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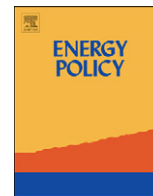
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The Tyndall decarbonisation scenarios—Part I: Development of a backcasting methodology with stakeholder participation

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ABSTRACT

The Tyndall decarbonisation scenarios project has outlined alternative pathways whereby a 60% reduction in CO₂ emissions from 1990 levels by 2050, a goal adopted by the UK Government, can be achieved. This paper, Part I of a two part paper, describes the methodology used to develop the scenarios and outlines the motivations for the project. The study utilised a backcasting approach, applied in three phases. In phase one, a set of credible and consistent end-points that described a substantially decarbonised energy system in 2050 were generated and reviewed by stakeholders. In phase two, pathways were developed to achieve the transition to the desired end-point. The impacts of the scenarios were assessed in phase three, by means of a deliberative multi-criteria assessment framework. The scenarios to emerge from this process are elaborated in Part II, and conclusions drawn in relation to the feasibility of achieving the 60% target.

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1. Introduction

Between 2000 and 2005, the Tyndall Centre's 'Decarbonising the UK' programme explored a range of technical, managerial and behavioural changes to meet the UK's target of reducing CO₂ emissions by 60% by 2050. To integrate the individual projects, the decarbonisation scenarios project developed a new set of UK energy scenarios that articulate alternative carbon-constrained futures.

Three primary objectives underpinned the research. Firstly, emissions from international aviation and shipping had not been included in earlier UK energy scenarios upon which the 60% target was based, therefore the Tyndall decarbonisation scenarios sought to explore the impact of the inclusion of these hitherto ignored emissions. Secondly, whilst taking different approaches, little of the work underpinning the Energy White Paper (EWP) explicitly considered the transition from the present energy system to the low-carbon future. Finally, the scenarios informing UK Government relied principally on the SRES scenarios, a 'twin axis' typology; this approach can potentially constrain creative thinking and thus the energy landscapes resulting from the analysis.

With these objectives in mind, a methodology was developed that combined elements of backcasting and forecasting in a

stakeholder process. This paper (Part I) outlines the Tyndall Centre's decarbonisation scenario methodology. To place the scenarios in context, Section 2 briefly reviews existing UK energy scenarios; the methodology is described in detail in Section 3; Section 4 discusses its application. Part II describes the Tyndall decarbonisation scenarios, drawing conclusions from these with respect to the 60% target, and the transition to a low-carbon energy system.

2. Existing UK energy scenarios

Scenario analysis emerged during the 1970s and 1980s in response to the limitations of forecasting approaches to forward planning. Given the complexity of human systems, our ability to predict the long-term future is highly constrained, making it potentially dangerous to plan for the future on the basis of medium- to long-term forecasts. Recognising this, scenario analysis was developed as a means of exploring alternative futures, enabling decision making to be based on a broad assessment of the possibility space. Furthermore, long-term, complex and inherently uncertain problems, such as climate change, require responses that shift society away from long-term trends (Dreborg, 1996; Robinson, 2003), hence the more radical thinking permitted by scenario analysis.

This section reviews a number of UK energy scenarios, and characterises them using four key indicators identified from the

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scenario literature (Rotmans et al, 2000), with an additional fifth indicator to describe the focus of the scenario.

2.1. Is the scenario backcasting or prospective?

Prospective scenarios look forward and outline possible futures based on the extension of a number of key drivers; they tell us 'where we will be'. Backcasting scenarios, by contrast, tell us 'how to get to where we want to be', taking into account the pathways to achieving a defined and desirable future (Dreborg, 1996; Robinson, 2003). The majority of scenarios take a prospective approach. The energy policies outlined in the EWP were informed by energy scenarios based upon the DTI Foresight scenarios and produced by the Cabinet Office's Performance and Innovation Unit, (Performance and Innovation Unit, 2002). The Foresight approach uses a set of four scenarios that sit within a twin axis framework, where one axis represents social values (from community values to consumerist values), and the other represents spatial scales of governance (from autonomous to interdependence) (Department of Trade and Industry, 1999). These socio-economic futures were themselves developed from the IPCC's SRES scenarios,¹ and provide a set of assumptions that are broadly consistent with the descriptors—World Markets, Global Sustainability, Provincial Enterprise and Local Stewardship (Performance and Innovation Unit, 2002).

A backcasting approach takes a desired end-point as a starting point, and the analysis steps back in time to explore how it may be achieved. Backcasting was used by the Royal Commission for Environmental Pollution (RCEP) in their influential report 'Energy the Changing Climate', and on which the UK's 60% carbon reduction target was based. Scenarios were developed to describe snapshots of the energy system with different patterns of energy demand and supply in 2050 that achieved the 60% target (Royal Commission on Environmental Pollution, 2000). The approach was also used to develop a set of energy scenarios for the UK Research Councils (IAF and IoR., 2004). To date only these two sets of scenarios have taken a backcasting approach, and both stop short of describing the full transition to the desired end-point.

