UKERC Technology and Policy Assessment

How consistent and comparable are ecosystem services and energy system scenarios?

Working paper

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Executive Summary

This working paper identifies UK and global scenarios that have examined natural capital, ecosystem services and energy systems, and considers the extent to which they are consistent and comparable.

This work can be considered within the context of the UK governments Climate Change Act (DEFRA 2008) and Carbon Plan (Department of Energy and Climate Change 2011) that considered that meeting carbon budgets must be achieved in a way that contributes to sustainable development. Specifically, policy options that addresses climate change should be identified that appropriately recognise the value of nature.

In total we were able to identify and obtain information from 22 ecosystem service scenario exercises of which 6 where specifically UK focused, and 18 energy scenario exercises of which 13 were specifically UK focused.

A number of key similarities and difference emerge from the comparison and analysis:

1. Energy and ecosystem services pathways can be grouped based on a number of broad factors that include the level of international engagement, the balance of fossil and non-fossil sources of energy, and decarbonisation targets;
2. Energy models are employed across both types of scenarios. A key difference arises in high level aggregation of energy systems in ecosystem services scenarios;
3. Energy scenarios are biased towards exploring routes to decarbonisation of the energy system;
4. Ecosystem service scenarios typically consider the success or failure of society to achieve decarbonisation targets by considering the implications of climate change on the provision of ecosystem services;
5. Energy systems are likely to form just one component of an ecosystem services pathway, such that other drivers may exert considerable influence on the narrative of the scenario.

We conclude that the two sets of scenario exercises are consistent in that they explore the implications of success or failure to decarbonise the energy system. However, the limited focus of energy scenarios on implications for ecosystem services, and the highly aggregated nature of energy systems in ecosystem services scenarios, make direct comparisons between scenarios challenging. This does not represent a failure of the scenario exercises but arises from the scope of each scenario exercise as set by the original commissioning body.

Future energy pathways can be considered to represent a single driver within ecosystem services scenarios. Given that options for decarbonisation are extremely diverse and will be associated with a range of economic, social and environmental consequences, the evidence from the analysis conducted for this working paper suggests that future ecosystem service exercises should consider taking a more detailed view of the energy system in order to identify low carbon pathways that minimise ecosystem service consequences. Similarly, the evidence suggests that energy scenarios should increasingly consider the wider environmental consequences of energy pathways in order to differentiate between the most desirable options.

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1. Introduction

1.1 Background and context

The use of scenarios to explore different possible futures and identify uncertainties increasingly features in business and government planning. Broadly speaking scenario exercises can encompass three objectives (Hughes and Strachan 2010); (i) protective decision making – to increase resilience by identifying external factors that could have significant implications; (ii) proactive decision making – to identify future opportunities and actively shape future events in a desirable way; (iii) consensus building – to facilitate understanding between different actors and achieve consensus about desirable future options. The specific balance of each of these objectives will depend on the role that the scenario is intended to perform (Hughes and Strachan 2010). According to the typology of Börjeson et al. (2006) scenarios may be predictive (what will happen?), explorative (what can happen?) or normative (how can a specific target be reached?). Irrespective of this typology, scenarios facilitate engagement with stakeholders, enabling consideration of responses to challenges that the scenarios raise (Haines-Young et al. 2011).

This working paper is written within the context of the UKERC Pathways Development project, and explores the links between the energy and environmental dimensions of energy system pathways. We use the term scenario and pathway in line with (van Vuuren et al. 2014). Pathways are focused on specific components of the scenario. For example they describe future carbon emissions, changes in energy mix, population etc., and it is the integration of such pathways that define a scenario. Within the context of the wider UKERC project this report will contribute to the exploration of the whole system dimension of pathways that will consider environmental, economic, technical, institutional, political and social dimensions aspects of future options.

Currently, much of the discourse relating to interactions between environment and energy systems is focused on climate change. The resultant alignment of climate and energy policy has led to the adoption of a number of energy strategies that, while delivering benefits for climate change, have the potential to negatively affect other key aspects of the environment (Pittock 2011). A central feature of the development of the whole system dimension of energy pathways will therefore be to incorporate a broad consideration of implications for the environment. To achieve this pathways will be developed that consider the implications of energy choices for the world's natural capital and ecosystem services. This work can be considered within the context of the UK Government Climate Change Act (DEFRA 2008) and Carbon Plan (Department of Energy and Climate Change 2011) which proposes that carbon budgets are met in a way that contributes to sustainable development. Specifically, policy options that addresses climate change should be identified that appropriately recognise the value of nature (Department of Energy and Climate Change 2011).

Within this working paper we refer to both ecosystem services and natural capital. Ecosystem service(s) is used as a general term that encompasses the pathway from ecological processes to the delivery of benefits to human society (Mace, Norris, and Fitter 2012). Ecosystem services flow from the world's natural capital, the living and non-living components of nature. We can think of ecosystem services as the 'dividends' that the natural 'capital' provides (Costanza et al. 1997; Sukhdev 2010), for example fish stocks represent a form of natural capital with the amount that can be harvested sustainably representing the ecosystem service.. In these terms, for economic development to be sustainable it is essential that society lives off the ecosystem service dividends and does not erode the natural capital base. The idea that ecosystem services are essential for human well-being is increasingly embedded in policy at local, national and global scales (Daily and Matson 2008; Gomez-Baggethun and Ruiz-Perez 2011). As such, consideration of future energy pathways for ecosystem services may have strong resonance with decision makers, and has a key role in the identification of energy options that will allow the UK to meet its national and international obligations for both decarbonisation (Edenhofer et al. 2014) and halting the loss of biodiversity and degradation of ecosystem services (Convention on Biological Diversity 2012).

Scenarios have been widely used in the energy domain to explore alternate futures of energy system. Indeed the scenario exercises undertaken by Shell in the 1970s remain some of the defining examples of the value of such work in managing business risk (Wack 1985a; Wack 1985b; Hughes 2009). Recent reviews of energy scenario exercises such as those of Hughes and Strachan (2010) and Söderholm et al. (2011) find that the focus of recent scenario exercises has been to explore routes to decarbonisation of the energy system. This raises a number of substantial challenges in predicting societal and technological changes occurring over time frames of 50-100 years (Hughes and Strachan 2010). Such challenges are also present in studies such as the UK National Ecosystem Assessment (UK NEA) and the Millennium Ecosystem Assessment (MA) where scenario exercises explore drivers of change and implications for the delivery of ecosystem services across a range of possible futures (Haines-Young et al. 2011; Millennium Ecosystem Assessment 2005).

1.2 Research questions

The review is structured around one central research question:

To what extent are energy and ecosystem scenarios consistent and comparable?

The approach to answering this overarching question can be broken down into a number of constituent parts that are considered in detail within the results and discussion sections of this working paper.

Firstly, relating to the evidence base that exists;

1. What ecosystem services scenarios have been published, and what are their key drivers and features?
2. What energy scenarios have been published, and what are their key drivers and features?

Secondly, to examine the relationship between energy and ecosystem service scenarios;

3. What are the commonalities and differences between scenarios?

4. To what extent is there consistency between scenarios of energy system and ecosystem services?
5. If there is inconsistency to what extent does this affect the lessons that can be drawn from the scenarios?

Finally, to guide the whole systems analysis of UK energy systems;

6. What are the recommendations in the light of the evidence base for integrating ecosystem services in energy pathways?
7. How will this inform UKERC phase 3 research and beyond?

1.3 Report structure

Section 2 of this working paper describes the (differing) approach taken to identify the ecosystem and energy system scenarios, and the criteria used for assessing, where applicable, the relevance of the source studies.

Sections 3 and 4 of the paper provide, respectively, an overview of the ecosystem and energy system scenarios that emerged from the searches described in Section 2.

Section 5 draws out the key differences and similarities between scenarios, comparing and contrasting those scenarios used in energy systems and ecosystems analyses, and Section 6 concludes the working paper.

2. Identification of literature

Ecosystem services scenarios were identified using a systematic literature review and assessed for relevance using a Rapid Evidence Assessment methodology (see Section 2.1 below). Energy scenarios were selected based on expert knowledge from the UKERC community and from previous reviews to represent those scenarios considered to be most influential (see Section 2.2 below).

Given the focus of UKERC and that the UK has been an international leader in the use of low carbon scenarios (DEFRA 2008; Hughes and Strachan 2010) and ecosystem service scenarios (Haines-Young et al. 2011) the geographic scope of studies considered is those of primary relevance to the UK. The growing understanding of the international implications of national energy strategies means that we also consider a number of major global studies relating to both energy and ecosystem services and consider the insights that these can provide.

