Science and Implementation Plan

Valuing Natural Capital in Low Carbon Energy Pathways Programme

A UKERC Phase 3 Challenge

Version 7

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1. INTRODUCTION

The UK Government is committed to ensuring that the value of our natural assets (ecosystems and their living/non-living, renewable/non-renewable components) and the flow of goods and services from them is properly understood and reflected in the economy and policy-making (Figure 1). The value of a particular good or benefit derived from natural capital and/or ecosystem services needs to be expressed in a specific context (e.g., of decision-making) usually in terms of something that can be counted, often money, but also through methods and measures from other disciplines (e.g., sociology, ecology etc.).

The overarching aim of this UK Energy Research Centre (UKERC) Challenge is to understand the implications for natural capital and the provision of ecosystem services of a range of future energy scenarios, including scenarios that are compatible with the UK's energy policy goals of maintaining energy security, keeping energy affordable and cutting greenhouse gas (GHG) emissions by 80% by 2050.

With a legacy of North Sea oil and gas production, the UK energy system has been largely dependent on indigenous, finite, non-living components of natural capital. As North Sea production runs down, the UK is becoming more dependent on imported energy while, at the same time, new opportunities are emerging to exploit indigenous resources of both renewable and non-renewable energy.

The future development of the UK energy system holds unusually profound implications for natural capital and the provision of ecosystem services that go far beyond the protection of the climate as a regulating ecosystem service. Lower levels of energy demand, increased use of electricity, nuclear generation, renewable energy production (solar, tidal, wind energy, bioenergy), fossil fuel imports, the onshore extraction of unconventional fossil fuels and carbon capture and storage (CCS) all have different implications for land use and ecosystem function. Such changes could exacerbate or give rise to potential new conflicts, but could also provide opportunities for synergies between energy and a range of other ecosystem services (biodiversity, food, soils, potable water etc.) underpinned by the same stocks of natural capital. For example, land-use change driven by rapidly increasing demand for biofuels has been cited as causing significant damage to biodiversity and ecosystem service delivery in parts of South America and south-east Asia[1,2]. The local ecosystem service impact of extracting indigenous shale gas is very different from the global impact of importing liquefied natural gas.

[1] Fargione F, Hill J, Tilman P, Polasky S, Hawthorne P. (2008) Land clearing and the biofuel carbon debt. Science 319:1235–8

[2] Fitzherbert EB, Struebig MJ, Morel A, Danielsen F, Brühl CA, Donald PF, et al. (2008) How will oil palm expansion affect biodiversity? Trends Ecol Evol 23:538–45.

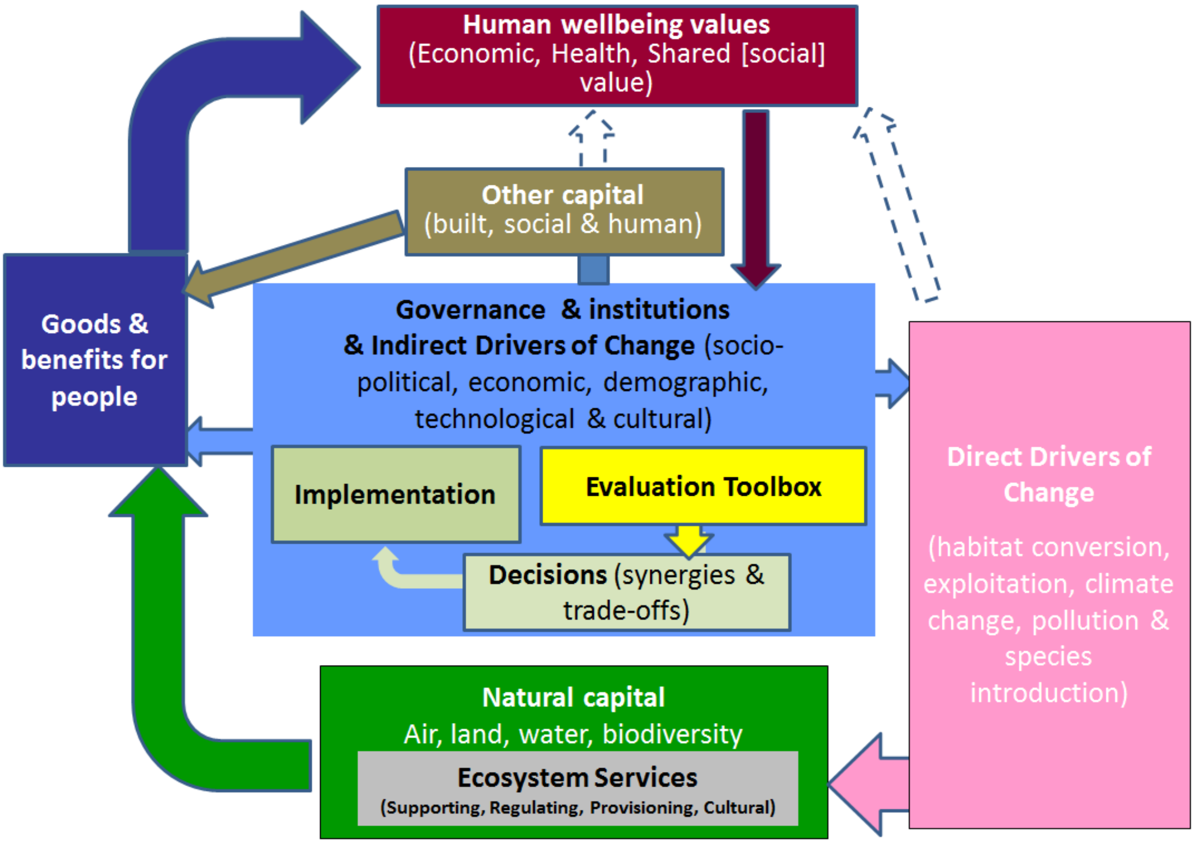

Figure 1: Decision-making framework for natural capital
Source: NEA Follow-On Phase 2014

Spatial and temporal heterogeneity of natural capital resources means that energy system design and delivery must incorporate an element of spatial targeting to mitigate its impact on the wider environment and meet related policy targets. It is therefore important that energy generation, storage and supply be viewed as a dynamic, spatial system, linked to specific geographic locations, so that associations with natural capital stocks and ecosystem services are better contextualised and assessed at appropriate scales.