2.2. Is the scenario qualitative or quantitative?

Broadly speaking, quantitative scenarios are based on models, whereas qualitative scenarios are narrative based, often because the relevant information cannot be adequately quantified. In practise, scenarios may have both qualitative and quantitative elements, though the synthesis of the two types of data is challenging from a methodological perspective (Kok et al., 2006). The majority of UK energy scenarios are essentially quantitative, describing a set of assumptions that inform the input into a model, with the output presented only in a quantitative format. An important and recent example of such a study is the quantification of the PIU scenarios conducted as part of the Interdepartmental Analysts Group's (IAG) contribution to the EWP (IAG, 2002).

An example of a purely qualitative approach is the Foresight 'Energy for Tomorrow' report, which interprets the Foresight scenarios for the energy system (Energy Futures Taskforce, 2001). Combining both qualitative and quantitative data are Johnston et al's scenarios exploring the technical feasibility of achieving CO₂ emission reductions in excess of 60% within the UK housing stock by the middle of this century (Johnston et al., 2005). In this work,

the outputs from an energy model of the UK housing stock are supported by narrative storylines.

2.3. Is the scenario normative or descriptive?

Whilst the scenario literature distinguishes between normative and descriptive scenarios, the distinction is in some respects artificial as all scenarios are developed by people who, to some extent, bring their own normative values and judgements to the process (Van Notten et al., 2003). A normative scenario is therefore defined as one that explores probable or preferable futures, whereas a descriptive scenario outlines possible futures. For example, scenarios for the domestic sector developed by Johnston et al., (2005) are normative; the authors conclude that each is feasible, and make an assessment of the ease with which they could be achieved. Descriptive scenarios have been developed by Gough and Shackley, (2006) to describe alternative penetrations of carbon capture and storage into the UK electricity supply system with no suggestion as to which is more likely. Slightly more than half of the scenarios examined for this review are normative, and of these, five sets have been developed within the Foresight framework and therefore outline probable futures based on the value assumptions made within this framework (see for example Boardman et al., 2005; Performance and Innovation Unit, 2002; IAG, 2002).

2.4. Is the scenario approach expert or participatory?

Much of the scenario literature recommends that scenarios are developed in a participatory manner, to include a diversity of different perspectives (Rotmans et al., 2000; Van der Heijden, 1996). A distinction is therefore made between expert scenarios that are developed by a small academic team, and participatory scenarios that are developed with elements of stakeholder input. In practise, very few scenarios are solely developed through a participatory process, but most include an element of stakeholder contribution and input in addition to the expertise of the project team. See for example Boardman et al., (2005) or the work of the Foresight panel (Energy Futures Taskforce, 2001) for scenario sets that combine participatory approaches with expert analysis.

2.5. Is the scenario of the whole energy system or sector specific?

Of the scenarios examined in this review, six claim to explore the UK energy system as a whole, taking into account both the energy supply system and the full range of demand sectors (Chapman 1976; Royal Commission on Environmental Pollution, 2000; Performance and Innovation Unit, 2002; IAG, 2002; Energy Futures Taskforce, 2001). However, international shipping was not included in these analyses, nor is the energy systems own energy use; hence the full energy system is, in effect, not covered. The remaining studies focused on specific sectors, mainly demand sectors such as households (e.g. Boardman et al 2005; Johnston et al., 2005) or transport (e.g. Tight et al., 2005).

2.6. Summary

This review has highlighted that prior to the Tyndall decarbonisation scenarios no existing UK energy scenarios have explored the whole energy system, including international shipping. Moreover, with the exception of the RCEP and UK Research Council scenarios, existing scenarios took a prospective approach, with the inclusion of values often following the Foresight framework. The relevance of each of these issues is

¹ Special report on emission scenarios (Intergovernmental Panel on Climate Change, 2000)

now outlined in turn, starting with the exclusion of international aviation and shipping.

The 2006 Energy Review and the UK's Draft Climate Change Bill endorse the target previously proposed by the RCEP in 2000 for a 60% cut in CO₂ emissions as representing the UK's fair contribution to stabilising the atmospheric concentration at around 550ppmv (Department of Trade and Industry, 2006; Department of Environment Fisheries and Rural Affairs, 2007). This concentration was, at the time widely accepted to be necessary to avoid 'dangerous and destructive climate change' (Royal Commission on Environmental Pollution, 2000, p. 1; see also Intergovernmental Panel on Climate Change, 2001 or Arnell et al., 2002 for evidence on stabilisation). It is clear from the RCEP's references to the Global Commons Institute (GCI) contraction and convergence model that the 60% target is based on the principle of contraction and convergence (Royal Commission on Environmental Pollution, 2000, p. 57), with the data underpinning the target based on the emissions that are published in the UK's national emissions inventory and reported under the United Nations Framework Convention on Climate Change (UNFCCC). The absence of an agreed methodology for the allocation of international emissions to countries under UNFCCC means that the emissions from international aviation and shipping are not included in the national emissions inventory, and have subsequently not been included when calculating the 60% target. Thus, the proposed 60% reduction in emissions does not correlate with stabilisation at 550ppmv, since the 'true' level of world emissions is higher than that upon which the target has been based, and these emissions have been excluded from the apportionment model used to calculate the 60% target.

