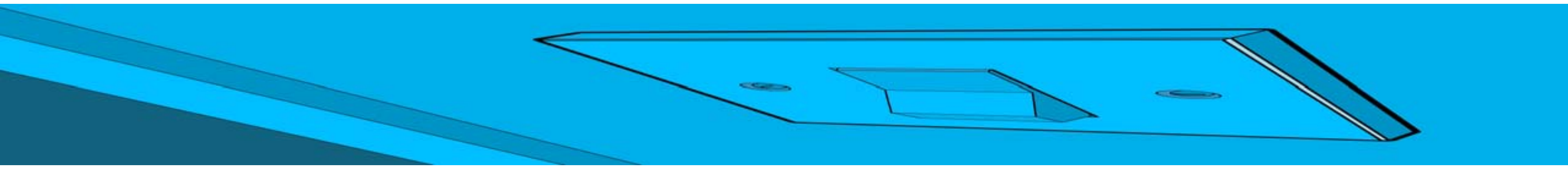

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Review and Analysis of UK and International Low Carbon Energy Scenarios

Working Paper

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Executive Summary

Background
This paper is the second in a series which aims to provide insights into the use of scenarios for informing low carbon energy policy. Building on insights from a historical overview of strategic scenario planning in the first working paper of the series (Hughes, 2009), this paper reviews selected recent UK and international low carbon energy scenarios, analyses their strengths and weaknesses, and offers some suggestions for improving the strategic power of future UK low carbon energy scenarios.

This paper adopts the broad characterisation proposed in Hughes (2009), that scenario thinking is the use of the imagination to consider possible alternative future situations, as they may evolve from the present, with a view to improving immediate and near-term decision making. The three key objectives of scenario thinking identified in Hughes (2009), improving protective decision making, improving proactive decision making, and consensus building, are also highlighted.

Nonetheless, it is acknowledged that low carbon energy scenarios face particular challenges which are unlike those experienced by most of the studies reviewed in Hughes (2009). In particular, the need to consider future technologies in some detail opens up major uncertainties, particularly as the objective of decarbonisation is a driver for even greater technological change than might normally be expected. Further, the way in which society interacts with technology, particularly when considered as a dynamic process in an evolving socio-technical system, is a highly complex process, but a central aspect of considering low carbon transitions. Finally, the number and diversity of actors which must be considered in imagining a plausible low carbon transition is greater than that required by many other previous scenario processes.

The paper notes that from the approaches and methodologies outlined in Hughes (2009), two approaches in particular have been strongly drawn upon in the construction of low carbon energy scenarios. The first is the derivation of broadly consistent future scenarios from 'high level trends', sometimes represented within a '2x2 matrix'. The second is the concept of 'backcasting' from a normatively constructed future end point. This observation informs a three-fold typology for reviewing the low carbon energy scenarios in this paper:

- **Trend driven studies**: developed around high level trends
- **Technical feasibility studies**: demonstrate technical feasibility of end points, sometimes 'backcasting' from them
- **Modelling studies**: complex quantitative models are used to generate results, often operating within exogenous emission constraints

Review and analysis

The paper then reviews 21 studies, grouped within these three categories. A comparison of the strengths and weaknesses of the studies is made, and summarised in Table 5.

Table 5: Strengths and Weaknesses of Scenario Study Categories

	Strengths	**Weaknesses**
Trend based studies	Social drivers, global political dynamics, unquantifiable cultural shifts	Lack of technological detail and actor depiction, role of policy to influence 'high level trends' is unclear
Technical feasibility studies	Technological detail, particularly at specialised sectoral levels	Lack of actor depiction, policies, and simplified political dynamics. End point constraints often overly deterministic
Modelling studies	System-wide technological detail, economic interactions, resource availability and trade-offs, micro and/or macroeconomic outputs	Lack of cultural, behavioural social, political dynamics. Lack of actor depiction and policies. End point constraints often overly deterministic

The major strength of the studies reviewed in this paper is considered to be that through imagining in some detail how future low carbon societies could operate, they take the first step on the journey towards achieving them. By characterising possible low carbon futures they can make 'desirable ends a powerful enough lever to act on the present' (Massé, 1966). In particular, their demonstration, at least in theory, of the technical feasibility of certain aspects of the decarbonisation challenge, provides crucial encouragement as we take our first tentative steps. Indeed, it seems clear that studies such as these have had a positive influence in the setting and subsequent upwards-revision of the UK national carbon-reduction targets. Further, these studies throw up important questions, relating for example to costs and public acceptability of the transition, and raise the prospect of futures which could be quite different to the present.

However, this paper finds that on the whole the studies lack the aspect of strategic applicability which would give stronger information as to how to construct the path towards a low carbon future. There are three aspects which are found to recur particularly frequently across all categories of low carbon energy scenario reviewed, and proposed by this paper to be at the root of this lack of strategic applicability.

The exogenous constraint

A large number of the scenario studies reviewed in this paper operate within some form of normative constraint. This often takes the form of a system-wide carbon emissions reduction target to be achieved by a certain year. The deterministic nature of this constraint can create an 'illusion of inevitability' about the end point, diminishing the significance of important potential obstacles to success, and arguably verging into 'wishful thinking'. It tends to put the emphasis on defining in some detail the system configuration in the end point year. Though there is validity in exploring the technical feasibility of that system, the focus can reduce attention on transition issues, and particularly the first few crucial steps which must be taken from where we are at the present time. Further, exogenous constraints are applied with reference to the technical energy system, but are not explained in terms of the actions of system actors which would in reality bring about the technical changes envisaged. The binding, system-wide exogenous constraint has no direct correlation with any action that a real-world actor could take, hence the strategic insights from scenarios which are structured around such a constraint, are limited.

Reliance on high level trends

The use of high level trends to explain and justify events that take place within scenarios is common in all studies, whether their predominant focus is quantitative or qualitative. Though they are employed as a uniting force within scenarios, to lend consistency and therefore plausibility, they can lead to scenarios which are overly polarised and homogenised, and not reflective of the divergences and conflicting views which characterise society as we know it. Further, though high level trends are used both as explanations for the events which take place, and as justification for the plausibility of those events within particular scenarios, their effect is to avoid the attribution of developments to the actions of particular actors. This creates scenarios which are highly abstracted from human processes, and provide no information as to how the effects attributed to the high level trends may in reality be brought about or avoided.

The co-evolution of social, technical and political changes

Major socio-technical change is not brought about by technology alone. Rather, it is a complex, 'co-evolutionary' process involving the interaction of technology with social, cultural, and political dynamics. A large number of the studies reviewed in this paper focus heavily on the technical aspects of the energy systems. Though others focus on more on social aspects, none takes a view which balances equally the social, political and technological systems and considers the evolving dynamics between them. This often results in a simplistic representation of the operation of policy. Developments in scenarios, in terms both of technical progress and social and behavioural change, are frequently explained in the broadest terms by 'strong' or 'weak' policy. The implication is that policy is a constantly available lever which can at any time be switched on or off.

However, in reality the successful implementation of policy is an iterative process. It both leads and reacts to the state of social and technical development. Governments can be limited in the kinds of policies they feel empowered to implement, on the basis of what they consider politically feasible; however, policy can also have a role in leading and influencing behaviour, and initial policy experiments can sometimes pave the way for more ambitious measures. The balance between government vision and electoral pressure is constantly evolving in the context of any issue; a useful exploration of this process within scenarios would involve a detailed depiction of the range of societal actors, their motivations and interrelationships.

Suggested approaches for future low carbon energy scenarios

On the basis of the review and analysis undertaken in this paper, it is proposed that low carbon energy scenarios could deliver more strategically useful information regarding how a low carbon transition can successfully be brought about, if they were enhanced in two ways. First, they should consider socio-technical systems as 'co-evolving', understanding that successful implementation of policy is a process which has ongoing interactions with the state of social and technical development. Second, they should identify developments with clear reference to actors, their motivations and the networks between them, rather than explaining developments in terms of high-level trends.

Contents

1. Introduction

1.1. Background to paper

This paper is the second in a series which aims to provide insights into the use of scenarios for informing low carbon energy policy. This series of working papers has a dual function as it is related to and funded by two long-term research projects. The initial research for both the first working paper in this series (Hughes, 2009), and this second working paper, was carried out as part of the scenarios workstream of the UK Energy Research Centre's (UKERC) Energy Systems and Modelling Theme, with subsequent refinements and further research being carried out under the EON/EPSRC funded project, Transition Pathways to a Low Carbon Economy. These papers are therefore joint UKERC and EON/EPSRC working papers. A third, forthcoming paper will be carried out wholly under the EON/EPSRC project.

Recent years have seen a proliferation of energy policy related studies employing the concept of scenarios. The aim of this working paper series is to evaluate the success with which this work has been carried out, and to make suggestions for future approaches. The first working paper (Hughes, 2009) explores the broader history of scenario building and highlights points of best practice. **This second working paper develops a typology to review recent energy scenarios, concentrating on low carbon energy scenarios of the UK, but with several international energy scenarios also reviewed for context. The paper provides an evaluation of their strengths and weaknesses, and concludes with some suggestions for improving the strategic power of future UK low carbon energy scenarios**. The third working paper will combine insights from these two papers, along with insights from the literature on technological transitions (e.g. Geels, 2005), to make suggestions for the future use of scenario thinking in low carbon energy policy studies.

1.2. Characterisation of scenarios

An exploration of the historical background to the use of scenario techniques was conducted in Hughes (2009). This paper found that scenario thinking could be described as the use of the imagination to consider possible alternative future situations, as they may evolve from the present, with a view to improving immediate and near-term decision making. In these terms, scenario thinking can be understood as a natural human activity, practiced virtually every day in circumstances ranging from the instinctive and relatively mundane (such as deciding whether to hang the washing outside on a cloudy day) to the more organised and potentially much more critical (such as practice safety routines for unpleasant events such as fires or terrorist attacks). Thus, formal strategic scenario planning is 'simply an attempt to effect improvements in a natural activity of the mind' (de Jouvenel, 1967), and the objectives are not dissimilar. The historical review conducted in Hughes (2009) found that the objectives of a range of strategic scenario planning activities could be encompassed by one or more of the following key objectives:

- Improving **protective decision making**- allowing us to be better prepared for, and more robust to, different possible external and largely uncontrollable environments (i.e. safety routines, contingency planning)

- Improving **proactive decision making**- allowing us to identify opportunities to intervene upon and influence the external environment, to render its conditions more favourable according to our priorities (utopias, dystopias, and intuitively thinking through consequences of actions)

- **Consensus building**- encouraging diverse actors to see their role in and participate in a project which can only be brought to successful fruition through the engagement of all actors (political vision building)

In any given scenario study the balance between these objectives is established through an understanding of the role of actors in the scenario, and in particular the role of any central 'scenario user'. Some scenarios have a clear 'scenario user', who as an actor within the system is using the scenarios to orient itself within a range of possible future external environments, where these external environments are considered beyond the control of the scenario user to influence directly. Such scenario studies will clearly be focussed on protective decision making. Other scenarios have a scenario user who expects and intends to influence the system, such as a government intending to pursue a particular policy objective. Though there is likely to be a balance between factors within and outside of this scenario user's control, nonetheless, the objectives are likely to shift towards identifying proactive decision opportunities, as well as purely protective ones. Other scenarios are constructed in support of a desired transition which no single actor has the agency to effect unilaterally- in this case it is possible that there will not be a single specific scenario user. Nonetheless each actor within the system can be defined and the extent of its agency and particular role within the transition can be identified. Such scenarios are more likely to have consensus building as a key objective.

It is clear then that whatever the objective of the scenario process, the clear depiction of actors, their motivations and the extent of their agency, and the networks of influence between them, is crucial to ensuring the strategic power of the scenarios.

1.3 Particular challenges for low carbon energy scenarios

Having identified these central aspects of scenario building in Hughes (2009), the task of this working paper will largely be to examine the effectiveness of a number of recent low carbon energy scenarios in the context of these insights. However, before doing so, it is important to acknowledge that there are particular challenges to the construction of low carbon energy scenarios which are unlike those experienced in most of the scenarios reviewed in Hughes (2009).

The particular challenges are evident from considering the central area of enquiry for low carbon energy scenarios - possible levels of greenhouse gas (GHG) emissions from human activity in future years, often several decades distant. First, as GHG emitting activities involve the use of technology, it is clear that this area of enquiry automatically entails high levels of technological detail pertaining to future years. Even allowing for average levels of technological change, such speculations would involve considerable levels of uncertainty. However, such speculations take place against a canvass of proposed radical technological and system changes, which are inherent to the nature of the overall objective itself. Thus the underlying purpose of low carbon energy scenarios is itself one of the most significant sources of additional uncertainty. The words of French futurist Bertrand de Jouvenel, though they pre-date by some decades any major consideration of low carbon transitions, seem particularly apt: 'The great problem of our age is that we want things to change more rapidly, and at the same time we want to have a better knowledge of things to come. I do not say that the reconciliation of these desires is impossible, but it does raise a problem.' (de Jouvenel, 1967).

Further, the way that humans use technologies in satisfaction of energy service demands and other needs (often summarized as 'behaviour') is not a linear or evenly developing process. Humans may choose autonomously to use existing energy technologies differently (for example, through 'mode-switching' or demand reduction). Equally, new technologies may radically change social practices, developing entirely new or alternative kinds of energy service demand. Historical analysis shows indeed that certain key technology breakthroughs have not only met existing needs, but brought about new kinds of practices in the uses of other technologies- sometimes described as 'technological dynamism' (Bresnahan and Trajtenberg, 1995). Geels (2005) also observes that technologies which break into mainstream use from niche applications can have a disruptive and transformative effect upon social practices. Indeed it is this reformatting of the social-cultural sub-systems that ensures that the new technologies take root- they themselves create and define a need which did not previously exist.

