp>Rh
Rn	Rn>Kp	Rn>Kn	Rn>Kh	Rn>Rp	Rn>Rn	Rn>Rh
Rh	Rh>Kp	Rh>Kn	Rh>Kh	Rh>Rp	Rh>Rn	Rh>Rh

2

Expected pattern: sustainable substitution predominance (K>R type)

THREE

	Kp	Kn	Kh	Rp	Rn	Rh
Kp	Kp>Kp	Kp>Kn	Kp>Kh	Kp>Rp	Kp>Rn	Kp>Rh
Kn	Kn>Kp	Kn>Kn	Kn>Kh	Kn>Rp	Kn>Rn	Kn>Rh
Kh	Kh>Kp	Kh>Kn	Kh>Kh	Kh>Rp	Kh>Rn	Kh>Rh
Rp	Rp>Kp	Rp>Kn	Rp>Kh	Rp>Rp	Rp>Rn	Rp>Rh
Rn	Rn>Kp	Rn>Kn	Rn>Kh	Rn>Rp	Rn>Rn	Rn>Rh
Rh	Rh>Kp	Rh>Kn	Rh>Kh	Rh>Rp	Rh>Rn	Rh>Rh

3

Expected pattern: runaway substitution predominance (R>K type)

FOUR

	Kp	Kn	Kh	Rp	Rn	Rh
Kp	Kp>Kp	Kp>Kn	Kp>Kh	Kp>Rp	Kp>Rn	Kp>Rh
Kn	Kn>Kp	Kn>Kn	Kn>Kh	Kn>Rp	Kn>Rn	Kn>Rh
Kh	Kh>Kp	Kh>Kn	Kh>Kh	Kh>Rp	Kh>Rn	Kh>Rh
Rp	Rp>Kp	Rp>Kn	Rp>Kh	Rp>Rp	Rp>Rn	Rp>Rh
Rn	Rn>Kp	Rn>Kn	Rn>Kh	Rn>Rp	Rn>Rn	Rn>Rh
Rh	Rh>Kp	Rh>Kn	Rh>Kh	Rh>Rp	Rh>Rn	Rh>Rh

4

Expected pattern: runaway substitution predominance (R>K type)

0	
≤3 %	
≤6 %	
≤8 %	
≤12 %	
≤30 %	

Figure 4.3 A comparison between observed and expected patterns across scenarios. Intradomain substitution patterns are left out of the observed pattern (grey cells).

Do these overlaps actually occur? In all but one case the answer is yes. These overlaps can be appreciated in **Figure 4.3** where observed and expected patterns are compared side by side across all four scenarios. In all cases pattern matches are as imperfect as the reality they are meant to represent. What truly matters nonetheless is that they are sufficiently consistent for the purposes of conducting the pattern matching exercise. Before we can continue with the analysis, a brief qualification about the grey cells is needed.

As mentioned elsewhere (**Section 2.6**) *intradomain substitution* patterns of the "R>R" or "K>K" type (i.e. grey cells) have been left out of the analysis for the time being. This is because, for the purposes of conducting a preliminary proof of concept analysis, we have deemed it convenient to concentrate only on those "blind spots" or forms of substitution that are often "invisible" but which nevertheless appear to signal momentous *qualitative* transformations in society (as opposed to *quantitative* ones exclusively). While this at first sight restricts the analysis to some of the "low hanging fruit" of the problem we wonder whether this apparent weakness might not actually be more of a strength: one of the apparent virtues of the model is that, in turning the problem of substitution "inside out" so to speak (i.e. production failure first, market failure second) it makes it possible to address seemingly intractable or "analytically invisible" elements, as if they where indeed the "low hanging fruit" of the problem. From the perspective of the model's particular framing it truly *is* the low hanging fruit. If this intuition is correct, a substantial advantage might have been gained already. This said, we can now continue.

Overall, Scenarios 2, 3 and 4, exhibit consistent pattern matches between observed and expected patterns (this is true even though Scenario 4 also exhibits slight "unexpected behaviour"). These three matches suggest that the model is at least capable of doing "exactly what it says on the tin": it "translates" to the language of substitution things which are occurring "empirically" at the level of scenario storylines. Scenario 1, none the less, shows a clear mismatch or "unexpected behaviour" towards runaway substitution predominance. Far from disproving the model, it arguably does the opposite. That

is to say, it tells us something important about the "opposite case" in theory testing (Solow, 1974, p.11) and about Yin's (2009) notion of a "rival theory" in pattern matching analysis. Under the "opposite case" logic we assume that Scenario 1 would be as likely as Scenario 2 to yield a pattern of sustainable-substitution predominance (given that both represent a society implementing the Hartwick-Solow rule strongly). The "opposite case" assumption was proven wrong in the exercise. The expectation was that the way in which society organises itself to either consume or invest its "energy density bonus" during a HED-to-LED transition would be the overriding institutional arrangement influencing the character of both scenario pathway[98].

While the observed patterns in all four scenarios suggests the influence of the vertical axis is indeed very powerful, the observed patterns suggest (particularly for Scenario 1) a stronger-than-expected influence coming from the horizontal axis. Although this possibility was contemplated in our proof of concept protocol **(Figure 2.6)**[99] it also became part of the exercise to verify just how powerful the influence of IP in configuring scenario narratives could be. This was done by employing a more relaxed or "neutral" version of the expected pattern template **(Figure 2.5a)** allowing "the opposite case" (Scenario 1) to "compete" with the expected case (Scenario 2).

The IP-adjusted expected pattern set explored in **Figure 2.6** was effectively abandoned because it would have meant prematurely underestimating the potential contribution of IP-driven innovation to a more sustainable society scenario. One where runaway substitution occurrences would not proliferate as much[100]. Very importantly, it was pointed out earlier in **Chapter 1** that IP-driven innovation tends to trigger runaway substitution mechanisms only when IP leads to intellectual monopoly. It was also mentioned that, intellectual monopoly is no longer the defining characteristic of IP, particularly in the face of new technologies, ubiquitous internet, new business

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[98] Thus manifesting orthogonal-like behaviour between vertical and horizontal axes.

[99] Figure 2.6 "Expected pattern set adjusted for the influence of IP-driven innovation"

[100] Scenario which is vehemently advocated by a majority of business organisations, public institutions and multilateral agencies today (e.g. BERR, WTO. OECD, etc.)

models and new economic analysis of IP itself (Boldrin and Levin, 2008). At any rate, settling for one expected pattern or another was only of relative methodological importance. All in all, what truly matters at this point of our analysis is that the pattern-matching exercise can provides us with a sufficiently robust footing for further refinements so that a revised model of the expected pattern template closely fits the data. Such an objective has a simple but important logic that should not be sidestepped in refining our model:

> "A close fit is important to building good theory because it takes advantage of the new insights possible from the data and yields an empirically valid theory." (Eisenhardt, 1989, p. 541)

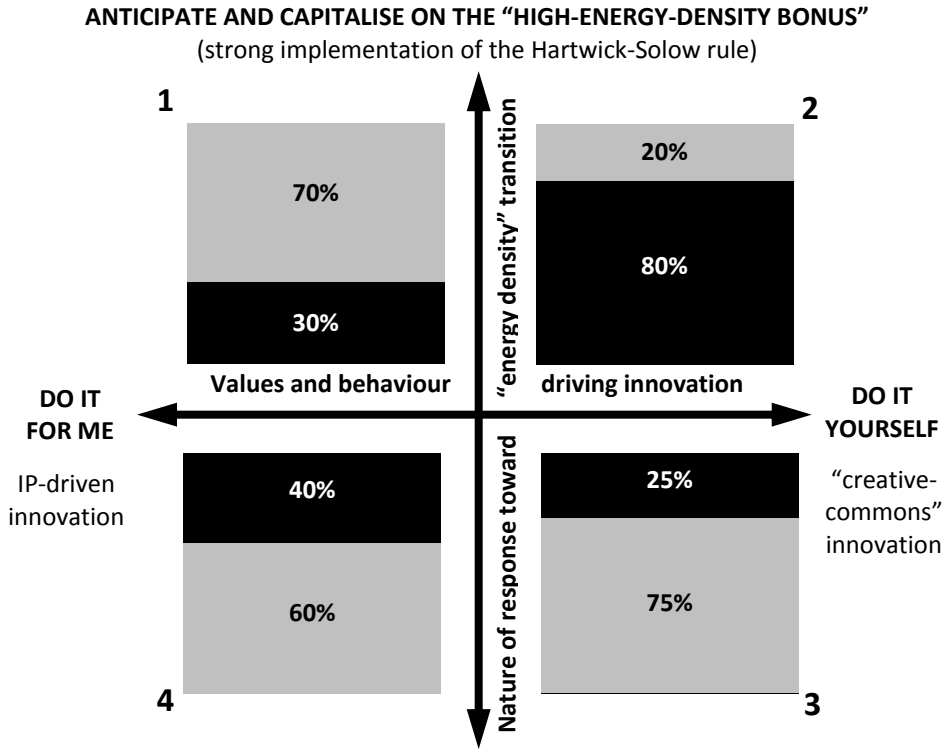
Refining the model

Notwithstanding (or perhaps thanks to) less-than perfect pattern overlaps, the preliminary test to our model seems to have led to a sufficiently robust outcome from which potential improvements should not be neglected. *Pattern identification* is a desirable and often inevitable intermediate step toward further model refinements (Campbell, 1966). Imperfect pattern matches are the natural outcome of comparing rough, flat patterns (e.g. the expected pattern template) with those yielded by storylines in all their complexity.

The improved version of the expected pattern template, after adjusting for the influence of the horizontal axis and indeed for the positive interaction between the two axis, is shown in **Figure 4.4**. That Scenario 2 and Scenario 1 are almost diametrically opposed (despite both being "strong implementation" scenarios) suggests values and behaviour driving innovation play a fundamental role in configuring their "reality". Thus, in contrast with the orthogonal behaviour assumed for the original expected pattern template, the newly adjusted pattern recognises that vertical and horizontal axes influence one another rather strongly.

The hypothesis yielded by the model would seem less ambiguous in the context of the revised version of the pattern: *long-run substitutability is likely to require processes of social legitimation and governance of capital inputs so that these capital*

inputs can yield services that are not in conflict with sustainable forms of wellbeing. Such processes have a greater chance to occur under conditions similar to those of Scenario 2. That is to say, where individuals and institutions learn to prioritise the use of creative-commons and open-source innovation strategies and business models to anticipate and capitalise on the high-energy-density bonus implied by society's transition to renewable energy use.