The international context, e.g. through displacement effects, must also be considered. Opportunities for delivering energy objectives are dependent on local, national and global stocks of natural capital as these affect the composition of potential energy mixes and the scale of the UK's energy system "footprint" on ecosystem services. Although dependent on the energy mix that emerges, this "footprint" will extend beyond UK borders.

So far, the scientific community and the policy world have given little attention to the energy/natural capital nexus. Unless evidence regarding this nexus is generated, unnecessary degradations in wider ecosystem service provision may result and opportunities to exploit synergies may be missed. The proposed Challenge will generate scientific evidence in the environmental and also socio-economic domains, to inform the development and management of energy-related activities.

A more integrated approach would allow a rigorous assessment of the options for managing energy and ecosystem services given available land, sea and resources. Comparable measures of the value of benefits from the different services will be a key challenge in that respect.

The outcomes of the Programme will include: a better integration of the hitherto separate energy and valuing nature communities; the establishment of energy services as key "provisioning" ecosystem services; a more comprehensive view of the linkage between natural capital and the decarbonisation agenda; the achievement of a genuinely whole systems approach encompassing the ecological system as a whole and energy systems rather than individual energy chains; and help for decision makers by allowing meaningful comparisons between alternative energy and ecological and system pathways and options.

2. THE NERC CONTEXT AND MECHANISMS

The Valuing Natural Capital in Low Carbon Energy Pathways programme will address some of the key challenges identified within the Sustainable Use of Natural Resources (SUNR) strategic theme of the 2007-2012 NERC Strategy 'Next Generation Science for Planet Earth'[3].

The strategic objective of the SUNR theme was to provide the science to optimise the use of renewable and non-renewable natural resources whilst living within the Earth's environmental limits. To deliver this, investment in science was proposed to bring together and advance understanding of the entirety of processes and consequent outcomes of natural resource use on terrestrial, freshwater and marine systems and on feedbacks to the atmosphere.

Following discussions between NERC's SUNR and Biodiversity Theme Leaders, this programme was identified as a NERC contribution to Phase 3 of UK Energy Research Centre (UKERC), specifically as a UKERC Challenge. The SUNR Theme Action Plan (TAP) specified that the scientific focus of the programme would draw on the Valuing Nature Network (VNN) and subsequent Valuing Nature Programme (VNP) and the UKERC energy research community which have so far had little interaction with each other.

In Phase 2 of UKERC (2009-2014), a conceptual framework for valuing the ecosystem service impacts of energy in the terrestrial, coastal margin and marine environments has been developing through two complementary projects on the impact of the UK energy system on global ecosystem services. UKERC Phase 3 (2014-2019) will explore UK energy transitions in an uncertain world, and the synergies and trade-offs between the key drivers for this transition. It will build on the Phase 2 framework to further investigate the integration of energy scenarios with the analysis of ecosystem services and natural capital. The VNP aims to better understand and represent the complexities of the natural environment in valuation analyses and to consider the wider societal and cultural value of benefits from ecosystem services, even where these have no perceived market value. Section 6 provides further details of the scope of UKERC Phase 3 and the VNP.

[3] http://webarchive.nationalarchives.gov.uk/20090104234536/http://nerc.ac.uk/publications/strategicplan/documents/strategy07.pdf

It is expected that the successful bidders for the Valuing Natural Capital in Low Carbon Energy Pathways (VNC) programme will develop their proposals in conjunction with both the UKERC Research Director and the VNP programme co-ordination team.

The new NERC Strategy "*The Business of the Environment*"[4] has three themes, the first of which is "***Benefiting from natural resources***". The VNC programme will help to deliver the theme which states: "Natural resources sustain life, wellbeing and economic activity. Yet growing UK and world populations make ever greater demands on food, water, energy, minerals and other essential services we get from nature. All natural resources are derived from physical, chemical and biological processes that interact in land, water and air. NERC science tells us how these environmental processes control resource availability, and how we can use resources responsibly. This knowledge will help us use and recycle resources safely and efficiently, live within the Earth's limits, and steward natural resources for future generations."

This science plan must address the specific research challenges agreed by NERC Council and identified in the TAP:

- to characterise the impact pathways of specific energy chains and energy infrastructure development in the UK's marine, aquatic, coastal margin and terrestrial environments under a range of energy scenarios;
- to understand how different means of sourcing energy from outside the UK would impact ecosystem services from a global perspective and to identify options for managing these impacts;
- to understand the cumulative and indirect effects of energy technologies/ infrastructure over time on the full range of ecosystems services – underpinning, regulating, cultural and provisioning, addressing both economic and non-economic values; and
- to understand better the nexus between energy, land and water and the trade-offs and synergies associated with different patterns of energy development.

These research challenges are developed further as the science goals in section 3.

3. SCIENCE PRIORITIES

3.1 Introduction

Natural capital includes the elements of nature that produce value (directly and indirectly) to people, including living aspects of nature as well as non-living, such as minerals and energy resources. This Programme will draw on the Valuing Nature Network (VNN) and subsequent Valuing Nature Programme and the energy research community to promote interaction and mutual understanding.