Finally, and in direct relation to the above points, it is clear that due to the complexity of the systems interactions associated with low carbon transitions, and the number of system actors such transitions would require to engage, the successful bringing-about of such a transition cannot be achieved unilaterally by a single system actor- rather it requires the coordinated action of a number of system actors, many of whom may have contrasting or conflicting priorities. This will involve a vast and complex 'system', made up of a number of interacting 'sub-systems'- which for example could be characterised as science, technology, politics, economics, culture (Freeman and Louca, 2001)

Despite these particular challenges faced by low carbon energy scenarios, the above discussion nonetheless highlights that the three potential objectives of scenarios identified by Hughes (2009) remain highly relevant to the consideration of low carbon energy scenarios in particular. Protective decision making involves being robust to uncontrollable external events (in the context of low carbon energy scenarios, examples could be changes in assessments of resource availability, technology failure or breakthrough); proactive decision making involves achieving greater awareness of opportunities for influencing the external environment (for example policies to change social behaviour, to synergise or galvanise industrial sectors, to have an influence on the global stage); consensus building acknowledges that key elements of the transition require the coordination of multiple actors (for example energy companies, regulators, system operators, consumers). Thus, notwithstanding the particular challenges to low carbon energy scenarios, insights from Hughes (2009) which were based on this three-fold characterisation of the potential objectives of scenarios, should remain highly relevant.

1.4 Theoretical underpinning of the low carbon energy scenarios literature

As was highlighted in Hughes (2009), from the wide range of approaches which constitute the overall 'family tree' of scenario building, there emerge two particular methodological approaches which have dominated in the construction of low carbon energy scenarios.

First, from a particular branch of a broadly US-based school of practice (sometimes referred to as the 'intuitive logics' school (Bradfield et al, 2005)), which constructs future scenarios around the interaction of a number of high level trends which are generally derived from hypothesising a continuation and strengthening of a currently perceptible trend. Such high level trends (sometimes called 'megatrends') are captured under broad headings such as consumerism, environmentalism, globalisation, fragmentation, etc. A common way of organising such trends is through placing pairs of them at opposite ends of two bisecting axes, creating a '2x2 matrix' such as the one illustrated in Figure 1.

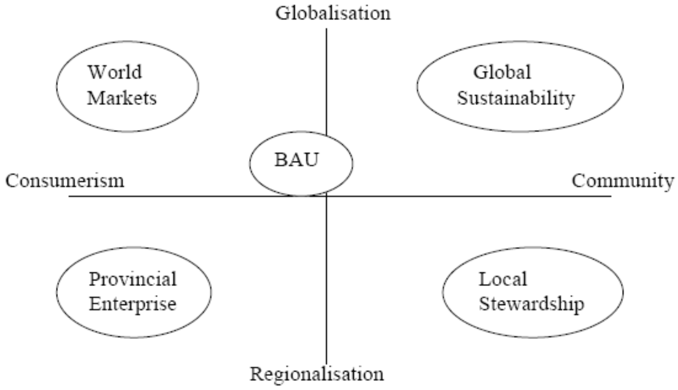


Figure 1: 2x2 matrix for representing scenarios based on high level trends (PIU, 2001)

For further discussion and critique of the '2x2 matrix' approach, see for example Mander et al (2008) and Hughes et al (2009).

The other main methodological influence is the concept of 'backcasting'. The term first appears in the futures literature in the 1980s, being proposed largely by a group of Canadian researchers (including Robinson (1982; 1988; 1990) and Valiskakis (1988)), as a means to identifying routes towards more radical futures such as the 'soft energy paths' proposed by Amory Lovins. Broadly the approach is to describe the desirable future and to identify retrospectively all the elements needed to reach it. Valiskakis and Robinson present some methodological approaches in the form of process flow-charts (e.g., Robinson, 1990, p. 824). Such details appear to have remained somewhat in the realms of theory, as examples of a successful application of this approach in its entirety are hard to identify. However, from 2000 onwards the concept in general was increasingly employed for a new generation of low carbon energy scenarios, particularly as a quantitative carbon emissions reduction target by a certain date provides a highly convenient and tangible point from which to 'backcast'. As a result the term has now achieved familiarity and popularity within the low carbon energy scenarios literature. However, although Mander et al (2008) and Eames and McDowall (2006) refer to this previous literature, very few other studies make reference to it beyond the use of the term itself, or engage in great depth with the details of the methodology proposed by Robinson and Valiskakis in the 1980s.

On the basis of Hughes (2009) it should be noted that these two approaches represent a small subset of the wider literature on scenario development. Insights from this wider literature, listed in Hughes (2009) and summarised in section 1.2 above, will be brought to bear in the analysis of the scenarios reviewed in this paper, in order to ascertain whether low carbon energy scenarios would benefit from drawing more widely from scenarios literature.

1.5 Organising the low carbon energy scenarios literature

The approach to arranging the literature chosen in this paper refers to the studies' degree of debt to these two particular methodological approaches. This typology produces the three categories as listed below. Note that a discussion of other low carbon energy scenario typologies, and a comparison with the typology chosen for this paper, is presented in the Appendix.

- **Trend driven studies:** scenarios developed around different combinations of broad, high level extrapolated trends, sometimes arranged within a 2x2 matrix.

- **Technical feasibility studies:** scenarios based around demonstrating the technical feasibility of the energy system, or part of it, to meet energy demands at the same time as meeting a carbon reduction target. In some cases additional external constraints are also imposed. Several studies describe their approach as 'backcasting' from this end-point target.

- **Modelling studies:** scenarios are essentially the outputs of model runs. In some cases these results are further explained, justified or explored through the elaboration of qualitative storylines based on them. In most cases the models are working within an end-point carbon constraint- however they usually do not use the term 'backcasting' to describe the approach.

Table 1 lists the studies selected for review in this paper within the above categorisation

Table 1: List of reviewed scenarios

	SCENARIO EXERCISE	AUTHORS, DATE	AFFILIATED ORGANISATIONS	SCOPE OF STUDY
Trend driven studies				
1	Special Report on Emissions Scenarios	Nakicenovic et al (2000)	Intergovernmental Panel on Climate Change	Global, energy use and land use change
2	Foresight Scenarios	Berkhout et al (1999)	Office of Science and Technology / Foresight Programme	UK society
3	Socio-economic scenarios for climate change impact assessment	UK Climate Impacts Programme (2000)		UK society
4	Scenario Exercise on Moving Towards a Sustainable Energy Economy	Institute for Alternative Futures, Virginia (2004)	Institute for Innovation Research, University of Manchester	UK energy and society
5	Transitions to a UK Hydrogen Economy	Eames and McDowall (2006)	Supergen UK Sustainable Hydrogen Energy Consortium	UK energy system
6	Electricity Network Scenarios for Great Britain in 2050	Elders et al (2006)	Supergen Future Network Technologies Consortium	UK electricity system
7	Electricity Network Scenarios for	Ault et al (2008)	Ofgem	UK electricity system

	Great Britain in 2050 (LENS project)			
Technical Feasibility studies				
8	The Changing Climate	Royal Commission on Environmental Pollution (2000)		UK energy system
9	Decarbonising the UK	Anderson et al (2005)	Tyndall Centre	UK energy system
10	The Balance of Power- Reducing CO2 Emissions from the UK Power Sector	ILEX (2006)	World Wildlife Fund	UK electricity system
11	Decentralising UK Energy	WADE (2006)	Greenpeace	UK heat and electricity
12	A Bright Future: Friends of the Earth's Electricity Sector Model for 2030	FOE (2006)		UK electricity sector
13	Powering London into the 21st Century	PB Power (2006)	Mayor of London, Greenpeace	London, heat and power from buildings
14	Technical Feasibility of CO2 emissions reductions in the UK housing stock	Johnston et al (2005)	Buildings Research Establishment	UK, energy demands from domestic buildings
15	40% house	Boardman et al (2005)	Environmental Change Institute, University of Oxford	UK, energy demands from domestic buildings
Modelling studies				
16	UK MARKAL (Energy White Paper and other work)	Strachan et al (2007)	BERR, DEFRA, Policy Studies Institute, AEA Technologies	UK energy system
17	Energy 2050	UK Energy Research Centre (2009)		UK energy system
18	Japan Scenarios	Fujino et al	National Institute for	Japan energy

	and Actions Towards Low Carbon Societies	(2008)	Environmental Studies	system
19	World Energy Outlook	International Energy Agency (2008a)		Global energy systems
20	Energy Technology Perspectives	International Energy Agency (2008b)		Global energy systems
21	World Energy Technology Outlook	European Commission (2005)	EU	Global energy systems

Sections 2-4 of this paper review the three categories of low carbon energy scenarios listed in Table 1.

2. Trend Driven Studies

The following studies use combinations of broad, high level trends to integrate ranges of assumptions in a coherent and consistent manner. In some cases these assumptions are quantitative in nature and are subsequently used as inputs into quantitative modelling processes.

2.1 Descriptions of trend driven studies

1. Special Report on Emissions Scenarios

The Intergovernmental Panel on Climate Change (IPCC) first produced long range emissions scenarios in 1990. The original purpose of the scenarios was to provide ranges of future greenhouse gas emission levels to drive global circulation models, and develop scenarios of potential future climate effects and impacts. Updated emissions scenarios were released in 1992, and following an evaluation process, the Special Report on Emissions Scenarios (SRES) was published in 2000.

The IPCC process is based in the understanding that the range of possible greenhouse gas emissions levels over the next century could vary quite significantly, as a result of different combinations of human activities. Thus, whereas climate models operate within the physical realms of natural systems, and grapple with remaining uncertainties related to the precise functioning of these systems but mitigated by ongoing efforts to improve the accuracy of the models in relation to them, emissions scenarios grapple with quite different kinds of uncertainty, namely those related to different combinations of human will and behaviour. This kind of unpredictability is not something that can be reduced purely through improving the operation of a model, hence a scenario approach is used. Therefore while the emissions scenarios are finally quantified by integrated assessment models, the assumptions behind them are linked to a qualitative process of scenario development.

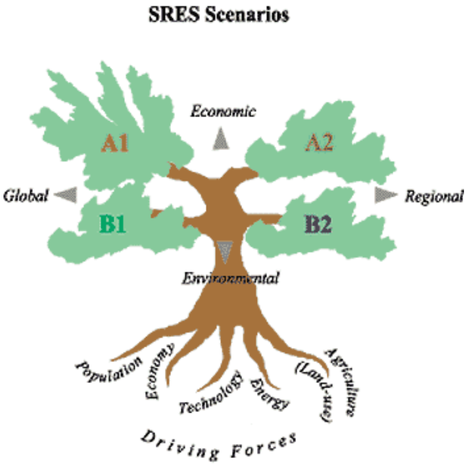


Figure 2: Schematic illustration of SRES scenarios (Source: Nakicenovic et al, 2000)

The scenario development began with a literature review to identify key drivers which had been previously identified as having a strong bearing on future global emissions trajectories. The key drivers were identified as demographic change, economic growth, and technological change. The review identified previous quantitative projections of these parameters.

A 2x2 matrix (Figure 2) was used as a means to integrate coherent and consistent combinations of these drivers. This produced four scenario 'families'. A1 describes a future of rapid economic growth, low population growth, and fast technological development. A2 describes a more fragmented and heterogeneous world of strong regional identities, high population growth, but lower economic growth and slower technological change. B1 envisages slow population growth, changing economic structures towards a service and information economy, and fast technological change towards cleaner and more efficient technologies. B2 describes a world with greater regionalisation than the A-scenarios, but with a focus on finding local solutions to environmental problems. It is characterised by moderate population growth, an intermediate pace of economic development and slower technological change.

These broad parameters were quantified using data from the literature review, and six Integrated Assessment (IA) models were used to produce emission levels (focussing on GHG and sulphur emissions) for each family. Several 'scenarios' (i.e. model runs) were produced within each family, some with assumptions between the models closely calibrated, others with a greater degree of variation, bringing out the differences in approach between the different IA models. In this way, a total of 40 'scenarios' were generated.

As a set, one of the most notable characteristics of the scenarios is the huge degree of variation in emissions levels by 2100, ranging from around half to six times 1990 levels. In interpreting this range, it should be noted that whereas in general the effects of policies are considered as affecting the drivers, specific new climate policies are excluded from the analysis.

The scenarios have been used extensively to drive climate circulation models, as the range of emission levels, and detailed breakdown of specific gases and emissions sources, offers a credible 'low' to 'very high' distribution of possible future emissions levels, to allow climate modellers to consider the contrast between extreme emission levels and somewhat milder outcomes. However, though the SRES authors suggest the scenarios could be used in policy analysis, how they could be used in this mode is unclear given the explicit decision to exclude climate policies from the scenarios. This creates a somewhat uneven playing field for considering the role of policy in relation to the emissions levels postulated.