%	ONE	TWO	THREE	FOUR
R>K	67.5	20.4	74.6	63.7
K>R	32.5	79.6	25.4	36.3

Figure 4.4 Expected patterns template revisited (rounded percentages)

The implication of arriving at a more refined model hypothesis (i.e. a more refined expected pattern template) is of course that it more closely fits the data. This, however, also poses risks associated with the level of complexity that is "right" for the model. Adjustments must be done carefully, iteratively and preferably without loosing the parsimony that characterises

good theory, in other words without trying to make everything fit into the model:

> "The intensive use of empirical evidence can yield theory which is overly complex. A hallmark of good theory is parsimony, but given the typically staggering volume of rich data, there is a temptation to build theory which tries to capture everything. The result can be theory which is very rich in detail, but lacks the simplicity of overall perspective. Theorists working from case data can lose their sense of proportion as they confront vivid, voluminous data." (Eisenhardt, 1989, p. 541)

Behind the new hypothesis of the model there is also a new hypothetical storyline that puts into context the economic intuition that to achieve greater sustainability and "true" substitution possibilities, individuals, communities and institutions must reinvest their "high-energy-density bonus" wisely (i.e. the Hartwick-Solow rule) within the coming decades. This story in turn is affected by the fact that individual and institutional stakeholders have different values with regards to such things as individualism, technology development and social change. Alongside the message of our hypothetical storyline, Scenario pathways 3 and 4, still exemplify alternative hypotheses as to what society could look like by the year 2050, should those same technological and social investment opportunities be wasted. In all scenarios, speculations are advanced with regards to what those investment decisions might involve in terms of social change.

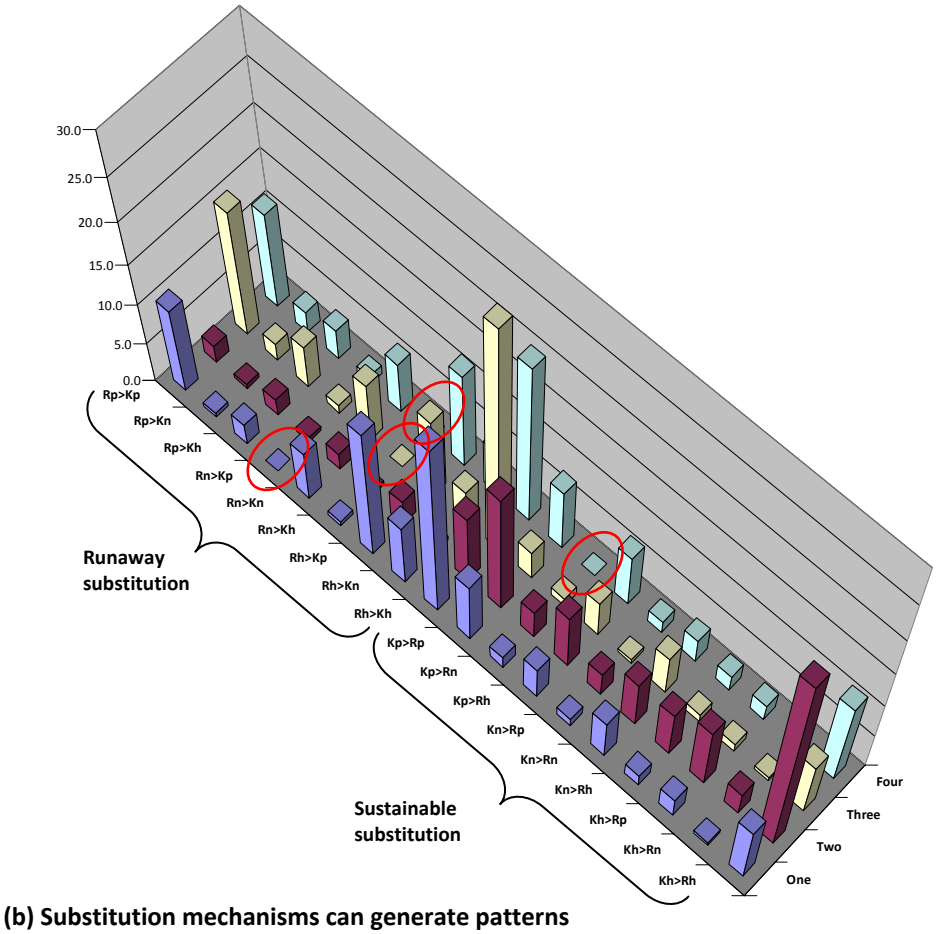
Although as a matter of methodological principle perfect or "true" substitution possibilities are higher in Scenario 2 than in any other scenario, the more pragmatic interpretation points instead at the real-life implications for such a principle to hold true: a sustainable society is one which manages to use its institutional and cultural capacities to keep its capital means in check and "under control" by processes of social legitimation and reflective governance of science and technology (Stirling, 2009). How these processes can be carried forward in future is moot. The narratives presented in this study sought to provide a few interpretations. In any case, what seems clear is that the processes in question must occur if "production failure" is to be addressed and some form of sustainability attained.

Testing the model: the answer to the second research question

In our second research question we asked the following: *are there particular mechanisms and patterns that are likely to be relevant to a characterisation of long-run substitution possibilities?* This question was answered by the model as follows: there are 3 general, 36 particular substitution mechanisms which together form patterns that can be used to characterise long-run substitution in context-specific situations. To test these answers the following questions were posed: Did the 36 specific substitution mechanisms register occurrences in all scenarios? To what measure can it be claimed that the intended taxonomy of substitution mechanisms "covers" the reality of scenario storylines? Did they yield patterns?

The answer to the first question is that all scenarios exhibited correspondence and found an expression in all substitution mechanisms but four: Rn>Kp (in Scenario 1); Rn>Kh, Kp>Rn, (in Scenario 3); and Rn>Kh (in Scenario 4). We will explain in a moment what this means. **Figure 4.5a** seeks to provide a panoramic view of the correspondence and "coverage" achieved through the taxonomy put forward. Moreover it is at least apparent that the taxonomy in question is suitable to "translate" storylines into *substitution patterns* which in turn can be used to characterise long-run substitution possibilities in context-specific situations **(Figure 4.5b)**. If this is true then our methodology is able to perform "exactly what it says on the tin". The fact that the substitution mechanisms indicated above did not register any occurrence does not meant they are irrelevant to the model or irrelevant to describe reality, it only means improvements are possible in the making of the storylines themselves. It also suggests a reverse operation is possible and perhaps desirable: deriving scenarios of substitution by employing the substitution taxonomy as aid could greatly improve the quality of the storyline making process from its design and research stages down to its final delivery. It would ensure for instance that research is appropriately directed where is needed, that narratives follow a comprehensive set of issues, that the interplay between them is addressed with acceptable complexity and equity, and so on.

(a) All scenarios exhibit correspondence and find an expression in all substitution mechanisms except for four specific ones (red circles) This is not a serious problem.



(b) Substitution mechanisms can generate patterns

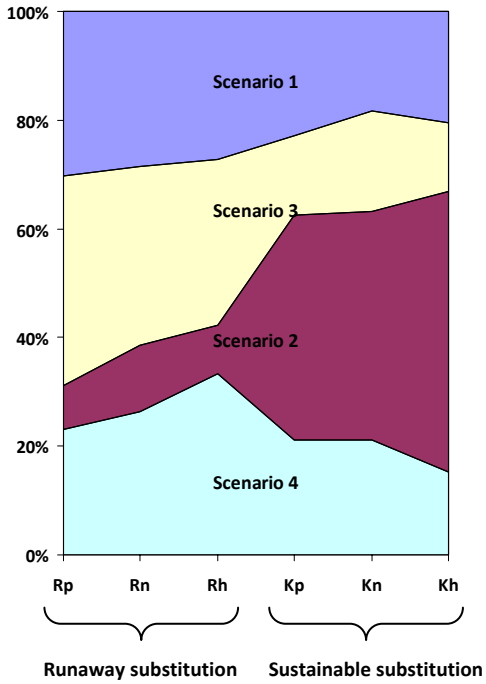


Figure 4.5 Composite. Testing the model: the answer to the second research question

Can it be falsified?

If the assumptions and terms of reference underpinning the model are proved to be systematically ineffectual (through "reproducible effects" refuting the model) then the model may be falsified (Popper, 2002 [1935])[101]. That is to say, the model is falsifiable if it can be proven that it is not compatible with every possible course of experience. In previous chapters we have argued against a number of unlikely instances where this might be the case, including:

- If the government decides for political reasons that the LED economy transition must be delayed beyond 2050.
- If the LED-economy-transition assumption is overridden by several commercially viable technological breakthroughs.
- If consumer preferences or other aspects of standard economic theory become irrelevant because of drastic unforeseen changes invalidating *ceteris paribus* conditions for sound economic analysis —in this case for the long run— as some analysts have suggested (Costanza 2000; Gowdy 2004; O'Neill, 2009; Pearce, Hamilton and Atkinson, 2001).

In addition, there are a number of shortcomings and clarifications that must be taken into account as part of a full evaluation.

Shortcomings and a few clarifications with regards to implementation

The proof of concept protocol in **Section 2.7** included the terms of reference underlying the model. After the previous analysis however, commenting on a few shortcomings and making a few clarifications regarding the implementation of the model is in order:

[101] "We say that a theory is falsified only if we have accepted basic statements which contradict it. This condition is necessary, but not sufficient; for we have seen that non-reproducible single occurrences are of no significance to science. Thus a few stray basic statements contradicting a theory will hardly induce us to reject it as falsified. We shall take it as falsified only if we discover a *reproducible effect* which refutes the theory. In other words, we only accept the falsification if a low-level empirical hypothesis which describes such an effect is proposed and corroborated. This kind of hypothesis may be called a *falsifying hypothesis*." (Popper, 2002, p.66)

(i) Given the time-bound nature of the scenario exercise, plausibility and comprehensiveness were prioritised over the development of detailed timelines. In the end scenarios were considered in terms of final outcomes in the year 2050 only.

(ii) Although it was not a key requirement for the proof of concept to be valid, collective work or a peer review process to make for more robust storylines was not possible under the conventional time and budgetary constraints of a PhD-level study. Notwithstanding the less than ideal circumstances, our first generation of scenarios showed that even a one-person exercise could deliver insights that could be engaging to readers or even perhaps attract some level of interest to the topic.

(iii) A difficulty arising during the making of our storylines was getting the balance right between two seemingly conflicting objectives: plausibility (complex enough) on the one hand, and scenario focus (simple enough) on the other, so as to delineate important factors. Our scenarios were meant to be dramatisations —hence simplified realities— of variables which in real life would translate into more complex, interdependent and correlated phenomena (as opposed to, say, orthogonal variable behaviour between the scenario axes). For instance, at the time of writing the storyline for Scenario 1, we saw seemingly inescapable correlations —and in fact causation effects— with some aspects defining Scenario 2. The way we grappled with this problem was by incorporating some of those effects into the reality of storylines themselves (e.g. incorporating the use of creative-commons technology into those scenarios where IP-driven innovation is said to be prevalent). The outcome seemed much more improved and engaging as a result.