[4] See http://www.nerc.ac.uk/latest/publications/strategycorporate/strategy/the-business-of-the-environment.pdf

The concept of “services” that benefit humankind is central to both communities. The Millennium Ecosystem Assessment[5] explicitly included energy as a provisioning service. The first phase of the UK National Ecosystem Assessment (NEA) highlighted issues relating to bio-energy[6]. The NEA noted that the market value of energy, subject to qualifications about taxes, subsidies and market imperfections, could be the starting point for establishing the value of energy as benefit derived from a provisioning service. The “services” concept is well established in the energy field. The key insight is that consumers do not want energy per se, but rather the underlying benefits, such as mobility, heat, light and information / communication that energy provides. Making coherent use of the “services” and “benefits” concepts across the environmental sciences and the energy domain is an essential element of this programme.

Delivering a whole system assessment of the contribution of energy to and its impacts on ecosystem services, goods and benefits, including non-market goods, requires that the currently separate energy and ecosystem service assessment frameworks and research communities be more fully integrated. The approach must be based on a whole-system perspective rather than valuing only energy generation potential. The impacts and/or interactions of energy systems – comprising supply, distribution, use and end-of-life - with natural capital needs must be considered holistically. The valuation of some elements of natural capital could be based on monetary approaches, but other approaches (e.g. multi-criteria assessment among others) will also need to be considered.

The programme will be expected to advance a framework for integrating the analysis of energy systems and technologies with natural capital considerations and exemplify this with specific case studies. Research should be new but complementary (based around existing concepts but filling important gaps) and draw communities together whilst respecting existing concepts. Elements of the programme could include:

- Integrating energy systems, considering all components including construction, generation, end-use demand, decommissioning, storage and supply, into the ecosystem services framework;
- Undertaking whole-system assessment of consequences for natural capital of adopting different patterns of energy development, exploring potential trade-offs and synergies with other ecosystem services and mitigation strategies where appropriate;
- Exploring implications for natural capital value through the enhancement and integration of existing models alongside the development of UKERC’s Phase 3 energy pathways and/or using existing energy/NEA scenarios,
- Ensuring full scope of energy system impacts on natural capital (spatial and temporal) are considered, bearing in mind that, depending on the energy mix selected, the impacts on ecosystem services could extend beyond UK borders, with potential impacts around the globe;

[5] Millennium Ecosystem Assessment Board, Ecosystems and Human Well-being, Island Press, 2005

[6] Chapter 22, Economic Values from Ecosystems, UK National Ecosystem Assessment: Technical Report: http://uknea.unep-wcmc.org/Resources/tabid/82/Default.aspx

- Developing the concept of ecosystem services embedded in the trade of goods and services, in a vein similar to embedded carbon or water, associated with energy system; and/or
- Examining the scope and benefits of spatial and temporal targeting of the energy system to make use of heterogeneity in natural capital stocks and other ecosystem services.

3.2 Science goals

The four goals set out in this section are inter-related. Goals 1 and 2 are spatially differentiated, with Goal 1 focused on the UK and Goal 2 taking a wider global perspective (which includes local and regional impacts outside the UK). Goals 3 and 4 are cross-cutting in nature, Goal 3 addressing the cumulative and indirect impacts of energy activities on ecosystem services and Goal 4 addressing the wider energy-land-water nexus. The programme will encompass all of these goals.

Goal 1: To characterise the impact pathways of specific energy chains and energy infrastructure development in the UK's marine, aquatic, coastal margin and terrestrial environments under a range of decarbonisation scenarios.

This goal focuses on characterising the consequences for natural capital stocks and ecosystem services of the development of energy chains, technology and infrastructure under different scenarios. This can be achieved only if the energy and ecosystem assessment communities come together to develop scenarios that integrate energy with ecosystems and their services. This approach will also contribute to Goal 4 concerning the water-energy-food nexus. The development of new metrics may be needed to help characterise the impact pathways in specific energy chains.

Different energy scenarios will have consequences for land and sea use and ecosystem services across the UK. The characterisation framework should encompass complete energy chains from energy supply (oil, gas, coal, nuclear, biomass and renewables) through to infrastructure and demand, and cover terrestrial, freshwater and marine/coastal energyscapes.[7] Expanding bioenergy production, for example, could reduce the availability of land for agricultural production, with implications for food security, and was thought to be a driver in the recent food price spikes[8]. One key element to consider would be the link between energy and water use; particularly the spatial and temporal heterogeneity in water resource availability, biomass production costs and energy sector demand.

Energy and ecosystem services have been incorporated in a number of scenarios developed as decision support tools. To a large degree, those that incorporate energy and ecosystem

7 D.C. Howard, P.J. Burgess, S.J. Butler, S.J. Carver, T. Cockerill, A.M. Coleby, G. Gan, C.J. Goodier, D. Van der Horst, K. Hubacek, R. Lord, A. Mead, M. Rivas-Casado, R.A. Wadsworth, P. Scholefield, Energyscapes: Linking the energy system and ecosystem services in real landscapes, Biomass and Bioenergy. 07/2012; 55:17–26. DOI:10.1016/j.biombioe.2012.05.025

8 HM Government (2009). The 2007/08 Agricultural Price Spikes: Causes and Policy Implications.

services have developed independently of each other. A strong driver of ecosystem service scenarios is projected climate change which has significant impacts on future ecosystems. For energy scenarios a key driver is reduction of carbon emissions, and hence the extent of climate change impacts. Scenarios developed under the National Ecosystem Assessment Follow-On (NEAFO) phase were considered both plausible and relevant to the concerns of different groups of stakeholders and have significant potential as tools for developing dialogues between people with differing interests and perspectives. The NEAFO has extended scenario-based models beyond projections of changes in land cover[9]. To understand how critical levels of natural capital can be affected by changes in the energy system, future scenario development will need to consider the impact on ecosystem stocks and tipping points and a broader understanding of the change in ecosystem services as tipping points are approached and exceeded.