2.1 Ecosystem services

2.1.1 Rapid evidence assessment methodology

Identification of relevant ecosystem service studies was conducted using a Rapid Evidence Assessment (REA) approach, defined as "a short but systematic assessment on a constrained topic" (GSR 2013). REA's have been designed to maintain the rigour of a full systematic review, but to deliver results rapidly within constraints imposed by cost and time (Hailey et al. 2000; Khangura et al. 2012).

The approach followed the procedures established in previous TPA assessments that are directly comparable to established protocols for conducting REAs (Collins et al. 2014). As such the REA involves the following steps[1]:

1. Publication of this scoping note on the UKERC website;
2. Convening an Expert Group, representing a variety of opinions and perspectives, to advise the project team;
3. A systematic search of a clearly defined evidence base using keywords;
4. Categorisation, prioritisation and analysis of the evidence, including an appraisal of methodological quality;
5. Drafting of a report;
6. Expert feedback and review of this draft report;
7. Publication and dissemination through appropriate mechanisms.

2.1.2 Scope

We considered studies conducted at three spatial scales: (i) UK focus, either as whole country or regional breakdown; (ii) European focus, with the UK considered either

[1] Many of these steps apply to the overall approach to the working paper i.e. both ecosystem services and energy system scenarios.

individually or as part of aggregate region; (iii) global focus, with the UK considered either individually or as part of aggregate region.

In terms of ecosystem services we considered studies to be relevant if they encompassed individual or multiple services. Ecosystem services were defined as those considered under the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin 2012). The CICES system has been developed to support work on environmental accounting within the European Union and the United Nations Statistical Division (European Commission. et al. 2014; European Commission et al. 2013). We also retained scenario studies that considered other environmental factors of relevance to the provision of ecosystem services, for example scenarios of future land use change or biodiversity loss.

2.1.3 Literature search

Evidence was identified through keyword searches of the Thompson Reuters Web of Knowledge and Elsevier Science Direct databases using Boolean combinations of relevant terms (Table 1). Returned results were firstly filtered for relevance based on their title. Following this the full text of retained search results was retrieved, and a second stage of filtering conducted based on the abstract. During this second filtering stage the sole criterion for retention was that the study considered ecosystem service or environmental scenarios. Finally the full text of the remaining references was used to identify qualifying studies based on the scope outlined above.

For each of the retained studies, scenarios identified were cross-referenced to remove duplication and key metadata was compiled. Each scenario set was then scored based on the dual criteria of relevance (Table 2) and robustness (Table 3).

Table 1: Keywords used in literature search.

Ecosystem service keywords	Scenario keywords
Ecosystem	Scenario
Ecosystem service	Future
Natural capital	Storyline
Land use	Pathway
Landuse	
Biodiversity	
Provisioning	
Regulating	
Supporting	
Cultural	

Table 2: Scoring criteria for relevance of studies to UKERC Pathways project.

Category	Criteria	Score
Geographic region	Global (UK as aggregate region)	1
	EU (UK as aggregate region)	2
	UK specific	3
Ecosystem services	1 service	1
	2-5 services	2
	6+ services	3
Energy	Little detail of energy systems	1
	Moderate detail of energy systems	2
	High detail of energy systems	3
Scenarios	Mainly quantitative, limited narrative scenario	1
	Scenario with limited scope	2
	Well defined narrative scenarios	3

Table 3: Scoring criteria of robustness of studies.

Category	Criteria	Score
Ecosystem service and energy	Either little information on methods used for development of scenarios limiting our ability to assess robustness of approach or significant limitations identified in the approach.	1
	Robust approach that is well documented. However, there are identifiable weaknesses in study (e.g. small pool of experts).	2
	Robust and clearly documented method likely to produce rigorous outputs. Study represents best practice.	3

2.2 Energy Scenarios

There is now a vast research and policy literature on energy pathways and scenarios. Some of this literature is more conceptually and methodologically oriented, while other parts are more results-oriented and prescriptive. In this working paper energy scenarios were identified based on existing reviews (Hughes and Strachan 2010; Söderholm et al. 2011) together with expert knowledge from the UKERC community about which scenario exercises are prominent in UK and global energy policy.

3. Overview of ecosystem service scenarios

3.1 Literature review

Based on the keywords detailed in Table 1, the initial search conducted in April 2015 returned over forty-five thousand references across the Thompson Reuters Web of Knowledge and Elsevier Science Direct databases. Using the title and abstract this was reduced to 338 references after applying the filtering approach described in Section 2 and the removal of duplicates (see Table 4). The full text of these 338 references was then examined resulting in a pool of 74 candidate studies. Cross referencing these studies to identify where different studies had used the same underlying scenarios resulted in a list of 34 potential scenario studies. Of these we were unable to locate documentation in 12 cases. Finally, the EU Pathway project which uses the IMAGE Integrated Assessment Model was identified as a potentially important piece of work given that it integrates a number of different models relating to energy, biodiversity, water resources etc. (see van Vuuren et al. 2015). At the time of writing scenarios for this model were still under detailed development so we did not include it in our analysis, although we note that the IMAGE framework was used in studies such as the Global Environment Outlook 5 (United Nations Environment Programme 2012).

Table 4: Number of references returned and retained at each stage of the evidence review.

Search term: Scenario OR future OR storyline OR pathway AND	Returned hits	First Filter	Second filter	Duplicates removed
Ecosystem service	1,260	163	39	35
Natural capital	231	18	4	3
Land use	13,249	1,359	114	224
Landuse	270	19	4	2
Biodiversity	10,597	647	171	47
Provisioning	925	42	12	2
Regulating	18	3	0	0
Supporting	413	14	2	1
Cultural	22	3	0	0
Ecosystem	18,061	552	96	24
TOTAL	45,046	2,820	442	338

3.2 Scope, methodology and content of ecosystem service scenarios

Scenario studies were first compared in terms of scope and methodology (see Table 5). In contrast to energy scenarios, which are funded from a broad range of sources, ecosystem service scenarios are predominantly funded by governments, NGO's or intergovernmental organisations. Exceptions include scenarios developed by the World Business Council for

Sustainable Development that examine possible futures for water resources globally to 2025 (Flowers and World Business Council for Sustainable Development 2006).

It is often difficult to identify the target audience for the scenarios as this is seldom stated explicitly. However, we conclude that the scenarios are of relevance to governments, academics, NGO/IGO's and business. The relevance to each of these individual stakeholder groups arises through a number of different routes. Given that governments are often the instigators of the work, the scenarios are of direct relevance where they explore the implications of different policy options. Relevance for business can arise through the implications of policy or where the scenarios identify future resources constraints, notably for water (Flowers and World Business Council for Sustainable Development 2006).

Development of scenarios is predominantly through approaches that combine quantitative and qualitative techniques. Quantitative analysis may include both changes in underlying socioeconomic or environmental drivers (e.g. population, energy mix, climate), as well as the implications of changes for factors of interest (e.g. land use, water availability). Qualitative analysis involves the use of various techniques to gather expertise from stakeholders. There is considerable crossover between the two approaches as stakeholders may define what drivers should be incorporated into the quantitative analysis or define the most relevant questions to be addressed by those quantitative analyses (for example see the UK NEA (Haines-Young et al. 2011)). In addition, stakeholders can also play a key role when considering the policy or societal implications of outcomes prompted by changes in the provision of ecosystem services revealed through quantitative techniques.

It is possible to make a distinction between two broad categories of scenarios based on how they are constructed. Firstly, there are those that can be termed normative (Börjeson et al. 2006) which define the endpoint that we may wish to reach over the timeline of the scenario, and then consider the economic, social etc. conditions that are required to achieve it. For example using existing international treaties Global Environment Outlook 5 explores a pathway whereby trends in the degradation of the global environment are halted and/or reversed over the coming decade. This normative scenario is compared with a "business as usual" scenario to explore the implications for biodiversity and the environment. The second category of scenarios are those that may be termed explorative (Börjeson et al. 2006). These do not define a specific endpoint but rather ask "what can happen" and consider how changes in key drivers (e.g. energy price, population) will influence the environment and provision of ecosystem services to the time horizon considered.

A comparison of the reviewed studies in terms of key drivers and implications is set out in Table 6. In broad terms scenarios can be placed within a space represented by two dichotomous axes. Firstly, a distinction based on the extent of international engagement. Secondly, a distinction based on the extent they are environmentally reactive or proactive. Such a dichotomous division (based on varying factors) is common in scenario studies and suggests four contrasting futures: (i) environmentally proactive, globally; (ii) environmentally proactive, nationally; (iii) environmentally reactive, globally; (iv) environmentally reactive, nationally.