The exclusion of international emissions is acknowledged by the RCEP and IAG. Whilst the IAG do estimate that the additional emissions resulting from international aviation are between 14 and 21 MtC by 2050, depending on the rate of improvement in carbon intensity (IAG, 2002, p. 25), the modelling work does not include these emissions. Neither the RCEP nor IAG quantify the emissions from international shipping. These sectors are not currently the largest in terms of either overall energy consumption, or carbon emissions, but they are two of the highest growth sectors in terms of emissions (Department of Environment Fisheries and Rural Affairs, 2006a) and therefore must not be ignored given that the ultimate objective of UK climate change policy is to achieve a target atmospheric CO₂ stabilisation level.

Whilst two scenario studies (Royal Commission on Environmental Pollution, 2000; IAF and IoIR., 2004) take a backcasting approach, neither makes an explicit consideration of the transition from the present day energy system to one which is substantially decarbonised. By backcasting from a defined end-point to define the pathway from the present day to that end-point, and including all emission sectors, the Tyndall decarbonisation scenarios consider how the transition to alternative futures, all of which achieve a 'real' 60% reduction in CO₂, could be achieved.

Within UK energy policy, the most popular approach to scenario development to date is that of the Foresight programme's twin axis typology. This typology is, however, theoretically problematic because the axes are a synthesis of more than a single variable, an issue often overlooked when the framework is applied, resulting in a lack of transparency and a constraint on creativity. 'Community values' are not at the opposite end of an axis that has 'consumerist values' at the other end as an individual or collective may hold both sets of values concurrently. The presence of high or low environmental values is frequently equated in the Foresight typology with the community to consumerism axis, but this simplifies the complex relationship

between environmental values and social values. It is plausible to combine 'deep green' values with a disengagement from society (i.e. low community values), or to combine consumerist values with environmental concerns. Furthermore, political systems can be, and often need to be, in some respects, both autonomous and interdependent (Shackley and Wood, 2001).

A further limitation of certain applications of the Foresight scenarios is that they tend to over-polarise futures: World Markets or Local Stewardship, Global Sustainability or National Enterprise, rather than the more realistic, complex and 'messy' world in which all means of organising co-exist (Shackley and Gough, 2002). Within the energy domain, a frequent real-world tension occurs between policies driven by environmental objectives, those driven by competitiveness and cost-reduction objectives, and those driven by issues of social equity. The real-world challenge is to try and accommodate these potentially conflicting policy objectives within scenarios, not assume that one will win out over the others.

Essentially, whilst use of the Foresight scenarios is one valuable approach to thinking about different futures, it is vital that other frameworks are also used. A problem arises if Foresight-based scenarios become the 'default' methodology since they, like all other scenario approaches, have their limitations. The analysis underpinning the EWP provides a good example of how a single scenario approach has become hard-wired into Government policy. Given the number of UK Foresight-based energy scenarios, stakeholders could be forgiven for believing they represent the full range of credible possibilities; this is certainly not the case. Within the Tyndall decarbonisation scenarios process, an alternative approach to scenario generation was developed; this approach is described in Section 3.

3. Methodology

Backcasting techniques, as alternatives to conventional and model-based forecasting approaches to energy planning, emerged during the 1970s with the 'soft energy path' approach proposed by Amory Lovins (see for example Lovins 1976, 1977). Given the inherent uncertainty in accurately predicting future energy supply and demand, Lovin's considered it more appropriate to describe a range of energy futures and explore how these may be implemented. Since future energy demand is the result of present day policy decisions, a more useful analysis is to work backwards to achieve a desired objective, rather than allowing undesirable trends to continue. Robinson's backcasting regime (Robinson, 1982) translated Lovin's principles of 'looking backwards' and 'exploring pathways' into a defined framework for the development of backcasting scenarios (see Hennicke, 2004; IAF and IoIR., 2004; Royal Commission on Environmental Pollution, 2000 for example of studies taking this approach).

The backcasting methodology underpinning the Tyndall decarbonisation scenarios project was devised by Anderson (2001), as follows: (Based on Anderson, 2001 and Robinson, 1990) The remainder of Section 3 outlines the application of the methodology.

3.1. Defining the end-points

The first stage of developing an end-point scenario was to define the energy consumption in 2050. The scenarios explore a range of energy consumption levels in 2050, with the range chosen to balance the desire to develop challenging scenarios with the need for the scenarios to be considered credible by the wider energy community. Two scenarios were devised for each of a low energy consumption future (90 Mtoe), a high energy

consumption future (330 Mtoe) and two medium levels (130 and 200 Mtoe). Current UK consumption is in the region of 170 Mtoe, hence the scenarios span from a near halving of current levels to a near doubling. The only explicit constraint imposed on the system was that a 60% reduction in CO₂ emissions must be achieved by 2050. Overall, the range allowed for scenarios requiring significant reductions in energy consumption, extensive low-carbon supply and various combinations of large-scale demand and supply changes.

The scenarios are intended to consider key factors that would impact upon the future of the UK energy system. Brainstorming techniques were used to identify interesting issues to investigate; these were clustered around four demand-side, and seven supply-side themes, as outlined in Tables 1 and 2.