A number of analytical tools are available for developing scenarios in the UK energy domain including the DECC 2050 pathways calculator, the ETI ESME model and the MARKAL/TIMES modelling system. UKERC used the latter in the Energy 2050 project, the results of which have recently been updated.[10]

In bringing energy and ecological scenarios together, the development of energy systems at different temporal and spatial (national to regional to local) scales and location specific trade-offs and co- benefits between scenarios needs to be considered to inform decision making.

A range of interventions for sustaining the delivery of ecosystem services, including conventional responses such as statutory regulation, planning and protected areas, as well as more novel initiatives, such as voluntary or market-based schemes, and the role of partnerships and networks, need to be considered. These need to inform decisions-makers at the policy and practice/operational levels.

Goal 2: To understand how different means of sourcing energy from outside the UK would impact ecosystem services from a global perspective and to identify options for managing these impacts.

The central aim is to build an understanding of the impact that energy choices made in the UK, specifically choices that affect the balance between indigenous and imported sources of energy, would have on natural capital and the provision of ecosystem services at the wider global level. This Goal therefore complements Goal 1. Work will focus on energy

9 UK National Ecosystem Assessment Follow On Phase (2014) The UK National Ecosystem Assessment: Synthesis and Technical Report. UNEP-WCMC, Cambridge (In preparation) http://uknea.unep-wcmc.org/

10 Ekins, P., Keppo, I., Skea, J., Strachan, N., Usher, W. & Anandarajah, G. 2013. The UK energy system in 2050: Comparing Low-Carbon, Resilient Scenarios. UKERC Research Report. London: UKERC.
Watson, J., Gross, R., Ketsopoulou, I., Winskel, M. (2014). UK Energy Strategies Under Uncertainty – Synthesis report (UKERC: London)
Ekins, P. and Watson, J. (eds.) (2014). UK Energy in a Global Context – Synthesis Report (UKERC: London)

generation, and the ecosystem service impacts of consumption in general (textiles, smartphones etc.) are outside the scope of this programme although it is recognised that methodological aspects of the work may have a wider application.

Although the ecosystem service impacts may be global in the sense that they take place outside the UK, they are likely to manifest themselves at the local, regional and national levels in other countries. The ambition of this Goal is acknowledged. A realistic set of outcomes would involve building on the early work conducted under UKERC Phase 2 to establish a framework and methodologies for assessing global impacts and demonstrating this with selected case studies.

Several indicators of resource use at the UK and International levels already provide partial information relevant to impacts on ecosystem service and natural capital. These include emissions data, material and energy flow accounts, water footprints, ecological (and related) footprints and human appropriation of net primary production (HANPP). Our understanding of the global implications of different energy scenarios for GHG emissions is already much larger than our understanding of the impacts on many of the other ecosystem services and natural capital (including water). Measures such as these have been shown to be closely correlated[11]. 'Ecological' or environmental footprints have been widely used in recent years as indicators of resource consumption and waste absorption transformed on the basis of biologically productive land required per capita with prevailing technology[12,13,14].

Multi-regional input-output (MRIO) modelling has been used to characterise the GHG emissions embodied in trade flows[15], while hybrid life cycle assessment-MRIO approaches have been used to assess the global consequences of specific energy technology choices in terms of GHG emissions[16]. Such techniques could be extended beyond GHG emissions in addressing this goal. For example, biofuels produced through lignocellulosic conversion may create opportunities to use energy crops that can be grown on land unsuited for

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11 Haberl, H., J.K. Steinberger, C. Plutzar, K.-H. Erb, V. Gaube, S. Gingrich and F.Krausmann, 2012. 'Natural and socioeconomic determinants of the embodied human appropriation of net primary production and its relation to other resource use indicators', Ecological Indicators, 23: 222-231.

12 Cranston, G.R., G.P. Hammond and R.C. Johnson, 2010. 'Ecological debt: exploring the factors that influence national environmental footprints', Journal of Environmental Policy and Planning, 12 (2): 121-140.

13 Hammond, G.P., 2006. ''People, planet and prosperity': the determinants of humanity's environmental footprint', Natural Resources Forum, 30 (1): 27-36.

14 Turner, K., M. Lenzen, T. Wiedmann and J. Barrett, 2007. Examining the global environmental impact of regional consumption activities – Part 1: A technical note on combining input-output and ecological footprint analysis, Ecological Economics, 62: 37-44.

15 Wiedmann, T., & Barrett, J. (2013). Policy-relevant applications of environmentally extended MRIO databases – Experiences from the UK. Economic Systems Research, 25, 143–156

16 Acquaye A; Wiedmann T; Feng K; Crawford R; Barrett JR**;** Kuylenstierna J; Duffy A; Koh L; McQueen Mason S (2011) Identification of 'Carbon Hot-Spots' and Quantification of GHG Intensities in the Biodiesel Supply Chain Using Hybrid LCA and Structural Path Analysis, Environmental Science and Technology**,** 45**,** pp.2471-2478.

conventional arable crops. Perennial feedstocks suited to marginal (degraded or low productivity pasture) or non-agricultural land include, in the UK, Miscanthus and short rotation coppice (SRC) willow[17,18]. Bioenergy is likely to prove one fruitful area of inquiry under this goal but the research undertaken should move beyond bioenergy and not focus exclusively on that topic.

Developing a better understanding of the 'footprint' of energy systems on the natural environment and the consequences, within and beyond the UK, of energy decision-making, will be a key contribution of this goal.

Goal 3. To understand the cumulative and indirect effects of energy technologies / infrastructure over time on the full range of ecosystems services – underpinning, regulating, cultural and provisioning, addressing both economic and non-economic values.