(iv) More accurate translations of storylines into substitution mechanisms and patterns could have been possible. However, those are the class of refinements which collective work, say a scenario workshop or a scenario panel (Ogilvy, 2009) are meant to deliver more efficiently time-wise and more easily in every other respect.

(v) That substitution possibilities are analysed generally and with a strong bias towards the topical entry points is also true. Yet, an effort was made to extend the variety of topics covered by storylines by crossing them with the questions that gave structure to the scenario narratives, hence covering a wider range of issues, from the international and political dimensions of technological change and innovation down to institutional and cultural aspects influencing social norms and individual behaviour. Having said that, the 36 substitution mechanisms provided by the model uncover many new dimensions of substitutability in a systematic manner. This sort of added value is rare to find elsewhere in the relevant literature.

(vi) It proved to be difficult for the person carrying out the entire exercise, to disassociate the storyline making process from ensuing analyses. That is to say, although we did our best to minimise this problem, storylines might have been slightly biased towards substitution regimes which were expected to occur *ex ante* because of the variables involved in the first place. This shortcoming suggests that both tasks (storyline making on the one hand and analysis on the other) could be made easier and more effectively if performed not just collectively but by isolated groups of people not influencing one another. Maybe this perception is unfounded and the way we did was right , however this was our first impression immediately after doing the exercise.

(vii) Perhaps a devil's advocate would point at the fact that Scenario 1 was set up to have runaway capital substitution predominance right from the beginning. This, which is of course true, allows us to explain a less obvious dimension of the exercise: we were meant to explore those institutional arrangements and social conditionings which would be reasonably consistent with each scenario "version" of a sustainable society; in the aforementioned case this meant consistent with a scenario pathway of runaway capital substitution predominance; the relevant conditionings and institutional arrangements of such a scenario may not be receiving enough attention today but

that does not mean they will not in the future. So our job was to speculate reasonably. We speculated for instance that in a tough IP-driven society, perhaps many economic activities could only occur — perhaps after a governmental cost-benefit analysis of the situation— partly at the fringes of the formal economy, and yet, ironically indeed, some part of the supply chain of those activities would still be subsidised by government for political reasons (reasons of governance). Likewise, and to extend this picture a little further, we speculated about the existence of semi-regulated global networks of suppliers of all kinds of inputs, depending on the sector. We did this because we found early indication in our research pointing in that direction, for all three sectors. (e.g. interviewing farmers just outside Norwich, interviewing local car-making entrepreneurs). It was curious to watch a few months later The BBC TV series *Fake Britain,* recounting stories similar to ours though actually referring to present experience in various sectors of the economy. Whether such a phenomena might escalate in the future is moot, at any rate, the taxonomy of substitution put forward by the model was most useful to envision the possibilities.

(viii) We realise there might be valid objections with the "sustainability test to capital" contained by the model. The simplified test appeared reasonable because all tests are in fact interdependent elements of analysis. Each focuses on a particular aspect for the purposes of appraisal. That is to say, in reality all three tests are the same test: the issue-framing test focused on how problems are *defined*, the social-legitimacy test focused on how knowledge about problems and solutions is *legitimised*. The asset-valuation test focused meanwhile on how some problems *originate* in the first place; it looks at the congruence between pricing mechanisms and whether they allow for a level playing field between economy and the natural world to exist.

(ix) The "empirics" of substitution often emerged in the form of unexpected connections between elements which together had to make sense and be internally consistent in order to be robust (e.g. organic agriculture's adoption of

genetically modified plant varieties in Scenario 2). When scenarios are used to visualise possible interconnected developments in this way they are effectively enabling users to perform "complex operations" between numerous variables at once, something which has no equivalent in formal analysis. The enormous power of the scenario tool was not recognised fully by us until we were actually performing the exercise (both of writing up storylines and employing the model to translate them into the language of substitution).

(x) Our scenarios were useful to hypothesise how "economic person" individually and collectively innovates in the different sustainability scenario versions. In some storylines (particularly those of Scenario 2 and 3) access to sustainable capital inputs were shown to determine innovation rather than the other way around. The other way around is the prevalent view today in many organisational contexts: innovation is typically seen as dependent upon access to financial resources as well as intellectual property protection to incentivise and reward innovation (Hargreaves 2011). Some scenarios told different stories —hopefully useful stories— where these conditionings were potentially harmful to innovation. Visualising all these entwined properties together was the reason behind employing an appreciative approach to modelling long-run substitutability. The choice of scenario variables delivered enough complexity to imagine what was likely to occur in whole sectors of the economy. Yet variables also set for us enough limits to allow for a much more simplified storyline making process. Thanks to simplification, it became easier to come up with dramatised versions of what could have been perhaps less focused and less communicable outcomes.

(xi) As pointed out earlier in the thesis, it is understood that the use of an "appreciative" model instead of a formal one meant that capturing such things as "marginal" willingness to pay values, discounting the future and the like were far beyond the purpose of the model and the use of scenarios.

4.3 Lessons learnt: a discussion

Out of the experience gained from looking at long-run substitution possibilities contextually and via future scenarios, a few lessons (20) were drawn for discussion, at least in preliminary form. Whilst some are methodological in nature, others reflect upon different aspects of the state of research on the topic and how the model's potential contribution fits in.

"[if] you want a description of our age, here is one: the civilization of means without ends."
Richard Livingstone[102]

Lesson 1.- Long-run substitution possibilities are interdependent in ways that can only be understood contextually. Future scenarios, if done consistently, can provide the context from which to understand these interdependencies. Like other assumptions fulfilling a role in economic theory, the "perfect substitutability" assumption used in sustainability analysis is meant to be a useful caricature of reality.

> "All theory depends on assumptions which are not quite true. That is what makes it theory. The art of successful theorizing is to make the inevitable simplifying assumptions in such a way that the final results are not very sensitive. A "crucial" assumption is one on which the conclusions do depend sensitively, and it is important that crucial assumptions be reasonably realistic. When the results of a theory seem to flow specifically from a special crucial assumption, then if the assumption is dubious, the results are suspect". (Solow, 1956, p.65)

The contextualisation of caricature-style assumptions via future scenarios seems to allow for more nuanced and plausible stories about long-run substitution possibilities than is possible via formal approaches. Economics is a context-dependent social science. Things such as money, property or economic behaviour are taken as given and economics seeks to understand the "laws" that regulate these phenomena in so far as they are

[102] Cited by Flyvbjerg (2001)

socially defined concepts (Flyvbjerg, 2001). In the model, substitution possibilities are warranted through scenario consistency. That is to say, to the extent that scenarios are plausible and consistent, substitution possibilities are plausible and consistent too (even though substitutability is assumed away as "perfect")[103]. Far from implying a belief in nature being wholly substitutable, operating our model in this way follows the principle that first approximations are an essential and well-accepted method in science (Costanza 1998).

> "It is a well-accepted method in science to make initial first approximations to complex problems and allow the results to determine whether it is worth investing the effort to do more elaborate studies" (Costanza 1998, p.68)

Moreover, without a first approximation, refining the model as we did would not be possible (see **Figure 4.4**). Although the model assumes substitution to be consistent with "very weak" and "weak" sustainability (Turner, 1993), it is nonetheless subject to practical limits imposed by the plausibility and internal consistency of scenario storylines themselves. To the extent that storylines are consistent, assumptions are meant to fulfil their role whilst encountering their "true" limits within the scenario itself.

Lesson 2.- The study of long-run substitution possibilities is the study of how society's relative valuations of man-made and natural capital might change over time. It is also the study of the evolution of human goals and institutional change. To look at substitution in terms of how much environment can be safely "used up" or "run down", overlooks the fact that human society has a tendency to value the natural world *relatively* rather than *absolutely* (i.e. in absolute terms). Substitution of certain forms of capital for others takes place accordingly. This said, relative valuations are also relative to

[103] Therefore, for the purpose of modelling things that have priority in our analysis (e.g. institutional arrangements, sustainability conditions) it is sensible to get the substitution variable "out of the way" , by assuming its possibilities as "smooth" (Turner, 1993) "large" (Pezzey and Toman, 2005) or "perfect" (Solow, 1974). These are parameters in formal modelling which are more nuanced when used in an appreciative model employing scenarios.

goals (Costanza, 1998) which is perhaps one of the important contributions of the ecological economics literature to the debate on substitution.

> "One cannot state a value without stating the goal being served. Conventional economic value is based on the goal of individual utility maximization. But other goals, and these other values, are possible. For example, if the goal is sustainability, one should assess value based on the contribution to achieving that goal — in addition to the value based on the goals of individual utility maximization, social equity or other goals that may be deemed important. This broadening is particularly important if the goals are potentially in conflict. Ecological economics is built on the three integrated goals of sustainable scale, social fairness and economic efficiency. Ultimately, valuation has to address all three of these goals." (Costanza et al. 1998, p.69)

It is apparent that from the viewpoint of our model much can be done towards understanding substitution possibilities by paying more attention to institutional arrangements and human goals than to natural threshold limits. Contextualising long-run substitution possibilities in the way we did in this study can lead us to wonder whether context-independent approaches are not taking the substitutability assumption perhaps a little too far. For instance, not having agreed parameters of what "plausible" means in certain contexts has enabled many theorists to argue things such as the following:

- That "relative" (Pearce, 1993) or even "absolute" (OECD, 2001) "decoupling" of environmental impacts from economic activity is possible[104];
- that a "knowledge economy" is sustainable (Romer, 2008);
- that sustainability is "feasible unless proven otherwise" (related by Stern D., 2004, p.40).

We do not suggest that these type of arguments lack logical consistency. Rather, we get the impression that —implicitly or

[104] According to the OECD special report on the issue[104], the term decoupling refers to, '[…] breaking the link between environmental bads and economic goods. Decoupling environmental pressures from economic growth is one of the main objectives of the OECD environmental strategy for the first decade of the 21st Century, adopted by OECD Environment Ministers in 2001'. (OECD 2001 p.1)

explicitly— the formal framework they employ seems to rely on taking the substitutability assumption far beyond genuine plausibility. For instance, OECD's report cited above, mentions in its caveats section that "the international dimension of decoupling is not taken into account" (OECD, 2001, p.3). As if such an omission was not self-defeating of the whole rationale for decoupling. In contrast, most future scenarios, almost by convention, take international dimensions quite seriously.
Our analysis also suggest that many natural scientists and ecological economists in particular, may have taken the perfect substitutability assumption even more seriously than economic theorists have. They debate biophysical, "material-balance" or thermodynamic limits to substitution whilst taking the perfect substitutability assumption out of the economics context where it has a meaning. Their critique in reality seems to be about the relevance of economics and about its perceived and *de facto* role to inform policy. Some economists themselves recognise that economics is being asked things it may not be able to provide (Neumayer and Dietz, 2009; Common, 1995; Norgaard, 1990). At any rate, it appears that by assigning so much value to the limits-imposed-by-nature approach other facets of the substitution problem —notably institutional arrangements and social change— have been kept in the dark or underexplored.

