Marine Pollution Bulletin 90 (2015) 247–258

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Renewables-to-reefs? – Decommissioning options for the offshore wind power industry

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A R T I C L E I N F O

Article history:
Available online 18 November 2014

Keywords:
Decommissioning
Offshore wind power
Ecosystem services assessment
Renewables-to-reefs
DPSIR framework
SWOT analysis

A B S T R A C T

The offshore wind power industry is relatively new but increasing globally, hence it is important that the whole life-cycle is managed. The construction–operation–decommissioning cycle is likely to take 20–30 years and whilst decommissioning may not be undertaken for many years, its management needs to be addressed in both current and future marine management regimes. This can be defined within a Drivers–Activities–Pressures–State Changes–Impacts (on human Welfare)–Responses framework. This paper considers the main decommissioning options – partial or complete removal of all components. A SWOT analysis shows environmental and economic benefits in partial as opposed to complete removal, especially if habitat created on the structures has conservation or commercial value. Benefits (and repercussions) are defined in terms of losses and gains of ecosystem services and societal benefits. The legal precedents and repercussions of both options are considered in terms of the 10-tenets of sustainable marine management. Finally a 'renewables-to-reefs' programme is proposed.

1. Introduction

Although the offshore wind power (OWP) industry has existed for only two decades, it is of growing importance as a source of energy across the globe. There is a European potential for 40 GW of offshore installed capacity by 2020, with an additional 110 GW installed by 2030 (EWEA, 2011, 2013); in the US 54 GW by 2030; and in China 30 GW by 2020 (EWEA, 2011). The increase in renewable energy results from a decreasing reliance on fossil fuels especially as worldwide demand for energy is expected to treble by 2050 (WEC, 2012) increasing carbon dioxide emissions from 30.2bn metric tonnes in 2008 to 43.2bn metric tonnes by 2035 (IEO, 2011). In the European Union (EU) for example, in 2009 only 3% of the UK energy was from renewable sources whereas the EU target is for Member States to collectively achieve 20% of energy from renewable sources by 2020 (Renewables Directive 2009/28/EC annex 1). Across Europe, Member States have set targets in National Action Plans in support of the EU goals that vary according to their national capabilities: Denmark and Germany have targets of 20% of energy consumption from renewable sources and Finland has a target of 38% (EC, 2010).

Given the increasing growth of OWP, and the need to understand the environmental, economic and social aspects of any development as required by the Ecosystem Approach, it is essential for marine managers to have a complete understanding of the full life cycle of any offshore wind farm (OWF) project. The underlying marine management can be defined within the DAPSI(W)R framework which represents Drivers–Activities–Pressures–State Changes–Impacts (on human Welfare)–Responses (Elliott, 2014). This is modified from the DPSIR risk analysis and risk management (RARM) framework, a systems-based approach to capture key relationships between society, its environmental demands and the natural environment (Atkins et al., 2011; Gregory et al., 2013). It allows the assessment of management options associated with the offshore wind sector and has been recently used for similar evaluations, *e.g.* in the context of seabed restoration following the cessation of aggregate dredging (Cooper et al., 2013). The DAPSI(W)R approach is consistent with the Ecosystem Approach which is advocated, for example, by the Marine Strategy Framework Directive (2008/56/EC) with the boundary of the system captured by the framework being dependent on the issue of concern (Svarstad et al., 2008). A DAPSI(W)R framework for the management of the UK offshore wind sector is given in Fig. 1.

The framework encompasses the key *Drivers*, which are the UK and export demands for renewable energy, which results in the building of offshore wind farms. Several *Activities* are associated

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http://dx.doi.org/10.1016/j.marpolbul.2014.10.045
0025-326X/

with this, namely, the installation, operation, maintenance and ultimately the removal of components and infrastructure. In turn the *Activities* create several *Pressures* on the system, for instance maintenance of the subsea cabling is a pressure on the local system. These *Pressures* may lead to *State Changes* on the natural system which affects, for example, the physical nature of the seabed, water column and marine organisms, and these *State Changes* may then produce *Impacts* on the provision of ecosystem services for society and hence potential changes to human *Welfare*. There is then a need for management *Responses*, to control the *State Changes* and *Impacts on Welfare*, which in the case of the offshore wind sector include licensing conditions, monitoring and decommissioning. Given the cyclical nature of this framework, the *Response* then affects the *Drivers*, *Activities*, *Pressures* and *State Changes* thus producing an iterative system. The content of this figure is further discussed throughout the paper.