Goal 3 focuses on the need to understand cumulative and indirect effects on ecosystem services, and the value of their benefits, of multiple and extended energy technologies and infrastructure as these may differ from effects of individual technologies and infrastructure developments.

As new energy mixes associated with lower carbon emissions emerge in the UK, there are multiple potential sources of land-based energy (including bioenergy from forests, arable crops, energy crops and waste, solar heating and electricity, hydroelectricity, ground-source heat wind-energy, coal, oil and gas including shale gas, nuclear) and of marine based energy (including oil and gas, wind, tidal and wave, and bioenergy from macro-algae). Individually, each of these has implications for ecosystems and the services they provide; as do some of the mitigation and demand reduction opportunities, such as sub seabed carbon capture and storage and electrification of transport. Depending on the energy mix implemented, and the spatial scale at which the different associated infrastructures are implemented, these then also have the potential to have further cumulative and interactive effects. Cumulative effects of energy development can relate to a wider range of social and economic, as well as environmental effects, and may be positive as well as negative.

For example, increasing pressure for on-shore wind farms has raised concerns over cumulative effects. These include combined impacts on the landscape and its ecology, on bird life and on visual aspects such as those associated with wind farms themselves and ancillary developments such as tracks and grid connections[19]. In the marine environment the increasing spatial scale of offshore wind farms from round 1 to round 3 has barely addressed the possibilities of cumulative effects. Here the concern is that the impacts of multiple offshore developments, as well as the increasing scale of developments, could

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17 Hammond, G.P. and S.M. Seth, 2013. 'Carbon and environmental footprinting of global biofuel production', *Applied Energy*, 112: 547-559.

18 Smith, P., Taylor, S., Lovett, A., Taylor, G., Firth, G., Finch, J., Morison, J. & Moran, D. 2014. Spatial mapping of Great Britain's bioenergy to 2050. *Global Change Biology Bioenergy* 6, 97–98. doi: 10.1111/gcbb.12149.

19 Scottish National Heritage 2012. Assessing the cumulative impact of onshore wind energy developments pp41

create a cumulative impact greater than or different to that of each individual wind farm. There is some uncertainty over the wider cumulative impacts on the energy resource itself, and considerable uncertainty over the cumulative impacts on fish and hence fisheries, birds and sea mammals as well as visual amenity which impacts on cultural services, and on marine biodiversity in general impacting on underpinning and regulating services. At present, efforts have concentrated largely on addressing the understanding needed to comply with consenting procedures, i.e. biodiversity components in the EU Birds and Habitats Directives. There is some understanding of squeeze on livelihoods of inshore fishermen of increasing wind farm developments that exclude access to fishing grounds, but also recognition of opportunities that arise that could benefit shellfisheries, static gear fishermen and recreational fishers[20].

Cumulative impacts can be assessed using scenarios and scenario analysis[21].Computer based numerical modelling projects funded by e.g. UKERC Phase 2, the NERC Marine Renewable Energy (MRE)[22] programme, and the Supergen Marine Challenge are developing tools that can start to examine some of the future implications of cumulative marine energy development on marine energy resources and selected elements of marine ecosystems and their functioning. Similar approaches, often combined with GIS, have been developed for bioenergy[23,24,25] shale gas and onshore wind[26]. These modelling approaches are, as yet, still largely untested, requiring validation and quantification of uncertainty. The models are also currently of limited scope with regard to the multiple natural capital elements and functions of the ecosystem that provide ecosystem services although elements of these limitations are being addressed in the NERCs' Biodiversity and Ecosystem Service Sustainability (BESS)[27] and Marine Ecosystems (ME)[28] programmes. Valuations of the benefits that derive from ecosystem services rarely take into account how cumulative impacts might affect these values (especially non-market and non-economic valuations).

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[20] Hooper T. and Austen M. 2014. The co-location of offshore windfarms and decapod fisheries in the UK: Constraints and opportunities. Marine Policy 43:295-300. http://www.sciencedirect.com/science/article/pii/S0308597X13001371

[21] Evans JS, Kiesecker JM (2014) Shale Gas, Wind and Water: Assessing the Potential Cumulative Impacts of Energy Development on Ecosystem Services within the Marcellus Play. PLoS ONE 9(2): e89210. doi: 10.1371/journal.pone.0089210

[22] http://www.nerc.ac.uk/research/funded/programmes/mre/

[23] Smith, P., Taylor, S., Lovett, A., Taylor, G., Firth, S., Finch, J., Morison, J., Moran, D., 2014. Spatial mapping of Great Britain's bioenergy to 2050. Global Change Biology Bioenergy 6, 97–98. doi: 10.1111/gcbb.12149.

[24] Tallis, M.J., Casella, E., Henshall, P.A., Aylott, M.J., Randle, T.J., Morison, J.I.L., Taylor, G., 2013. Development and evaluation of ForestGrowth-SRC a process-based model for short rotation coppice yield and spatial supply reveals poplar uses water more efficiently than willow. GCB Bioenergy 5, 53–66.

[25] Thomas, A., Bond, A., Hiscock, K., 2013. A multi-criteria based review of models that predict environmental impacts of land use-change for perennial energy crops on water, carbon and nitrogen cycling. GCB Bioenergy 5, 227–242.

[26] Evans JS, Kiesecker JM (2014) Shale Gas, Wind and Water: Assessing the Potential Cumulative Impacts of Energy Development on Ecosystem Services within the Marcellus Play. PLoS ONE 9(2): e89210. doi: 10.1371/journal.pone.0089210

[27] http://www.nerc.ac.uk/research/funded/programmes/bess/

[28] http://www.nerc.ac.uk/research/funded/programmes/marineecosystems/

Modelling and scenario analysis needs to be developed and extended to improve understanding of the cumulative and indirect effects of energy technologies/infrastructure over time on the full range of ecosystems services. This will need underpinning with sound empirical data on impacts (Goal 1). Furthermore the model outputs need to link to economic and non-economic valuations of the benefits that derive from the impacted ecosystem service, and the valuations themselves need to address the influence of cumulative impact.