Initially eight end-point scenarios, two for each of the four different levels of energy consumption, were described in terms of the 11 demand and supply variables outlined in Tables 1 and 2 (outlined in Anderson et al. (2004)). The end-points were mapped onto a matrix to ensure that the full range of variables was covered within a scenario set that differed from other UK energy scenarios and challenged current policy thinking. Following the methodology outlined in Fig. 1, a qualitative description of the end-point was written, translated into a quantitative description of the energy system and expressed in terms of a number of parameters contained within the ‘scenario generator’ (listed in Table 3). The selection of these parameters was framed in part by the qualitative scenario story, but also set within the boundaries of historical changes going back to 1970 and an understanding of the societal and policy changes that have brought these changes about (Eyre, 2001). Outlined in Section 3.2, the scenario generator is a spreadsheet model enabling a detailed picture of 2050 energy consumption and its associated

Table 1
Demand themes

Demand sector	Impact on carbon emissions
Household	Households emit approximately 27% of UK carbon emissions (Department of Environment Fisheries and Rural Affairs, 2006b). Current policies and programmes will not reduce emissions from households to 40% of current levels by 2050, therefore radical changes in technology and consumption practices are required (Boardman et al., 2005).
Passenger transport (land and aviation)	Land transport emits 28% of UK carbon emissions (Department of Environment Fisheries and Rural Affairs, 2006b) and emissions have proved difficult to tackle despite technological options, low-carbon fuels and viable alternatives to the private car (Tight et al., 2005). Aviation emissions are growing rapidly, with few opportunities to significantly improve fuel efficiency, no viable alternative fuels in the short- to medium-term, and fewer opportunities for modal shift (Bows and Anderson, 2007).
International shipping and the influence of globalisation	Carbon emissions from shipping are increasing as a consequence of globalisation (Eyring et al., 2005; Foreign and Commonwealth Office, 2003). There is a lack of international emissions agreements for shipping.
Structural changes to the economy	Although the UK economy is currently driven by the service sector (ONS, 2006), technological change may lead to a growth in new industries such as nano-technology, which would impact on carbon emissions (Dewick et al., 2004).

Table 2
Supply themes

Supply sector	Impact on carbon emissions
Availability of fossil fuel	Cheap and readily available fossil fuel is the foundation of our current energy system (Unruh, 2000); the availability of fossil fuels will therefore impact on the transition to a less carbon-intensive society.
Successful implementation of CO ₂ capture and storage (CCS)	If technical, social and political challenges can be addressed, CCS has the potential to significantly reduce UK carbon emissions from electricity generation (Gough and Shackley, 2006).
Role of nuclear power	Nuclear power is a low-carbon source of electricity that is considered important by the UK Government (Department of Trade and Industry, 2003, 2006).
Penetration of renewables	The UK has extensive renewable energy resources, which could contribute significantly to meeting energy demand.
The role of hydrogen	Hydrogen as an energy carrier is a central facet of many low-carbon visions though views diverge concerning the drivers for such a transition, and the shape of a hydrogen future (McDowall and Eames, 2006).
Penetration of biofuels	Given limits on sustainable global supplies of biofuels, their use either for transport, heat or electricity generation, will have a knock-on effect upon the remainder of the energy system.
Localised versus centralised generation	The UK currently has a highly centralised electricity generation system and localised generation, whilst often more efficient, faces technical, political and institutional barriers (Jenkins et al., 2004).

supply system to be developed. The tool is essentially a means of calculating the carbon emissions for a given end-point, allowing a user to “simulate[s] alternative scenarios such that the user can iterate through the scenario generation process until they reach a future scenario with which they are happy” (Robinson, 2003, p. 844).

The energy consumption in 2050 for each of the demand sectors could then be calculated. For a given qualitative story-line and quantified pattern of energy consumption, the supply-side was developed in relation to fixed parameters, listed in Table 3. The energy supply system was matched to the pattern of consumption envisaged within each of the demand components of the scenarios by specifying the most appropriate fuel source for a particular end-use as outlined in the qualitative story-line. Once both the demand and supply-sides were specified within the scenario generator, the carbon emissions were calculated. A 60% reduction in carbon emissions from a 2002 baseline (165 MtC) necessitated that final carbon emissions arising from the UK’s primary energy demand were in the region of 65 MtC by 2050, hence iteration was necessary to ensure the end-point was in line with the carbon constraint.

3.2. Quantitative characterisation

The spreadsheet model (referred to as the ‘scenario generator’) used 2002 as the baseline year. Energy demand² was divided into

² A distinction is also made between electricity and other energy.