Many of the studies considered here produce scenarios that correspond approximately to each of these four divisions (Millennium Ecosystem Assessment 2005; Haines-Young et al. 2011; Creedy et al. 2009; Pinnegar et al. 2006). Other studies produce scenarios that correspond to at least one of the futures. However, as argued by (Haines-Young et al. 2011) such grouping can be unhelpful in understanding the complexity of scenarios and the drivers considered. For example proactive environmental approaches can arise through top-down government policy mechanisms (Foresight Land Use Futures Project 2010), through changing business objectives (Flowers and World Business Council for Sustainable Development 2006), through changing societal values (Raskin, Electris, and Rosen 2010) and combinations of all these factors. Similarly, inherent in many choices about ecosystem services is that fact that there may be trade-offs between the provision of different services. As such a proactive approach to ecosystem services can still result in sharply diverging scenarios based on government, business and social objectives.

Thematically, scenarios vary from those that examine a single issue (Hirsch and Secretariat of the Convention on Biological Diversity 2010; Spangenberg et al. 2012) to those that consider a far broader scope (Haines-Young et al. 2011; Creedy et al. 2009). Across scenarios biodiversity, climate change, water and food security emerge as core ecosystem services considered reflecting recent interest in “nexus” issues (Godfray et al. 2010). Changes in land use are also commonly considered and can be linked to alteration in the provision of ecosystem services through multiple mechanisms. Reflecting a pattern in the broader ecosystem service literature, cultural services are rarely considered, featuring only in those studies that specifically take a holistic view across ecosystem service categories (Millennium Ecosystem Assessment 2005; Haines-Young et al. 2011; Creedy et al. 2009).

Examples of specific drivers that are consistent across studies include changes in population, land use, greenhouse gas emissions, energy technologies, resource use (e.g. energy, water) demand, food availability and social and political values. This is consistent with findings of (Haines-Young et al. 2011) who, in the UK National Ecosystems Assessment (NEA), identified five categories of driver relevant for ecosystem services: socio-political; economic; science and technology; cultural and religious; and demographic.

The majority of studies provide detail on assumptions about future energy and climate targets, with varying degrees of specificity. The most common projections of future energy and climate used in scenario development (e.g. Schröter et al. 2004; Foresight. The Future of Food and Farming 2011; Harrison and CLIMSAVE consortium 2013; Spangenberg et al. 2012; European Environment Agency 2007) are the Special Report on Emissions Scenarios (SRES) provided by the IPCC (Nakicenovic et al. 2000). The use of the SRES, which have subsequently been superseded by the Relative Concentration Pathways (RCP,) reflects the time frame over which many of the scenarios considered have been published. Of the other studies considered, many provide descriptions of energy mixes in terms of changes in the proportion of non-fossil and fossil sources with varying degrees of detail relating to the exact energy mix. For example (Foresight Land Use Futures Project 2010) uses projections of electric demand and generation from MARKAL whilst Global Europe 2050 (European Commission 2012) uses projections from the IEA. Certain studies do not consider the entire energy mix but rather consider the relationship between specific energy technologies of relevance to a focal region or habitat. For example Alternative Future Scenarios for Marine Systems (Pinnegar et al. 2006) considers implications of changes in offshore energy infrastructure (e.g. oil rigs, wind farms) for the marine environment.

Table 5: Scope and methodology of ecosystem services studies considered in the current review.

Scenario study	Funder	Target audience	Scope	Timeframe	Geographical boundary: UK vs global	Methodology: quantitative (Qn) vs qualitative (Ql)	Participatory input
Global environment outlook 5	Government, NGO	Government, NGO, Business, General	Biodiversity and environment	2050	Global	Ql, Qn	Wide consultation with stakeholders. Use of expert working groups.
Global environment outlook 4	Government, NGO	Government, NGO, Business, General	Biodiversity and environment	2050	Global	Ql, Qn	Wide consultation with stakeholders. Use of expert working groups.
Environmental Outlook	OECD	Government, NGO, Business	Four "red light" issues - climate change, biodiversity, water and health/environment.	2050	Global	Qn	
Business in the world of water	Business (World Business Council for Sustainable Development)	Government, Business	Water availability	Coming century	Global	Ql	Workshops - wide range of participants from across sectors.

Scenario study	Funder	Target audience	Scope	Timeframe	Geographical boundary: UK vs global	Methodology: quantitative (Qn) vs qualitative (Ql)	Participatory input
Global scenarios group	NGO, Academia	Government, NGO, Business, General	Pathways to sustainability	2100	Global	Ql	Dialogue with targeted stakeholders across broad range of sectors
Advanced Terrestrial Ecosystem Analysis and Modelling (ATEAM)	EU	Government, NGO, Business, General	Ecosystem services and adaptive capacity of human sectors	2020, 2050, 2080	Europe	Qn	Stakeholder guided process
EURuralis	Dutch Ministry of Economic Affairs, Agriculture and Innovation	Government, NGO, Business	Implications of CAP reform. Impacts on agricultural production and biodiversity	2020	Europe	Ql, Qn	
Millennium Ecosystem Assessment	Multiple UN, foundations, science organisations, governments	Government, NGO, Business, General	Ecosystem service provision.	2015, 2030, 2050	Global	Ql, Qn	Participatory approach but full description not given.
Foresight Food and Farming	Government	Government, NGO, Business	Food security	2050	Global	Ql, Qn	Wide stakeholder consultation

Scenario study	Funder	Target audience	Scope	Timeframe	Geographical boundary: UK vs global	Methodology: quantitative (Qn) vs qualitative (Ql)	Participatory input
Global Europe 2050	EU	Government, NGO, Business	Scenarios are expressed as six dimension from environment, economic and demographic challenges	2050	Europe	Ql, Qn	Expert dialogue
CLIMSAVE	European Commission	Government, NGO, Business	To explore climate change impacts and adaptation options across Europe.	2050	Europe (with a Scottish focused case study as well)	Ql, Qn	Participatory workshops with key stakeholders
ALARM	EC, EU	Government, NGO, Business	Large scale threats to biodiversity and to evaluate mitigation options.	2050	Europe	Ql, Qn	Consultation with stakeholders through forum events
Natural England Environment in 2060	Natural England	Government, NGO, Business	Implications of plausible future for the UK environment.	2060	UK	Ql	Consolation with broad range of stakeholders
Looking ahead to 2050	Foundations, science organisations, governments, UN	Government, NGO, Business	Focussed on water use to meet human demand, mainly on food production.	2050	Global	Ql, Qn	Expert consultation through workshops and reviews
Agrimonde	Government research organisations	Government, NGO, Business	Feeding the world in the future	2050	Global	Ql, Qn	Expert panel

Scenario study	Funder	Target audience	Scope	Timeframe	Geographical boundary: UK vs global	Methodology: quantitative (Qn) vs qualitative (Ql)	Participatory input
PRELUDE	EU	Government, NGO, Business	Future land use across Europe	2035	Europe	Ql, Qn	Stakeholder panel
UKCIP02	Government	Government, NGO, Business	Implications of climate change for UK.	2050	UK	Ql, Qn	Surveyed stakeholders to see needs for scenarios and content that was important
UK National Ecosystem Assessment	Government	Government, NGO, Business, General	Changes in provision of ES.	2060	UK	Ql, Qn	Wide stakeholder consultation. Including use of surveys
Global Biodiversity Outlook 3	Government, EC, UN	Government, NGO, Business, General	Implications of global environment change for biodiversity	Dependent on study considered. Up to 2100	Global	Qn	Wide range of scientists to develop consensus view of implications for biodiversity
AFMEC (Alternative future scenarios for marine systems)	Government	Government, NGO, Business	Status of the marine environment	2020, 2050, 2080	UK	Ql, Qn	Stakeholder workshops
Net benefits	Government	Government, NGO, Business	UK fishing industry	2020	UK	Ql, Qn	Steering group from stakeholders (govt., business)

Scenario study	Funder	Target audience	Scope	Timeframe	Geographical boundary: UK vs global	Methodology: quantitative (Qn) vs qualitative (Ql)	Participatory input
Foresight Land Use Futures	Government	Government, NGO, Business	UK Land use	2060	UK	Ql	Expert workshops

Table 6: Key drivers and implications of scenarios identified for each of the ecosystem service scenario studies.