2. Foresight Scenarios

The Foresight Scenarios were developed as work towards the IPCC's SRES was reaching its conclusion, and were strongly influenced by its development. They first appeared in a report for the Office of Science and Technology in 1999 (Berkhout et al, 1999). The scenario framework was again derived from literature review of existing exercises, but the influence of the SRES process is clear to see (Figure 1). The contrast between 'global' and 'regional' dynamics is echoed by the Foresight vertical axis, whereas the SRES environmental-economic axis is slightly adapted to present 'consumerism' against 'community' values. As with the SRES, the intersection of these two axes creates four scenarios for which narrative descriptions are created which explain the convergence of the two driving forces in each case. The values implied in each case are assumed to be generally descriptive of the future societies as a whole, accounting simultaneously for the actions of a wide range of actors including consumers or citizens, as well as policy makers and private companies. World Markets is defined by an emphasis on high levels of private consumption, mobility, materialist values, and integrated world trading, with 'sustainable development' becoming marginalised as a priority within global politics. Provincial Enterprise also maintains an emphasis on private consumption with little concern for sustainability issues, but where globalised markets are hampered by strong lower level policy making which prioritises regional and national economic concerns. Global Sustainability describes a highly interconnected world which establishes a strong consensus on the importance of social and ecological values, allowing a growth in global trade regulated by strong international agreements to protect environmental and social assets, thus providing a strong stimulus for green technology development. Local Stewardship is a world of high social and ecological values but where strong regional governance is the primary expression of this, emphasising the importance of regional cultural identities. In the absence of fast technology development sustainability objectives prompt lower consumption, mobility and energy use.

These broad interpretations of the 2x2 matrix are then used to derive more detailed descriptions within each scenario of elements such as energy use, technological change, fiscal and regulatory structures and localised environmental policies.

The Foresight scenarios have been used to provide underpinning assumptions to a number of subsequent reports, including broad technology and policy reviews (OST-DTI, 2001), techno-economic analyses (Marsh et al, 2003), technical analyses (PIU, 2001) as well as other scenario development processes (Watson, 2002).

It is usually stressed in the presentation of the Foresight scenarios that no scenario is intended as a prediction, and that probabilities are not attributed to any of the individual scenarios. Such caveats can be particularly strong, as in the Energy Futures Task Force report Energy for Tomorrow (OST-DTI, 2001), which assures its readers that 'none of these scenarios are expected to happen as stated and none form a vision of the future that the Task Force or the Foresight Programme wants to promote'. It might be observed that such strong statements of how not to interpret the scenarios, are in general not balanced by equally unequivocal insights as to how they should be used or interpreted, or simply, what they are for.

On the other hand, some users have succumbed to a perhaps natural tendency when encountering scenarios so fundamentally defined by 'values', to identify most strongly with, and to a certain extent imply the greater likelihood of, those scenarios whose values seem most familiar to those of the present. This is clear from the tendency in some subsequent uses of the Foresight scenarios to identify the space on the matrix considered as 'business as usual' (PIU, 2001; and Figure 1) or equivalent to 'conventional development' (UKCIP, 2000; Watson, 2002).

These observations perhaps indicate a tension in the understanding, use and interpretation of the Foresight scenarios, around questions of uncertainty, probability and desirability.

3. Socio-economic Scenarios for Climate Change Impact Assessment

In 2000 the UK Climate Impacts Programme (UKCIP) published a set of socio-economic scenarios (SES) which it intended to be used to inform regional assessments of possible future climate impacts (UKCIP, 2000). The basis for this intention was the acknowledgement that physical climate-related effects and changing socio-economic conditions are interrelated. Climate impacts can have socio-economic effects (flooding damage, impacts on productivity of agriculture, loss of biodiversity); equally socio-economic changes can affect the severity of climate impacts (new housing built on flood plains, coastal management and defences, population growth and change in demand for resources such as water).

The UKCIP SES relate very strongly to the previous two studies reviewed, as is acknowledged in the report itself: 'The UKCIP SES have been able to draw on the work for the DTI's Foresight programme, which itself was related to new work developed for the IPCC' (UKCIP, 2000). A 2x2 matrix very similar to that of the

Foresight scenarios is used. The key difference is that in place of an axis running between 'Globalisation' and 'Regionalisation' in the Foresight matrix, there is an axis contrasting 'autonomy' and 'interdependence', which relate to levels of governance in the UK and its place within supranational governance arrangements. 'Interdependence' represents the tendency for governing power to shift 'upwards, downwards and outwards away from the national state level'; 'autonomy' represents greater localisation of power, though notably this involves two quite different interpretations, with this power shift being either to 'national' or 'regional' levels, depending on the scenario. To reflect this different interpretation, the Foresight's Provincial Enterprise is re-named National Enterprise. This makes a clearer distinction from Local Stewardship, which sees stronger governance at the sub-national level. The other two Foresight scenario names, World Markets and Global Sustainability, are retained.

The four scenarios thus retain a similar character to the Foresight set, though their descriptions explore in greater detail issues of relevance to regional planning and possible climate impacts, such as population growth, policies on economic development, housing and coastal zone management, and attitudes towards agriculture, water use and biodiversity. The scenarios are further supported by quantitative indicators on each of these areas, which are derived from intuitive assumptions about how much each scenario would differ under each indicator from a 'business as usual' trend. A subsequent report offered quantitative indicators for the scenarios with a greater degree of regional disaggregation (Dahlström and Salmons, 2005).

The similarity to the IPCC set is intended to allow the 'mapping' of the socio-economic scenarios onto the emissions scenarios, to allow an integrated assessment of climate impacts within socio-economic conditions. However, such direct mapping of each UKCIP quadrant on to its IPCC equivalent is more problematic than it might first appear. First, as has been noted the IPCC scenarios do not assume additional climate policies, which is not the case for the UKCIP SES. Second, the two scenario sets explore quite different levels of governance and decision making. The IPCC scenarios describe aggregated global developments, whereas the UKCIP scenarios consider regional policies and values; clearly, an exact correlation between the two is not inevitable. For example, it is possible that global emissions could be heading in the direction of an A1 IPCC scenario, whereas a single UK region could decide to implement 'Local Stewardship' type policies.

The UKCIP SES has been used within a number of regional future climate impact assessment studies, as described in (Hughes et al, 2008).

4. Scenario Exercise on Moving Toward a Sustainable Energy Economy

A scenario set which combines some technological detail of the energy system with broader social trends within a qualitative framework is the Scenario Exercise on Moving Toward a Sustainable Energy Economy, by the Institute of Alternative Futures, Virginia, and the Institute for Innovation Research, University of Manchester

(IAF, 2004). Its scenarios stem from a pre-defined scenario template which contrast the following general scenario archetypes identified as most useful by IAF in its previous scenario work: business as usual, hard times, structural reconfiguration, visionary change. These were then refined with issues raised in previously existing scenario studies, to deliver a set reasonably familiar in its contrast of continued growth and ideologically inspired non-growth. This set was then populated with energy systems deemed to be associable with the broad priorities of each scenario: innovative technologies for the high growth based scenarios; demand reduction and decentralised energy for the localised, low growth scenarios. A form of 'back-casting' is conducted, to identify what trends would lead towards such scenarios- but these social trends remain relatively generalised (for example 'consumption, materialism... hold less appeal than today, as people find more satisfaction in family and community life'). Detail is added to these trends through the inclusion of 'way-markers'- some of which are quite specific (i.e., 'by 2018 fuel poverty is eliminated'; 'by the 2020s... high speed trains cut commuting times; 'new bio-fuels for aviation are developed and begin to get accepted on a wide scale by the 2040s'). It is notable though that it is the trends which provide the driving rationale for these developments- they are not in general argued as being the results of the activities of specific actors. As such, the events tend to be described as 'happening' to the scenario, rather than 'being made to happen'

5. Transitions to a UK Hydrogen Economy

The UK Sustainable Hydrogen Energy Consortium (UKSHEC) produced in 2005 a set of 'hydrogen visions' (Eames and McDowall, 2005). These had been developed through a process of iterative stakeholder engagement, with a view to exploring the various possible ways in which hydrogen stakeholders were envisaging the 'hydrogen economy'. This initially resulted in six 'visions', which whilst being technologically specific, were not fully quantified. These visions essentially contrasted the possible final uses of hydrogen (transport or stationary power), its mode of distribution (pipeline, trailer; gaseous, liquid, methanol) and its scale and method of production (large fossil, nuclear, distributed renewables). The visions were assessed by a range of 15 expert stakeholders from the hydrogen 'community' as well as from the energy industry and policy making communities more generally, using a process of 'Multi-Criteria Mapping' (McDowall and Eames, 2006a).

Subsequently the overlapping elements of the six visions were consolidated into a set of four, which were then each associated with a 'transition scenario'. This involved a back-casting approach which tried to identify in retrospect a plausible sequence of events through which the four scenarios could be brought about - including key technological breakthroughs, actions by government or private sector, and developments in other policy areas. This process located the new consolidated scenarios within a 2x2 matrix with high level drivers which represented something of a departure from the somewhat similar grids employed by IPCC, Foresight and UKCIP. The high level drivers were developed with reference to work produced by Berkhout et al (2004) which produced a categorisation of technological transitions. This work identified that technological transitions could be distinguished according to the degree to which they were 'co-ordinated' or 'intended', and the degree to which they were brought about by institutions already existing within the regime, or by actors taking on new roles (Eames and McDowall, 2006). These aspects provided the two axes for the consolidated hydrogen scenarios (Figure 3).

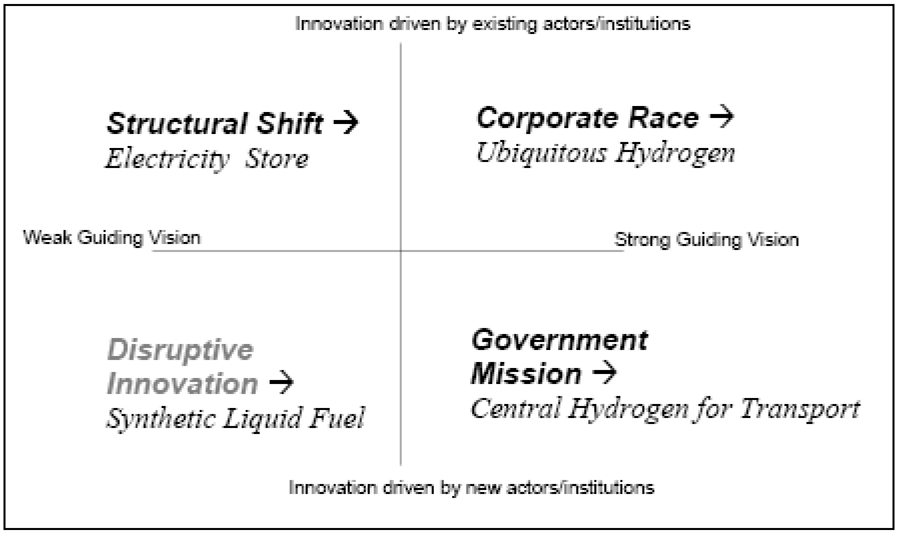


Figure 3: UKSHEC Transition Scenarios (Eames and McDowall, 2006)

Whilst the scenarios discussed the technologies which would be involved in each possible future, a detailed technical feasibility assessment was not part of the scenario development process (although a quantification exercise using the MARKAL model was undertaken at a later stage in the project (Balta-Ozkan et al., 2007)).

The approach taken for the UKSHEC transition scenarios was in many ways highly exploratory, and detailed in its wide canvassing of stakeholder views- although it was inevitably and intentionally constrained by its own terms of reference to focus on hydrogen futures. The process drew on a range of tools, perhaps most notably the MCM process which is an unusual feature among scenario processes reviewed in this paper (although the Tyndall scenarios were also subsequently subjected to a similar multi-criteria analysis process (Mander et al, 2008)). The scenarios are also explicitly grounded within a wider literature on socio-technical transitions, and are thus more detailed than most in their consideration of transition dynamics which lead towards the four futures, and take into account interactions between actors within government, private sector and society more generally.

6. Electricity Networks Scenarios for Great Britain in 2050

Electricity Network Scenarios for Great Britain in 2050 (Elders et al, 2006) is a set of scenarios designed to give more emphasis to the possible configurations of the electricity networks in the decades up to 2050. In doing so these scenarios address an issue of major importance, but which is significantly under-represented in other low-carbon energy scenarios. Several of the other studies reviewed in this paper report in some detail on the portfolios of generation technologies which will be required to meet certain energy demand levels, usually within certain carbon constraints. However, the question of what additional demands would be placed on electricity networks by such portfolios is almost entirely disregarded in most other studies.

It should be observed that these are not explicitly low carbon scenarios- carbon emissions of the system are not quantified, but it is clear that each scenario would be associated with different levels of carbon emissions. However the scenarios do suggest that the transformation of the electricity generation sector due to decarbonisation would be the strongest driver for a significant transformation of the electricity networks. This is for the following reasons:

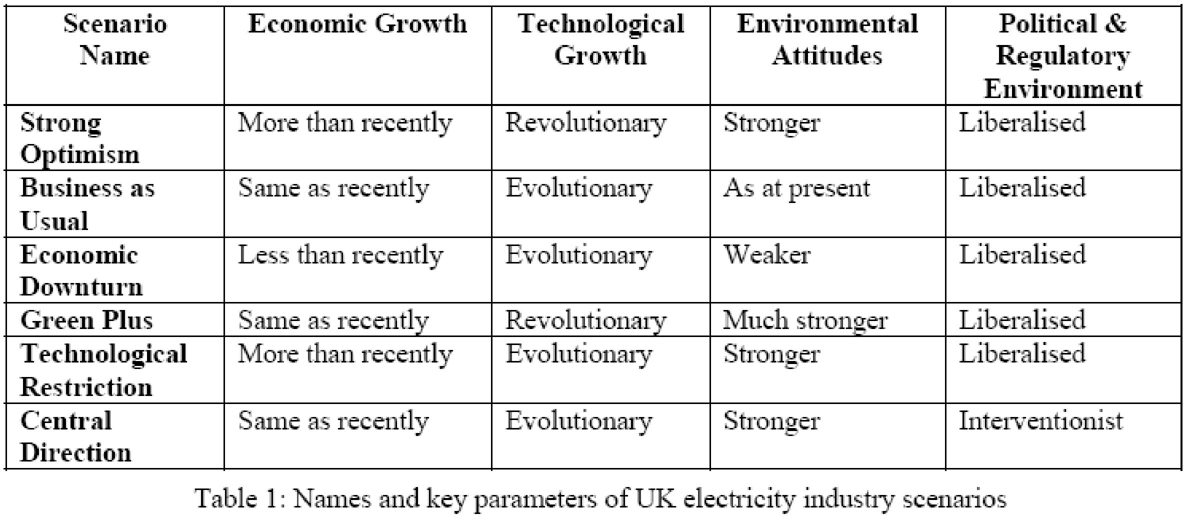
- the challenge of intermittent renewables and the possible need for electricity storage
- the overall increase in electricity demand due to increased electrification of sectors such as heat and transport, as a means to their decarbonisation
- the likelihood of low carbon electricity sources being located in different places to the current major generation sources, and of their being more distributed

The report states that a 2x2 axis approach, such as that employed by Foresight and other scenario studies, was experimented with at the early stages of the scenario development process. However, it was felt that this 'tended to encourage the consideration of technically uninteresting and mutually similar scenarios, while failing to adequately represent the diversity of issues of interest'. Instead, four key activities relating to electricity networks were identified: energy use, electricity generation, energy transportation, markets and regulation. Views of how such activities could evolve over the coming five decades were collated from a range of government and industry surveys and forecasts. This resulted in a number of 'partial scenarios', which were compared and elements of mutual similarity or redundancy identified. At various stages in this process opinions were sought from experts within the Supergen Future Network Technologies consortium.