When we look at long-run substitutability contextually, the salient message seems to be that substitution possibilities need to be seen more in terms of institutional change than in terms of nature and its limits. In other words, in a hypothetical sustainable society, the limits to substitution are those imposed to society, for society and by society, even if the environment is considered only in terms of revealed preferences and not in terms of non-economic indicators such as carrying capacities and other measures of stress and shock to underlying natural resource systems (Pearce, 1993). Hence, while extended interpretations of the "perfect substitutability" assumption are useful parts of a debate, our model suggests they could be distracting too much attention from the potential usefulness of models, that seek to contextualise the social sustainability conditions and institutional arrangements that are consistent

with "perfect" substitution possibilities. In our case four scenarios were designed to provide four different versions of sustainability. Which versions, under what conditions, favour substitution possibilities the most? This is the sort of question our model sought to provide an answer to.

Lesson 3.- In a hypothetical "sustainable-society" model substitution possibilities are a normative and strategic issue rather than just an "empirical" one. Some authors have regarded substitution possibilities as an "empirical issue" (Castle, 1997; Pearce, 1997). Whilst this rings true, from the logic of our sustainable society model —and from that of most neoclassical growth models too (Solow, 1974, Stiglitz, 1974, Dasgupta and Heal, 1974)— it can also mislead us into thinking that substitution "possibilities" are the result of society's *reactive* rather than *active* calculated choices. That is to say, once sustainable development is assumed as feasible the question is no longer what substitution possibilities are available in the long run. Rather, the question becomes this: out of those that are likely to be available, which ones will also be consistent with the processes, values and goals of a sustainable society? Our scenario template sought to represent this key ambivalence in society in its vertical axis, whereby the nature of response towards an energy transition configured different versions of sustainability and substitution possibilities. This leads us rather smoothly into a complementary lesson.

Lesson 4.- Long-run substitutability is not only about society doing things "just because it can". It is also about society and individuals deciding who they want to be. In a sustainable society model substitution possibilities are about people having a say in the redefinition of their own identity and choices with regards to the sort of future they want for themselves and for those around them. This might mean choosing, individually or collectively, not to go ahead with certain things even if they are "possible". It might be *possible* for a society to substitute microchip implants for banknotes but it may not be consistent with people's tastes or worldviews. It might be possible in the future to bring a cure for HIV out to market but it might not be

as profitable as today's palliative alternatives. The "runaway capital" concept is for this reason a relevant one to the model. Our sustainable-society model suggests substitutability is an area of decision where people can choose their own character, identity, values and goals by learning when to make many "impossible" things possible and when not to do certain things even if they are possible. Unlike more lineal ways of conceiving an enquiry about these matters, in the context of scenario based analysis, substitutability resembles a *vector*; with a certain normative direction that results from the interplay of many forces and actors operating across different capital domains (e.g. physical, intellectual, natural). This was made apparent in all scenario storylines. This analogy resembles Stirling's notion of innovation as a vector:

> "Innovation is a vector, rather than just a scalar quantity. It includes the crucial but neglected normative property of direction. Accordingly, the form and orientation taken by science and technology are no longer seen as inevitable, unitary, and awaiting discovery in Nature. Instead, they are increasingly recognized to be open to individual creativity, collective ingenuity, economic priorities, cultural values, institutional interests, stakeholder negotiation, and the exercise of power." (Stirling 2008, p.263).

The analytical usefulness of the perfect substitutability assumption appears to be more meaningful and nuanced when future scenarios are employed to contextualise what the limits to substitution possibilities might be as a result interactions which for the most part remain invisible in formal approaches.

Lesson 5.- Once sustainability is assumed as feasible, the idea of capital needs a conceptual adjustment so that it is consistent with our sustainable-society model. The "runaway capital" category (which addresses an old problem in economics) is pivotal to investigate the meaning of capital in a sustainable society. Once we assume sustainable development as feasible we engage in some sort of intellectual or theoretical "commitment" to find out what it is that counts as "sustainable capital". That is to say, capital that is consistent with the a sustainable society model. In our model, a

sustainable society requires that institutional arrangements and institutions themselves (including markets and government) keep capital "under control" (i.e. "sustainable capital"). The category of "runaway capital" introduced in our model recasts an old abstract problem in economics into a practical one today effectively becoming "old wine in new bottles" (the new bottle being a transition to sustainable development). The runaway capital notion sought to convey the idea that some forms of capital yield services which fail to produce sustainable wellbeing. Runaway capital leads to some form of "production failure" and to people's apparent inadequacy to freely express their preferences. These are issues which presumably need to be addressed analytically when discussing long-run substitutable consumer preferences. The modern drama of obesity epidemics illustrates the point rather clearly: while people do not prefer to be obese, they have no choice but to live in, adapt to, and —by omission— "prefer" the food, the jobs, the places, and lifestyles of obesogenic environments (Foresight, 2007). A similar idea to that of "runaway capital" leading to some sort of "production failure" in the economy is not a new one economic theory:

> "While man may not on the surface be aware of any destructive effects of environmental deterioration, because his tastes adjust themselves, chronic physical and mental health problems are often the end result. If true, the implication of this for economic theory is that consumer's choices at any moment of time cannot be taken as an expression of his best interest as he would see it if he knew what was happening to him. The difficulties this presents for economic welfare theory are serious. Perhaps an even deeper question […] is as follows: what if man adapts to what we would, from our present perspective, view as a badly deteriorated environment but with no manifestly harmful mental or physical effects —indeed let us say he is very happy? This is what we might term the 1984 question. We might visualise, man living at very high densities, sealed off from any natural environment (because it is toxic), benignly stoned on much improved psychedelic drugs, resting on his effortless exerciser. Is there anything in a relativistic view of preferences which would provide grounds for judging such a state to be unwholesome? The answer appears to be no — but we shiver at the thought." (Herfindahl and Kneese, 1972, p.393)

Although not a new concern in economic theory, not many solutions have been put forward to address the human-adaptation or what we call the "production failure" problem. Partly this is because "trying to introduce taste-formation into the corpus of economic theory would present [economists] with complexities as yet unmeasured (op. cit. p.391). Collective and institutional intervention to improve the conditions under which individuals make choices (Pearce and Turner, 1990) is the condition *sine qua non* before sustainability is seen as the outcome of people's preferences and of fully internalised externalities (Van den Berg, 2010). There are many unwanted "services" yielded by "runaway capital" for which there is neither a market, nor a green tax scheme, nor a standard measure of, say, permissible "parts per million". In other words, it needs to be handled in a special way. Being an exploratory concept one thing that can be safely said about "runaway capital" is that it is meant to account for things which far from yielding "services" people prefer, it yields services that "escape" those legitimation processes that a sustainable society would demand, originating a sort of "production failure" into the economy.

Lesson 6.- Having an idea of what "sustainable capital" means makes it easier to define what "sustainable forms of substitution" are in our hypothetical "sustainable society" model. Once we have a systematised means to indicate what "sustainable capital" is in our hypothetical sustainable society model, it is easier to differentiate those substitution possibilities that are consistent with sustainability (e.g. K>R) from those which are not (e.g. R>K). "Sustainable capital" and "sustainable substitution" are both made possible by the existence of institutional arrangements that improve the conditions upon which individuals make choices in a sustainable society. These institutional arrangements can take many unexpected forms as they might also overlap and alter one another's course. The sustainability test to capital in **Section 2.5** suggested these institutional arrangements would (hypothetically) include at least three components or "tests" society would perform: *issue framing, asset valuation* and *social legitimacy* tests. To speculate

about the possibilities and dynamics of institutional arrangements is one of the reasons why the scenario appraisal of substitution possibilities is a good idea.

Lesson 7.- Once we have means to understand what "sustainable substitution" is in a sustainable society, it is easier to investigate, what the differences between "productive investment" and "wasteful consumption" might be. These issue has not been sufficiently addressed in formal economic analyses (see Solow, 1991; Pearce and CSERGE, 1993). Scenarios help us differentiate the things that are more of an investment (as a function of other variables in the "scenario system") from those that may turn out to be "wasteful consumption". Things look different when, for instance, the international dimension of substitution possibilities is included. Something the neoclassical sustainability literature generally ignores (Stern 1995)

Lesson 8.- Ignoring the international dimensions of the sustainability problem might be one of the reasons why input substitution in production has received more attention in the literature than substitution in consumption (Stern, 1997)**.** Since international trade affects material consumption more visibly than inputs to production in "knowledge-based economies, this has made it easier to ignore the international dimensions of substitutability.

Lesson 9. - System-wide effects can only be appraised through non-monetised interactions which are typically made visible in scenario analysis. Our model is a good example of that. It is possible that many economic theorists today, share with many "practical people" (Solow, 1997, p.70) the constant risk of paying inadequate attention to many interconnections that did not matter to them in the 1950's —or even in the 1990's— but that seem to matter today and are likely to matter even more in the future. Willingness to pay surveys for instance, are meant to capture individuals relative monetised valuations "at the margin" (Bateman, 1999). Insofar as it is meant to capture individual perceptions of an interconnected reality of choices

(Herfindahl and Kneese, 1974) economic analysis can be regarded as "holistic". Nonetheless, formal economic analysis does not seem to capture the system-wide effects of a society in transition; something which has worried institutional economists for a long time (Hamilton, 1919) and which worry the technological transitions research community today (Geels, 2005; Elzen et al., 2004; Smith et al. 2005; Shove, 2007).

Lesson 10.- A good alternative to a model that is too difficult to make formally is its "appreciative version". Moreover, in our case, an "appreciative" version was not only the feasible option but arguably the best. Economists such as Robert Solow used to introduce their formal models with "appreciative" versions that most people could understand. Our attempt to produce the "appreciative version" of a formal model of long-run substitutability that does not exist, had the double purpose of making things possible in the process of making them understandable. Our model sought to simulate what the appreciative version of the model would look like if there was a formal one. After careful consideration of a diversity of positions in the literature, we opted for a heuristic or "appreciative" approach (Nelson and Winter, 1982) to modelling substitutability. Ours was a model where a future scenario set was employed to simulate various hypothetical ways in which society could be transformed by the dynamics of substitution whilst a variety actors played out their preferred versions of a sustainability transition. Looking at substitution in the context of a few scenario alternatives seemed like a fruitful way to appraise its possibilities. Given its multiple dependencies (places, people, technology, geography) it is hard to see how formal modelling would have gone about tackling the same problem. This suggests that, in future, one potential obstacle for this line of research will be the many reasons people have for not working together. Whilst good scenarios are best done collectively, formal modelling may be the more individualistic alternative.