Scenario study	Focus areas	Drivers & key variables	Governance implications	Societal implications	Energy & climate targets	Environmental implications
Global environment outlook 5	Biodiversity and environment	Population, income, consumption, energy, greenhouse gas emissions, land use	Alternate vision is highly connected society with leadership at every level.	Envisions a systematic transformation of society with most citizens engaged in sustainability.	In conventional scenarios GHG emissions have increased by 70%, alternate is a 50% reduction. In the alternate scenario there is rapid global electrification and access to modern energy sources.	Conventional scenario leads to loss of biodiversity, forests, and fisheries. Negative implications for society through access to food and drinking water.
Global environment outlook 4	Biodiversity and environment	Population, income, consumption, energy, greenhouse gas emissions, land use	Range of implications from a national security focus to interconnected world.	Different levels of public engagement across scenarios	Different levels of emphasis on economic, environmental and security considerations	Different levels of sustainable use of natural resources in all scenarios.
Environmental Outlook/OECD (OECD)	Four "red light" issues - climate change, biodiversity, water and health/environment.	Population, economic growth, energy use, land use	Implementation of Green Growth Strategy will require significant political leadership.	The alternate future would encourage social equity through the policy mechanisms designed to limit environmental impacts.	Baseline assumes current energy mix and leads to 80% increase in GHGs. Alternate models 450 ppm scenario based on tax and trading scheme and innovative clean energy.	Baseline scenario highlight significant problems for biodiversity, water, environment.
Business in the world of water	Water	Urbanisation, industry, food production, economic, trade. All are sketched in terms of broad trends.	Considers different models for water governance driven by government or market drivers.	Contrasting futures between sustainable water use globally or increasing distinction between have's and have not's.	Not considered in detail. Under some scenarios water becomes a limiting factor in energy production.	Choice between societal/environmental balance in water provision or between competition between them.

Scenario study	Focus areas	Drivers & key variables	Governance implications	Societal implications	Energy & climate targets	Environmental implications
Global scenarios group	To explore possible pathways to sustainability. The aim of the work was to look at contrasting scenarios but with a focus in achieving a "Great Transition" scenario that enhances hukan well-being and environmental reilience.	Social, economic, environmental factors.	From a strong global government to market driven policies. Scenarios with significant environmental problems receive major policy interventions.	Contrasts between an isolationist and connected world. One with significant social and economic equality and one with more equal distribution between countries and people.	Climate targets met in some scenarios. Achieved through rapid uptake of renewable energy and CCS, and through efficiency.	Scenarios paint contrasting implications for environment, with particular focus on food and agriculture.
Advanced Terrestrial Ecosystem Analysis and Modelling (ATEAM)	To assess the vulnerability of human sectors relying on ecosystem services to global change. Vulnerability is considered in terms of potential impacts and adaptive capacity.	Socioeconomic, climate, land use, nitrogen deposition.	Differing strength of government, markets and international cooperation	Loss of ES has a negative impact on society in most projections.	Uses elaboration of the SRES scenarios that define energy pathways.	Main anticipated trend are for decline in ecosystem service supply. However, for different ES there are contrasting patterns across Europe.
EURuralis	Implications of CAP reform. Impacts on agricultural production and biodiversity	CAP reform, land prices, macroeconomic factors	Transformation of the Single Payment Scheme to targeted payments in the agricultural sector	Implications for farm incomes, production, trade, prices		Targeted at protection of environment, biodiversity and ecosystem services

Scenario study	Focus areas	Drivers & key variables	Governance implications	Societal implications	Energy & climate targets	Environmental implications
Millennium Ecosystem Assessment	Ecosystem service provision.	Demographic, economic, socio-political, cultural and religious, Science and technology. Scenarios chapter specifically Includes N-S deposition, Climate change, invasive species, land use change, water use, poverty	Differing strength of government, markets and international cooperation	From a security and protectionist view to a highly mobile global workforce	Reliance on differing energy and varying success in achieving climate goals.	Range from general improvement, to significant regional variation, to general decrease environmental health.
Foresight Food and Farming	Focused on food security	Global population, changes in size and nature of per capita demand, governance, climate change, competition for resources (water, energy, land), changes in values and ethics of consumers.	Need to strengthen policy links between the food and environment sectors.	Considers options for the eradication of hunger and implications for global agriculture.	Uses SRES. Considers that the proportional contribution of agriculture to GHG emissions is likely to increase in future.	There needs to be recognition of interdependence between food security and ES. Policy options must be designed to address both.
Global Europe 2050	Global demographic and societal challenges; Energy and natural resource security and efficiency, environment and climate change; Economy and technology prospects; • Geopolitics and governance: EU frontiers, integration	Institutions, Financial globalisation, energy efficiency, education, TFP EU, Energy price, obsolescence, Migration, Emissions, Trade costs, agriculture.	From isolationist policy to global coordinated effort. May see significant geopolitical changes with growth of new powers.	Increasing competition for natural resources could have significant implications for society. May need to redefine what is meant by global progress to measures beyond GDP.	Differing energy strategies results in contrasting futures with low emissions or very high. Balance of renewables, and technology in other regions of world is key.	Project trends focussed on food, water and loss of biodiversity. Worst climate scenarios project major problems.

Scenario study	Focus areas	Drivers & key variables	Governance implications	Societal implications	Energy & climate targets	Environmental implications
	and role on the global scale; Territorial and mobility dynamics; Research, education and innovation.					
CLIMSAVE	To explore climate change impacts and adaptation options across Europe.	GDP, population, protected area, oil price, technological change	Governance is defined isolationist or global approach, and by effectiveness in dealing with economic shocks. Most effective approach is one based on redistribution of wealth. The beyond GDP agenda.	Most robust adaptation strategies rely on increasing social and human capital. Must be supported by strong institutions.	SRES scenarios	Biodiversity and water stress increase in South and East Europe. Food production and land use diversity in North Europe.
ALARM	To develop and test methods to assess large scale threats to biodiversity and to evaluate mitigation options. Scenarios are used as a tool to do this and explore policy responses.	Land use change	Range of future impacts is defined by the extent of policy interventions.	Discussion is limited to varied economic consequences.	Broad description of changes in energy and climate consistent with SRES scenarios. Energy systems have varying amounts of renewables and changing consumption patterns play a role.	All scenarios lead to loss of biodiversity. The coherent sustainability scenario slows this loss most.

Scenario study	Focus areas	Drivers & key variables	Governance implications	Societal implications	Energy & climate targets	Environmental implications
Natural England Environment in 2060	The focus of the report is to consider the implications of plausible future for the UK environment.	Climate change, technology, demographics, energy, food security, global economics, governance, health and wellbeing, infectious disease, marine, mobility, money/wealth/economy, resources, values and people.	From strong central government, to market led.	Different levels of public engagement. From strengthening of social capital to increasing disparity between groups.	From a policy aimed at adapting to climate change without addressing it to one where progress is made in cutting emissions	From valuation based on provision of goods and services, to valuation for symbolic and aesthetic reasons.
Looking ahead to 2050	Focussed on water use to meet human demand, mainly on food production.	Simulations of water demand for various sectors. Changing diets, changing fish production, water use in food/feed and bioenergy production, non agricultural use. Estimates of drivers taken from wide literature.	Governance has to balance food production with other environmental targets.	Significant issues for food security under certain scenarios associated with water stress.		Agriculture will remain largest user of water worldwide.
Agrimonde	Feeding the world in the future	Food availability, population	Alternate market led economy or one where global governance regulate food availability.	Focus of scenarios is on food security with associated social issues.	Steep rise in energy demand under Agrimonde GO only 10% by renewables. Agrimonde 1 project major technological investment in energy.	Ecological intensification has potential to limit impacts of agriculture on water, biodiversity and soil. However, environmental concerns could be secondary to meeting food production targets.

Scenario study	Focus areas	Drivers & key variables	Governance implications	Societal implications	Energy & climate targets	Environmental implications
PRELUDE	Future land use across Europe	Subsidiarity, policy intervention, settlement density, population growth, ageing society, immigration, internal migration, health concern, social equity, quality of life, environ awareness, economic growth, international trade, daily mobility, self-sufficiency, techno. growth, agricultural intensity, climate change, renewable energy, human behaviour.	From nationalist to European coordinated effort.	Major shifts are in changing rural/urban populations and society driving the environmental agenda.	Climate predictions are based on SRES scenarios. There are a range of energy futures from similar to now to high reliance on renewables.	Broadly positive impacts on environment under most scenarios.
UKCIP02	Implications of climate change for UK.	Multiple indicators. Scenarios are defined by (i) the composition and rate of economic growth (ii) technological change (iii) governance (iv) social and political values.	Divergent pathways between autonomy and interdependence	Divergent pathways between consumerism and community	From heavy reliance on fossil fuels to a mix of different solutions based on renewables or tightly regulated local resources.	Range of implications for based on economic conditions and public concern.
UK National Ecosystem Assessment	Changes in ES under different future storylines.	Multiple including: Land use, rainfall, energy resource and price, biofuel consumption, agricultural production, food prices, governance, innovations, population, rural and environment economy, urban growth	Local, national, EU, Global dependent on scenario. Markets dominate some options.	Changes in dwelling patterns and economic income in rural and urban areas. Changes in regional prosperity.	CC response in all scenarios with focus on different environmental aspects. Broad range of potential energy mixes depending on energy security options.	From general poor environment to good protected landscapes. Optimised trade-offs in some scenarios.