The above process culminated in the identification of the following four key parameters, variations within each of which defined and differentiated the final scenarios:

- **Economic growth**- low or high
- **Technological growth**- revolutionary or evolutionary
- **Environmental attitudes**- weak or strong
- **Political and regulatory attitudes**- liberal or interventionist

The six scenarios are clearly shown to be derived from varying combinations of these parameters, in the following table from the scenarios report.



Scenario Name	Economic Growth	Technological Growth	Environmental Attitudes	Political & Regulatory Environment
Strong Optimism	More than recently	Revolutionary	Stronger	Liberalised
Business as Usual	Same as recently	Evolutionary	As at present	Liberalised
Economic Downturn	Less than recently	Evolutionary	Weaker	Liberalised
Green Plus	Same as recently	Revolutionary	Much stronger	Liberalised
Technological Restriction	More than recently	Evolutionary	Stronger	Liberalised
Central Direction	Same as recently	Evolutionary	Stronger	Interventionist

Table 1: Names and key parameters of UK electricity industry scenarios

Figure 4: Parameters of UK Electricity Network Scenarios (Elders et al, 2006)

These scenarios perform a valuable task in identifying the kinds of technical updates that could be required to be made to grids in order for them to be equal to the task of managing a low carbon generation portfolio. They deal with technical aspects such as electricity storage, Flexible Alternating Current Transmission Systems (FACTS), interconnectors, microgrids, distribution vs. transmission, DC vs. AC.

Though they are constructed around the four key parameters and resulting high-level trends, they also identify in broad terms some of the key actors who may be brought into play by such developments. There is some focus on electricity generation companies and consideration of their degree of vertical integration, and mention of the potential roles of new actors such as Energy Service Companies.

However, these mentions of actors are occasional and not underpinning. More often, developments are described in technical terms, within the context of the broad parameters outlined in Figure 4, but missing out the full specification of what actor actions make them happen. It is also notable that actor motivations are not precisely identified- what would motivate an actor to change its behaviour from that which it currently exhibits, to something approaching that described or implied by the scenario. Such actor-specific details are subsumed within the general high level tapestry established by the four key parameters.

Similarly, the operation of policy is represented at a general level, with few references to specific policies. There are developments mentioned within the narratives which imply some form of policy action. These are usually associated with one of the four high-level key parameters, which are used to characterise and contrast the scenarios. However, it is not clear what role policies have in relation to these- the extent to which policies can actually bring about such developments, or to which they are beyond the control of policy, with policy being required to adapt to them (for example, is the strengthening of environmental attitudes a phenomenon which policy can in part affect, or is it a largely external phenomenon, simply providing the limits within which environmentally focussed policy is able to operate?)

Though the scenarios describe evolutions away from the present networks towards alternative ones, these evolutions are not presented as a timeline or a contingent sequence of events. The focus is rather on presenting descriptions of completed and functioning electricity networks and generation systems. This perhaps under-emphasises questions of what needs to happen by when in order for certain kinds of networks to be brought into operation before 2050, and avoids of questions of lock-in and path dependency which could have the strongest effect on electricity sector investments- where each actor to a certain extent invests according to what it expects from other actors.

Relatively little space is devoted to drawing insights and conclusions from the scenarios. The scenarios are presented as possible futures, though the report refrains from drawing explicit implications for near term decisions. However, it is noted in the report that an important subsequent outcome for the scenarios would be to provide a basis on which to run models to explore and test further aspects of the network scenarios, such as their cost, reliability and CO2 emissions reductions.

Perhaps the major conclusion of the study is a more general one- that the kind of electricity networks that would be required to support the extent of decarbonisation hoped for by UK national targets, would almost certainly be significantly changed from those of the present day. Exactly how such change is to come about, when, and led by which actors are also key questions, but questions provoked by this report, rather than addressed within it.

7. Electricity Networks Scenarios for Great Britain in 2050 (LENS Project)

This project developed scenarios designed to explore potential future implications for electricity networks in the UK, and represented these within the MARKAL MED model. It elected not to pre-constrain any of the futures according to carbon reduction targets, but to take a more exploratory approach to identifying a number of themes which would be of particular relevance and impact on the electricity networks in the UK. Following extensive consultation with electricity network stakeholders, facilitated by Ofgem, the most important themes were identified as:

- extent of environmental concern
- active / passive behaviour of electricity consumers
- institutional governance - government intervention or market led

These themes were integrated in a comparable way to the 2x2 axis approach, except that the additional theme resulted in a '3-dimensional' matrix. The resulting 8 possible scenarios were reduced to 5 based on considering the consistency and plausibility of the different combinations of the three themes, as well as with some consideration for adequate contrast within the set. The combinations of each theme were then developed into scenario storylines which explored the potential pathways through which such futures could evolve from the present, with key 'way-markers' identified at 2025.

This project was unusual in comparison to the other studies in this section, in that it employed an energy systems model. Therefore there would clearly be a case for locating it in the 'modelling studies' section of this review. However, the study differed from most modelling studies, in which the scenarios are entirely defined by the quantitative outputs of the model. In this case, detailed qualitative scenarios were developed prior to any modelling work, and it was the scenarios which led the construction of the model. This led to some challenges, as the model results did not precisely replicate the scenario descriptions. However, differences where they emerged were not modified, but highlighted as points of comparison between the alternative quantitative and qualitative 'perspectives', and thus became part of the analysis.

2.2. Summary of trend studies

Table 2 outlines a summary of the 'trend' studies reviewed[4].

Table 2: Summary of Trend Studies

Scenario	**How were trends identified?**	**Key Trends**	**Technological detail**	**Quantification**
Nakicenovic et al (2000)	Review of other scenarios and projections	Demographic change, social and economic development, technological change	Significant technological detail in energy and other sectors, including land use change	Provided by 6 IA models delivering 40 quantified 'scenarios' grouped within the four families
Berkhout et al (1999)	Review of other scenarios	Consumerist vs. community values; globalisation vs. regionalisation	Minimal	None
UKCIP (2000)	Review of other scenarios	Consumerist vs. community values; interdependence vs. autonomy	Minimal	Sets of quantified indicators provided for economic development, population, housing, land use, water demand and other indicators.

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[4] Note headings of tables 2-4 are intentionally not consistent due to the different parameters operating within each category of scenario study. Comparison across the three types of scenario study is provided by Table 5.

				Derived by modifying BAU projections
IAF (2004)	Review of other scenarios, and IAF scenario 'archetypes'	Economic growth, technological development, community vs. consumerist values	Descriptive references to innovative technologies in high growth scenarios, e.g. high speed trains, biofuels for aviation etc	None
Eames & McDowall (2006)	Review of other scenarios, stakeholder workshops, and technological transition literature	Strength of 'guiding vision'; extent to which transition is driven by existing institutions or new ones	Descriptions of key hydrogen technologies, e.g. electrolysis, liquefaction, fuel cells, pipelines, methanol	None, though scenarios were later represented in MARKAL
Elders et al (2006)	Review of other scenarios and expert consultation	Economic growth, technological change, environmental attitudes, regulatory attitudes	Fairly detailed descriptions of novel network enabling technologies e.g. FACTS, HVDC, microgrids, etc	Approximations of total and relative generation capacities, and electricity demand levels
Ault et al (2008)	Review of other scenarios and stakeholder workshops	Environmental concern, active or passive consumers, regulatory approach	Fairly detailed descriptions of novel network enabling technologies	Approximations of total and relative generation capacities, and electricity demand levels, the tested in MARKAL

One aspect brought out by Table 2 is the somewhat similar sources for identifying high level trends to be used in the scenarios. As all studies include a review of other scenarios in this process, there is inevitably some cross-referencing, which it might be observed leads to somewhat similar trends dominating in many of the studies. However, new themes have notably emerged from electricity network focussed scenarios, with their particular consideration of technical network issues and consumer interactions, as well as in the UKSHEC scenarios which drew on technological transitions literature in formulating their trends.

The studies involve differing degrees of quantification and technological detail. Some speculate descriptively as to the kinds of technologies that could be involved. It is interesting that this often involves assumptions which associate particular technologies with particular high level trends or values- for example distributed generation technologies tend to be associated with scenarios characterised by a broad trend of 'community' values. It hardly needs to be said that there is nothing inherently contradictory about the valuing of social communities and a centralised generation system. However, a scenario approach built around high level trends has a constant tendency to make such implicit associations.

Inevitably, trend-based studies attach major system changes to a limited number of generalised trends, which both define the characteristics of the scenarios (trend x is a characteristic of this scenario, necessitating the inclusion of event y), and provide the justification for the plausibility and consistency of the scenarios (event y is plausible and consistent in a world characterised by trend x). The reliance on broad trends as both generators and justifiers of events can result in a kind of circular logic. This can risk undermining the strategic effectiveness of the scenarios, as events are frequently not related to behaviour and actions of actors, or to the operation of policy.

3. Technical Feasibility Studies

Technical feasibility studies are perhaps the most novel contribution of low carbon energy policy to the ever-widening pool of scenario approaches, and therefore, perhaps, the most recognisable as a distinct and new category. Though broadly recognisable under the general concept of a 'backcasting' approach, they attempt to bring particular focus to two particularly pressing aspects of the low carbon transition- the need to reach a carbon reduction target, and the need to identify technologies which can supply energy within that constraint. Put quite simply, the approach is to hypothesise a future level of energy demand, and then to populate an inventory of future technologies which will have the physical and technical capacity to supply that demand, often within an exogenously imposed carbon constraint. The approach has been applied to the whole energy system as well as to parts of it. The approach currently appears to be quite distinctively UK based; all the studies reviewed were prepared with direct reference to the UK. This may be because the UK policy discourse has been particularly dominated by the idea of long term, high level emissions reductions targets. '60% by 2050' was first proposed by the RCEP study reviewed below, and subsequently adopted in the government's Energy White Paper of 2003. Following updates in the projections of climate scientists, a target of 80% by 2050 began to be discussed as more appropriate, and was accepted in the UK's Climate Change Act of 2008. It is noteworthy that all of these studies set out and justified the emissions reduction targets selected for their scenarios with some reference to the context of these policy developments. Moreover, some selected targets which were more stringent than contemporary government policy thinking, were subsequently adopted by the government. It is worth noting therefore that the production of such studies is likely to have assisted in the establishment and subsequent revisions of the UK Government's high level emission reduction targets.

In order to demonstrate the 'technical feasibility' of their scenarios, authors in general employ high levels of technological and quantitative detail. In some cases the tool used to manage and manipulate this data is referred to in the reports and in this review as a 'model'. However, these studies, which are mostly characterised by relatively simple and controlled manipulation of data within an accounting or spreadsheet tool, are differentiated from the modelling studies reviewed in the following section which are generally more complex in their underlying formulae, economic and cross-sectoral interactions.

The technical feasibility studies are reviewed in three sub-sections, whole system, technologically normative, and demand-side focussed technical feasibility studies. The distinctions between these three sub-categories will become apparent in the discussion.

3.1. Descriptions of whole system technical feasibility studies

Whole-system technical feasibility studies aim to demonstrate long term CO_2 reductions across the 'whole' energy system- although differences emerge in the boundaries chosen for this system, as will be discussed.

8. Energy- The Changing Climate

In many ways a benchmark study for this approach was the report of the Royal Commission on Environmental Pollution, Energy - The Changing Climate (RCEP, 2000), which was highly significant in its influence on subsequent studies in at least two ways. First, it firmly established the proposed target of (at least) 60% reduction of UK carbon emissions by 2050 in the UK's environmental and energy policy discourse; this target was based on a calculation of the UK’s fair contribution to achieving a stabilisation of atmospheric concentrations of CO_2 at 550 parts per million, under the principle of global ‘contraction and convergence’ (Meyer, 1997). This 60% target gained almost axiomatic status in the UK energy policy debate in the years that followed, becoming a guiding principle for most of the scenario studies reviewed here, as well as for key government policy papers (BERR, 2003; 2007). The RCEP report was also significant in that it established an approach to energy scenarios, based on defining assumed levels of future energy service demand and drawing up a number of lists of supply technologies which would have the technical capability to meet these demand levels within an exogenously defined carbon constraint - an approach which in one form or another has been dominant in UK energy scenarios since.