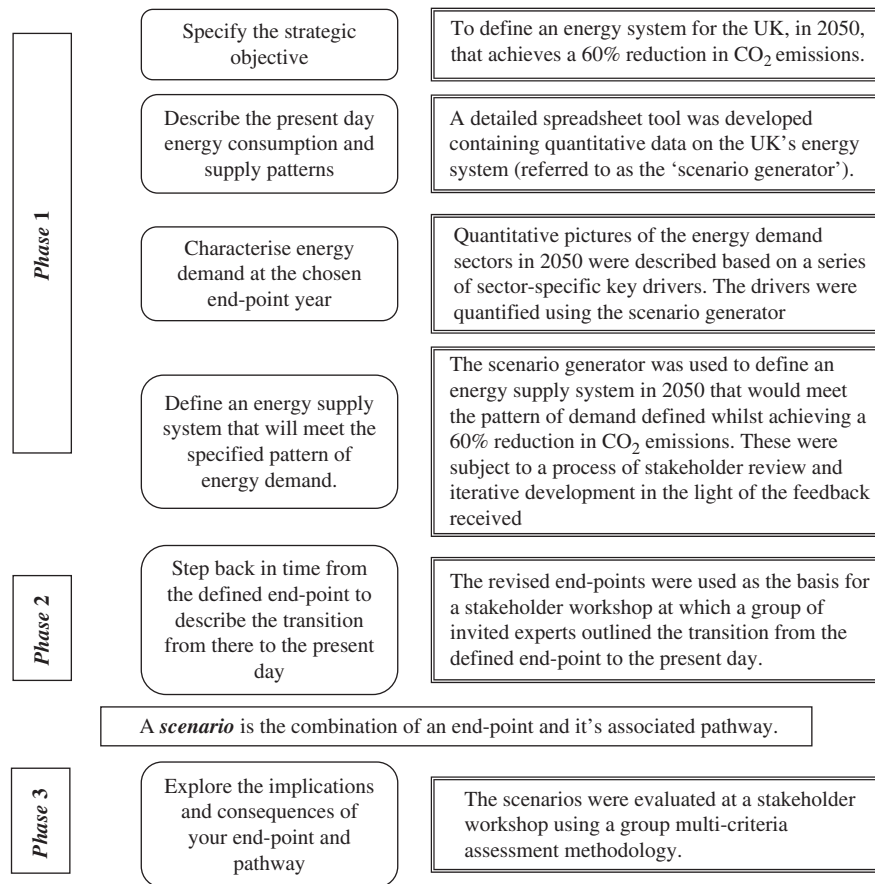


Fig. 1. Backcasting methodology.

Table 3
Demand parameters

Demand sector	Parameters
Households	Population Household number Percentage change in household number by 2050 Change in per capita affluence Change in household efficiency energy Change in energy intensity of economic activity
Energy-intensive industry ^a	Change in economic activity Change in energy intensity
Non-intensive industry	
Public	
Commercial	
Agriculture	
Road passenger	Change in mobility (passenger km or freight tonne km)
Road freight	Change in energy efficiency of mobility
Domestic aviation	
International aviation	
Rail	
Domestic shipping	
International shipping	
Energy industry	

^a Energy intensive industry is defined as the *metals, minerals and chemical* sectors, which are a blend of subcategories from DUKES and ONS. This was necessary as economic activity (GVA) data is from one source and energy consumption from the other.

15 sectors, and described in terms of a number of parameters, outlined below, as well as ratios defined from 'decomposition analysis' (Agnolucci et al., 2007).

For any given sector, the energy consumption in 2050 was calculated on the basis of a 'mean' annual change in energy consumption compounded over the 48 years from 2002 to 2050.³

Supply technologies, as outlined in Table 4, focused on current technologies operating at state-of-the-art efficiencies and included future technological options that are either established or acknowledged to be 'on the horizon'. The supply technology categorisation was in broad terms, rather than attempting to define specific renewable technologies for example, and assumptions concerning the efficiency of supply-side technologies were made within the spreadsheet (see Anderson et al., 2006 for more detail).

A carbon emission coefficient for each fuel was specified (CO₂ emissions per unit of fuel combusted) and total carbon emissions were derived from these for each unit of energy delivered by a particular generating technology. International air transport and shipping emissions were allocated using a 50:50 division of emission estimates between the UK and the departure and destination countries.

3.3. End-point workshop

The scenario literature generally recommends that scenarios are developed to include diverse knowledges and disciplines and therefore capture a 'rich' set of perspectives (see for example Van der Heijden, 1996 or Rotmans et al., 2000). Participative processes

³ The use of a mean value permits different values to dominate at different times over the 40+ years within the scenarios. These differences, when considered in the aggregate, provide the mean value.

Table 4
Supply technologies

Supply type	Energy source
Grid electricity	Coal combustion, with and without CCS Gas combustion in combined cycle gas turbines with and without CCS Nuclear Biofuels Renewable sources
Combined heat and power (CHP)	Coal Gas Biomass Nuclear
Hydrogen production	Electrolysis from renewables Electrolysis from nuclear power Coal gasification with CCS Thermal decomposition of water using heat from nuclear power stations
Direct use for heat and motive power	Biofuels Coal Gas Oil Renewables

are also crucial to facilitate communication between scientists and stakeholders and thus improve acceptance of scenarios from within a user community (Berkhout et al., 2002). Given highly constrained resources, it was not possible for the Tyndall decarbonisation scenarios to be developed in an entirely participatory manner, instead specific experts were consulted as required and a 1-day workshop was held for 20 invited participants from the fields of energy supply, energy demand and scenario methods to review the eight draft end-points that had been developed by the project team. Whilst this approach imposed some boundaries upon the involvement of stakeholders in the process, most notably that they did not have the opportunity to develop their own 60% carbon reduction end-points, the principle bounding of the scenarios within the 60% target was of sufficient interest to, and within the consciousness of, those stakeholders engaged in the project for the boundaries to be on the whole accepted.

Participants were asked to critically examine the credibility of both the methodology and the end-points themselves. In addition they were asked to comment on whether the end-points encompassed a sufficiently wide range of 60% futures, and could be considered different to, and more challenging than, existing scenario sets. Breakout groups focused on the demand-side representation, the supply-side technical assumptions and the socio-economic characterisation of the end-points with plenary discussions providing the opportunity for all participants to feedback on the work of other groups.

The feedback generated through this workshop resulted in four end-points being taken forward for further development (one of each of the energy consumption levels).