Scenario study	Focus areas	Drivers & key variables	Governance implications	Societal implications	Energy & climate targets	Environmental implications
Global Biodiversity Outlook 3	Implications of global environment change for biodiversity	Numerous driver define individual trajectories for biodiversity.	Contrasts government and market led strategies, and regional and global engagement.			
AFMEC (Alternative future scenarios for marine systems)	Marine systems	Climate, socio economic, policy, energy, tourism	All scenarios seek to balance top down and bottom up governance and emphasise role of regional stakeholders.	Potential for highly diverse outcomes across the UK with winners and losers.	Contrasts increasing oil and gas production with a shift towards renewables from wind and barrages.	Possibility of heterogeneous impacts. Local negative implications of infrastructure can be offset by reduced impact of climate change.
Net benefits	Focused on the UK fishing industry and its future	Climate, trade, sustainability, regulation, technology. Fleet projections are key and are based on profitability, catch limits etc.				
Foresight Land Use Futures	Land use change in the UK.	Climate change, rate of adaptation, concentration of people/economic activity, and resistance to change	Contrasting scenarios of government cooperation globally, or failure to address global challenges.	A critical uncertainty identified is whether there is resistance to land use change.	From business as usual and increased GHG emissions leading to significant environmental problems, to increased reliance on renewables.	From coordinated regional approach to loss of biodiversity and threats to water security.

3.3 Relevance of ecosystem service studies to the UKERC Pathways project

Using the criteria described in Tables 2 and 3 each scenario study was scored based on relevance and robustness. The highest ranked studies were the UK NEA (Haines-Young et al. 2011) and Foresight Land Use Futures (Foresight Land Use Futures Project 2010) followed by Alternative Future Scenarios for Marine Systems (Pinnegar et al. 2006), UKCIP02 (UK Climate Impacts Programme 2001), PRELUDE (European Environment Agency 2007), CLIMSAVE (Harrison and CLIMSAVE consortium 2013), and ATEAM (Schröter et al. 2004).

In interpreting the scores presented in Table 7 there are a number of points that should be considered. Firstly, it proved impossible to separate scenario studies based on their methodological robustness. The majority of scenario studies have either been published, or are based on analysis that has been published, in the peer reviewed literature. Although the quantitative or qualitative methods differ between scenario studies, we could identify no significant weaknesses in approaches when viewed in the context of the overarching aims of the respective scenario exercises. For example Haines-Young et al. (2011) consider that an approach that divides scenarios into four contrasting futures based on a dichotomous division of drivers would seriously limit the ability of the UK NEA to address framing questions set by stakeholders. However, in other studies such a division presents contrasting worldviews that can be seen as useful in exploring future scenarios (e.g. Natural England Environment in 2060; The Millennium Ecosystem Assessment). That is not to say that a detailed analysis of the methods employed across studies, conducted by technical experts in the relevant disciplines would not identify weaknesses, however such a comparative assessment is beyond the scope of the current report

Secondly, scenario studies such as Global Biodiversity Outlook 3 (Hirsch and Secretariat of the Convention on Biological Diversity 2010) and Business in the World of Water (Flowers and World Business Council for Sustainable Development 2006) received low scores for ecosystem service relevance as they deal with single services (i.e. biodiversity, water). Although they lack the scope of other scenario exercises, such analysis can provide insight into a focal area that can inform understanding of implications of energy pathways.

Finally, there was little to separate scenario studies in terms of scenario detail, with a number of exception. EURuralis has a limited scope dealing mainly with consequences of CAP reform, and does not provide a detailed narrative extending beyond this focus. Foresight Food and Farming is constructed around existing scenario studies and so discusses food production and its interaction with other environmental and socioeconomic systems within the context of different pathways and environmental goals, and therefore does not present a single set of unified narratives.

Table 7: Scoring of studies identified through the literature review based on relevance and robustness. Total score across all categories are combined and then ranked, with (1) being the highest and (22) being the lowest.

Scenario study	Author	ES relevance	Energy relevance	Geographic relevance	Scenarios detail	Robustness	TOTAL (RANK)
Global environment outlook 5	(United Nations Environment Programme 2012)	2	3	1	3	3	12 (11)
Global environment outlook 4	(United Nations Environment Programme 2007, 4)	2	3	1	3	3	12 (11)
Environmental Outlook/OECD	(OECD 2012)	2	3	1	3	3	12 (11)
Business in the world of water	(Flowers and World Business Council for Sustainable Development 2006)	1	2	1	3	3	10 (19)
Global scenarios group	(Raskin, Electris, and Rosen 2010, 20)	2	3	1	3	3	12 (11)
Advanced Terrestrial Ecosystem Analysis and Modeling (ATEAM)	(Schröter et al. 2004)	3	3	2	3	3	14 (4)
EURuralis	(Helming et al. 2011)	1	1	3	2	3	10 (19)
Millennium Ecosystem Assessment	(Millennium Ecosystem Assessment 2005)	3	3	1	3	3	13 (9)
Foresight Food and Farming	(Foresight. The Future of Food and Farming 2011)	3	2	3	1	3	12 (11)
Global Europe 2050	(European Commission 2012)	2	3	2	3	3	13 (9)
CLIMSAVE	(Harrison and CLIMSAVE consortium 2013)	3	3	2	3	3	14 (4)
ALARM	(Spangenberg et al. 2012)	1	3	1	3	3	11 (17)
Natural England Environment in	(Creedy et al. 2009)	3	3	3	3	3	15 (1)

2060							
Looking ahead to 2050	(de Fraiture et al. 2007)	2	1	1	3	3	10 (19)
Agrimonde	(Paillard, Treyer, and Dorin 2014)	2	3	1	3	3	12 (11)
PRELUDE	(European Environment Agency 2007)	2	3	3	3	3	14 (4)
UKCIP02	(UK Climate Impacts Programme 2001)	2	3	3	3	3	14 (4)
UK National Ecosystem Assessment	(Haines-Young et al. 2011)	3	3	3	3	3	15 (1)
Global Biodiversity Outlook 3	(Hirsch and Secretariat of the Convention on Biological Diversity 2010)	1	1	1	3	3	9 (22)
AFMEC (Alternative future scenarios for marine systems)	(Pinnegar et al. 2006)	2	3	3	3	3	14 (4)
Net benefits	(Cabinet Office 2004)	1	1	3	3	3	11 (17)
Foresight Land Use Futures	(Foresight Land Use Futures Project 2010)	3	3	3	3	3	15 (1)

4. Overview of energy scenarios

4.1 Scope, methodology and content of energy scenarios

The substantial variation between energy scenario exercises shown in Table 8 reflects the wide-ranging, multi-disciplinary, and to some extent fragmented, nature of energy research in the UK and globally. The reviewed scenarios have been commissioned by a variety of funding bodies including the UK government, the academic and industry communities, as well as combinations of those. This variation in source of funding and context has led to a differentiation in scope and key motivation behind each scenario. (Mai et al. 2013) suggest that underlying biases stemming from the commissioning agent of each scenario exercise should not be overlooked when considering the insights provided by the exercise. In most studies the authors have included caveats emphasising that the scenario exercises are exploratory in nature and that outcomes should not be considered prescriptive but plausible futures developed in order to inform decision making and strategy development.

Consensus building around the inevitable changes required for a successful transition towards a desired future seems to be a particularly prominent aim for scenario development among government-driven analyses. The transformation of the UK energy system is a complex process that will require the contribution and support of many actors. The Carbon Plan (Department of Energy and Climate Change 2011) underlines the need to develop a coalition for change between government, industry and the public and states: *'.. public opinion is in favour of tackling climate change, there is little agreement about how to go about it… it will require the public to accept new infrastructure and changes..'*. It is interesting to note that the Carbon Plan, as an 'official' version of the future, is more prescriptive about future actions and actor responsibilities than other scenario exercises, and it is clear about the leading role in effecting the transition being placed on industry, while the government takes on a supporting role: *'Industry must lead, but the Government can facilitate'* (Department of Energy and Climate Change 2011).

The need to develop momentum towards a preferred and policy-compliant energy future is highlighted by the fact that in most government scenarios futures are in alignment with (the UK's) statutory emissions targets. Consensus building towards a low carbon future is also the main objective behind the one set of scenarios that were commissioned by an NGO where the economic impacts of the legislated fourth carbon budget were explored and contrasted to a scenario with diminished political support towards the UK's climate goals (Pollitt, Summerton, and Billington 2014).

Scenarios developed by private sector organisations appear to be largely geared towards decision making and strategy development, both in proactive and protective mode. The majority of academic scenarios also lean towards strategy development and opening up the debate on plausible energy futures. It should be noted that the purpose of scenario exercises is not only driven by the source of funding but is also a function of the target audience. Scenarios that are more outward-facing tend towards the development of common ground between actors with different interests while scenarios whose primary function is inward-facing, such as private sector scenarios geared towards company stakeholders, frequently emphasise strategy development.