Goal 4. To understand better the nexus between energy, land and water and the trade-offs and synergies associated with different patterns of energy development.

Goal 4 focuses on developing scientific understanding to inform spatial choices for locating energy generation and distribution and supporting long term decision-making. Both UK and wider global perspectives are relevant.

Stocks of natural capital are fundamental for all the processes upon which human health and wellbeing depend, and specifically underpin the production of goods including food, water and energy. This common interdependence creates the food-energy-water nexus. At a national scale, every aspect of the food-energy-water nexus is influenced by government actions but there is a lack of integrated study and coordination. Drivers of change that impact on one component of natural capital (e.g. water, land, biodiversity), or policy levers designed to influence the market of one particular good (e.g. food production), will inevitably impact on other components of natural capital.

The UK's production of oil and gas has declined by 60% in recent years[29], leaving the UK economy more exposed to price fluctuations in the world energy market. Local and global pressures also influence the market value of other goods (e.g. the food price spikes of 2008), and these are likely to grow in frequency and severity in the future[30]. The interconnected nature of the elements of natural capital mean that environmental and policy pressures upon food, water and energy will inevitably lead to other impacts on wildlife, habitats, recreation and greenhouse gases[31,32] and result in the need to consider the trade-offs and synergies between different elements of natural capital and ecosystem services.

29 DECC, Digest of UK Energy Statistics, 2013

30 Godfray, H.C.J., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Nisbett, N., Pretty, J., Robinson, S., Toulmin C., and Whiteley R. (2010). The future of the global food system. Phil. Trans. R. Soc. B 2010 365, doi: 10.1098/rstb.2010.0180

31 Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.J., Tew, T.E., Varley, J., and Wynne, G.R. (2010) Making Space for Nature: A review of England's wildlife sites and ecological network, report to Defra, available at http://archive.defra.gov.uk/environment/biodiversity/index.htm.

32 UK National Ecosystem Assessment Follow On Phase (2014) The UK National Ecosystem Assessment: Synthesis and Technical Report. UNEP-WCMC, Cambridge (In preparation) http://uknea.unep-wcmc.org/

An example of the interconnectedness can be illustrated by considering the relationship between energy and water. Different energy sources use greatly varying amounts of water, yet water scarcity is often absent from debates around which energy sources will be most sustainable. Electricity generation is responsible for a significant proportion of water withdrawals although the large proportion used for cooling purposes is returned to the environment. However, the proportion of water abstraction for power generation varies across the country (c.80% of abstraction in Wales and only 2% in SE England) so competition with other abstraction uses, mainly domestic supply, manufacturing industry, agriculture, aquaculture, also varies spatially. Water availability varies temporally, potentially leading to shut-down of power stations during drought conditions when supply needs to be sustained for other abstraction purposes or for environmental protection. These trade-offs are as yet rarely considered and are likely to be further exacerbated by population growth and the impacts of climate change which is predicted to change runoff patterns across the UK and to leave a large proportion of the population in areas of significant water deficit (SE England) by 2050[33].

Development of the UK's shale gas reserves through hydraulic fracturing could have consequences for the quality and quantity of water supplied at the regional level, but this remains largely un-tested. An increasing number of small scale hydropower schemes require impact assessments to take account of river flow, habitat and fisheries interests.

There is increasing awareness that resource allocation must also include "water for nature" and maintaining environmental flows to support aquatic ecosystem structure and function. Consequently, extraction of water for energy could have impacts on local biodiversity.

Goal 4 will require the development of a robust framework for assessing the energy-land-water nexus and the use of case studies to demonstrate the methodological approach.

4. MULTI/INTERDISCIPLINARY NEEDS

A key methodological challenge is to link and establish a two-way flow between data and models in the ecological and energy domains.

In the ecological domain, UKERC's Phase 2 *Energy and Environment* Theme has been modelling physical and biological ecosystem processes in the marine and coastal margin environments at scales relevant to the development of energy activities such as offshore wind and CO_2 storage. Using approaches developed under the VNN, these models are being used to establish socio-economic benefits through improved ecosystem services (e.g. habitat creation, fish stock recovery and recreational fishing). Similar work is being carried out in the terrestrial environment at the catchment scale in relation to the exploitation of energy crops with the development of a new land-use model (NEA Follow-On Phase 2014).

33 Rance, J., S.D. Wade, A.P. Hurford, E. Bottius and N.S. Reynard (2012). CCRA Risk Assessment for the Water Sector, UK 2012 Climate Change Risk Assessment, Defra, London.

In the energy domain, UKERC has developed technologically rich energy systems models, at the UK and global levels, which maximise human welfare and multi-region input-output models characterising links between the UK and the rest of the world. Drawing on the ecological models, UKERC Phase 2 has started to adapt these to account for the value attached to ecosystem services. Linking data and modelling activity across the two domains will deliver new scientific insights concerning the interplay between natural capital, decarbonisation objectives and energy delivery. Strengthening collaboration across the environmental and energy domains is central to the programme.

5. RELATIONSHIP TO OTHER INITIATIVES

A number of initiatives in this area are already underway or in planning and this programme should not duplicate these efforts. Therefore, it is important to make the distinction between programmes with which the challenge aims to collaborate directly and those which are doing similar and/or relevant science with which the programme can engage or align.

Successful proposals must collaborate with UKERC and the VNP.

5.1 UKERC

The **UKERC Phase 3 hub** (2014-2019) is being funded by EPSRC[34], ESRC and NERC (£13.799M), with co-funding from others including the Energy Technologies Institute (ETI)[35]. It includes an interdisciplinary research programme, complemented by engagement and knowledge exchange activities, some of which will be performed on behalf of (or in conjunction with) the wider UK energy research community.