3.4. Socio-economic characterisation

Within the Tyndall decarbonisation scenarios, specified external variables, such as level of economic growth and change in energy efficiency, etc. were used as determinants to characterise visions of the energy system in the year 2050. The end-points

were not quantified within a defined social, cultural and political context using such as the Foresight twin axis typology. That said, since the pathway to a given future depends on the nature of society, which exists at that end-point, some framing of society was needed to provide the context in which the backcasting would occur.

Within the scenario literature, some writers call for a high degree of internal consistency within a scenario (see for example Rotmans et al., 2000; Rotmans and Dowlatabadi, 1998), however, consistency is not itself a consistent feature of society. This inconsistency is illustrated by, for example, the support for renewable energy expressed in polls, which is not translated to support for schemes seeking planning permission. Within energy policy, there are many examples of inconsistent policies, for example the substantial expansion of aviation outlined within the Aviation White Paper is at odds with the EWP's carbon reduction targets (Bows and Anderson, 2007). A sustainable energy system in 2050 is likely to combine elements from several storylines, so for example the private consumption characteristics of the 'World markets' scenario are not necessarily incompatible with the ecological values within the 'Global sustainability' scenario, and a 60% reduction future may combine these apparently 'inconsistent' elements. Thus, attempting to frame the Tyndall scenarios within a stylised Foresight-type framework was deemed too constraining, as has been the case for other studies (Kok et al., 2006). In the light of this, the challenge was to broadly define the form and socio-economic structure of societies in which such reductions could be achieved.

In contrast to relying on a model of policy as internally consistent and coherent, the Tyndall scenarios developed along a more open, discursive and iterative route in which the energy policy realm was assumed to remain characterised by a range of tensions and potential conflicts. This dialectic approach embraced often opposing views and paradigms (Bullock and Trombley, 1999) to reveal more interesting and potentially novel responses to the carbon issue. In so doing the approach gave rise to a series of important socio-economic factors to consider in developing the scenarios; these are summarised in Table 5.

For any energy demand end-point, the resulting energy system is inevitably a function of these and other socio-economic tensions. Since the Tyndall end-points were initially described in a highly quantitative manner, each end-point could relate to a range of different 'patterns' of interactions. Within the Tyndall process these interactions were illustrated with radar diagrams, and from this visual interpretation of the socio-cultural system, a qualitative description was derived.

3.5. Backcasting

The four end-points, revised following the first workshop and linked to the socio-economic descriptions, provided the foundations for the backcasting workshop. Backcasting is intended to be a participatory process where a diverse group of stakeholders step back in time and articulate the transition from a defined end-point to the present day. Twenty stakeholders were recruited from organisations responsible for energy policy delivery, along with a small number of academics. The backcasting was approached in three stages, with participants working initially in small groups before discussing outputs in a plenary session:

- (1) 'Critical factors' (defined as 'a level of change in technologies, values, behaviours, infrastructure, or other physical or social variables, excluding policy instruments, necessary to bring about an end-point scenario') were identified for each end-point for the years 2015 and 2030; these are listed in Table 6.

Table 5
Socio-economic factors

Factor	Energy policy impact
Influence of government	Government may take a range of actions to promote a sustainable energy system ranging from interventionism, e.g. market transformation measures (Boardman, 2004), to a more hands off approach typified by a more liberalised energy market.
Public sustainability values	The public exhibits a range of values in its active support and rejection of the sustainable use and production of energy; research within household and transport sectors suggests that issues around public sustainability values are central to achieving a decarbonised society (Boardman et al., 2005; Tight et al., 2005).
Energy security concerns	Energy security was a central issue within the 2003 EWP and the Government's commitment to a diverse energy system based on a mix of fuel types and supply routes as the principal mechanism for ensuring security will inevitably influence the form of low-carbon energy systems. Such influence is well illustrated by the expansion of the French nuclear industry in response to fossil price rises of the 1970s (Taylor et al., 1998).
Global conflict	Military conflicts, even those in which the UK is not directly involved, will have varying consequences for the UK's approach to developing a low-carbon future, impacting on resources available for investment.
Climate change impacts	Major climate-related impacts are likely to effect the development of sustainable energy policies and the ease with which such policies are implemented.
Technological innovation drivers	Achieving a significant reduction in carbon emissions will require significant levels of technological innovation (Foxon, 2003).
The scope of liberalism	The extent to which societies (national and/or global) apply the concept of 'freedom' to individuals, institutions, religions, enterprise and economics (Bullock and Trombley, 1999) would result in different policy mechanisms. Thus, strong liberalism would tend to focus sustainability policy on individual choice, entrepreneurship, light-regulation and a belief in market forces and mechanisms.

