

## Incorporating ecosystem services into the design of future energy systems

Robert A. Holland<sup>a,b,\*</sup>, Nicola Beaumont<sup>c,b</sup>, Tara Hooper<sup>c,b</sup>, Melanie Austen<sup>c,b</sup>,  
Robert J.K. Gross<sup>d,b</sup>, Philip J. Heptonstall<sup>d,b</sup>, Ioanna Ketsopoulou<sup>b</sup>, Mark Winskel<sup>e,b</sup>,  
Jim Watson<sup>f,b</sup>, Gail Taylor<sup>a,b</sup>



<sup>a</sup> Biological Sciences, University of Southampton, Life Sciences Building (B85), Highfield Campus, Southampton SO17 1BJ, UK

<sup>b</sup> UK Energy Research Centre, 11 Princes Gardens, London SW7 1NA, UK

<sup>c</sup> Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth PL1 3DH, UK

<sup>d</sup> Centre for Environmental Policy, Imperial College London, South Kensington, London SW7 2AZ, UK

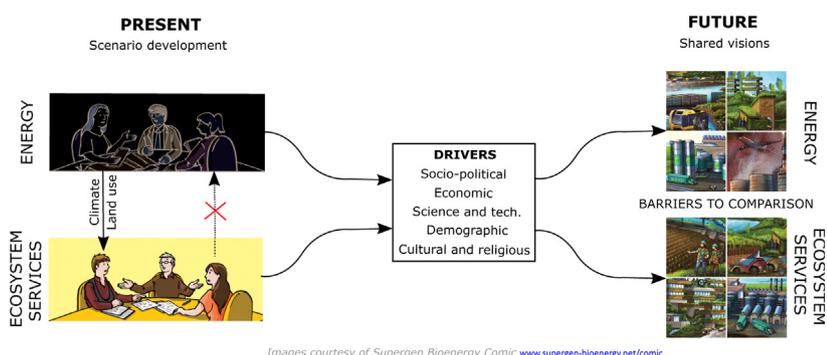
<sup>e</sup> School of Social and Political Science, University of Edinburgh, Edinburgh EH1 1LZ, UK

<sup>f</sup> Sussex Energy Group, University of Sussex, Brighton BN1 9RH, UK

### HIGHLIGHTS

- The study is a comparison of influential energy and ecosystem service scenarios.
- Across domains, scenarios exercises explore similar futures.
- There exist barriers to comparisons that limit policy relevance.
- Integration of ecosystem services would inform optimal routes to decarbonisation.

### GRAPHICAL ABSTRACT



### ARTICLE INFO

#### Keywords:

Ecosystem services

Energy

Scenarios

Self Organising Map (SOM)

### ABSTRACT

There is increasing recognition that a whole systems approach is required to inform decisions on future energy options. Based on a qualitative and quantitative analysis of forty influential energy and ecosystem services scenario exercises, we consider how the benefits to society that are derived from the natural environment are integrated within current energy scenarios. The analysis demonstrates a set of common underlying themes across scenario exercises. These include the relative contribution of fossil sources of energy, rates of decarbonisation, the level of international cooperation and globalisation, rate of technological development and deployment, and societies focus on environmental sustainability. Across energy scenario exercises, ecosystem services consideration is primarily limited to climate regulation, food, water resources, and air quality. In contrast, ecosystem services scenarios consider energy systems in a highly aggregated narrative form, with impacts of energy options mediated primarily through climate and land use change. Emerging data and tools offer opportunities for closer integration of energy and ecosystem services scenarios. This can be achieved by incorporating into scenarios exercises both monetary and non-monetary values of ecosystem services, and increasing the spatial representation of both energy systems and ecosystem services. The importance of ecosystem services for human well-being is increasingly recognised in policy at local, national and international scales. Tighter integration of energy and ecosystem service scenarios exercises will allow policy makers to identify pathways consistent with

\* Corresponding author at: Biological Sciences, University of Southampton, Life Sciences Building (B85), Highfield Campus, Southampton SO17 1BJ, UK.  
E-mail address: [r.a.holland@soton.ac.uk](mailto:r.a.holland@soton.ac.uk) (R.A. Holland).

international obligations relating to both anthropogenic climate change and the loss and degradation of biodiversity and ecosystem services.

## 1. Introduction

Anthropogenic climate change and the loss and degradation of biodiversity and ecosystem services are acknowledged as being among the most substantial challenges facing humanity in the 21st century [1]. Scenario exercises are one route to identify and explore such challenges and are increasingly utilized by governments, business and the third sector. They are intended to provide plausible, comprehensive, integrated and consistent descriptions of how the future might unfold [2]. In doing so they provide a tool to engage with stakeholders, build consensus and develop responses to challenges identified [3,4]. Given the energy sectors' contribution to total anthropogenic greenhouse gas emissions, the identification of routes to decarbonisation is central to development of energy policy at global and national scales [5], with scenario exercises widely used to examine the options that are available [4,6]. Similarly, scenario exercises have been used to explore drivers of environmental change and implications for biodiversity and ecosystem services at global [7–9] and national scales [3].

