Renewable and Sustainable Energy Reviews 70 (2017) 230–241

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

The implications of energy systems for ecosystem services: A detailed case study of offshore wind

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ARTICLE INFO

Keywords:
Offshore wind farms
Ecosystem service assessment
Environmental impact
Impact assessment
Common International Classification of Ecosystem Services (CICES)

ABSTRACT

Globally, the deployment of offshore wind is expanding rapidly. An improved understanding of the economic, social and environmental impacts of this sector, and how they compare with those of other energy systems, is therefore necessary to support energy policy and planning decisions. The ecosystem services approach provides a more holistic perspective of socio-ecological systems than traditional environmental impact assessment. The approach also makes possible comparisons across disparate ecological communities because it considers the societal implications of ecological impacts rather than remaining focused on specific species or habitats. By reporting outcomes in societal terms, the approach also facilitates communication with decision makers and the evaluation of trade-offs. The impacts of offshore wind development on ecosystem services were assessed through a qualitative process of mapping the ecological and cultural parameters evaluated in 78 empirical studies onto the Common International Classification for Ecosystem Services (CICES) framework. The research demonstrates that a wide range of biophysical variables can be consistently mapped onto the CICES hierarchy, supporting development of the ecosystem service approach from a broad concept into an operational tool for impact assessment. However, to improve confidence in the outcomes, there remains a need for direct measurement of the impacts of offshore wind farms on ecosystem services and for standardised definitions of the assumptions made in linking ecological and cultural change to ecosystem service impacts. The process showed that offshore wind farms have mixed impacts across different ecosystem services, with negative effects on the seascape and the spread of non-native species, and positive effects on commercial fish and shellfish, potentially of most significance. The work also highlighted the need for a better understanding of long term and population level effects of offshore wind farms on species and habitats, and how these are placed in the context of other pressures on the marine environment.

1. Introduction

Almost 1500 MW of offshore wind capacity was installed in European waters in 2014, bringing the total to 8045 MW in 74 offshore wind farms [1]. The UK has over half of Europe's capacity, and in 2014 offshore wind contributed 4% of UK electricity generation mix, compared to 5% for onshore wind [2]. Offshore wind farms have been installed in 11 countries across Europe (particularly the UK, Germany and Denmark), and there is an emerging trend in Asia: China installed 229 MW of offshore capacity in 2014, and Japan has 12 projects (totalling 874 MW) in the planning pipeline [1].

There is a need to understand the economic, social and environmental impacts of this rapidly expanding sector, and to compare them with those of other energy supply options, in order to support specific planning decisions and the development of wider energy policy. However, there is debate as to whether the existing Environmental Impact Assessment (EIA) process is adequate, particularly for renewable energy. The EIA framework emphasises negative impacts, and is less effective at evaluating positive and non-local benefits, such as climate change mitigation [3]. The ecosystem services approach moves beyond evaluating impacts only in terms of harm caused by human activity [4]. It considers more holistically the integrated socio-ecological system [5], potentially providing an enhanced framework for impact assessment.

The ecosystem service approach focuses on the benefits society receives from the environment, and considers the delivery of environmental goods and services across four main categories: i) Provisioning services (food and raw materials); ii) Cultural services (direct uses such as recreation as well as the less tangible contributions to wellbeing made by interaction with the environment); iii) Regulating services (including flood protection, waste/toxin remediation and carbon sequestration); and finally iv) Supporting, or intermediate, services,

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http://dx.doi.org/10.1016/j.rser.2016.11.248
Received 22 December 2015; Received in revised form 11 November 2016; Accepted 21 November 2016
1364-0321/

which underpin the delivery of all other services [6,7]. The first three categories are described as final ecosystem services, as they contribute directly to the supply of goods and benefits that affect human welfare [7]. Progress in the ecosystem services approach has included the development of systems to classify individual ecosystem services within these broad categories (e.g. the Common International Classification for Ecosystem Services (CICES) [8]). This potential to standardise the process and outputs of evaluations may be an advantage in the adoption of the ecosystem service approach to impact assessment, as it allows results to be compared across different studies.

In addition to comparability across studies, a key strength of ecosystem service assessments is that the approach makes possible comparisons across disparate ecological communities. It considers the societal implications of ecological impacts rather than remaining focused on the specific species or habitats. For example, changes to fish and crop yields can both be considered in terms of impacts on food production, or changes to the extent of saltmarshes or forests can be evaluated according to the respective change in carbon sequestration. This is key to the evaluation of the relative impacts of diverse energy supply options, which will affect different ecosystems in different locations.

The capacity of the ecosystem service approach to frame environmental impacts in societal terms may also better support communication of these impacts to stakeholders and decision-makers [5], and facilitate making trade-offs against other social and economic costs and benefits. The ecosystem service approach is also the foundation of monetary valuation, allowing impacts to be reported in a single metric which can support the use of quantitative comparison tools such as cost benefit analysis.