Table 6
Critical factors identified in the backcasting workshop

End-point	Full list of critical factors (stage (1))	Elements of the backcasts that were developed by participants during the workshop (stages (2) and (3))
Red (90 Mtoe)	Transport	Transport—increasing public transport network and deployment of non-carbon fuels Reducing the attractiveness of the private car (complement to increasing public transport) Enabling H ₂ use in transport—new infrastructures
	Building energy use Demolition rates for buildings	Reducing energy consumption of the building stock
	Supply issues	Supply side changes—deployment of CCS and H ₂
	Energy efficiency Low energy demand scenario	Demand reduction—constraints on high carbon technologies and behaviour

Table 6 (continued)

End-point	Full list of critical factors (stage (1))	Elements of the backcasts that were developed by participants during the workshop (stages (2) and (3))
	Knowledge International Employment	
Blue (130 Mtoe)	H ₂ for terrestrial transport Carbon capture and storage	Hydrogen use in transport—production from coal gasification
	Emergence of energy supply companies Investment CHP Restructuring of the energy industry	Energy industry restructuring—development of Energy Service Company Framework
	Retro-fitting Households Buildings Land use planning	Buildings: radically changing energy use by buildings, across all sectors
	Nuclear energy Public acceptance	
Turquoise (200 Mtoe)	Aviation	Growth in the number of airport runways Aviation management systems to limit increased numbers of airports
	Nuclear power	Expansion of nuclear power plants to provide electricity and hydrogen
	Biofuels and biomass Railway infrastructure Renewables Integrating renewables in buildings Household energy consumption Natural gas Energy-intensity reductions IGCC plants with CCS	Biofuels for transport applications Expansion of railways infrastructure
Purple (330 Mtoe)	Planning for a step change Networks and infrastructure	Infrastructure—pathway considers the development of integrated supply and demand infrastructure
	Siteability Nuclear energy Attitude	Large-scale deployment of nuclear power—development of new technology, siting, regulation and licensing
	Renewable energy	

- (2) The critical factors identified in stage (1) were further unpacked to define the changes in energy and transport technologies, behaviour, social patterns, industries and services, etc., required to realise them.
- (3) Policies were outlined to bring about the social, value, technological and economic changes underpinning (2).

In essence, participants identified all the factors that they considered critical to the achievement of a particular end-point,

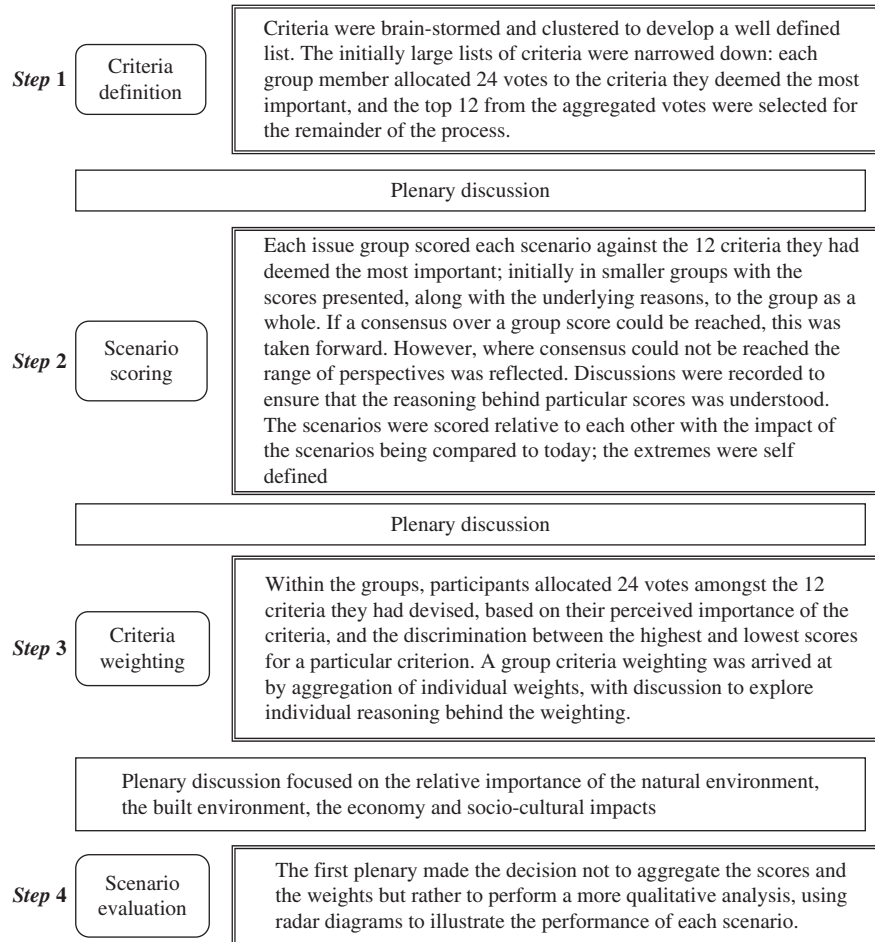


Fig. 2. MCA methodology.

then identified which were the most important and defined pathways for these critical factors. The full range of critical factors devised during the workshop is listed in Table 6, along with those deemed to be the most important, and for which full backcasts were developed by participants (stages (2) and (3)). Pathways for the remainder of the critical factors were developed by the project team, and incorporated into the final scenarios. It is a limitation of the project that, due to resource constraints, the scenario pathways were not developed in an entirely participatory manner. The pathways covered a cross section of policy steps, technology, social, cultural and political milestones, as well as the necessary infrastructure developments required to achieve a particular combination of energy consumption and supply by 2050. Breaking the process down into different time frames ensured that a cumulative emissions trajectory framed the backcast, and that new technological innovations came on-stream within appropriate timeframes. The detailed outputs from this workshop can be reviewed in Anderson et al. (2006).