This study is motivated by the increasing recognition of the need for a whole systems approach to energy systems [10] that considers environmental, economic, technical, institutional, political and social dimensions of future options. The study examines the environmental aspect of this whole systems approach by assessing the extent to which influential energy scenario exercises have considered implications for ecosystem services. This study also considers whether there are existing ecosystem service scenario exercises that are compatible with leading energy scenarios exercises.

Throughout ecosystem services is used as a broad term to describe the benefits that humans derive from nature [11,12]. Ecosystem services are typically divided into provisioning services (e.g. food, fibre, fodder), regulating and maintenance services (e.g. water and air quality), and cultural services (e.g. spiritual and intellectual interactions) [13]. Ecosystem services stem from the world's natural capital, representing stocks of physical and biological resources [11]. It is by combining this natural capital with other forms of capital (i.e. through processing [14]) that we generate goods and services such as crops and timber, that directly contribute to human well-being. Ecosystem services can be subjected to valuation in either monetary or non-monetary terms. Incorporating values into the design of policy, such as through scenarios exercises, can exert a considerable influence on our understanding of the desirability of different policy options. For example, Bateman et al. [15] demonstrate that incorporating ecosystem service values, beyond those associated with agricultural markets, into land use planning in the UK would substantially alter decisions about optimal land use. We would highlight that valuation of ecosystem services remains a highly contested area, and it is beyond the scope of this study to detail the debate. Instead we refer reader to discussions such as those presented in [16–18] for background and methodological approaches. Our study also considers biodiversity, as defined by the 1993 Convention of Biological Diversity as the variability among living organisms, given that it is considered to both underpin many ecosystem services and to exist as a good that has value in its own right [19].

The importance of our study is that the international community has obligations to address climate change (e.g. the Paris Agreement), and the loss of biodiversity and ecosystem services (e.g. Aichi Biodiversity Targets [20]). With the establishment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), a body with a similar remit to the Intergovernmental Panel on Climate Change (IPCC), the importance of biodiversity and ecosystem services will move up the policy agenda. We would argue that this will have

substantial implications for energy scenario exercises. A review of the history of influential (that is scenarios that have shaped policy) energy scenario exercises [10] demonstrates a changing focus through time in response to international agreements and concerns. In the 1970s and 1980s scenario exercises addressed questions around energy security, primarily taken to mean a stable supply of affordable oil [21]. The Chernobyl accident in 1986 saw scenarios emerge that considered an end to nuclear energy [10]. The late 1980s and early 1990s saw a focus on renewable energy to address nitrogen oxide and sulphur oxides [10]. Since the 1992 UN Framework Convention on Climate Change and the 1997 Kyoto protocol, a primary focus of energy scenario exercises has been identification of routes to address climate change [10]. Indeed, one could draw parallels between the history of scenario exercises and the evolving definition of energy security. Four decades ago energy security was focused on security of supply [21]. From the 1980s this definition has evolved to the current form that recognises “availability, affordability, technological development, sustainability and regulation” as important factors that determine energy security [22].

As evidence of the negative implications for human wellbeing and the economy associated with the loss of biodiversity and ecosystem services is presented to governments, we argue that the environmental implications of energy pathways beyond climate change will become increasingly important in shaping energy policy. For this reason those groups involved in the development of energy scenarios must begin to incorporate ecosystem services within their work. This study represents an initial step in this process. We present for the first time a comparison of scenarios produced by practitioners working in the energy and the ecosystem service domains. We compare the scope, methodology, key drivers and implications of 40 individual energy and ecosystem services scenario exercises. A subset of 10 scenario exercises are quantitatively analysed, and a typology of scenarios developed to describe correspondence across the energy and ecosystem service domains. We consider the implications of our findings from the perspective of those involved in the development and use of energy scenarios to inform policy.

## 2. Material and methods

### 2.1. Selection of scenarios

Given the number of scenario exercises that exist, the study focussed on two spatial scales, global and UK. At the global scale, the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) represent two organisation with a common goal of providing independent scientific advice to support development of multilateral environmental agreements [23]. Decisions emerging from COP21 (Paris), the Aichi Biodiversity Targets [20], and work such as the Millennium Ecosystem Service Assessment [12] indicate the relevance of considering scenario exercises conducted at this scale. At the national scale, the UK has been a leader in establishing a legally binding set of carbon budgets [24], and in the integration of ecosystem services within policy, informed by exercises such as the UK National Ecosystem Assessment [25]. With reference to energy scenarios, as an example of such integration the UK Government's Climate Change Act [26] and Carbon Plan [27] consider policy options that addresses climate change should be identified that appropriately recognise the value of nature [27].

Energy scenarios selected for the current study were those produced and used by key organisations in policy, strategy and research i.e. by

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