The diversity in the focus areas of the reviewed scenarios partly mirrors the different goals of the 'energy trilemma': sustainability, energy security & affordability. The majority of academic studies appear to focus on the decarbonisation of the energy system, which falls under the sustainability aspect of the trilemma. The timeframe for most academic and government-driven studies is to 2050, which is in line with the UK's legally binding reduction commitments according to the 2008 Climate Change Act (DEFRA 2008). This contrasts with private sector scenarios by Shell and Exxon Mobil that don't place specific focus on any of the trilemma aspects and instead are driven by the need to develop a robust business strategy. Furthermore, their geographical boundary is wider, emphasising the global scale rather than the UK. The timeframes of the private sector scenarios also vary; with the academic and government scenarios typically looking out to 2050, whilst the Shell (Royal Dutch Shell 2013) and Exxon Mobil (Exxon Mobil 2013) scenarios looking out to 2100 and 2040 respectively.

In terms of methodology various analytical approaches are observed. The majority of studies follow either a modelling-driven quantitative approach or a combination of quantitative and qualitative methods, while only the Foresight scenarios are purely qualitative. The quantitative scenarios place more emphasis on the technological aspects of energy system transitions, while in some cases the focus is on economic factors, such as investment requirements. Modelling driven scenario exercises tend to use either bottom-up whole systems models, such as MARKAL which has been extensively used during UKERC Phases 1 and 2, or sectoral models. Quantitative scenario exercises are usually back-casted, in the sense that they are developed under exogenously imposed emissions or other constraints – the advantage of this approach being that the modelling outputs are internally consistent.

The studies that combine quantitative and qualitative methodologies aim to present a more holistic view of energy system transitions and often take into account a greater number of parameters, such as behaviour change, governance implications, leadership and institutional structures. The studies that follow a socio-technical approach to scenario development are sometimes characterised by a higher degree of participatory input towards scenario development. This can range from participation in an online survey to specialised workshops and invited interviews. A higher level of stakeholder input can facilitate the consideration of certain transition elements that are not adequately represented through modelling techniques, such as actor dynamics and institutional implications. Opening up the dialogue on different energy futures can enrich the debate, allowing for the consideration of system interactions and uncertainties that are not tractable in models; in fact (W. McDowall et al. 2014) argue in favour of engaging with a range of different stakeholders in order to draw out contesting viewpoints and priorities.

Table 8: Scope and methodology of energy studies considered in the current review.

Scenario exercise	Funder	Target audience	Scope	System boundary	Timeframe	Geographical boundary: UK vs global	Methodology: quant vs qual	Participatory input
UKERC Global Energy Scenarios (Ekins et al. 2013)	Academia: UKERC	Academics, policy	Decarbonisation	Whole-system	2050	Global	Quant: TIAM-UCL	
Transition Pathways & Realising Transition Pathways (Foxon and Pearson 2013)	Academia & industry: EPSRC/ E.ON UK	Academics, policy, industry	Decarbonisation	Electricity	2050	UK	Quant & qual	Interviews & workshops
Foresight Scenarios: Powering our Lives (Devine-Wright et al. 2009)	Government: Government Office for Science, DCLG	Policy	Decarbonisation, energy security, fuel poverty	Whole-system	2050	UK	Qual: 2x2 framework	Workshops
CLUES (Sherriff and Turcu 2012)	Academia: EPSRC	Local authorities	Centralisation lock-in risk	Whole-system	2050	UK	Quant & qual	Online survey
Infrastructure Transitions Research Consortium (Tran et al. 2014)	Academia: EPSRC	Academics, policy, industry	The provision of resilient, effective infrastructure systems	Whole-system	2050	UK	Quant: NISMOD	

Scenario exercise	Funder	Target audience	Scope	System boundary	Timeframe	Geographical boundary: UK vs global	Methodology: quant vs qual	Participatory input
Energy 2050 (Ekins et al. 2013)	Academia: UKERC	Academics, policy	Decarbonisation & system resilience	Whole-system	2050	UK	Quant & qual	
Transition Pathways for Hydrogen (Will McDowall 2014)	Academia: EPSRC		Decarbonisation in energy & transport	Hydrogen	2050	UK	Quant & qual	Interviews & workshops
Shell New Lens Scenarios (Royal Dutch Shell 2013)	Industry: Shell	Company stakeholders	Strategy development	Whole-system	2100	Global	Quant & qual	
National Grid Future Energy Scenarios (2014)	Industry: National Grid	Government, industry	Security of supply, affordability, sustainability	Whole-system	2035/ 2050	UK	Quant & qual: 2x2 framework	Annual FES conference, workshops, online survey, questionnaire, social media.
The CCC 5th Carbon Budget (The Committee on Climate Change 2015)	Government: CCC	Government	Decarbonisation	Whole-system	2020/ 2030/ 2050	UK	Quant	Open Call for Evidence, stakeholder workshops, roundtables and individual meetings
CCC 4th Carbon Budget (2013 revision) (Committee on Climate Change	Government: CCC	Government	Decarbonisation	Whole-system	2020/ 2032/ 2050	UK	Quant	Open Call for Evidence, stakeholder workshops & 3 dialogue workshops

Scenario exercise	Funder	Target audience	Scope	System boundary	Timeframe	Geographical boundary: UK vs global	Methodology: quant vs qual	Participatory input
2013)								with the wider public.
Carbon Plan (Department of Energy and Climate Change 2011)	Government: DECC	Industry, the public: consensus building	Decarbonisation & security of supply	Whole-system	2050	UK	Quant: MARKAL/ ESME/ 2050 calculator	
Project Discovery (Ofgem 2009)	Government: Ofgem	Consumers, industry, government	Investment levels required for supply security	Whole-system	2025	UK	Quant	Open consultations for consumers, industry & government
The Economics of Climate Change Policy in the UK (Pollitt, Summerton, and Billington 2014)	NGO: WWF-UK	Government	Macroeconomic costs and benefits from climate change policies in line with the first four CBs.	Whole-system	2030	UK	Quant: MDM-E3	
World Energy Scenarios (World Energy Council 2013)	Intergovernmental	Government, industry	Decarbonisation. Future of energy system.	Whole-system	2050	Global	Quant: MARKAL & Qual	Bottom up. Modelling and regional workshops
World Energy Outlook 2015 (International	Intergovernmental: IEA	Government, Industry	Evolution of the energy system	Whole-system	2040	Global	Quant: World Energy Model & Qual	Modelling and series of workshops.

Scenario exercise	Funder	Target audience	Scope	System boundary	Timeframe	Geographical boundary: UK vs global	Methodology: quant vs qual	Participatory input
Energy Agency 2015)								
The outlook for energy, a view to 2040 (Exxon Mobil 2013)	Industry: Exxon Mobil	Company stakeholders	Strategy development	Whole-system	2040	Global	Quant	
ETI Scenarios (ETI 2015)	Public-private partnership: ETI	Government & industry	Decarbonisation	Whole-system	2050	UK	Mainly quant: ESME	Engagement with ETI members & eternal stakeholders- no details provided

Table 9: Key drivers and implications of scenarios identified for each of the ecosystem service scenario studies.

Scenario exercise	Focus areas	Drivers & key variables	Governance implications	Societal implications	Energy & climate targets	Environmental implications
UKERC Global Energy Scenarios (Ekins et al. 2013)	Carbon emissions	Resources, technologies, processes and interactions of energy system to end use. Costs and economic metrics.	Decarbonisation of UK Electricity system, electrification of heat and power, switch from use of vehicles with internal combustion engines.	Behaviour of consumers is critical for uptake of low carbon technologies and energy efficiency measures	Model runs for temperature that meet and exceed targets aimed at 2°C warming	
Transition Pathways & Realising Transition Pathways (Foxon and Pearson 2013)	Key actors & timing: governance, institutional changes and effects on innovation	Actor dynamics	Three pathway framings that imply distinct governance arrangements: markets, central government, civic society	The role of different actors in effecting change is a key part of the analysis. In Thousand Flowers society takes up a leading role.	Achievement of 2050 targets was a given	
Foresight Scenarios: Powering our Lives (Devine-Wright et al. 2009)	Built environment & sustainable energy systems	Innovation investment, wider geopolitical uncertainties	Different governance structures among the scenarios. Regional governments and localism are strong in Resourceful Regions& Sunshine State.	Exploring the impact of social values and behaviour change. Transition in social values away from consumerism in Sunshine state, towards universalism in Green Growth. Transitions in underlying social values seen as driving forces towards the metamorphosis of the energy system.	Scenarios built around the climate trajectory in the *Climate Change Scenarios for the UK* under the 2002 UK Climates Impact Program	