A method for assessing the impacts of different energy systems on ecosystem services has been proposed and piloted [9,10]. However, this proof of concept considered a limited data set, as a result of the limitations of the approach used for systematic data sourcing. This paper provides a more comprehensive evaluation of the implications of offshore wind farms for ecosystem services. In doing so, it further tests the concept of an ecosystem services approach to energy impact assessment by considering a wider range of metrics and an expanded hierarchy of the ecosystem services onto which the services map, compared to the work of Papathanasopoulou et al. [10]. This extension of Papathanasopoulou et al.'s [10] work contributes to the further practical evaluation that is needed to allow the ecosystem services approach to develop from a concept to operational tools. It also provides a detailed empirical assessment of the impacts of offshore wind farms on ecosystem services, with outputs that have the potential to be easily compared with similar evaluations of alternative energy supply options. The focus of this review is on local impacts; there is no meaningful way to attribute climate change mitigation at the scale of individual OWFs, and the implications for ecosystem services more widely from the development of a decarbonised electricity sector are beyond the scope of this paper.

2. Method

A review of 78 publications in the peer-reviewed and grey literature was undertaken to establish the environmental and socio-economic parameters considered in assessment of the impacts of offshore wind farms (OWFs). A formal systematic review process (e.g. [11]), was not followed in identifying this literature as the objective of the review was to identify the largest possible body of studies to permit a comprehensive evaluation of the application of an ecosystem services approach to energy impact assessment, not to facilitate replication. The publications reviewed were sourced using academic and internet search engines (including Web of Science, Scopus, Open Grey and Google Scholar), with the main search terms combining *offshore wind farm* (and alternatives) with general terms such as *ecosystem service* and *environment* as well as descriptors for key species, habitats, coastal uses and potential impacts on cultural services (e.g. *fish, benthic, recreation, seascape*). Wider social and economic impacts such as job creation were not considered as they do not relate to ecosystem services. Further sources were identified through 'snowballing' from the reference lists of articles identified through the search process, and by using expert knowledge of the literature. Each publication was scored against quality assurance criteria used in Rapid Evidence Assessment [12] and those achieving less than a 'moderate' score were excluded.

The review considered primary evidence from empirical research on OWFs or from very closely related experiments involving, for example, playback of recorded OWF noise or cables with equivalent electromagnetic properties. Studies that speculate on potential impacts based on experiences of other offshore infrastructure (such as other pile driving or seismic activity, piers, or artificial reefs), which have often featured prominently in previous reviews of OWF impacts (e.g. [13–15]), were excluded. Reports from statutory monitoring programmes were generally avoided, as questions have been raised about the reliability of the data as the approaches, methods and data analysis are not always fit for purpose [16–18]. The main elements considered in the review were: i) the principal ecological or socio-economic focus of the study; ii) the specific variable(s) evaluated in the assessment; iii) the metric(s) used; and iv) the direction of impact. Some publications considered more than one variable, and where this was the case, each element was considered separately. The location of the study, the scale at which impacts were considered, and the OWF lifecycle stage were also recorded.

The experience of Papathanasoupoulou et al. [10] suggests that most research on the impacts of energy technologies is not carried out in an ecosystem services context. Therefore, a process was required to map the results as reported in ecological and social metrics onto an ecosystem services framework. Following Papathanasopoulou et al. [9], the framework for this mapping process used the Common International Classification for Ecosystem Services (CICES, [8]) version 4.3, a system that seeks to standardise the classification of ecosystem services in order to support environmental accounting and wider ecosystem service assessment. CICES is a hierarchical classification, with the main categories of ecosystem service (provisioning, regulating, cultural) described as 'sections', which are successively expanded into divisions, groups, and classes (Table 1).

The environmental accounting focus means that CICES considers only final ecosystem services that directly link to goods and benefits that are valued by people. However, many of the impacts of energy developments affect the underlying environmental processes that provide these final services. In order to accommodate these impacts, the CICES classification was supplemented by the Millennium Ecosystem Assessment [6] category of supporting services. No attempt was made to attribute species- or community-level changes to particular supporting services such as food web dynamics or nutrient cycling mainly because each species/community is likely to support ecosystem maintenance in several ways. The exact role of particular species and the linkages between ecological communities and specific services remain uncertain. This complexity and uncertainty perhaps explains the absence of a standard classification system for supporting services.

Expert judgement was used to map the impacts as reported in the reviewed studies onto the ecosystem services classification (after Papathanasopoulou et al., [9]). The mapping process generated a qualitative output based on potential changes to ecosystem services, as there remains too much uncertainty in the linkages between species, habitats and ecosystem services for a quantitative approach to be attempted. Impacts were recorded as the direction of the potential change in ecosystem service provision: positive, negative, no change and uncertain. This latter category reflects where there is: i) no clear trend in the effects reported within the study; or ii) where the observed response does not translate directly into a well-defined impact, for