Lesson 11.- The model made the topic of analysis easier to grasp. This is not a minor advantage. At present there exists enormous misunderstanding about the true meaning of substitution and about how it relates to sustainability policy. The idea of "translating" a formal economic model, into an "appreciative" schematic version (Nelson and Winter, 1982) potentially makes economic messages easier to understand and discuss with non-economists. In the context of sustainability discussions, this has enormous value, not least because economic models need to be made compatible with social dialogue (Costanza, 2000), with social appraisal (Stirling, 2009) and other group-learning and decision-making activities. In our case, a scenario workshop involving various participants would no doubt have strengthened the outcome (Ogilvy, 2009). However, in terms of learning and appreciating with some level of depth the economic side of the problem, ours has been a small but highly beneficial task.

Lesson 12.- The model made formal assumptions transparent and expectations about their role more realistic. In doing so, the model seemed to vindicate the role of theory. All the mystery and misunderstanding around the "perfect substitutability" assumption in formal growth models (Pearce 2006) appears to dissolve when future scenarios are used to contextualise and make transparent how the assumptions work and what they mean within the model. For example, Pearce and colleagues (1991) note how the elementary point that capital is substituted either explicitly or implicitly has escaped most of the critics of environmental asset valuation. This relates to what was said earlier: at issue are the sustainability scenario conditions under which substitutability can be highest . Being able to assume sustainable development as feasible because large substitution possibilities have also been assumed as feasible (Pezzey and Toman, 2005)[105] can be a valid method to

[105] "Economic analyses of sustainability generally start from a premise that natural and other forms of capital are adequately substitutable for each other to make nondecreasing wellbeing over time achievable. In other words, broadly speaking, sustainability is held to be feasible, though it is by no means guaranteed by the operation of unfettered markets, or of policies that focus only on internalization of current environmental spillovers." (Pezzey and Toman, p.130)

understand the conditions and institutional arrangements surrounding both assumptions[106]. In doing so, however, it is important not to fall into a common trap in formal models. Stern has described such a trap as the "tendency among mainstream economists to assume that sustainability is technically feasible unless proven otherwise" (Stern, 2011, p.29). This said, a further lesson can be drawn: much of the existing "mystery", misunderstanding and discrepancy in the ecological economics literature around the perfect substitutability assumption tends to dissolve under the nuanced context offered by a scenario set. Pearce (2006) clearly saw the need to dissolve such a mystery when he noted that:

> "[Substitutability] has generated much misunderstanding. […] No one suggests that one can dispense with all environmental assets […] In economics jargon, substitution is always "at the margin". It is never about removing assets wholesale." (Pearce, 2006, p.203).

In practice, substitution possibilities are feasible up to a certain point only. For instance "no one has yet found a way of (feasibly) recreating the ozone layer" (Pearce, Markandya and Barbier, 1989, p.37). However, that has never been the claim nor the purpose of assumptions about substitution. Assuming perfect substitutability was originally a thought experiment: what would need to happen elsewhere in the system in order to assume substitution possibilities as perfect or unitary?

> "The "constant" capital rule is consistent with removing the Amazon forest so long as the proceeds from this activity are reinvested to build up some other form of capital. The constant capital rule requires that environmental assets be *valued* in the same way as man-made assets, otherwise we cannot know if we are on a "sustainable development path". We cannot know if overall capital is constant in the Amazon deforestation case unless we know the value of the services and functions that we surrender when it is lost. To put it another way: valuation is

[106] In any case and in real life sustainability still depends on variables such as population growth and the international dimension of the global environment, which formal economic models typically assume away (Stern D. 1995). Scenarios however, may still bring in some of these variables for analysis.

> essential if we are to trade off forms of capital. This is the relevance of valuation; nor is there any escape from it. We " trade off" either explicitly or implicitly, since all decisions imply valuations […] This elementary point appears to have escaped most of the critics of valuation." (Pearce et al. 1991, p.2. Last sentence is the author's footnote, p.10).

Lesson 13.- The model carries the potential to address the problem of how relative valuation changes might affect long-run substitutability options "in practice". At a PhD-level, this study demonstrated such a point modestly but significantly (or at least to warrant further research). Difficult issues in formal modelling such as evolving relative prices and the valuation of nature can be processed by scenarios. It was mentioned in the introduction that two major obstacles to model long-run substitution possibilities are the difficulties posed by the valuation of nature that is necessary to justify substitutability (Pearce et al. 1991) as well as the difficulty to determine sustainability relevant prices, or "sustainability relevant value" (Stern D. 1995, p.13; Pezzey and Toman; 2005, p.132; Sterner and Hoel; 2007; Stern N.2009).

Our model, which allows us to simulate and test against one another future events and decisions across a wide variety of stakeholders, seems particularly appropriate to address the problems of how relative prices and valuation changes will transform substitutability. It also seems useful to understand the extent to which valuing nature can warrant substitutability in practice, that is to say, at a time of transition when many small incremental changes are likely to bring about a whole transformation of society. A formal model would hardly help us visualise the existence these issues even imperfectly as our model does. The uncertainty of relative prices seems particularly acute when one considers that the whole economy runs on the same hydrocarbons society is trying to phase out. Such contingency makes it hard to understand how the transition itself will play out in the end, politically, culturally, technologically and across national borders.

Lesson 14.- Market failure correction would not warrant long-run substitutability according to theory and to our model. This is for at least two reasons:

(i) Equity and distribution would not be necessarily addressed. Although correcting externalities may lead to allocation efficiency over time, such correction may still be incompatible with the equity and distributional dimension of sustainable development (Common, 2011; Common and Perrings, 1992). Scenarios 1 and 3 exhibit versions of this particular problem as it would manifest in reality. Societies in these scenarios are divided economically and cultural values are polarised.

(ii) What our model seems to suggest, particularly in Scenario 2 (the most "sustainable" of all) is the following: if it is true that the category of "runaway capital" captures unintended aspects of substitutability, then our hypothetical sustainable society of the future understands "market failure" alongside "production failure" and learns to act upon both to correct them. Sustainable development implies a social and cultural transformation so significant that it will hardly be achieved through efficient markets alone. It requires "production failure" to be "corrected" too.

> "The notion of a "sustainable" society is radical. Sustainable development confronts modern society at the heart of its purpose, because the human race is, and always has been a colonising species without an intellectual or institutional capacity for equilibrium (O'Riordan, 1993). Existing patterns of production, distribution and consumption thrive on creating environmental externalities in the form of pollution, habitat loss and ubiquitous waste disposal. Yet, it must be said that the present society is supported by a democracy that is led to believe that its best interests are served by minor adjustments to the status quo. This is buttressed by a general feeling of satisfaction amongst Western society's "Contented Majority" — the economically dominant sections of society—with this state of affairs (Gailbraith, 1992)." (Jordan and O'Riordan, 1993, p.184)

Understanding substitution possibilities in the long run may require that we complement the internalisation of externalities agenda with an enquiry about the problems that arise from "production failure". **Figure 4.6** attempts to visualise their

similarities, their radical differences and complementarity at once. This seems relevant even if preference formation in welfare economic modelling is conventionally seen as exogenously given, effectively "foreclosing economists from inquiring into the normative basis of the utility functions which they assume all consumers to have" (Herfindahl and Kneese, 1974, p.391).

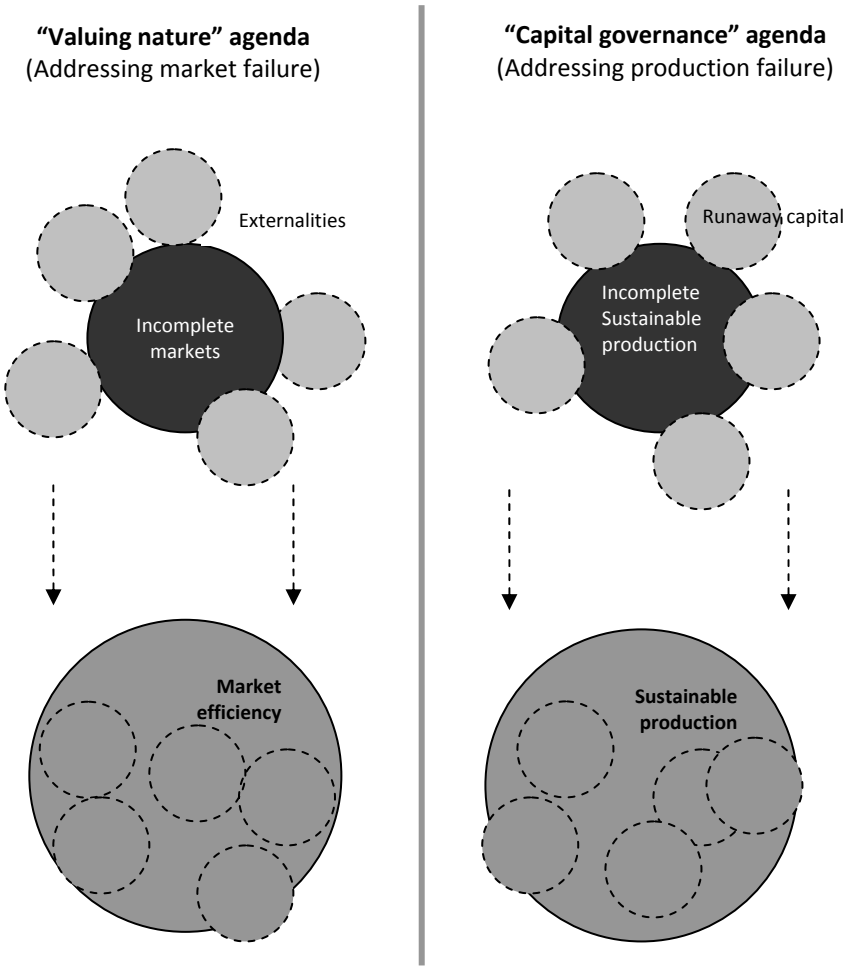


Figure 4.6 Two agendas: "valuing nature" and "capital governance"

To the extent that the category of runaway capital has been useful to address the problem of "adaptation" it might also be worth investigating more in depth what the notion of "production failure" might entail.

Lesson 15.- The LED transition[107] represents one of the most important "institutional arrangements" to come out of the model. Such transition, unlike the HED transition[108] during the 18th and 19th centuries, will have to be engineered by society (Cleveland, 2008; Smil, 2010). Under the lessons outlined so far the Hartwick-Solow rule acquires a more operative meaning to that assigned conventionally. This was made apparent throughout the scenario storylines. The Hartwick-Solow rule seems to make more sense when understood in the context of a LED transition where events shape the circumstances under which individuals and institutions make LED-related investment decisions. The appreciative model tested for this study allowed us to make more practical sense of weak sustainability assumptions. It can be deduced from the analysis carried out by some authors (Stern D. 2011; Stern N, 2009; Sterner and Persson; 2007; Mäler, 2007; Turner et al. 1996), that implementing the Hartwick-Solow rule of non-declining welfare overtime, though a very good idea, it is also a very difficult one to pin down and put in practice, amongst other things because it is hard to anticipate what the relative prices will be in the long run as the low-carbon growth society (Stern N. 2006) is transformed by uncertainty.