The RCEP report considers four scenarios with differing levels of energy service demand, in order to assess the portfolio of technologies required to meet each case. In Scenario 1, energy demand remains at 1998 levels; in Scenarios 2 and 3 demand is reduced by 36%; in Scenario 4 it is reduced by 47%. The study finds that to maintain demand at 1998 levels in Scenario 1, a portfolio of renewables will have to be augmented by either nuclear power or carbon capture and sequestration (CCS). In Scenario 2 the lower demand means that the target can be met through a renewables portfolio with some fossil fuels but avoiding nuclear power and CCS. Scenario 3 on the other hand will require nuclear or CCS to boost the renewable resource, despite being the same demand as Scenario 2 - this is because this scenario avoids the construction of the Severn Barrage. Finally, Scenario 4 is dominated by renewables with significantly lower demand obviating the need for nuclear or CCS.

The RCEP study examines the trade-offs involved in various combinations of more or less controversial technologies and measures in achieving a single goal. The kind of information it is giving is to demonstrate how the absence of any element may necessitate the presence of another. Messages such as ‘if demand remains high and nuclear power stations are not built, CCS is essential’; and ‘if both nuclear and CCS are unacceptable, then significant demand reduction will be required to meet the target’, are what emerge from this study.

9. Decarbonising the UK- Energy for a Climate Conscious Future

The Tyndall Centre Report Decarbonising the UK- Energy for a Climate Conscious Future (Anderson et al, 2005), is also at heart a technical feasibility study. It uses a sectorally disaggregated spreadsheet model, to conduct detailed assessments of technical and physical potentials for contribution to the energy supply and demand balance of the UK, in order to meet a pre-defined end point constraint - once again the 60% reduction by 2050. It considers changes in energy demand, through behaviour change and energy efficiency, as well as the availability of supply side technologies. However, the scope of the energy system it examines is wider than that of the RCEP study, as it includes the UK’s share of emissions relating to international aviation.

Having produced five technical descriptions of UK energy systems in 2050 which would reduce carbon emissions by 60%, the next step was to identify the socio-economic drivers which could deliver those systems. It is this process of cladding a purely technical depiction of an energy system with socio-economic detail which is referred to by the report as 'backcasting'. 'Critical factors’ required for a particular end point to be achieved, were identified, including changes in ‘technologies, values, behaviours, infrastructure, or other physical or social variables...'. However, policy instruments were not considered amongst these 'critical factors', as ‘the back-casting process is specifically intended to determine what policy and other mechanisms would be needed to arrive at a particular end point, rather than what outcomes would result from current policies.’

The back-casting process succeeds in identifying some detailed descriptions of technological developments, social trends, and despite the avoidance of describing specific policy measures, some general policy trends are indicated (e.g., 'CCS is strongly promoted'; 'policies to encourage the production of hydrogen are in place by 2020'). The back-casting process extends to very close to the present day, with way-markers identified in 2015 and 2010. However, despite the relative temporal proximity of these scenario events, the descriptions still do not directly link up to the present day - they do not show how policies, institutions, and trends in evidence now can evolve into those described as happening, even in 2010. This means that despite the technical and temporal detail, the descriptions still read to a certain extent like a list of assumptions- certainly in many ways an attractive list, and by no means implausible- but lacking a strategic power that relates these assumptions to our present day actions. In spite of the back-casting process, the greatest detail is reserved for the end point descriptions. Additionally, whilst it is entirely valid that policy recommendation should be an output of the report; this does not necessarily justify the exclusion of specific policy measures from the set of critical factors. In reality there is a dynamic and iterative relationship between policy and all the critical factors mentioned above. Strong policy may bring about a change or improvement within one critical factor; this change in that factor may itself alter conditions such that even stronger policy is subsequently more politically feasible than it would have been.

3.2. Descriptions of technologically normative technical feasibility studies

The technical feasibility approach is a highly normative one, in which typically each scenario successfully meets a carbon reduction target, exogenously imposed from the outset. Within this constraint the above two studies are essentially technology neutral, the mix of technologies selected in each scenario reflecting authors' assumptions about the character of that scenario, not a value judgement on the authors' part about the acceptability of any particular technology. Some studies however employ the technical feasibility approach with highly normative constraints relating to the explicit and conscious avoidance of particular technologies. Sometimes such constraints are additional to a system-wide carbon constraint. Such studies aim to demonstrate the lack of need within the energy mix for these undesired technologies, by demonstrating the technical feasibility of reducing carbon emissions without them. All four of the studies reviewed below were undertaken in 2006 in the context of the UK Government's Energy Review of the same year, which had been specifically tasked to investigate the prospects for nuclear power in contributing to decarbonisation of the electricity sector.

10. The Balance of Power- Reducing CO_2 Emissions from the UK Power Sector

A study commissioned by WWF from ILEX Energy Consulting, The Balance of Power- Reducing CO_2 emissions from the UK Power Sector (ILEX, 2006) was intended to feed in to the 2006 Energy Review with the explicit purpose of demonstrating the feasibility of achieving carbon reduction targets by the year 2025 without the building of a new generation of nuclear power stations. The results are generated by ILEX's GBGen model, an Excel based tool designed to simulate investments and plant operation by companies in electricity markets.

The report presents three scenarios, each pre-constrained to allow for no new nuclear build, and each relying on essentially familiar technologies, with no assumptions of major technological change. A 'Business as Usual' scenario assumes the continuation of existing policy measures with the current likelihood of success. It delivers power sector CO_2 emissions reductions of 18% below 1990 levels by 2025. A 'Policy Delivered' (PS1) scenario assumes the successful delivery of existing policy measures and targets, and delivers power sector emissions reductions of 43%. A 'Policy Evolution' (PS2) scenario allows the successful implementation of new and ambitious policy measures, and delivers power sector CO_2 reductions of 55% by 2025.

Though the model is intended to simulate rational investment behaviour by electricity generation companies under different policy regimes, the assumptions as to the strength of political will which underlie the implemented policies are sometimes substantial. In particular, the Renewables Obligation is assumed to rise to 20% and 25% by 2025 in PS1 and PS2 scenarios respectively; and government action on energy efficiency is assumed to reduce electricity demand, resulting in lower electricity bills for consumers in PS2 than in BAU.

11. Decentralising UK Energy

Decentralising UK Energy (WADE, 2006) was commissioned by Greenpeace from the World Alliance for Decentralised Energy (WADE). The results are derived from WADE's own economic model which is designed to compare costs and impacts on CO_2 reduction of centralised and decentralised portfolios. The technology mixes which characterise the different scenarios are defined entirely by the model users, according to broad storylines which are attached to each scenario. Each scenario runs from 2003 to 2023. Two 'baseline' scenarios contrast the assumption that a new generation of nuclear plants begins to come on-stream from 2018 and that subsequently all new generation is centralised, with the assumption that no new nuclear is built and that 75% of future generation capacity is decentralised. Two further 'Greenpeace' centralised and decentralised scenarios assume rapid deployment of renewables, demand reduction and energy efficiency in each case, and further sensitivities test the impact of altered assumptions around fossil fuel prices.

Major conclusions of the report are that decentralised systems can reduce CO2 emissions by a greater amount and at a lower cost than centralised systems. The baseline decentralised scenario achieves 17% lower CO2 emissions over the 20 year period than the baseline centralised and nuclear scenario, as well as a slight cumulative cost reduction of £1.4 bn. The 'Greenpeace' decentralised scenario (with additional measures on demand reduction, renewables, and energy efficiency) achieves 30% emissions reduction compared to the centralised nuclear baseline scenario, with a cumulative cost reduction of £18 bn. Due to greater efficiency of small scale CHP the decentralised scenarios also reduce dependence on imported fossil fuels.

Some key assumptions are inherent in the analysis. One is that in the baseline nuclear / centralised scenario, new nuclear plants do not begin to become available until 2018, resulting in large scale gas generation being constructed to fill the looming energy gap, resulting in a system which is in fact gas dominated. Others relate to the costs which are included- the model incorporates the costs of decentralised systems relating to transmission losses and costs of network upgrades, however it is unclear from the report the extent to which infrastructure costs of decentralised energy, for example investment in distribution networks, new connections for renewables and the installation of heat distribution networks, are also included.

12. A Bright Future: Friends of the Earth's Electricity Sector Model for 2030

A Friends of the Earth Report, A Bright Future: Friends of the Earth’s Electricity Sector Model for 2030 (FoE, 2006) also aims to illustrate the feasibility of significant decarbonisation of the power sector in the absence of new nuclear build, this time looking out to 2050. It employs a customised model to represent six scenarios characterised by broad bands of technologies, and by strength of policy. In technology terms the scenarios are differentiated according to whether their large scale thermal generation capacity is gas dominated, coal dominated, or a mix. In policy terms a distinction is made between 'good progress' and 'slow progress' in respect of low carbon electricity generation policy. The range of CO_2 emissions reductions from the electricity sector by 2030 across the scenarios is 48-71%.

The generation portfolios developed by each scenario are manually controlled by the model-users according to their assumptions about likely levels of deployment of different technologies derived from the general scenario drivers of policy strength and general balance of preference between coal and gas. There is no consideration of investment strategies of generation companies, policies are largely unspecified and therefore the political will and public acceptance that would underlie them is unexplored. The prominence of CHP reflects the low specific emissions level attributed to it, 'to illustrate the full efficiency benefits of this technology in the electricity sector.' Clearly this is a simplification as the efficiency benefits of CHP are due to its working across electricity and heat sectors. Representing this benefit as actual reductions in emissions in the electricity sector could be misleading, particularly in very low emissions scenarios. Such cross-sectoral interaction is hard to capture in sectorally focussed approaches of this kind.

13. Powering London into the 21st Century

A report commissioned from consultants PB Power by the office of the Mayor of London and Greenpeace, Powering London into the 21st Century (PB Power, 2006), considers how emissions associated with the heat and electricity demands of all buildings in Greater London may succeed in being reduced in the context of a centralised nuclear dominated system, versus a decentralised system. Two scenarios assume centralised national electricity and heat systems system, one with no nuclear plant replacement, and one with a high rate of replacement. A further two scenarios assume no nuclear replacement with different assumptions on decentralised technologies- Low DE assumes the roll out of decentralised technologies is restricted to 'technically proven' sources, mainly gas CHP, whereas High DE allows more decentralised technologies 'currently closer to the limits of technical constraints'.

It is found that only the decentralised systems are successful in meeting a target in 2025 which is commensurate with a 60% reduction by 2050. The Low DE scenario achieves a 27% reduction in emissions from London buildings' heat and power compared to 2005 levels, and the High DE scenario achieves a 33% reduction. Both decentralised scenarios maintain a central role for gas CHP and assume major policies on retrofitting existing buildings and tough standards on new buildings, as well as the construction of district heat networks.

3.3. Demand-side focussed technical feasibility studies

The studies reviewed thus far have mainly applied the technical feasibility approach to supply-side decarbonisation, either with a whole system view or focus on the heat and power supply. Other studies have taken a similar technical feasibility approach but explicitly applied it to considering the potential for demand-side changes.

14. Technical Feasibility of CO_2 emissions reductions in the UK housing stock

An exploration of the Technical Feasibility of Achieving CO_2 Emissions Reductions in the Excess of 60% within the UK Housing Stock by the Year 2050 (Johnston et al, 2005) uses the BREHOMES model, a 'selectively disaggregated physically based bottom-up energy and CO_2 emission model of the UK housing stock' to generate scenarios exploring the potential for carbon reduction within the housing sector. To preserve transparency in the model, the housing stock is divided into only two types of dwellings, representative of pre- and post-1996 construction. Other aspects of the model use high levels of technical detail. Data on number of households, dwelling size, insulation and ventilation characteristics, occupancy details and energy demands, including accounting for effects of global warming, are fed into the model, to deliver information on energy use and CO2 emissions scaled up to the level of the whole UK housing stock.

The input data were organised into three scenarios. A business as usual scenario envisages 'continued trends in building fabric performance, end-use efficiencies and the carbon intensity of electricity generation'. A 'Demand Side' scenario imagines that strong concern for reducing CO_2 emissions at both the UK and EU levels, combined with the success of some housing demonstration projects, leads to a strong and ambitious focus on improving demand side efficiency, though supply side carbon intensity remains as in the business as usual scenario. An 'Integrated' scenario assumes the same ambitious demand side measures as in 'Demand Side', but also postulates significant progress in decarbonisation of electricity generation. These broad storylines are used to produce intuitively derived quantitative indicators as inputs into the BREHOMES model, to generate each of the scenarios.

Each of the scenarios achieves reductions in the CO2 emissions of the housing stock compared to 1990 levels: BAU by 37%, Demand side by 61%, and Integrated by 67%. The study is able to achieve significant levels of technical detail due to its use of a customised, sectorally specific model. These details provide the possibility of highlighting specific technology related policy measures. Insights include, that space heating will continue to be factor in household CO2 emissions in 2050; that external insulation of existing solid wall dwellings is necessary to achieve large CO2 reductions if large-scale demolition is to be avoided; and that the very highest CO2 emissions reductions (including up to 80%) are likely to require a strategic shift away from the use of natural gas for space and water heating, and towards the use of electricity based technologies such as heat pumps, in combination with a decarbonised electricity system.

15. 40% House

The Oxford Environmental Change Institute’s 40% House study (Boardman et al, 2005) is also focussed on the demand side. It explores the potential for 60% reductions in the housing sector through a survey of the potential contributions of the range of current and near term technologies. It is unusual in that it focusses on developing just one scenario (the '40% House Scenario') which is based on the one hand on mid-range assumptions of population growth, housing and occupancy trends, and on the other on strong implementation of policy measures to implement technology uptake across existing and new-build stock. The scenario is quantified using a custom built housing sector emissions model, the UK Domestic Carbon Model (UKDCM).