3.6. Multi-criteria assessment

The final phase of Robinson's generic backcasting framework (Robinson, 1990) is to explore the impacts and consequences of the scenarios, developed through the backcasting process. A comprehensive assessment of the economic, social and environmental impacts of the scenarios is required; hence a multi-criteria assessment (MCA) approach was adopted. MCA

techniques offer a systematic framework through which the impacts of scenarios can be explored against a broad set of defined criteria. As such the technique is particularly appropriate for capturing the full dimensions of the economic, environmental and social realms embodied within the tenets of sustainable development (Stirling and Meyer, 1999; Gough and Shackley, 2006) and this stage of the analysis can be viewed as an assessment of the sustainability of the scenarios themselves.

The MCA element of the project sought to make explicit the consequences of the end-points and pathways rather than select the 'best' scenario for the UK energy system in 2050. Based on the techniques developed by the Environment and Society Research Unit at UCL (ESRU, 2004; Burgess et al., 1998) the assessment was conducted at a workshop of invited academics and stakeholders as outlined in Fig. 2. The workshop format firstly ensured that the assessment was based on a diversity of expertise, and perspectives and secondly allowed for a rich exploration of the consequences of and the trade-offs between scenarios, and the reasoning behind these to emerge from discussions amongst participants.

Participants were split into one of four issue groups, with the groupings maintained for the duration of the workshop: natural environment, built environment or infrastructure, socio-cultural/political impacts and economics according to their area of expertise. The separation had three purposes: to ensure that criteria were devised and scored by those with appropriate expertise; to potentially diffuse tensions between stakeholders with different sustainability concerns; to generate as large a number of evaluation criteria as possible.

Scoring the scenarios provided an indication of the consequences of each scenario with respect to a particular criterion, whereas the criteria weighting made explicit the trade-offs between the areas of impact. The results of the assessment are presented in Part 2 of this paper.

4. Conclusions

This paper has outlined the participative process through which the Tyndall decarbonisation scenarios were developed. Combining elements of backcasting and forecasting, the approach allowed the quantification of qualitative storylines, and the articulation of pathways for the transition to the described endpoint. The qualitative descriptions themselves emerged as a consequence of the backcasting workshop, but also from an analysis of the interacting tensions used to define the direction of energy policy. One important strength of the backcasting method is that it quantifies 'what has to be done' to remain within a given emissions trajectory. For many workshop participants, the quantification was a very powerful means of communicating the scale of the challenge across all sectors of the economy. The implications and consequences of these scenarios were assessed using an MCA framework that was applied in a deliberative workshop setting. It is hoped that the approach will prove useful and interesting to those engaged in participative scenario development, and concerned with the formulation of energy policy, particularly given the scale of action required to mitigate carbon emissions from the energy system. A number of issues emerged with respect to the methodology and are discussed below.

Stakeholders were invited to participate in the project workshops, with participant selection based on the skills and expertise deemed to be required at a given stage of the process; as a result, no participants attended all three workshops, with a small number attending two of the three. There was therefore a trade-off made between the greater of ownership stakeholders had over the scenarios, and inviting people according to the expertise and skills required. Moreover, stakeholders were not involved in devising the overall goal of the backcasting scenarios, though this was somewhat mitigated by acceptance of the overall goal of the project, namely to explore the UK's 60% carbon target, with the inclusion of all sectors, and the fact that the process provided an alternative approach to exploring UK energy policy.

The issue of ownership over the scenarios also arose as resource constraints meant that the first two workshops were limited to 1 day each, and it proved challenging to perform the backcasting in the time allocated. As a consequence the scenarios themselves were further developed by the project team, based on the workshop outputs, rather than by the stakeholders themselves. Similarly, it proved extremely challenging to perform the MCA assessment in the day and a half workshop and no attempt was made to weight the relative performance of the criteria defined by the different issue groups. Consequently, no feeling emerged as to whether environmental criteria were more or less important than socio-cultural ones (for example).

The MCA element of the work was the most contentious and challenging part of the process, in terms of stakeholder interactions. The issue of a lack of ownership over the scenarios has already been highlighted, and in terms of the MCA specifically, many participants wished to discuss the content of the scenarios themselves, as opposed to perform the assessment. Issues also emerged with the MCA method per se, and in particular whether scenario scores and criteria weights could be combined to give an overall quantified scenario performance. Ultimately, the project team chose, for a number of reasons, not to go down the route of

quantitatively combining the weights and scores. The first reason for the more qualitative method was the inherent uncertainty in attempting to quantitatively score criteria, which described impacts in the year 2050, though comparison was still possible using ordinal scales. Secondly, the MCA literature raises theoretical issues with respect to the scoring of options under criteria since people performing the evaluation perceive scales of unit differently and therefore a unit of score may not mean the same thing to two people (Stirling and Meyer, 1999). The open manner, in which the assessment was conducted, with participants defining their own scales and extremes of performance as individuals and in groups, meant that no calculations were performed; rather the scores and weights were assessed in terms of emergent patterns and common features.

The scenarios that were developed through this process and the results of the MCA are described in Part II of this paper. Overall, this approach was found to be successful in exploring how the UK may achieve a 60% reduction in CO₂ emissions by 2050, inclusive of the hitherto ignored sectors of international aviation and shipping.

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