> "It is difficult to apply [the Hartwick-Solow rule] in practice, as the rents and capital must be valued at sustainability compatible prices, that is, the prices that would emerge if the sustainability constraint were imposed. In a practical sense, such prices are unknowable given that we have poor understanding of even the costs of current environmental damage and resource depletion or of the future development of the economy." (Stern D. 2011, p.30).

Lesson 16.- The LED transition seems to have important implications for the socio-technical transitions literature. The influential multi-level perspective model (MLP) (Geels, 2005) fails to capture the LED transition altogether.

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[107] Low-energy-density carrier transition (see **Section 1.1**)

[108] High-energy-density carrier transition (op. cit.)

The multi-level perspective model (Geels, 2005) which is frequently construed as the central model in the technological transitions literature (Shove, 2010), apparently fails to accommodate the system-wide effects of a shift from high to low energy density carriers implied (though not always made sufficiently explicit) by a transition to low-carbon economies. The MLP model draws on historical case studies typically reflecting society's high-energy-density-carrier consolidation period with higher entropy and productivity, viz., the transition from horse-drawn carriages to automobiles in America (1860-1930), from sailing ships to steamships (1780-1890), and from piston engine aircraft to jetliners (1930-1973), see **Figure 4.7.**

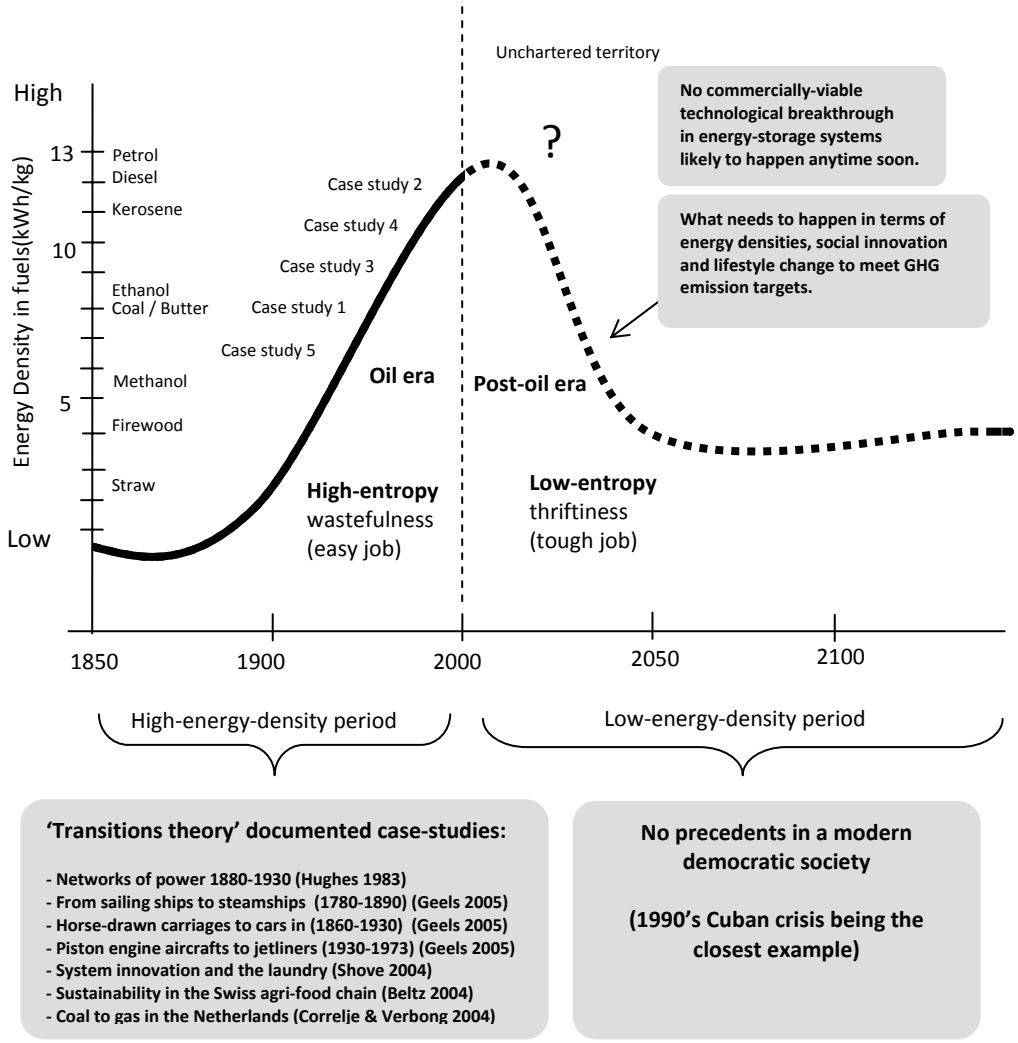

Figure 4.7, The high-energy-density (HED) to low-energy-density (LED) carrier transition The figure is meant to be descriptive rather than analytical.

Holding constant (or simply ignoring) the energy-density variable, allows the MLP model to characterise the comparatively benign conditions of societies which, riding the *upside* of the energy-density curve, did not have any historical concern for sustainability. Such a methodological blessing seems to result in considerable costs to the explanatory value of the MLP model at a time when understanding the *down slope* of the energy-density curve presents itself as a manifestly imperative and urgent requirement in policy decisions and social dialogue.

Lesson 17.- China matters, and so does the international dimension of long-run substitution possibilities. Our model sought to capture both. Apparently, formal descriptions make it easier to overlook such influences. This might be because context-independent formal analyses remains largely unchallenged from within its own discipline. Our model sought to correct that deficit by offering formal economic analysis an "appreciative" version of its own endeavours to understand substitution possibilities. Beyond the "sustainability test to capital", there are international dimensions of the substitution problem which can be readdressed by the following question. How would certain types of substitution "not be sustainable" over time according to our scenarios? To put it another way, in what way would scenarios tell us about the sustainability or unsustainability of certain types of substitution, such as, say, those made possible by carbon trading, or financial services? While answering such questions may require more sophisticated interpretations of scenario storylines and indeed more sophisticated storylines, it is possible to suggest a few entry points from which some answers can be derived:
(i) At the moment, most people in government, business, and even the voluntary sector seem to be talking about the low-carbon economy, low-carbon technologies and low-carbon industries and markets. However, the more serious public discussion about low-energy density carriers implied by that transition has not been publicised or made fashionable yet. There is no doubt, we have reasons to think, that this shortcoming is at the moment obscuring our judgement about

objective possibilities of analysis for the low carbon transition, let alone long-run substitutability. This point has been discussed mostly by physicists and other natural scientists such as Smil (2006; 2010) MacKay (2009) and Cleveland, (2008). Yet, it remains relatively in the dark. As mentioned earlier, entire research communities committed to deliver insights about technological transitions remain abstracted from the LED transition. Hopefully not for long.

(ii) Institutions in general, as well as individual entrepreneurs refer constantly to intellectual property rights and the "creative economy" (DCMS, 2008) but only very few analysts (Fergusson, 2010, Hines and Lucas 2006) seem to be talking about what is likely to happen to employment, income, and IP rights themselves in the knowledge intensive industries when China and India begin to compete not only with cheap labour but also with green high tech in all areas of industry, from aerospace down to nanomaterials and genetic engineering.

(iii) Many analysts refer to such things as green industries, carbon markets, and "low-carbon growth" (Stern N. 2009, p.191) but serious discussions about the sustainability of the balance of trade, fiscal debt, tax revenue and the like when the economy hits the lowest limits on access to high energy density carriers to run the whole economy have not even begun. Does "low carbon growth" (op. cit.) means "low growth" too? These are the type of unpopular questions that will require more courage from society to address in the foreseeable future if unpleasant emergency measures are to be avoided.

Lesson 18.- Provided some refinements are made, all the necessary features seem to be in place for the model to pass a "reality test". Such a test must be able to "indicate the human welfare consequences of alternatives relative to existing policy and management options (status quo)" (Pearce and Barbier 2000, p.236). The evaluation of the different policy options may in turn depend, where possible, on valuation; that is the quantification of the specific welfare impacts —or costs and benefits— of each policy option to facilitate comparison by decision makers. Where quantification of welfare impacts is not possible, then policy evaluation may be qualitative, which in

itself presents no problem as long as the overall objective is the same: employing the results [of analysis] to inform policy makers of the various welfare consequences of alternative policy options relative to existing policy (op. cit.)

Lesson 19.- Long-run substitutability is a function of individual preferences which are by definition relative (as opposed to absolute) forms of valuation. Notwithstanding, a large literature on substitution has been developed for decades by natural scientists and other non-economists who appear to have an incomplete understanding of what this piece of information means within the economic scientific method and for the problem they are trying to analyse. Clearly more communication is required in all directions. The model may contribute significantly to facilitate some communication. The words *substitut-ability* and *sustain-ability* are not only close to being homonyms; they both attract multidisciplinary interest, hope for the future and untold, often unnecessary, confusion. Had Professor Heisenberg been as interested in substitutability as he was in elementary particles, the chances are he would have referred to the possibility of its scientific appraisal as a function of *who asks the question*, *for what purpose* and whether the answer will be seen "as a wave or as a particle" so to speak. What he probably would not know is that substitutability is all about *people's preferences*. It is a telling fact that, out of all the references listed at the end of this thesis, only one was altruistic enough to remind readers —in a footnote— that substitutability between man-made and natural capital boils down to "society's relative valuations of the two" (Pearce, Markandya and Barbier, 1989, p.50). It would be interesting to find out what proportion of those habitual readers of the journal *Ecological Economics* are actually aware of this unspoken gem in the economics repertoire of unspoken rules and axioms. And what about environmental economics journals? Can we rest assured unspoken principles have not led to some misunderstanding amongst economists themselves? Why do environmental economists contributing to the literature on substitution do not clear out elementary questions more often,

so as to stop the same confusion they sometimes complain about?

> "Who does ecological economics?. Given that many contributors to the journal, Ecological Economics, have no background in economics, and that many of these argue that ecological economics offers nothing less than a new paradigm, most economists have been persuaded that they need to know no more." (Turner, Perrings and Folke, 1996, p.1)

The foregoing suggests, there is some work to be done toward improving the "consilience" between those who have become united by sustainability analysis yet separated by deficient forms of communicating basic terms of reference between the sciences (Wilson, 1998).

Lesson 20.- Economics, like other sciences, appears to be facing a communication dilemma. Economists often behave *as if* they were faced with the following dilemma: in conveying economic messages to non-economists too much clarity may provide non-economists with ammunition to argue against them. If, on the other hand, economists convey their ideas poorly similar results are obtained: they get reprimands for being obscure. This seems to explain why most economists are neither good nor bad but *ambiguous* communicators.