One of the most striking aspects of the 40% House scenario is that it does not assume that grid electricity will have reduced its carbon intensity at all. As a result, by 2050 the UK housing stock does not draw any grid electricity, though it is still heavily dependent on gas for CHP. However, every house is installed with small scale low carbon generation technologies, which mean that the housing stock becomes a net exporter of electricity to the grid.

Strong policy action underpins all the assumptions in the scenario, with ambitious measures on existing stock including the insulation of 100% of all cavity walls and lofts, and 100% of windows to be 'high performance'. 14% of the current stock is also required to be demolished. Significant social changes are also required, as the 40% House scenario assumes modest future energy demands- a continuation of current trends of energy demand growth would not allow the 40% house targets to be achieved.

3.4 Summary of technical feasibility studies

Table 3 summarises the technical feasibility studies reviewed in this section[5].

Table 3: Summary of Technical Feasibility Studies

Scenario	**Primary exogenous constraint[6]**	**Additional exogenous constraint**	**Sectors covered**	**Treatment of socio-political dynamics**	**Treatment of economics**
RCEP (2000)	60% by 2050	-	All major domestic demand sectors	Minimal	None
Anderson et al (2005)	60% by 2050,	-	As above plus international aviation and shipping	Broad social trends and policy dynamics inferred from technical configurations, though specific policies not specified	None
ILEX (2006)	No nuclear	-	Electricity sector	Simplistic- scenarios are distinguished by assumptions about strength and success of policies, but do not explore iterative socio-political dynamics	Model simulates investment and deployment decisions in electricity markets, but wider economic impacts not explored
WADE (2006)	Nuclear dominated vs. no nuclear and	-	Electricity sector	Minimal- the contrasting scenarios are constructed in	Cumulative electricity system costs are

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[5] Note headings of tables 2-4 are intentionally not consistent due to the different parameters operating within each category of scenario study. Comparison across the three types of scenario study is provided by Table 5.

[6] In all cases, '60% by 2050' refers to energy related CO_2 emissions, compared to a base year of 1990

	highly decentralised scenarios are compared			technical terms only	calculated and compared
FOE (2006)	No nuclear	-	Electricity sector	Assumptions about strength and speed of policy interventions drive availability of technologies	None
PB Power (2006)	Nuclear vs decentralised scenarios compared		Heat and power demand of buildings in London	Minimal	None
Johnston et al (2005)	60% emissions reduction by 2050 in UK housing stock		All emissions of UK housing stock	Assumptions about focus of UK policy on supply vs. demand side are varied between scenarios	None
Boardman et al (2005)	60% emissions reduction by 2050 in UK housing stock	No decarbonisation of energy supply	All emissions of UK housing stock	Integrated assumptions about very strong policy measures and social changes which produce significant demand reduction	None

It is clear from a review of Table 3 that, perhaps unsurprisingly, the focus of technical feasibility studies is on the physical configuration of the energy system. It is clear on reading these studies that such novel configurations will not be able to assemble themselves autonomously but will require strong policy and institutional frameworks, which in turn require appropriate levels of social acceptance. However, in the above studies such socio-political dynamics are in general given minimal exploration. In some of the studies interpretations of the physical systems in socio-political terms are made as a subsequent step, though these frequently return to quite broad and generic trends, rather than specific steps or measures. Specific policies are generally absent from the scenario descriptions, although some of the studies employ very general indications of 'strong' or 'weak' policy. In some cases major assumptions about cultural or social changes are made, often to generate contrasting assumptions about future reductions in energy service demand- however these remain largely as stated assumptions, with little exploration or justification as to how such trends would in reality come about. In particular, the use of an exogenous applied directly to the technical energy system imposes an unrealistic inevitability of this technical target, diminishing the social and political changes which would be required to support it.

In summary, though several of the studies touch on the social and political contexts which could be associated with the physical infrastructures they describe, this is always as a secondary stage, or ex post analysis of the physical depiction. No studies capture the iterative dynamics of policy, technology and social acceptance and behaviour change, as simultaneously changing and co-evolving, which would permit a more accurate depiction of how technological systems are in reality constructed over time.

4. Modelling studies

The modelling approaches discussed in the following section in many ways serve similar purposes to the technical feasibility studies described above, as they are able to provide depictions of energy system supply mixes which will meet certain energy service demands, again, usually within a system-wide carbon constraint. Due to stronger computing power than the largely customised spreadsheet tools of the studies reviewed in the previous section, modelling studies are usually able to employ even greater levels of technological detail, with some also able to express wider economic issues and global energy resource dynamics. Several of the studies described below use optimisation models, which in general optimise for the system-wide least-cost solution, within the constraints and inputs given. Whilst it is by no means an unreasonable objective to seek to achieve objectives at least possible cost, it must be acknowledged that this particular optimisation process introduces another uncertainty alongside those already discussed in preceding sections, that of trying to make comparative assessments of future costs of technologies and resources. The highly significant effects of small changes in cost assumptions, well within margins of error, upon final optimal solutions, is frequently one of the most hotly debated issues thrown up by studies whose scenarios are generated by economic models. An approach to account for the significant effects of such critical assumptions is to conduct wide-ranging sensitivity analyses- however such approaches to begin to resemble less and less a 'true' scenario process, at least in terms of the literature described in Hughes (2009).

4.1 Descriptions of modelling studies

16. UK MARKAL (Energy White Paper and other work)

In the UK, the MARKAL family of energy systems models has played an iterative role in providing analytical underpinning into all recent major energy policy reviews. An initial analysis using a simplified version of UK MARKAL provided details of low carbon technology pathways in the 2003 Energy White Paper (BERR, 2003). An enhanced, more detailed MARKAL model was subsequently developed and included the development of a general equilibrium version (MARKAL-Macro) to provide additional macroeconomic insights, and an aggregate behavioural response, both areas that policy makers considered important for gaining further insights from this type of modelling. This model was used to provide analytical underpinning for both the 2007 Energy White Paper (BERR, 2007) as well as the regulatory impact assessment of the draft Climate Change Bill (DEFRA, 2007).

As a body of work, these modelling-scenario exercises, as reported in Strachan et al (2007) provide a classic example of sensitivity analysis with a very wide range of runs (>100) focusing on the key inputs including technology costs, resource prices, behavioural responses, societal decisions on technology classes, international drivers such as innovation and emissions trading, and policy options. Within these sensitivity-scenarios, the key robust insights are firstly that all sectors contribute to mitigation efforts, with trade-offs between resources and infrastructures and between technology vs. behavioural responses. Secondly the electricity generation sector has an early and key role to play in decarbonisation efforts, with transport transitions and diffusion of buildings conservation measures also important. Thirdly, these radical energy system decarbonisation targets require a consistent and high CO_2 price signal (>£200/tCO_2 for an 80% reduction, with GDP costs similar to the published literature of 1-3% (Stern, 2007).

Ongoing work on model-scenario studies with the UK MARKAL model family is focused on consistent depiction of scenarios, and on identifying and quantifying uncertainty.

17. Energy 2050

Energy 2050 is a project being undertaken within the UK Energy Research Centre (UKERC, 2009). It aims to use a scenarios format to explore a number of technical questions relating to how the energy system could perform under various combinations of policy and societal imperatives. The model employed is the UK MARKAL Elastic Demand (MED) model – this retains technological detail across the energy systems and adds a detailed behavioural response to price changes, albeit at the loss of insights into macro-economic impacts.

Its set of 'core' scenarios is derived from a 2x2 axis focused on low carbon and energy resilience: in this case rather than exploring values which define the scenarios, the grid defines what are felt to be the key policy imperatives which the scenarios must respond to: carbon reduction and security of supply. The core scenarios are then further explored through a number of variants which place additional requirements on the system: these include behavioural lifestyle drivers, global energy markets, technological change, carbon reduction ambition levels, and limitations on generation capacity due to environmental impact, or so called 'NIMBY' concerns.

Whilst the scenario 'storyline' development aspect of all of these assumptions is receiving careful attention, the project is strongly oriented to producing model inputs to generate model runs, for the purpose of conducting analyses with high levels of quantified detail, including sectoral contributions to CO_2 mitigation effort, economic impacts, and the effects of changing key economic assumptions such as discount rates.

18. Japan scenarios and actions towards low carbon scenarios

A national energy scenario study for Japan by the National Institute for Environmental for Environmental Studies (NIES) illustrate the feasibility of very deep (–70%) long-term carbon reductions in Japan (Fujino et al. 2008). Two scenarios were developed to achieve 70% reduction in CO_2 emissions from Japanese economy by 2050:

- Scenario A: an active, quick-changing, and technology-oriented society, with an annual growth rate of per capita GDP of 2%.
- Scenario B: a calmer, slower, and nature-oriented society, with annual growth rate of per capita GDP of 1%.

These two narrative scenarios were developed through expert engagement, albeit with a back-casting view of long-term low carbon societies (LCS). A linked set of models then quantified socio-economic drivers into energy service demands, then into patterns of energy use and innovation (particularly in the buildings and transport sectors) and then into macro-economic costs of the transitions. Strategies for realizing LCS include three key elements: demand reduction through structural transformations to reduce energy service demands; development and deployment of energy-efficient technologies; and decarbonisation of energy in the supply-side.

Scenario A showed that key decarbonisation routes are energy efficiency options in demand-side, such as implementation of energy-efficient appliances in the industrial, residential, commercial and transportation sectors, and fuel-switching options from conventional energy sources to low carbon energy sources, such as nuclear power and hydrogen. The macroeconomic cost is 0.83–0.90% of GDP in 2050. Scenario B showed that the use of low-carbon energy, such as biomass and solar energy, in demand-side, would result in drastic reductions of CO_2 emissions. The macroeconomic cost is 0.96–1.06% of GDP in 2050.

Although CO_2 reductions vary by sector, both scenarios share many policy and technology options:

- No-regret investments, which reduce energy costs and are profitable.
- R&D activities for such technologies that yield desirable outcomes for society.
- The technology options that take long periods of time for implementing, such as hydrogen, nuclear power and renewable-based energy systems, require early and well-planned strategies with consideration of uncertainties.
- A clear low carbon goal setting process by government

This scenario illustrated the combination of qualitative and quantitative techniques to investigate consistent visions of low carbon energy futures. With exceptions (e.g., Strachan et al., 2008), this scenario process has generally not been carried out for UK energy modelling studies as discussed below.

19. World Energy Outlook

The International Energy Agency (IEA) has two flagship publications. The first of these - the World Energy Outlook (IEA, 2008a) - undertakes exploratory scenarios analysis of possible global energy futures, based on national government expert's expectations and then quantified using a simulation model of the global energy system. As such it is heavily routed in present thinking about energy trends and quantified using historical data on key variables and relationships.

WEO's two main scenarios are firstly a Reference case which extrapolates current government policy, energy service demand trends, current technology innovation etc, to project prices and quantities of energy use. Such extrapolations are generally pessimistic in the supply side implications of meeting very large energy demand growth, especially from developing countries. The Alternate Policy Scenario then maps on the impact of currently planned governmental police and investigates the role of increased fiscal and technology policies to meet the challenges of expended energy supply, energy security and climate change mitigation. Such a scenario illustrates the magnitude and difficulty in achieving long-terms energy policy goals with the existing portfolio of measures

20. Energy Technology Perspectives

The second flagship publication of the IEA - Energy Technology Perspectives (IEA, 2008b) -is comparable to the UK MARKAL approach in that is employs a model optimising within a system-wide carbon constraint. This publication utilises a global optimization model (IEA-MARKAL), to find least cost strategies for the long term (to 2050). Scenarios investigated are a reference case, a moderate carbon price case and a stringent carbon reduction (-50% from 2000 levels) designed to correspond to a global climate mitigation target. The model runs are heavily based on IEA's WEO expert stakeholder assumptions and focus on technologies and demand side technical measures.

21. World Energy Technology Outlook

The European Commission's World Energy Technology Outlook (European Commission, 2005), in contrast to the carbon constraint-driven approach employs an exploratory energy modelling-scenario approach. As with the ETP, this publication utilises a global model, but in this case it is an integrated world energy sector simulation model (POLES) which elaborates long-term energy supply and demand projections for the different regions of the world under a set of consistent assumptions concerning, in particular, economic growth, population and hydrocarbon resources.

The WETO study developed a Reference projection of the world energy system to test different scenarios for technology and climate policies through 2050. Variant scenarios are considered notably a carbon constraint case and hydrogen-economy scenario. This latter scenarios considers alternative technological and socio-economic pathways that illustrate possible ways of incorporating hydrogen into the world energy system. It implies a certain number of technology breakthroughs to make hydrogen technologies, mainly on the end-use side.

4.2 Summary of modelling studies

Table 4 summarises the modelling studies reviewed in this section[7].