UKERC Phase 3 is based on a hub and associated challenge model. The hub comprises:

- a core function including core staffing, leadership and central functions to provide a focal point for the whole-systems energy research community such as networking/integrating, international engagement, research analysis, data and knowledge exchange activities;
- a clearly defined and structured research programme; and
- a flexible research budget that can deployed quickly as the need arises.

The RCUK Energy Programme, and/or or individual research councils, then work with UKERC to identify and make available funding for appropriate whole systems energy research priority areas that are not included in the hub, through subsequent challenge calls.

Challenge calls are intended to bring additional research and research groups (including those new to UKERC activity) into the hub to augment and strengthen the work that is already being undertaken. Proposals will be expected to demonstrate that they would have

[34] AHRC: Arts and Humanities Research Council; BBSRC: Biotechnology and Biological Sciences Research Council; EPSRC: Engineering and Physical Sciences Research Council; ESRC: Economic and Social Research Council; and NERC: Natural Environment Research Council.

[35] See http://www.eti.co.uk

an effective fit with existing research being undertaken by UKERC, and with UKERC's Phase 3 research themes. The Institutions involved in the successful applications under challenge calls will become associate members of UKERC. The successful project(s) will be branded as UKERC and are expected to work closely with UKERC. Additional grant conditions will apply.
The Phase 3 research programme is organised into six interrelated themes:

- future energy system pathways for the UK;
- the implications for energy resources and vectors;
- the roles and interactions of energy systems at different scales;
- interactions between energy systems, the economy and society;
- the analysis of decision making; and
- supporting evidence reviews.

Proposals should include in their management description information on how the project will interact with the UKERC management structure. Further information on UKERC Phase 3 should be sought by contacting Research Director Prof Jim Watson.

5.2 Valuing Nature Programme

The **Valuing Nature Programme**, (£7.2m) funded by NERC, ESRC, AHRC, BBSRC and the Department for Environment, Food and Rural Affairs (Defra) aims to better understand and represent the complexities of the natural environment in valuation analyses and to consider the wider societal and cultural value of ecosystems services, even where these may have no perceived market value. Further information on the VNP should be sought by referring to the VNP programme website and co-ordination team when it is in place (still to be announced)[36].

The programme has three main goals:

- First, to improve our understanding of the links between ecosystem stocks and tipping points; how the values of ecosystem services change as tipping points are reached and exceeded; and critical levels of natural capital that avoid abrupt and damaging ecosystem change.
- Second, to improve our understanding of the role biodiversity and ecosystem processes play in human health and wellbeing in three areas: natural hazards and extreme events; the exposure of people to vector-borne diseases and marine toxins; and health and wellbeing improvements associated with urban ecosystems (green space).
- Third, to continue to provide time-limited support to the Valuing Nature Network[37].

Proposals should include in their management description information on how the project will interact with the Valuing Nature Programme management structure. Further information should be sought by referring to the Valuing Nature Programme website.

5.3 Other programme and projects

Other initiatives which should be taken into account include:

[36] http://www.nerc.ac.uk/research/funded/programmes/valuingnature/

[37] See http://www.valuing-nature.net

The ***Nexus Network, funded by the ESRC***[38], aiming to support research that addresses a set of challenges that cut across the Energy- Environment-Food Security Nexus. The challenges recognise the connectedness and global nature of the issues around e.g. equitable access to resources; understanding and encouraging sustainable behaviours; cost-benefit analysis of climate change mitigation and adaptation interventions; economic threats and opportunities of the sustainability agenda; security of and competition for resources, and understanding trade-offs; green growth and innovation; financing the green economy; new technologies and public acceptance; and how to promote effective interdisciplinary working to address these complex and connected issues.

Sustainable Pathways to Low Carbon Energy (SPLiCE)[39], a new research programme funded by Defra and NERC that will fill gaps in knowledge about the sustainability of different mixes of energy supply and demand options needed to deliver 2050 greenhouse gas emissions targets, looking specifically at the effects of different energy options on the natural environment, society and the economy.

The EPSRC WholeSEM energy systems modelling consortium[40]. WholeSEM will build and link energy models to provide a fundamental underpinning role for the UK's national strategic energy modeling activity. The consortium will provide continuity of funding to develop new models, retain human capacity, and link modeling frameworks in innovative ways to answer new research questions

The EPSRC Realising Transition Pathways research consortium[41]. Its aim is to extend and enhance the work of the Transition Pathways consortium and explore what needs to be done to achieve a transition that successfully addresses the energy policy 'trilemma' i.e. the simultaneous delivery of low carbon, secure and affordable energy services. As part of that process, it has been evaluating the energy, environmental and economic implications of the transition pathways on a 'whole systems' or life-cycle basis.

NERC Biodiversity and Ecosystem Service Sustainability (BESS)[42] is a five year (2011-2015) research programme which aims to contribute to our understanding of the functional role of biodiversity in key ecosystem processes.

In order to address these research challenges, BESS is endeavouring to address the following scientific goals by undertaking replicated research across a small number of UK landscape study areas:

- to understand the functional role of biodiversity in UK ecosystems across a range of ecosystem goods and services, environmental gradients and scales typical of real landscapes;

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38 http://www.esrc.ac.uk/funding-and-guidance/funding-opportunities/27070/establishment-of-social-science-of-the-nexus-network-plus.aspx

39 http://www.lwec.org.uk/sustainable-pathways-low-carbon-energy

40 http://www.bartlett.ucl.ac.uk/energy/wholesem

41 http://www.realisingtransitionpathways.org.uk

42 http://www.nerc.ac.uk/research/funded/programmes/bess/

- to identify critical levels of biodiversity required to deliver a range of ecosystem services that meet societal needs, and the land and resource use associated with these biodiversity levels; and
- to develop impact assessment tools to explore the implications of land and resource use change on biodiversity and a range of ecosystem services in a changing environment.