Scenario exercise	Focus areas	Drivers & key variables	Governance implications	Societal implications	Energy & climate targets	Environmental implications
CLUES (Sherriff and Turcu 2012)	Development of decentralised energy systems in urban areas. Supporting local energy initiatives is a key consideration for the project.		In Greening Centralised Energy an Energy Agency is collaboratively established between the government and the big energy companies, tensions are present between different levels of governance. Local and regional authorities are a key driving force in Stretching the Energy Spectrum.	Different levels of public involvement & active engagement with energy systems expressed in the scenarios	Both scenarios achieve high emissions reductions. Unclear if 2050 target is met.	
Infrastructure Transitions Research Consortium (Tran et al. 2014)	Main infrastructure sectors (energy, transport, water, waste, ICT) & interdependencies	Population, economic growth	Governance implications and potential for co-ordination for different types of infrastructure outlined in each scenario. Governance interdependencies also explored.		Different levels of emissions between the 4 scenarios. Long-term emissions rise according to 2 of the scenarios.	
Energy 2050 (Ekins et al. 2013)	Carbon emissions & system resilience indicators in terms of demand reduction, supply diversity, investment in capacity &	Final energy use, efficiency measures take up, investment in supply infrastructure & technologies, supply technology mix, policy	The potential for local generation and DSM are examined, though none of the modelled pathways imply a highly decentralised future.	Additional Lifestyle scenario explored the effects of behaviour change and the disruptiveness caused by public attitudes towards specific technologies.	Not all scenarios meet the 2050 target.	Not explicitly, but environmental pressures and sensitivities explored to an extent.

Scenario exercise	Focus areas	Drivers & key variables	Governance implications	Societal implications	Energy & climate targets	Environmental implications
	infrastructure	frameworks				
Transition Pathways for Hydrogen (Will McDowall 2014)	Potential for hydrogen energy, emphasis on the transport sector.	User practices, technologies and business practices, government: niche maturity & nature of interactions	Transport government policy and business strategies are key areas of uncertainty.	Consumer behaviour, social innovation and institutional changes are key considerations	A continued commitment to decarbonisation is a given for all scenarios	
Shell Scenarios (Royal Dutch Shell 2013)	Economy, politics & energy	Governance& distribution of power, economic cycles, social and political instability, demographic transitions, technological advances, nexus pressures and energy demand	Power structures and governance key issues in the 2 scenarios. Some decentralisation in Oceans.	The balance of power & its effects on social mobility are key differentiating characteristics. In Mountains power lies with incumbent actors, while in Oceans power is devolved. The effect of increased connectivity through IT and social media is also considered.	In both scenarios emissions surpass the 2C trajectory.	Food, water, energy nexus is discussed.
National Grid Future Energy Scenarios (2014)	Wider economic conditions, politics, technology, societal trends,	Affordability & sustainability.	Political stability/ commitment to targets and the effect on investment certainty,	Public engagement and consumer attitudes are part of the analysis.	The Gone Green & Low Carbon life scenarios meet the targets. In other scenarios targets are missed or achieved at a later	

Scenario exercise	Focus areas	Drivers & key variables	Governance implications	Societal implications	Energy & climate targets	Environmental implications
	environment		government policy and the harmonisation with EU policy & targets are explored. Increased microgeneration in Gone Green. Local renewables in Low Carbon life.		date.	
The CCC 5th Carbon Budget (The Committee on Climate Change 2015)	Power sector, buildings, industry, transport, agriculture, land use & land use change	Population, economic activity (GDP), fossil fuel prices	Differences between devolved administrations. Policies must provide clarity on technology, infrastructure, energy markets, consumer acceptance and behaviour.	Big behavioural changes needed across transport, heating, efficiency, agriculture. Fuel poverty considered	In line with international and European commitments to limit warming to 2°C.	The effect on health and the environment is briefly addressed.
CCC 4th Carbon Budget (2013 revision) (Committee on Climate Change 2013)	Power sector, buildings, industry, transport, agriculture, land use & land use change	Population, economic activity (GDP), fossil fuel prices	Not explored explicitly. The level of EU ambition a key uncertainty. The differences between devolved administrations are briefly mentioned.	Fuel poverty & the impact of the 4CB on affordability are examined. Regarding the transport sector, particular focus is placed on the barriers and Incentives for EVs uptake.	In line with UK targets	The effect on health and the environment is briefly addressed.
Carbon Plan (Department of Energy and Climate Change 2011)	Power sector, buildings, transport, industry, agriculture, forestry, land management, waste & resource efficiency	Behaviour change, technology costs, innovation rates. Key uncertainties: degree of energy efficiency, lowest cost energy mix for remaining demand	Not in detail- the relationship between national government and the EU, as well as the role of devolved administrations, are briefly explored		In line with UK targets	

Scenario exercise	Focus areas	Drivers & key variables	Governance implications	Societal implications	Energy & climate targets	Environmental implications
		and electricity supply mix.				
Project Discovery (Ofgem 2009)	Gas & electricity markets	Speed of economic recovery & global coordinated environmental action Other variables: geopolitics & oil prices, speed of technological development, environmental policy.	Governance issues not explicitly explored. Policy instruments to overcome security challenges that could imply a stronger role for central government are recommended.	Impacts on bills.	Green Transitions & Green Stimulus: 2020 renewables targets met, emissions close to CB levels.	
The Economics of Climate Change Policy in the UK (Pollitt, Summerton, and Billington 2014)	Households (energy bills, food bills & car ownership), businesses (costs & competitiveness), the macroeconomy (GDP, net employment, import reliance, domestic	Technology costs, carbon price, fuel costs	Impacts on energy-intensive industries. Less dependence on fossil fuels and improved energy security. Improved government revenues	Households will be better off financially. Positive impacts on UK business. Higher net level of employment and GDP.	Carbon budgets 1-4 are met in two of the three scenarios	Improved air quality mentioned as environmental co-benefit of a low carbon transition

Scenario exercise	Focus areas	Drivers & key variables	Governance implications	Societal implications	Energy & climate targets	Environmental implications
	investment) and the environment (air quality)					
World Energy Scenarios (World Energy Council 2013)	Environmental sustainability, energy security and energy equity	116 drivers: Economic, resource availability, energy system and tech, consumer behaviour and acceptance, government policies	Difference in whether scenario is consumer or government driven.	Consumer behaviour must change to address climate change.	Difficult to meet 450ppm target. Efficiency is crucial.	Discusses some environmental benefits talks about a greener economy and worldview of consumers.
World Energy Outlook 2015 (International Energy Agency 2015)	Wider economic conditions, politics, technology, societal trends, environment	Economy, demographic, carbon dioxide prices, technology, energy supply costs and prices	Role of government policies in dictating degree of growth and decoupling of emissions and energy use.	Explores implications for energy security, economic development and the environment.	Contrasts climate and energy under current policies and under a 450ppm scenario.	Land, water, air pollution

Scenario exercise	Focus areas	Drivers & key variables	Governance implications	Societal implications	Energy & climate targets	Environmental implications
The outlook for energy, a view to 2040 (Exxon Mobil 2013)	Wider economic conditions, politics, technology, societal trends, environment	Affordability & sustainability.	Political stability/ commitment to targets and the effect on investment certainty, government policy and the harmonisation with EU policy & targets are explored. Increased microgeneration in Gone Green. Local renewables in Low Carbon life.	Public engagement and consumer attitudes are part of the analysis.	The Gone Green & Low Carbon life scenarios meet the targets. In other scenarios targets are missed or achieved at a later date.	
ETI Scenarios (ETI 2015)	Power, heat, transport, industry sectors	Global commitment to climate change mitigation& national technology choices: popularity vs cost-effectiveness	Central governance leadership is stronger in Clockwork, while local and regional government is more active in Patchwork. In Clockwork strong leadership provides certainty to investors.	Social engagement required for the transition. Society more actively engaged in Patchwork, developed environmental values. Public acceptability towards central planning decisions required in Clockwork, though consumption-based lifestyles need to be maintained.	2050 targets met in both scenarios	

5. Consistency and comparability of scenario exercises

5.1 Differences in the detail representation of energy systems

Energy scenarios primarily employ quantitative models (Jebaraj and Iniyan 2006; Baños et al. 2011) to identify future energy pathways. This contrasts with ecosystem service scenarios where, although results from energy system modelling may form an input, detailed information is seldom provided and narratives may be constructed based on qualitative descriptions of the relative contribution of different energy technologies. Across all studies where information was available (see Table 5 and 8), energy scenarios were constructed based on the contribution of between 5 and 19 individual energy technologies compared to ecosystem services scenarios that considered between 6 and 9 different technologies.