Table 4: Summary of Modelling Studies

Study	**Exogenous constraints**	**Sectoral coverage**	**Technological detail**	**Treatment of socio-political dynamics**	**Treatment of economics**
Strachan et al (2007)	UK Energy system CO_2 constraint (60 or 80%)	All domestic UK energy demand sectors	High detail particularly in electricity generation, transport and residential sectors, less in industry and agriculture	Limited- model driven by carbon constraint and cost optimisation	Micro and / or macro-economic issues depending on model variant. Insights include estimated required carbon price (£200/tCO_2 for 80% reduction) and GDP costs in range 1-3%)
UKERC (2009)	UK Energy system CO_2 constraint (60 or 80%)	All domestic UK energy demand sectors	High detail particularly in electricity generation, transport and residential sectors, less in industry and agriculture	Minimal in core scenarios, 'variant' scenarios explore potential effect of social objections to energy technologies,	Economic impacts presented in terms of 'welfare losses' due to energy service demand reductions

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[7] Note headings of tables 2-4 are intentionally not consistent due to the different parameters operating within each category of scenario study. Comparison across the three types of scenario study is provided by Table 5.

				and demand reduction from alternative lifestyles	
NIES (2008)	70% CO_2 reductions in Japan by 2050	All domestic Japan energy demand sectors	Details in demand side efficiency technologies as well supply side decarbonisation	Broad social trends- fast growth, technology oriented vs. slow growth nature oriented- used to integrate model input assumptions. No explicit policies.	Scenarios compared in terms of loss of GDP by 2050 (around 1%)
IEA (2008a)	None	All energy demand sectors within a global simulation model	Aggregated technology depiction	Reference scenario simulates impact of currently existing government policies only; Alternative Policy Scenario adds planned and moderately increased policy action	Simulates likely energy mixes based on empirically observed relationships between prices and demand, and on projected changes in prices of resources and technologies
IEA (2008b)	Varying between scenarios, up to 50% global energy CO_2 reduction from 2000 levels	All global energy demand sectors	Aggregated technology depiction	Limited- model driven by carbon constraint and cost optimisation	Costs of technologies and resource influence selection under global optimisation framework
EC (2005)	Carbon constraint case and hydrogen economy case are run	All global energy demand sectors	Aggregated technology depiction	Limited- model driven by carbon constraint and cost optimisation, though assumptions about	Costs of technologies and resource influence selection under global simulation framework

				breakthroughs in key technologies are integrated where appropriate into the scenario 'storyline'.	

A review of Table 4 identifies some key strengths of modelling studies. Although technical feasibility studies are sometimes able to achieve a high level of technical detail in specific sectors, modelling studies can employ a wider scope of technical detail, and enable consideration of interactions between different supply and demand sectors. Global models can achieve further detail in the consideration of global resource trades and macro-economic dynamics. The economic information relating to resources and technologies which forms a crucial component of the input data for the models, allows the derivation of insights such as welfare losses, GDP costs, and optimisation models can give an indication of the economically optimal technological solution under given combinations of assumptions. However, the prominence of economic information in both the inputs and outputs of these models introduces another layer of uncertainty, particularly given the time frames under consideration. This can invite criticisms of misleading impressions of accuracy, both of final economic outputs and of technology selection under economic optimisation criteria. These issues encourage the use of multiple sensitivity analyses.

Despite these considerable differences from the more deterministic manipulation of data in the quantitative tools of the technical feasibility studies, some similar questions are raised. The results are driven in most cases by an exogenously imposed carbon constraint, which ensures that the model reaches the desired technological result by the end of the time frame. This is essentially an artificial construct without a direct correlation to any policy which it would be possible to implement in the real world, making the interpretation of such runs ambiguous. A number of possible policy related and social changes which could have led to such technological implementation can subsequently be read into these quantitative characterisations, and are often described in the studies in broad terms of technological acceleration, growing environmental concern, etc. However, as with the technical feasibility studies, the sense of the iterations between policy, society and technology, and of socio-technical change as a co-evolving process is not represented in such modelling based scenario studies.

5. Discussion and Analysis

Table 5 compares at a high level the strengths and weaknesses of the three broad categories of low carbon energy scenario study reviewed in this paper.

Table 5: Strengths and Weaknesses of Scenario Study Categories

	Strengths	**Weaknesses**
Trend based studies	Social drivers, global political dynamics, unquantifiable cultural shifts	Lack of technological detail and actor depiction, role of policy to influence 'high level trends' is unclear
Technical feasibility studies	Technological detail, particularly at specialised sectoral levels	Lack of actor depiction, policies, and simplified political dynamics. End point constraints often overly deterministic
Modelling studies	System-wide technological detail, economic interactions, resource availability and trade-offs, micro and/or macroeconomic outputs	Lack of cultural, behavioural social, political dynamics. Lack of actor depiction and policies. End point constraints often overly deterministic

Each type of approach is contrasting, and each has different strengths. Trend based studies allow for more detailed speculation in areas of future social and cultural experience, often aiming to provide very vivid images of how people would live and interact with each other and with technologies in the various futures. Through such details the studies seek to encourage the reader to imaginatively experience the different futures. Technical feasibility studies allow a highly controlled theoretical manipulation of physical energy systems, according to a range of possible normative criteria. They are used as flexible 'testing grounds' for the theoretical plausibility of energy systems, and in some cases have been developed to explore in particular detail a sub-sector of the system. Modelling studies combine technological detail with data on resource availability and trade-offs, global trade and interactions, and wider economic issues.

However, the table also identifies some weaknesses, some of them in common between two or all three of the categories. Both technical feasibility studies and modelling studies raise questions about the correlation of the exogenous constraints frequently applied to real world dynamics. All three types of study have problems in locating the major technological change which must be a part of a low carbon transition, within a coherent and convincing description of an iterative and co-evolving process alongside political and social changes- either such changes are ignored, or abstracted to hard-to-interpret high level trends. All three types of study also fail to specify the transitions in terms of the necessary actions and motivations of clearly defined system actors- again, the focus is either on a technical system which is apparently autonomously self-assembling, or assembled by forces which become inscrutable as they have been abstracted to the realm of high level trends. Such abstraction and lack of actor depiction makes the process of deriving policy insights towards the three possible objectives posed at the start of this paper, particularly difficult.

5.1. Strengths of low carbon energy scenarios

The challenge of the low carbon transition is huge, and unprecedented. If successfully achieved it is certain to involve technical, social and political arrangements which are radically different to those of the present. We are faced with the task of deciding how we take steps towards bringing it about starting from where we are now.

With reference to the broad definition of scenarios offered in the first section of this paper, it is clear that an important initial step when contemplating moving towards such a radically different future, is to first imagine that future. As de Jouvenel wrote, 'In the order of desire or intention, the end .. comes before that which is done toward the end' (de Jouvenel, 1967), and Pierre Massé emphasising that the advantage of such imaginative activity is to make 'desirable ends a powerful enough lever to act on the present' (Massé, 1966).

The low carbon energy scenarios reviewed in this paper have made important steps towards this first critical process. By imagining, with the help of a range of qualitative processes and quantitative tools, what low carbon futures might look like, they raise important questions which should influence the preparations we make at the start of our journey. They raise questions about the physical feasibility of low carbon futures- for example what levels of installed capacity of which low carbon technologies could in theory meet certain energy service demands and still significantly reduce carbon emissions. They give economic context to the process, suggesting for example that the total energy system costs of the transition could be relatively manageable in the context of overall GDP. They also raise questions about the range of possible social configurations which could evolve in response to the low carbon transition, the possibility of radically different social futures, and questions relating to the public acceptability of the measures (for example, a carbon price of £100-£200/tCO_2) required to get us there.

5.2. Problems with low carbon energy scenarios

However, notwithstanding the importance of the initial imaginative step which raises these significant questions, low carbon energy scenarios are less effective in fulfilling the other key aspects of the definition proposed earlier in this paper. Specifically, they struggle to depict future situations as they may evolve from the present, with a view to improving immediate and near term decision making. In the studies reviewed, the low carbon future remains a realm of multiple possibilities, governed by unknowable uncertainties, the paths towards any of which are clouded and unclear. Essentially, the low carbon energy scenarios reviewed in this paper provide little strategic information as to what steps must be taken from where we are now in order to eventually arrive at the futures they describe.

What is the reason for this absence of strategic applicability? The summary of the broad low carbon energy scenario categories constructed for this paper, highlights three characteristics which are at the root of the problem.

1. The exogenous constraint

A large number of the low carbon energy scenarios reviewed in this paper operate within some kind of normative exogenous constraint. This often takes the form of a quantitatively defined, system-wide carbon emissions reduction target to be achieved by a certain year. This approach is sometimes theoretically located within the concept of 'backcasting' which in most cases is broadly understood as setting a desirable end point, and then working backwards in time to understand how it would be achieved.

A possible objection to such an exogenous constraint is that it creates an illusion of inevitability about the final goals. The deterministic nature of a set of scenarios constructed from the outset such that each scenario is bound to meet the same desirable objective can diminish and underestimate the significance of certain potentially highly significant obstacles, be they related to public acceptance, institutional capacity or basic technological issues such as construction lead times. Though creating positive images of the future is a valid activity, there is a danger that such images can slip into mere 'wishful thinking'. As was discussed in Hughes (2009) there can be equal validity in the detailed consideration of unhappy outcomes- by analysing in some detail the combination of factors which bring such outcomes about, it is possible to be much clearer about what steps could be taken to avert or avoid such a confluence of events.

Part of the aim of the backcasting approach is to connect a posited desirable future with the present day, by retrospectively tracing back a sequence of steps which demonstrate how we would move towards such a future from where we are now. However, in practice, because of its retrospective viewpoint, the sharpness of the focus tends to remain on the target year. As the path is traced back towards the present, justifications for the direction of the path are increasingly made in terms of generic high level trends, or very broad assumptions about the 'strength' of policies. In some senses it appears that the illusion of inevitability created by the exogenously set target can diminish the importance attached to identifying in specific detail those crucial first steps.

Part of the problem with such exogenously imposed constraints is that they are artificially imposed upon an inanimate system. They are expressed in terms of an overall constraint upon the physical energy infrastructure- not on the actors (energy companies, regulators, policy makers) who bring that system into being. In other words, such a constraint is an artificial construct of a model or quantitative tool, which has no direct correlation with any course of action that any real-world actor could take to impose- there is no real-world actor with a power over the energy system equivalent to that of an exogenous constraint over an energy system model. This creates major limitations in the strategic scope of the scenarios- they are being brought about by forces which cannot be replicated in the real system. This situation is analogously comparable to the concept of a deus ex machina, which dates from the Greek drama of the 5th century BC, and refers to a situation where the characters within the drama are unable to resolve a situation through their own efforts, but are saved by a force completely external to the previously established plot, and thus completely implausible within the structure of the drama previously established[8]. Such are the forces applied in many normative scenarios- whilst they achieve desirable aims, the manner in which they do so is frequently a construct of the model (such as an exogenously applied numerical constraint), rather than a force which can plausibly be understood to operate within the real system they represent (the decisive action of one or more actors within society). Just as Aristotle criticised the device, maintaining it was 'evident that the unravelling of the plot, no less than the complication, must arise out of the plot itself,'[9] so scenarios, if they are to have any strategic use, must ensure that the means by which ends are brought about can be plausibly explained by the interaction of the actors in the scene, not through an artificially imposed force which has no direct equivalent in the real society.

2. Reliance on high level trends

The low carbon energy scenarios reviewed in this paper are also overly reliant on high level trends. The use of such high level trends in scenarios is popular, as they are found to be a useful means to ordering and differentiating the scenarios, as well as lending consistency and plausibility to the integrated range of assumptions with which each scenario is populated. Faced with the apparently almost infinite diversity of the future, high level trends are a means of establishing some differentiation, and therefore order.

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[8] The original *machina* was a crane with which the deity was lowered down onto the stage, to make the crucial intervention

[9] Aristotle, Poetics, 8.1. Translation by S.H. Butcher. Available at: http://www.leeds.ac.uk/classics/resources/poetics/poettran.htm

Criticisms of the use of high level trends in low carbon energy scenarios can be made in two broad areas. The first broad area questions the ability of a high level trend approach to recreate sufficiently plausible representations of the way societies actually operate. The authors of the Tyndall Scenarios in (Anderson et al, 2005; Mander et al, 2008), argue that scenarios derived from high level trends can risk false polarisation- the positing of two generic values as opposites, when it is plausible that they could held concurrently, even by individuals, as well as within society at large. A related point is that the infusion of a scenario with such high level values tends to create an unrealistic homogeneity in the scenario described, implying that all actors act and are motivated by similar, shared values. The reality we experience is seldom like this- society can very seldom be characterised by a small number of overarching shared values. Rather society is heterogeneous, divergent, and characterised more by conflicting and competing priorities of diverse actors, than by widespread common assent. Ironically, though the high level trend approach is intended to lend consistency and therefore increase the plausibility of scenarios, it might be argued that the scenario characterised by homogeneous sharing of common values, is least plausible of all.

The second broad area of criticism questions the effectiveness of high level trend based scenarios in elucidating a strategic understanding of plausible and desirable routes forward. Again, the problems which high level trend scenarios experience in trying to contribute to such analysis stem from the fact that they do not adequately identify and differentiate the various system actors, and the effects these actors have in bringing about events. The developments assumed within any particular scenario are abstracted from the actions of actors- their presence is justified on the basis that they appear to be consistent with a high level trend associated with that scenario. However the high level trend itself is an priori assumption which defines the nature of that scenario. This leads to a circular logic- it is not possible to identify how to bring about any of the high level trends, as these are merely inherent to the nature of the scenario, which means it is not possible to understand how to bring about (or avoid) any of the developments in the scenario, as these are merely inherent to the high level trends.

High level trends are in reality not an explanation for why things happen- they are generalisations applied retrospectively, after sufficient time has passed to allow a smoothing over of the many contradictions and counter-movements with which any present day reality is manifestly replete. Though they may work as summaries of events, they do not work as explanations of events; therefore if applied in a prospective manner to suggest how events might develop from the present time, it is not surprising that they are strategically unenlightening. Events are brought about by the actions and intentions- sometimes reinforcing, sometimes conflicting- of the many and various actors who operate within a given system. Therefore to understand in a more strategic way how events might develop, and particularly critically for low carbon energy scenarios, how events might be influenced, an actor-based perception of the evolution of events would be much more useful than one based in high-level trends.