NERC Marine Ecosystems (ME)[43] is a £6M five year research programme co-funded by NERC and Defra. The goal of this programme is to address key knowledge gaps in marine ecosystems research by combining existing long-term data with new field-based and experimental observations. This, along with recent theoretical advances from marine and terrestrial ecology, will facilitate the development of more realistic marine ecosystem models, which in turn will help explore the impact of environmental change on marine ecosystems, including testing potential management solutions.

NERC Marine Renewable Energy (MRE)[44] is a four year collaborative research programme with a budget of £2·4m funded by NERC and Defra. The overall aim is to understand the environmental benefits and risks of up-scaling marine renewable energy schemes on the quality of marine bioresources (including biodiversity) and biophysical dynamics of open coasts.

NERC Land Based Renewables (LBR)[45] is a £2·4M investment in support of collaborative grants to address this topic, including a financial contribution from Shell UK of £350k. Natural England has contributed support in kind, which included expertise in helping to define the scope of the programme. The science goal was to develop an integrated, quantitative understanding of the consequences of using land for renewable energy production on the resilience of terrestrial and aquatic ecosystems. An exemplar objective is a whole-systems analysis of the use of land for carbon manipulation.

Data and modelling initiatives

- The Natural Environment Research Council and the Technology Strategy Board (TSB) are investing £4m in 33 feasibility studies which use environmental data to develop new solutions to business problems. £1m of this funding is for projects specifically using data from space satellites[46].
- The NERC Environmental Information Initiative aims to explore how NERC can use best practice data-processing techniques and cloud-based delivery mechanisms to (i) enhance fundamental scientific research and (ii) leverage NERC data to provide wider commercial impact through new products and services delivered by industry partners.

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[43] http://www.nerc.ac.uk/research/funded/programmes/marineecosystems/
[44] http://www.nerc.ac.uk/research/funded/programmes/mre/
[45] http://www.nerc.ac.uk/research/funded/programmes/landbased/
[46] http://www.nerc.ac.uk/innovation/activities/environmentaldata/businessproblems/

6. PROGRAMME ACTIVITIES

Studentships

It is likely that funding will be available for 4-5 PhD Associated Studentships tied to a funded consortium project.

Commissioning

The programme could be launched and developed using a two-stage bidding process, a sandpit approach or a facilitated event associated with the announcement of opportunity. The decision on which approach is to be adopted depends on a variety of considerations including financial resources and timing. It is recommended that NERC takes these factors into account in making a final decision. Regardless of which route is chosen, a single consortium that delivers all of the goals is anticipated to be the best approach.

Timetabling

Assuming that the facilitated event/announcement of opportunity route is chosen, an indicative timetable would be as follows:

AO to be published:	July 2014
Call opens on JeS:	May 2014
Deadline on JeS:	September 2014
Review:	September - December 2014
PI response:	December 2014
Moderating Panel:	January 2015
Grants awarded:	February 2015
Grant start date:	1st March 2015
PhD studentships start:	1st October 2015

7. PROGRAMME MANAGEMENT

The roles and responsibilities of the groups are detailed below.

Programme Executive Board

The programme will have a Programme Executive Board (PEB). The PEB is the executive decision-making body for the programme and provides the overall strategic direction.

Management Team

The Management Team will be responsible for administering the programme. This team is run from NERC Swindon Office. Activity will involve: coordinating the production and publishing of a Science and Implementation Plan and Announcement of Opportunities; administration of the grants process; day-to-day management of the programme. This group will report to the PEB. The Management Team may seek advice from others as appropriate.

Assessment Panels

An independent assessment panel will be assembled to undertake the assessment of Research Grant proposals and to moderate the external reviews of the proposals. The panel will usually consider both quality of the proposed activity and the ability to deliver the requirements of the programme. The panel will consist of national and international experts in the field, including a member of the NERC Peer Review College for benchmarking. These assessments will inform the PEB's decisions on the award of funding to deliver the programme vision.

8. DATA MANAGEMENT

NERC requires that research programmes implement a data management scheme which covers practical arrangements during the programme and subsequent long-term availability of the data set. In line with the NERC data policy,[47] the data from the programme will be lodged with the appropriate NERC Designated Data Centre. NERC puts an obligation upon PIs to ensure that data management is undertaken in a suitable way.

This challenge will build on two existing programmes: the UKERC Phase 3 Hub and the NERC Valuing Nature Programme, and therefore the funded PIs will be required to work with both programmes to produce fully costed data management plans.

9. KNOWLEDGE EXCHANGE

Knowledge Exchange will facilitate the communication of the science delivered from this challenge to a variety of users including policy makers and industry, and exchange of views and knowledge from these stakeholders with a view to achieving the paradigm shift required. There will be two levels of KE, at the project level through Pathways to Impact and at the programme level via UKERC and the Valuing Nature Programme. KE is intrinsically linked to both the multi-/interdisciplinary partnerships and to associations with these other investments.

There will be a requirement to identify the target communities/stakeholders, consider how these various groups/individuals are likely to benefit from (or be affected by) the research, and create a plan to engage with them which is appropriate and goes beyond communication, timely and happens early in the design stage.

At this early stage in the process, where the research scope is not yet fully defined, the optimal range of KE activities at the programme level is unclear. It is clear, however, that this activity should support activities to stimulate innovation and new collaboration, avoid duplication of effort and allow effective project alignment and interaction. This will foster programme integration, achieve added-value and the production of high-quality deliverables.

[47] http://www.nerc.ac.uk/research/sites/data/policy/