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Energy systems and their impacts on marine ecosystem services

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ABSTRACT

Global warming and its link to the burning of fossil fuels has prompted many governments around the world to set legally binding greenhouse gas reduction targets which are to be partially realised through a stronger reliance on renewable (e.g. wind) and other lower carbon (i.e. natural gas and nuclear) energy commodities. The marine environment will play a key role in hosting or supporting these new energy strategies. However, it is unclear how the construction, operation and eventual decommissioning of these energy systems, and their related infrastructure, will impact the marine environment, the ecosystem services (i.e. cultural, regulating, provisioning and supporting) and in turn the benefits it provides for human well-being. This uncertainty stems from a lack of research that has synthesised into a common currency the various effects of each energy sector on marine ecosystems and the benefits humans derive from it. To address this gap, the present study reviews existing ecosystem impact studies for offshore components of nuclear, offshore wind, offshore gas and offshore oil sectors and translates them into the common language of ecosystem service impacts that can be used to evaluate current policies. The results suggest that differences exist in the way in which energy systems impact ecosystem services, with the nuclear sector having a predominantly negative impact on cultural ecosystem services; oil and gas a predominately negative impact on cultural, provisioning, regulating and supporting ecosystem services; while wind has a mix of impacts on cultural, provisioning and supporting services and an absence of studies for regulating services. This study suggests that information is still missing with regard to the full impact of these energy sectors on specific types of benefits that humans derive from the marine environment and proposes possible areas of targeted research.

Contents

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1. Introduction

The increased use of fossil fuels to meet ever rising energy demands [1] and intensive energy and material lifestyles [2,3] poses unprecedented pressures on the environment due to its associated greenhouse gases (GHG) emissions [4]. Carbon dioxide (CO_2) makes up the largest proportion of the basket of GHG and is predominately released during the combustion of fossil fuels in the generation of electricity. As a consequence of rising emissions, global land and ocean temperatures have increased by 0.72° over the last 135 years [5] contributing to sea level rises and extreme weather events which are threatening life as we know it [6]. Based on these trends many governments around the world have agreed, using international agreements such as the Kyoto protocol [7], to reduce their GHG emissions by 2020 to ensure that further global temperature rise will remain below 2° by 2100. For example, the UK has pledged to reduce its GHG emissions by 20% of 1990 levels by 2020 as part of its EU commitment, but has also set a further national reduction target of 80% by 2050 that is legally binding through its Climate Change Act [8].

As a consequence of similar commitments, countries are now evaluating strategies to achieve emission curbs with a primary focus on changes to energy production mixes. In the case of the UK, strategies for increasing its renewable energy and lowering carbon energy commodities are being considered [9]. Contributions of nuclear,[1] offshore wind farms (OWF) and offshore gas to total UK electricity generation are forecast to reach 33%, 28% and 11%, respectively, by 2030, which is a considerable change from the current contributions of 20%, 3% and 27% [10].

Such changes in the mix of energy production technologies and the required construction, operation and decommissioning of related infrastructure will have an impact on marine ecosystems. Assessments of energy technologies on ecosystems both spatially and temporally is an active field of research for the marine environment (see [11] for examples of the types of research currently being pursued in the UK). Internationally, a number of studies have focussed on different elements associated specifically with each of these energy systems. For instance, marine ecosystem impacts associated with nuclear power stations due to offshore discharges include the uptake of radionuclides by marine biotic and abiotic components [12,13], increased water temperature around nuclear offshore discharge tunnels and its effect on ecosystem functioning [14–19] and changes in water quality and community structures [18,20–21].

In terms of offshore wind farms some studies have focussed on the changes in community structure, diversity and habitat [22–25], behavioural changes of species [26–34] and changes in abundance of species [35–37] associated with their construction and operation. For offshore natural gas and oil platform some studies have considered how their construction, operation and decommissioning affect the bioaccumulation of hydrocarbons and their toxicity in biotic and abiotic elements [38–41], community structure and biodiversity changes [42–47] and changes in abundance of marine species [48,49].

Impacts on ecosystems will subsequently impact the services they provide to society and human well-being[2] [50,51]. Ecosystem services are the benefits humans gain from ecosystems [50] and are generally grouped into: (1) provisioning (e.g. the production of food, materials and energy); (2) regulating (e.g. the mediation of toxins and waste, the maintenance of physical, chemical and biological conditions); (3) cultural (e.g. physical, intellectual and spiritual interactions with biota, ecosystems and environmental settings); and (4) supporting (e.g. nutrient cycling, photosynthesis and soil formation) [50–52]. Evaluating energy policies using an ecosystem services approach provides a holistic assessment of how changes in one service, e.g. such as the provision of energy to satisfy human energy demand, will impact on other ecosystem services, e.g. such as the provision of food. This is therefore a framework well suited to identify trade-offs and opportunities for synergies between ecosystem services, and ultimately human well-being, providing an invaluable tool to support the management of the marine environment.

Despite the significance of ecosystem service impacts of energy systems, an objective synthesis has not, as yet, been carried out. This gap significantly challenges our current ability to forecast how rising low carbon energy demand [53] will impact on ecosystems and the ecosystem services they provide. To fill this gap, the present study develops a generic and transferable methodology which is tested in the marine environment. It employs a systematic review approach to collate the scientific literature of existing evidence on the impacts of the energy industry (OWF, offshore gas and oil, and the offshore components of nuclear) on marine biodiversity and ecosystem processes [54] as these are seen as fundamental parts of well-functioning marine systems [55]. The results of the review on ecosystem impacts are presented and then translated into ecosystem service impacts using an explicit and transparent ecosystem service classification framework. It is hypothesised that the impacts of different energy sectors on marine ecosystems would vary markedly because of differences in the types of pressures they represent (e.g. localised sea water warming by offshore nuclear discharge tunnels, physical disturbance caused by wind-farms). This study is therefore a significant step forward in the aggregation of the fragmented landscape of evidence about the footprint of the energy industry on marine biodiversity and processes which can help to inform the much desired ecosystem approach to marine management [50,55,56].

2. Method

Systematic reviews are structured and standardised protocols for the search and reviews of studies, and for the recording of the findings that is guided by an explicitly structured research question [57]. This approach was followed here to review the impacts of the selected offshore energy sectors directly on the marine environment. The impacts reviewed were then translated into ecosystem services explicitly employing the ecosystem services classification frameworks proposed by Haines-Young and Potschin

[1] The offshore structures of nuclear power plants are considered of significance to this study.

[2] Human wellbeing is defined in terms of: security, basic material for a good life, health, good social relations, freedom of choice and action.