3. The co-evolution of social, technical and political changes

Major socio-technical change is not brought about by technology alone. Rather, it is a complex process involving the interaction of technology with social, cultural and political dynamics. This leads many commentators to speak of a 'co-evolutionary' process of socio-technical change, facilitated by iterative developments across the social and technical spheres. Freeman and Louca (2001) for example argue that major socio-technological change can only take place when five 'sub-systems'- science, technology, economics, politics and culture- are co-aligned in a manner favourable to that change.

Table 6 adapts these sub-systems and applies them to a comparative analysis of the scenarios reviewed in this paper. Given the focus on low carbon energy scenarios, Freeman and Louca's 'technology' sub-system becomes 'energy', but refers to the technological hardware rather than to social or institutional aspects; for consistency with terms more often used in scenarios, 'culture' becomes 'social'; and the term 'science' is refined to apply to the understanding of 'natural' systems as opposed to energy technology systems. The full circles denote a full treatment of the sub-system within the scenario study, semi-circles denote a partial treatment, and crescents denote a passing or minor treatment.

Table 6: Treatment of five 'sub-systems' within reviewed scenario studies

	SCENARIO EXERCISE	**AUTHORS, DATE**	**Natural**	**Energy**	**Economic**	**Political**	**Social**
1	Special Report on Emissions Scenarios	Nakicenovic et al (2000)	◖	●	☾		◖
2	Foresight Scenarios	Berkhout et al (1999)		☾			●
3	Socio-economic scenarios for climate change impact	UK Climate Impacts Programme (2000)			☾		●
4	Scenario Exercise on Moving Towards a Sustainable Energy Economy	Institute for Alternative Futures; Institute for Innovation Research, University of		☾			●
5	Transitions to a UK Hydrogen Economy	Eames and McDowall (2006)		◖		☾	◖
6	Electricity Network Scenarios for Great	Elders et al (2006)		●		☾	☾
7	Electricity Network Scenarios for Great Britain in 2050 (LENS	Ault et al (2008)		●	☾		☾
8	The Changing Climate	Royal Commission on Environmental Pollution (2000)		●			

9	Decarbonising the UK	Anderson et al (2005)		●			☾
10	The Balance of Power-Reducing CO_2 Emissions from the UK Power	ILEX (2006)		●	☾		
11	Decentralising UK Energy	WADE (2006)		●	☾		
12	A Bright Future: Friends of the Earth's Electricity Sector Model for 2030	FOE (2006)		●			
13	Powering London into the 21st Century	PB Power (2006)		●			
14	Technical Feasibility of CO_2 emissions reductions in the UK housing stock	Johnston et al (2005)		●		☾	☾
15	40% house	Boardman et al (2005)		●		☾	☾
16	UK MARKAL (Energy White Paper and other work)	Strachan et al (2007)		●	◖		
17	Energy 2050	UK Energy Research Centre (2009)		●	◖		☾
18	Japan Scenarios and Actions Towards Low	National Institute for Environmental Studies		●	◖		◖
19	World Energy Outlook	International Energy Agency (2008a)		●	◖		
20	Energy Technology Perspectives	International Energy Agency (2008b)		●	◖		
21	World Energy Technology Outlook	European Commission (2005)		●	◖		

It is clear that each of the five sub-systems has a major effect on whether a low carbon transition is successfully carried through. Key observations from Table 6 are that a significant number of the low carbon energy scenario studies focus on the technological depiction of the energy system, leaving other sub-systems unaccounted for. Across all scenarios, politics (or the successful design and implementation of policy within political systems) is very poorly accounted for, and the contribution of elements of the 'natural' sub-system (such as land use change, or the impacts of natural 'feedback' loops on the urgency of the mitigation effort) are almost completely unexplored. Many scenario studies leave policy analysis as an ex-post process, rather than treating policy as an inherent component of the scenarios. No scenario accounts for all sub-systems in an integrated manner, and most have significant gaps in their treatment of more than one.

The focus on the energy-technology sub-system is in many ways justified- technologies are of course crucial to low carbon transitions, and for the reasons discussed in section 5.1 a detailed exploration of this sub-system can pay dividends. Moreover, many of the studies do mention the social and political dynamics which could be associated with technology development. However, the process of considering these various sub-systems is always a consecutive one- a technology mix is fully constructed, following which socio-political currents which would have brought them into place are inferred; or a complete socio-political value system is posited, following which 'appropriate' technologies are brought in to fill the technological gaps.

This is clearly not an accurate account of how socio-technical systems are brought into being. Rather the process in reality is iterative and reflexive, where developments in technology, policy and society constantly reinforce, conflict or in other ways rebound upon and affect each other. It is this reinforcing, co-evolving dynamic which is not captured in the low carbon scenarios reviewed, and which calls their plausibility, and thus strategic usefulness, into question. In particular the question of how policy operates tends to be dealt with in a very simplistic manner in the scenario studies reviewed. None of them consider the effect of policy with any specificity. Several of the studies state explicitly that specific policies were not included in the scenarios- rather the completed scenarios are intended to suggest policies when they are subsequently reviewed. This implies that once a satisfactory set of social and technological circumstances have been identified, the right policies can simply be 'switched on' to bring this set of circumstances about. In other cases, very broad assumptions about 'strong' or 'weak' policy are used as justification for more or less positive assumptions about technology development or behaviour change, within the different scenarios.

However, in reality the successful implementation of policy is an iterative process - it both leads and reacts to the state of social and technical development. Governments are to a certain extent limited in the kinds of policies they feel empowered to implement, on the basis of what they consider 'politically feasible' within their electoral mandate. However, policy also has a role in leading and influencing behaviour, and thus initial policy experiments can sometimes pave the way for more ambitious measures. It is a highly iterative process with the balance between government vision and electoral pressure ever evolving in the context of any social issue. The understanding of the interrelationships and motivations of the range of societal actors (including government, members of the public, businesses) thus becomes crucial.

A further issue relating to iterative policy is that of who the decision maker is and how effective their actions are. An excellent example is the relationship between technology innovation and policy. The assumption that 'strong' policy is a causal explanation for assumed high levels of technology innovation, misses both the unpredictable nature of invention-innovation and the international nature of the technology innovation process. On the first issue, public policy and funding can flow into technologies which nonetheless do not 'breakthrough'; occasionally genuine breakthroughs occur as a result of relatively poorly funded 'speculative' research; and sometimes breakthroughs occur as a result of research in one application, but which are ultimately taken up and put to widespread use in a completely different application, for which the original research had not been intended. On the second issue, innovation is a global phenomenon, requiring coordination between major economies and recognising the role of multinational companies. As a result national policy making may have a localised impact on overall innovation of new low carbon technologies.

All of these observations suggest that the relationship between 'strong policy' and 'strong innovation' is not linear. This suggests that while scenarios should treat the policy and market environment for low carbon technologies, derived from the interaction of politics and public acceptance, as a justifying background for positing strong diffusion of relatively well-established technologies, this would not necessarily justify assumptions about huge steps forward in currently more speculative or untested technologies. Given the significant unpredictability, based on past experience, with which such technologies might break through or fail in the coming decades, it is rather more appropriate to view such events as largely uncontrollable from the point of view of the policy maker. The successful integration of these different kinds of technology issues within strategically powerful scenarios requires the sub-division of the total spectrum of future technology uncertainty, into different kinds of uncertainty. This process will be discussed further in the third working paper of this series.

5.3. Suggested approaches for future low carbon energy scenarios and areas for future research

From the review of low carbon energy scenarios conducted in this paper, and the subsequent analysis and discussion, it has emerged that low carbon energy scenarios have so far played a useful role in imagining possible low carbon futures, and testing out where some of the key questions of material and social feasibility within them may prove most significant. However it has also emerged that current approaches to developing and structuring low carbon energy scenarios are not conducive to providing strategically useful information about how events may evolve, and indeed be directed, from the present time towards a low carbon future. Drawing on the above analysis it is proposed that future low carbon energy scenarios could be moved closer to performing such a function, if they were enhanced in the following two ways:

Consideration of socio-technical systems as 'co-evolving': Thus far low carbon energy scenarios have tended to focus either on the purely technical aspects of the energy system, or on broader social value shifts. In both cases, any incorporation of the other aspect, or indeed of the equally crucial question of policy development, takes place as a subsequent stage of the analysis, and often with limited detail. In order to develop a convincing and strategically useful account of potential low carbon transitions the 'co-evolving' nature of policy, social change and technological development should be central to the scenario development process. Clearly, important lessons could be learned from the well-established literature on socio-technical transitions.

Identification and delineation of actors and their motivations: Socio-technical changes are not brought about by disembodied high level trends, or by self-assembling technical infrastructures, but by the combination of decisions and actions taken by the numerous actors in the system. Certain of such decisions may be reinforcing, while others may be conflicting. A strategically useful scenario based depiction of a low carbon transition would identify which key actions taken by which combination of actors would create conditions conducive to that transition. An actor focussed approach would present much clearer indications of the role of policy within these interactions.

By incorporating these aspects more centrally into the generation of low carbon energy scenarios, it is argued that they will be much closer to addressing the three key objectives for scenarios set out at the beginning of this paper:

- **Protective decision making**- an integrated co-evolving scenario description is much more alive to potential threats to objectives, as is one which is not dominated by the tempting inevitability of an artificial end-point constraint.
- **Proactive decision making**- by identifying clearly the actor motivations and actions that bring about transitions, rather than ascribing all developments to high level trends or as part of an inexorable process towards a pre-determined end point, scenarios identify with much greater clarity who has to act, how they must act, and when they should act, in order to stimulate the transition. This gives much clearer policy messages.
- **Consensus building**- a low carbon transition cannot be brought about purely by policy makers pulling levers- however scenarios which demonstrate clearly the role each independent actor could take in the transition, increase understanding and potential involvement amongst those actors themselves.

The application of the two approaches suggested above to provide insights into the construction of future low carbon energy scenarios, with a view to increasing their effectiveness in relation to these three objectives, drawing both on the wider scenario literature and on technological transition theory (e.g. Geels, 2005), will be the subject of the next working paper in this series.

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APPENDIX

Discussion of previous low carbon energy scenario typologies, and comparison with typology chosen for this paper

Some recent studies and reports have produced methodologically based typologies of the energy scenarios literature on its own terms- that is without explicit reference to methodologies acquired from the wider scenario tradition[10]. Key examples of such reviews are McDowall and Eames (2006b), which reviews the literature specifically relating to hydrogen technology futures, and IEA (2003) which reviews a selection of global and national level energy scenarios. This a valid approach, as particular challenges in low carbon energy policy may require a new balance of methodologies. Such typologies do play an important role in emphasising two particular characteristics of low carbon energy scenario studies: the crucial need for technological detail, including in the realm of speculation as to the performance of future technologies; and the dominating presence, often created by the wider political debate, of a quantitatively defined emissions reduction target. These particular characteristics lead most low carbon scenario typologies to divide the literature according to two sets of contrasting approaches:

Quantitative or qualitative: quantitative studies respond to the need for technological detail in understanding how new portfolios of energy technologies could meet future energy demands, while meeting quantitatively defined carbon targets; qualitative approaches are applied to describing evolving socio-political contexts in which such changes might happen.

Normative or exploratory: normative scenarios externally impose a desirable outcome, and use scenarios to explore different ways of meeting it; exploratory scenarios do not predetermine outcomes, good or bad, but work on the basis of extrapolating possible trends.

The low carbon energy scenario review conducted in this paper was originally constructed around such a typology. However, it quickly emerged that frequent cross-overs between and combinations of these approaches (e.g. use of quantitative as well as qualitative information, elements of normative control over some scenario aspects combined with exploratory approaches to other aspects) meant that these were not distinct categories. The balance between all of these aspects is of course important to consider in analysing scenarios, and this is addressed through the discussions and summary tables in Sections 2-4 of this paper. However it was ultimately felt that the above characteristics cannot be used to construct impermeable category divisions.

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[10] Although qualitative vs. quantitative and normative vs. exploratory are common elements in the wider scenarios literature (see Hughes, 2009a)

Possible criticisms of typology developed for this paper

It will almost immediately be noted upon reading this paper, that there remain some cross-overs and grey areas within the typological arrangement of the literature selected here. For instance, though the Elders et al (2006) scenarios are derived from interactions of high level trends, they also move into questions of technical feasibility within the electricity sector; the LENS scenarios (Ault et al, 2008) may be similarly derived, but subsequently drive an energy system modelling exercise; the IPCC SRES (Nakicenovic et al, 2000) is structured around a 2x2 matrix, but its results are actually in the form of 40 'scenarios' which are the direct outputs of six Integrated Assessment models; though the NIES study produces modelling outputs, the inputs for these runs were derived qualitatively defined high level 'trends'. Nonetheless, in allocating such studies into the above three categories, a judgement has been exercised as to which kind of process was most significantly influential upon the character of the final scenarios.

Despite the perhaps legitimate concern expressed in the literature for the 'methodological chaos' surrounding the practice of scenarios, this paper does not provide a definitive solution to that particular problem. It seems that, within low carbon energy scenarios as much as within scenarios more generally, approaches will continue to evolve and change based on previous experience, the questions being asked as well as more practical issues of the availability of tools and resources to each particular set of study authors. It is therefore not intended that this arrangement serve as a final and definitive typology of low carbon energy scenarios, nor is it hoped that future scenario studies will attempt to align themselves methodologically within one of these categories. This arrangement is proposed because it emerged as the most useful way of structuring the discussion and critique in the final section of the paper.