Within ecosystem service scenarios, the most common form of aggregation is to consider non-fossil sources of energy as a single group, although bioenergy is often considered separately given the ongoing debate around the environmental, social and economic impacts of this option (Gasparatos, Stromberg, and Takeuchi 2011; van der Horst and Vermeylen 2011; Mohr and Raman 2013). Implications of energy pathways within scenarios are then primarily considered within the context of climate change. A minority of scenarios consider direct impacts of energy technologies that have a large biophysical footprint such as tidal power (Pinnegar et al. 2006) and bioenergy (United Nations Environment Programme 2012). The aggregation of energy technologies in this way may make it difficult for participants in ecosystem service scenario exercises to identify emergent environmental issues associated with decarbonisation pathways. However, it should be noted that reviews of the implications of energy systems for ecosystem services (Papathanasopoulou, Holland, et al. 2015; Holland et al. 2015; Bonar, Bryden, and Borthwick 2015; Lovett et al. 2015; Turney and Fthenakis 2011) suggest that even if such detail was provided, understanding of the implications of many forms of non-fossil energy for ecosystem services is limited, particularly at the commissioning and decommissioning stages of the life cycle.

For energy scenarios, the review conducted for this working paper and the previous review of Hughes and Strachan (2010), found that ecosystem services beyond climate regulation are rarely incorporated into the scenario exercises. Notable exceptions include improvements in air quality highlighted by a number of scenarios (e.g. (Pollitt, Summerton, and Billington 2014; The Committee on Climate Change 2015). A range of technology and policy options for decarbonisation exist (Committee on Climate Change 2013; Ekins et al. 2013; Chu and Majumdar 2012) each of which is associated with a diverse and complex array of social, environmental and economic impacts occurring at a range of spatial and temporal scales (Gasparatos, Stromberg, and Takeuchi 2011; Hastik et al. 2015; Papathanasopoulou, Beaumont, et al. 2015). Incorporating a broader understanding of the implication of different decarbonisation options for ecosystem services may help differentiate between energy pathways and so identify those that are most desirable.

5.2 Differences in worldview

Beyond details of the energy system, a number of broad narrative strands relating to decarbonisation, the use of carbon capture and storage, efficiency of the energy system and worldview emerged in the review.

Decarbonisation is considered as a specific driver in 55% of ecosystem service scenarios compared to 68% of energy scenarios. In both cases, scenario exercises tend to consider a reference state or states that fail to achieve decarbonisation targets, and compare this with alternate pathways that achieve decarbonisation through a range of mechanisms and over different time periods. Ecosystem services scenarios often explore a number of possible futures that incorporate levels or responses to climate change, or consider the implications of low, moderate, high, or very high increases in greenhouse gas emissions. This gives rise to the more even split in the number of scenarios that do and don't consider pathways to decarbonisation. The bias towards decarbonisation in energy scenarios arises as this is often the framing question for the exercise, with the commissioning body wishing to explore the implications of national and global ambitions to limit carbon emissions on the evolution of the energy system.

In percentage terms the use of carbon capture and storage in scenarios is broadly comparable between exercises (61% of ecosystem service and 70% of energy scenarios) with similar comparability in relation to a focus on efficiency of energy use (67% of ecosystem service and 84% of energy scenarios). However, such routes to decarbonisation are not considered in a number of ecosystem service scenarios, perhaps due to the fact that the energy system is only considered in a highly aggregated way. As with the implications of non-fossil sources of energy it is unclear how better integration of these options into ecosystem services scenarios would influence our understanding, as there is only limited research on the implications of such aspects of energy pathways for ecosystem services (e.g. Blackford et al. 2009 for CCS), and many unknowns exist.

Finally, energy scenarios are more likely to consider a worldview based on international cooperation and trade (with 85%) than ecosystem services scenarios (with 58%). There are a number of possible reasons depending on the scenarios considered. Examples include; (i) given the global nature of the energy trade it may be that energy scenarios are more likely to be based on this continued assumption; (ii) as climate change represents a global problem it may be that energy scenarios are more likely to consider international cooperation.

5.3 Implications of climate change

There is considerable variation in the way that implications of energy systems for climate change are presented. Most commonly, greenhouse gas emissions are stated as parts per million by volume (ppm) with estimates ranging from 450ppm to 710ppm for energy scenarios and <350ppm to 560ppm for ecosystem service scenarios, or as gigatonnes of carbon dioxide equivalent (Gt CO_2-eq) arising from the energy sector with estimates ranging from 19 Gt CO_2-eq to 44 Gt CO_2-eq for energy scenarios and 4.7 Gt CO_2-eq to 80.83 Gt CO_2-eq for ecosystem service scenarios. In many scenarios changes in global or regional temperature are not stated reflecting uncertainty in translating atmospheric gas concentrations into changes in global temperature where, although there is a linear response in most models, the rate of response (i.e. the angle of the slope function) is uncertain (Stocker 2014).

There are a number of exceptions, predominantly in ecosystem services scenarios. Variously these consider a range of between 1.5°C and 4.8°C change in global average temperature by 2050 (e.g. United Nations Environment Programme 2012; United Nations Environment Programme 2007), regional climate change (e.g. UK Climate Impacts Programme 2001), contrasting climate predictions within the same scenario (e.g. Haines-Young et al. 2011) and sudden climate switching (e.g. Spangenberg et al. 2012). For energy scenarios many narratives are framed in terms of a specified carbon budget designed to meet global obligations to limit climate change. The majority of energy scenarios state whether a <2°C threshold is met, with narratives describing the pathways that are either successful or fail to meet the threshold. As such the pathways are built on an underlying climate narrative, and any quantitative analysis is geared towards achieving the specified aim.

An interesting distinction that emerges is that many of the energy scenarios are UK focussed, and as such it could be argued that there is limited context for modelling or understanding levels of global emissions and thus future UK climate. Across pathways those that work toward decarbonisation of the UK energy system must implicitly consider that global efforts occur in tandem or make no assumption about climate change other than the UK meetings its legally binding targets. This raises an interesting question about the implications for different UK decarbonisation pathways if the UK follows a divergent route from the rest of the world. From an energy perspective are there implications for the UK energy system of pursuing a policy that does not align with the international community? A number of ecosystem service scenarios consider how ecosystem services could provide resilience for society in the face of climate change (Haines-Young et al. 2011). If, as such scenarios suggest, ecosystem services could provide a natural response to mitigate impacts of climate change (e.g. through mechanisms such as hazard reduction) it suggests that energy pathways should be identified that protect and enhance such key services to ensure that the UK benefits from natural approaches to climate change impact mitigation.

6. Conclusion

This working paper was framed around one central question; to what extent are energy and ecosystem scenarios consistent and comparable? The analysis suggests that energy and ecosystem service scenarios are broadly consistent, with climate change representing a unifying narrative. The most substantial difference is the detail of the energy systems and ecosystem services considered in scenarios. Comparisons between energy and ecosystem service scenarios can be made at the broadest level by considering the contribution of fossil and non-fossil sources of energy and whether ambitions to limit climate change are met.

Despite the level of aggregation, outputs from energy models are used to inform ecosystem service scenario exercises although these tend to be viewed through a climate change lens. In contrast, we identified few energy scenarios that considered implications for ecosystem services (notable exceptions being water resources and air quality), and none that use implications for ecosystem services (beyond climate regulation) as an input to the modelling exercise.

This difference in detail of the energy system and incorporation of ecosystem service implications between the two sets of scenarios is attributable to the scope as defined by the commissioning body (Table 5 and 8) and so does not represent a failure in the scenario exercises. However, it has important implications given that the principal objectives of scenarios are to (i) identify external risks, (ii) desirable options and (iii) build consensus.

From an energy scenario perspective failure to incorporate detailed understanding of ecosystem services could result in the identification of decarbonisation strategies that are not sustainable. Given that natural systems can ameliorate the impacts of climate change, such as the impact of extreme weather, failure to protect ecosystem services that contribute to hazard reduction could reduce the resilience of the UK to such events. More broadly it is necessary to incorporate the considerable economic value of ecosystem services to the economy into thinking about the desirability of specific energy pathways.

From an ecosystem service scenario perspective, the highly aggregated description of energy system within these exercises makes it difficult to explore the implications of contrasting decarbonisation strategies. However, even if detailed information on energy pathways were to be incorporated into ecosystem service scenario exercises there remains the question of whether a complete understanding of the implications across the full range of services exists.

As a final comment, these conclusions perhaps point the way forward in the development of both energy and ecosystem service scenarios exercises where the use of techniques such as integrated assessment modelling could simultaneously consider the linkages and provide insight into the two domains recognising the interconnectedness of energy and the environment.

7. References

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