> "Economic valuation is controversial largely because its purpose has not been clearly conveyed to non-economists" (Pearce, 1993, p.93)

Clearly, the study of economic problems starts with the study of economists themselves and with the way they think and communicate. To unravel the sort of scientific questions not covered in textbooks one has to read persistently and wait for an accident to happen every two or three weeks in the form of a lucid paragraph, which by then looks more like cheap hallucination than clear thinking. That is to say, to pretend that one can go and look up for specific answers —like one does in say, biology or history— sometimes works, but the economics literature rarely lends itself to such rare events. Instead, one must get familiar with a few authors that rank high on spelling

things out, read on between lines and wait a few days for answers to come about. Books and articles from up until the 1970s are often the most unrestrained and clear in exposition[109]. Some of them are even fun to read. With some honourable exceptions, much of that flavour has been lost nowadays making economics texts unnecessarily arid and spiritless. This is, however a problem present in most sciences nowadays. The independent scientist James Lovelock often complains about how in the name of rigour much of the flavour that is necessary in science is ruined. In times when many non-economists find themselves needing to understand some economics such a trend is somewhat disheartening. This suggests it might be time for economics and all other sciences, to open up to social appraisal (Stirling, 2008) as a means to reinvigorate its activities. Or as economists Herfindahl and Kneese suggested decades ago:

> "[I]t is hoped that economists and other scientists will be moved to build on the theory, to extend it, to improve it, and to make it an even more useful tool that it is now for decision making in the interest of society". (Herfindahl and Kneese, 1974, p.397)

4.4 Conclusion

Ecological economists have long questioned individual preferences for not being relevant to sustainability analysis in a number of ways (Norton, 1995; Gowdy et al. 1999). Some suggest that much can be accounted for through lexicographic preference ordering (Ayres et al. 1999). The answer to these arguments from a neoclassical perspective is not to question the usefulness of substitutable preferences, but to investigate how information and conditions upon which people express their preferences can be improved (Pearce and Turner, 1990, Pearce 1996). This is the basic idea our study builds upon. In our model consumer preferences remain analytically relevant provided some simple additions are made to our understanding of capital. This is important at a time when the preference-

[109] That is, those predating the advent of the "risk" society (Giddens, 1990) and all its fears.

satisfaction theory of wellbeing in welfare economics has been questioned for a number of years by sociologists, ecological economists and many natural scientists (O'Neill 2009). Although the model presented here features a few additions to the standard view of the problem of substitutability the most important without doubt is the "runaway capital" category. If it is true that people cannot express their preferences about runaway capital, then maybe the alternative is not to try to fix every market failure but to widen the sphere of things that are not for formal economic models to resolve and which ultimately belong to the sphere of unintended dimensions of sustainability (Common, 1995). The proof of concept contained in this study suggests an intermediate form of analysis is possible. Such a form of analysis is crystallised in a stylised model of long run substitutability which has gone through some first refinements already. As it stands, the model provides the double possibility of harmonising economic analysis with social appraisal. Moreover it offers such a possibility whilst addressing what seems to be a pressing issue within the whole sustainable development debate: economics, like other social and natural sciences needs to open up in such a way that neither science is compromised nor social actors exclude themselves by contributing with what economists see as nonsense. Our model is hopefully a significant attempt towards bridging the nonsense gap.

There was a time before Adam Smith when economics went through a long pre-scientific period where no lessons were systematically recorded and therefore economics did not evolve much (Stigler, 1987). Our times present us with unprecedented challenges in all areas of scientific enquiry. It would seem stubbornly unrealistic not to expect the science of our times —this study for instance— to be part of another sort of pre-scientific period (Costanza, 2000). We are writing these notes at a time when the first synthetic life form has been produced by a laboratory (Smith et al. 2003) and when a new "financial life form" known as *derivatives* is more than ten times the size of the world's economic output (Ferguson, 2008). We do not know if some of the things we are trying to know can be known. At the

moment governments are struggling between the need to perform politics with the need to find out with any degree of precision how independence from hydrocarbons will come about, or what sort of consumer preferences will be consistent with low-carbon growth (Stern, 2009) or —to be more precise— with real substitution possibilities in the foreseeable future. The likelihood of an increase in the participation of consumers in low-scale[110] productive activities involving the transformation of tangible resources associated with the satisfaction of human needs and wants is high (Renner et al. 2003, 2008). Likewise, some ecological economists suggest a likely increase in the productivity of natural capital and its total amount, rather than the increase the productivity of human made capital and its accumulation. (Costanza 2000). These are speculations about long-run substitution possibilities which can be better appraised contextually as they influence one another in space and time. That has been the argument put forward in the model advanced here. Back to our own humble present reality, it seems prudent to say that there is at least a case for "runaway capital" which affects our present and will affect our future. Its influence can be appraised if not "empirically" at least "contextually" via future scenarios with potentially useful applications for policy. It can also be used as a heuristic method to learn and communicate economic science. To the extent that the premises of the model hold true they have been useful to pin down substitution in such a way that further research questions can be posed in an interesting mannner, with a view to an answer.

[110] Though not necessarily low-tech

5. Postscript: implications for the economic analysis of sustainability

Overview

In this concluding chapter we look at our model from a distance and expand upon some of the ideas that came out of it. We explore the following topic: the reasons why the "survival value" of certain methodologies used in scientific research often hinges on the social process that precedes them, both within scientific communities and within the wider society. This social process, if recognised, has the potential to improve the way in which research is conducted. Moreover, it is arguably the case that to "stay relevant" economists conducting sustainability analysis are now required by society to make a move from "doing economic science" to becoming increasingly competent at producing and monitoring public debates about economic science on the environment. If this is true, the use of future scenarios to understand long-run substitutability can be used as a good example of how the new challenges just described can be tackled. All in all, the purpose of the chapter is to speculate about the place that the methodologies employed in this study might occupy within the wider scientific research map.

The need for science communication

Science communication is an increasingly important requirement for scientists in general and for economists in particular. Science communication in general is sought after and encouraged by most research councils and sponsoring bodies around the world (The Royal Society, 2006). Additionally, due to the increasing importance of lay and local knowledge in achieving sustainability targets (Murdoch and Clark, 1994, O'Riordan, 2004, Wynne, 1996), many scientific initiatives are now being asked to become more participatory, inclusive and deliberative in nature (Stirling, 1999, 2007). This is being commended —we suspect— not so much in the name of some new fashionable role for democracy, but because reality is

revealing itself as multifaceted and multidisciplinary. The truth and way out of many of today's problems —such as environmental unsustainability— is likely to be found in getting everyone involved; this is why science is being asked not to be afraid, mingle and socialise with the outside world. In this context, the need for sustainable development has led increasing numbers of non-economists to learn some environmental and ecological economics (Costanza et al. 2004).

Retaming "feral science"

Science needs to communicate its proceedings in ways that can be legitimised by social appraisal (Stirling, 2006; 2008). In practice this translates inter alia into the very tough challenge for scientists in general, but also economists in particular, to engage in dialogues (rather than monologue) with society about complex phenomena and what Funtowicz and Ravetz (1993) have called "post-normal" science. Let us assume for the sake of argument that, say, the relatively new phenomenon of "open science" —not just as a publishing practice but also as a work ethic and frame of mind— enables such legitimising process by bringing together relevant knowledge about the world in ways that are not restricted either by law, by technical means, by hard-core mathematics or by sheer intricacy of argument. Let us assume also that such "open-science methodologies", if they exist, would involve — in principle— some form of deliberative social appraisal. Although it might seem odd from a mainstream economics perspective, there appears to be some merit in looking at such an exchange of scientific methodologies as ways of increasing society's intellectual capital; that is to say scientific ideas which once released, are then shaped, reshaped, enriched and legitimised by a plethora of slow social processes, all very imperfect and typically lacking scientific rigour when looked at from a close distance, yet aimed at increasing the overall social appraisal and legitimacy of science and scientific research. A social process meeting such specifications, would be perhaps incompatible with "enclosed science". Just as domestic hamsters turn feral after a period of deprivation from human

company and care, it is useful to think of science as something which is often of risk of becoming "feral science" if bereaved from basic social transformation and human care. In such an analogy, "feral science" and "feral scientists" might come to be enclosed by their own methods — honouring Cooper's (2002) description of economics in our next section— although they could also self-segregate by simply not opening up their toolboxes and methods publicly. Some methodologies used in science have already made many scientific ideas very popular and dynamic over the past decades, others have made scientific ideas apparently more static and esoteric, causing them to eventually die out. There is some early indication in ever wider areas of science of what society might be expecting from scientists and scientific endeavour in the foreseeable future. Many scientists in fact might soon be required to transit from rigorously knowing how to "do science" to rigorously knowing how to produce and facilitate "public debates about science". They might also be expected to be competent at producing said debates in a programmatic manner while engaging a range of social actors through a range of communication channels. What are some examples of open-science methodologies?

Heuristic science and "appreciative" modelling

There is a wealth of experiences of how scientific story telling has unwillingly become more open and deliberative while apparently improving the way in which science itself is carried out in the eyes of the public. From the angle we are describing, the felt concern about science not being sufficiently open to public understanding and disclosure may appear as a relatively unfounded one. The following are some successful examples of scientific stories and methodologies that have emerged during the last few decades in the area of economics and that could be seen as preliminary evidence of openness and "social processing" or social appraisal. Consider for a start the now famous scientific story told at the end of the nineties by Robert Costanza and colleagues where they ambitiously set out to calculate *"The value of the world's ecosystem services and natural*

capital" (Costanza et al., 1998). It might seem true to an economist that it makes no sense to do such calculations (Dasgupta et al., 2000); to the point where the study might have "risked ridicule from both scientists and economists" (Turner et al., 1998, p.62). In some ways it did. Notwithstanding, it would be hard to deny that such an adventurous piece of analysis was also very successful in achieving at least two important public objectives: engaging environmental scientists and policy makers (Turner op. cit.) as well as leaving many non-economists no option but to improve their knowledge about how ecosystem services are valued and why. It raised the type of questions that force people to think and to understand economics in terms of clearly stated assumptions. By way of example, consider the controversy around the "impossibility" of global ecosystem's value exceeding that of global GNP, captured in all its complexity in a single paragraph:

> "One more detailed argument is that the total value of ecosystem services cannot exceed GNP (Ayres, 1998). This is not correct. GNP picks up only marketed goods and services. We argue clearly in our paper that ecosystems provide REAL income (contributions to human welfare), much of which never enters any market. The point of our paper is to estimate that income, which has no direct relationship with current, incomplete GNP." (Costanza et al., 1997, p.69)

Before the 1998 paper, a lot of people simply did not know that valuing the environment was a question of preferences. As Pearce (1993) notes, valuing the environment is controversial because its purpose is not clearly conveyed to non-economists. At any rate, Costanza and colleagues' piece was a remarkable example of Cooper's definition of economics, although in an unusually constructive way:

> "Economics seeks to simplify events and behaviour in the real world into a few "laws", preferably ones that look good when expressed mathematically, because this immediately excludes about 90% (that's nine out of ten) of the population from understanding them. To do this, it makes use of assumptions." (Cooper, 2006, p.2)

Methodologies of science such as the one exemplified by Costanza and colleagues could be regarded as open and deliberative in that they are able to accommodate scientific goals and enquiry alongside the possibility of allowing lay participants to learn and have a say on the matter by means and channels other than the academic. For this to happen, what is required from the scientist is a combination of flexibility, creativity scepticism about one's own endeavours, and reverence for other forms of knowledge. Some of the well-known works of Robert Solow, William Rees, James Lovelock and Richard Dawkins further illustrate how successful steps in the advancement of scientific knowledge and debate may depend less on the excessive deployment of analytical prowess and technical accuracy and more on the ability to sympathise and integrate cultural, educational and even humorous considerations into the scientific story that needs to be told. The key appears to be in taking our endeavours seriously but not so extremely seriously that science is undermined. Neoclassical theorist Solow curiously observes that;

> "I like the informal tone because I fear that the formal style of journal articles and treatises tends to disguise the essentially exploratory, almost playful, character of all theory and makes it look more self-important than it can possibly be". (Solow, 1997b, p.v)

Such a sense of roughness and tempered playfulness about the core essence of the scientific problem being tackled is what often makes some authors' approaches suitable for communication with undergraduate students and with heads of government alike. More than a decade after the publication of *The value of the world's ecosystem services and natural capital*, the story told by Costanza and colleagues continues to supply people inside and outside academia with material to discuss issues in economic science which would otherwise have remained shrouded by the equations and obfuscated terminology of mathematical economics. This becomes all the more important as difficulties experienced by non-scientists to grasp scientific messages about issues that directly affect them seems to provide fertile ground for particular interests to

discredit scientific endeavours. The e-mail hack ordeal at the University of East Anglia in 2009 sent an unsubtle warning to the scientific community in this regard. It is not entirely coincidental that for over a decade some environmental economists have been calling for a "methodological balance" between what often seem mutually exclusive targets: the need for scientific rigour as well as science communication:

> "In future, ecological economics will also need to formulate more participatory environmental discussion frameworks, underpinned by integrated ecological-economic modelling. Such frameworks will have to be able to cope with optimal scale, justice and distributional equity and uncertainty and ignorance problems. In order to be legitimate they will need to build trust between stakeholders through real participation and negotiation. Value judgements and ethical differences should be highlighted and debated, rather than being shrouded in overly technical analysis." (Turner, 2002, p.1029)

The obvious deduction at this point is that in devising an "appreciative" model and seeking to implement a proof of concept analysis to test its usefulness, we have tried to demonstrate that the appraisal of long-run substitutability between man-made and natural capital via future scenarios, potentially eases the path for social dialogue. This is done by telling plausible economic science stories that might have —or should have— an appeal to a wider range of stakeholders inside and outside economics. Perhaps economic-science story telling in general should be conceived in terms of its appeal to a wider range of stakeholders inside and outside academic circles. This seems particularly the case for environmental and ecological economics which have the remit to look into environmental and sustainability issues. Such an appeal might also be seen as a form of legitimating process which —one would imagine— often takes place in the course of many years of social "taming" of certain type of problem. Scientific story telling from the economist's viewpoint could also be seen as a "heuristic" activity —that is to say, science which allows wider audiences to learn by themselves the sort of problems economics seeks to address. If this presumption is true, what are some examples of "heuristic economic science"? Are they

really as rare as they seem? Self-proclaimed as someone not truly obsessed with cosmic truths about his subject matter (Solow, 1997), Robert Solow has been a good scientific story teller and perhaps also a good debate facilitator in that he has managed since the late 1950s to implacably "parasitize" mainstream economics with his postulates on growth — he won a Nobel price for his work. Solow has spelled out for us his own favourite how-to-do-it injunctions for successful scientific storytelling in economics but which seem to apply more widely:

- "Keep it simple
- get it right
- make it plausible" (Solow, 2007, p.4)

Following these steps Solow created fifty yeas ago a remarkably successful scientific story. Something that analysts have taken to call *the Solow residual* and which has explained modern economic growth to politicians since the 1950's (in terms of exogenous variables). The assumptions behind Solow's model might be regarded as risky from certain angles, they predate the internet era and were less vulnerable to controversy and debate; however, the important lesson is that his model shows how successful scientific stories *needed to be told* if they were to be approved by the institutions and society of his time: they "do not get lost in complications and blind alleys" just for the sake of analytical rigour (Solow 2007, p.4); successful scientific stories are plausible in the sense that they "fit the stylized facts" and "offer opportunities to test and to calibrate"; they also "tell you how to get from empirical beliefs to practical conclusions", finally says Solow, good scientific story telling does not "require you to believe something unbelievable" (op. cit. p.4-5). This said, we could short-hand define "heuristic science" as knowledge that is disseminated through scientific stories that take heed of Solow's favourite injunctions; stories which are told in a way that people can relate to and take home so they can learn, experiment and explain for themselves the workings of certain aspects of the world that interest them, even if this is done imperfectly. A widely criticised case of open heuristic science —and apparently an *annoyingly successful* one too— is

the scientific story of Ecological Footprints (EF) told by William Rees (1992). EF analysis might be seen as a faithful example of how enclosed science can be turned into open science by sustained interaction with society. Against the tide, the fitness and survival value of Rees' scientific story in "the marketplace of methods" to appraise sustainability (Stirling 1999, p.112) has been remarkable. Today EF analysis is the *de facto* indicator of unsustainability in practical conversations as well as in official reports. It is used as rule of thumb by many, from politicians (UK Sustainable Development Strategy 2005) down to school children; EF analysis has been applied at a macro level (e.g. countries, the planet) but also at a micro level (people, households)[111]. This has happened, despite numerous attempts to downplay its usefulness as an indicator or as a form of sustainability appraisal. (Ayres, 2000, DEFRA, 2007, Fiala, 2008, Pearce and Barbier, 2000, Proops et al., 1999, Van den Bergh and Verbruggen, 1999). All these seemingly "feral-science" criticisms have in common that they deny the powerful heuristic quality of EF analysis. This quality alone has made it transcend disciplinary and institutional domains; a test most other indicators —including World Bank's "genuine saving" indicator (Hamilton et al, 1998) — have not passed over the years and are perhaps unlikely to pass in the future given their low level of social ownership. There appear to be other well-known examples of successful scientific story telling such as Dawkins" *Selfish gene* story (1976) and James Lovelock's *Gaia theory* (1972). The latter was for a long time condemned as unscientific (Doolittle, 1981, Kirchner, 1989) but is today used in many university departments to understand aspects of climate science and the Earth system (Lenton et al., 2008) which would otherwise remain in the shade. It will be interesting to follow the survival value of UK's National Ecosystem Assessment (NEA) and whether it develops in a few year from now the ability to pass a "feral science test" (whatever features such a test might consist of by then).

[111] See the interesting project commissioned by London's sustainable development commission www.changinghabbits.co.uk

A final though

Focusing on the empirics and "survival value" of certain scientific stories, novel approaches and methods in economic science serves to illustrate how certain aspects of science in general might be already more socialised activities than we tend to acknowledge or think about. The need for sustainable development is also a source of interesting questions for the future of science in general and economic science in particular. Has economics become too "feral" for its own survival? How can it become more heuristic, socially approved and legitimate in its dealings with the environment and sustainable development? The examples in this postscript suggest the following: if economic scientists are to address sustainability issues effectively, they may —at some point in the foreseeable future— have to transit from "doing economic science" to becoming competent at conceiving, launching, conducting and monitoring public debates about economic science as well. Looking at the survival value of a few highly successful scientific stories, takes us almost inevitably to the wider question of how science in general appears to be transforming itself from within and in ways that seem to challenge rather fundamentally some established notions about relevant scientific practice. It is our hope that our scientific story about substitution possibilities is also a contribution to understand the above challenges a little bit better.

Appendix: the elasticity of substitution concept

The "elasticity of substitution" between different forms of capital alludes to the amount by which one input needs to be increased to maintain the same level of production when the use of a second input is decreased (Stern, 2004). The principle can be used to imply that capital inputs are substitutable for one another in *production*, while goods and services can also substitute for one another in *consumption*. "Resources are, to use a favourite word of economists, fungible in a certain sense" (Solow, 1991 p.181). Growth theorists for instance, distinguish between assumptions of "perfect elasticity of substitution" ($\sigma = 1$), infinite elasticity of substitution ($\sigma = \infty$) or no elasticity of substitution ($\sigma = 0$). Figure A above shows different combinations of inputs yielding different outputs for different "σ" elasticity of substitution values. "Perfect elasticity of substitution" ($\sigma = 1$) —as assumed in "Solow sustainability" (Turner, 1993, p.9)— means that as resource use decreases toward zero, production can be maintained by increasing capital use toward infinity. Infinite substitutability ($\sigma = \infty$) means that producers see no difference between inputs and use the cheapest one because they all are equivalently useful. No substitutability ($\sigma = 0$) means that input types are essential to production and have to be used at a fixed ratio (Stern D. 2004).

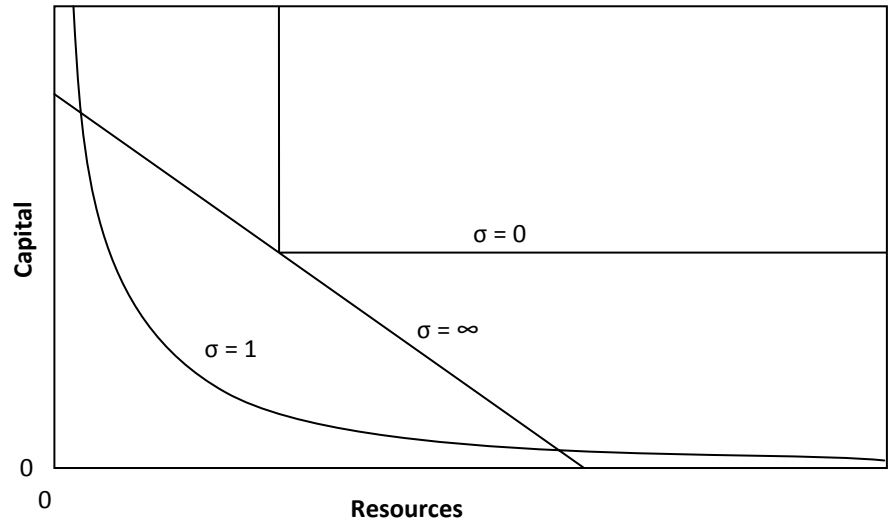

Figure A: Different elasticities of substitution. Different levels of output were chosen for the three values to make the figure clearer. Source: Stern (2004)

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