The focus of this paper is on decommissioning as a management *Response*. This paper assesses the possible environmental impacts of infrastructure (turbine monopile, cabling, armouring, etc.) removal on the physical site through a review of decommissioning options and the existing regulatory framework for decommissioning. Future options for decommissioned sites are explored using the Ecosystem Approach within a DAPSI(W)R framework. An evaluation based on a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis was undertaken to investigate the potential environmental and economic benefits from the different decommissioning options, leading to an initial assessment of the potential *Impact* on societal *Welfare* of the two decommissioning options using an existing ecosystem services framework. The legal precedents and repercussions of partial and complete removal are considered and are described in terms of the 10-tenets of sustainable marine management (Elliott, 2013). This approach is important in order to obtain a holistic view of the system and to allow a full comparison of the effects of any particular decommissioning strategy and has led to our proposal of a *renewables-to-reefs* programme as an alternative to a traditional site decommission. Although regional aspects of the North Sea are examined in the context of UK and EU policy and legislation, the discussion here relates to all offshore wind developments.

2. Review of existing decommissioning options

As offshore wind is a relatively new industry and, to date, no wind farms have been decommissioned, to review options for decommissioning, cases from the offshore oil and gas industries are used as a starting point.

The beneficial value of partial removal of offshore structures is illustrated by the novel method of protecting and enhancing the marine environment during decommissioning of oil platforms which began in the 1980s in the Gulf of Mexico (Kaiser and Pulsipher, 2005; Reggio, 1987). This 'rigs-to-reefs' programme is considered to offer significant environmental and commercial benefits given that complete removal can damage the seabed, the habitat and the new equilibrium which has been created. This is especially the case given the habitat created by the armouring to protect the cabling and main structure (Wilson and Elliott, 2009). Leaving an artificial reef, with benefits for commercial and recreational fishing plus the reduced costs for developers, are weighed against operational challenges of leaving parts in place, where these challenges relate to safety of navigation, ongoing maintenance costs, issues in relation to liability of the reef and potential for spread of non-indigenous species. This rigs-to-reefs programme was introduced through the US National Fishing Enhancement Act and is currently governed under the US National Artificial Reef Plan.

One of the most developed rigs-to-reefs programme exists in Louisiana, under permits from the US Army Corps of Engineers (USACE) and the US Coast Guard (via the Rivers and Harbors Act 1899 s10) who use that Plan for decision making. The requirement to remove a disused offshore installation within a year of decommissioning is waived for the development of an artificial reef programme provided the following criteria are met: the structure does not inhibit future development opportunities; the reef complies with the USACE permit conditions as outlined in the Plan and that a state fishing management agency accepts liability for the structure (Kaiser, 2006). The USACE will evaluate and permit proposed projects on a site-specific basis and the US Coast Guard is responsible for navigational safety of the remaining structure. Furthermore, following termination of the federal lease for oil extraction, the platform operator is absolved of all responsibility for the installation if it is accepted into the artificial reef programme provided that a responsible state agency will accept liability (Kaiser, 2006). Consequently, under the Louisiana Fishing Enhancement Act of 1986, the Department of Wildlife and Fisheries acts as an agent for the state and as such will assume ownership and all resulting liabilities of the installation including future maintenance costs.

It is also of note that the Louisiana State artificial reef planning process designated nine sites deemed appropriate for artificial reef operation. These site designations have considered all marine users and been identified as both environmentally and commercially viable and in line with navigational safety requirements.

3. Interdisciplinary analysis of decommissioning offshore wind developments

The 10-tenets framework for achieving sustainable management (Elliott, 2013, 2014) takes the view that a truly interdisciplinary approach is required which encompasses the economy, ecology, technology, governance, *etc*. Hence, within the context of OWF decommissioning, an interdisciplinary analysis has been undertaken which considers the regulatory framework and both the natural environmental and the socio-economic impacts of decommissioning options. This evidence-based analysis comprises a comprehensive regulatory review, a SWOT analysis and an assessment of ecosystem service provision, which is discussed in light of the 10-tenets of marine management, and results in a proposal for a *renewables-to-reefs* programme.

3.1. Regulatory framework for decommissioning [the management Responses in DAPSI(W)R]

A wind turbine reaches its designed life expectancy (20–30 years) when it cannot function properly due to failure or fatigue, or no longer satisfies the expectations or needs of its user (Ortegon et al., 2013). At this point there are two main options: to repower or decommission. Repowering allows the continued operation of the wind farm, with replacement of certain turbines by higher power capacity units and newer technologies. The size of individual structures has increased from 25–30 m blades to 75 m blades and so the possibility of replacing small monopiles and turbines with larger ones exists as is already done for terrestrial wind farms, for example in Denmark (Munksgaard and Morthorst, 2008). Repowering depends on Government energy policy, continued support for offshore wind and extension of lease or licence options, and is not considered further here. In contrast, offshore decommissioning guidelines were originally developed for oil and gas platforms which, unlike offshore wind turbines, exploit a finite natural resource and after exhausting the oil or gas field the platform cannot be used for its designed purpose (or