Journal of Environmental Management 141 (2014) 16–28

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Applicability of the "Frame of Reference" approach for environmental monitoring of offshore renewable energy projects

Erwan Garel [a,*], Cibran Camba Rey [b], Óscar Ferreira [a], Mark van Koningsveld [c,d]

[a] Centre for Marine and Environmental Research (CIMA), Algarve University, Edifcio 7, Campus de Gambelas, 8005-139 Faro, Portugal
[b] Acciona Energa, S.A. Avda, Ciudad de la Innovacin 5, 31621 Sarriguren, Spain
[c] Van Oord Dredging and Marine Contractors B.V., P.O. Box 8574, 3009 AN, Rotterdam, The Netherlands
[d] Delft University of Technology, Faculty of Civil Engineering and Geosciences, P.O. Box 5048, 2600 GA, Delft, The Netherlands

ARTICLE INFO

Article history:
Received 18 February 2013
Received in revised form
6 February 2014
Accepted 9 February 2014
Available online 23 April 2014

Keywords:
Marine renewable energy
Large-scale projects
Environmental monitoring
Environmental indicators
Monitoring framework
Frame of reference

ABSTRACT

This paper assesses the applicability of the Frame of Reference (FoR) approach for the environmental monitoring of large-scale offshore Marine Renewable Energy (MRE) projects. The focus is on projects harvesting energy from winds, waves and currents. Environmental concerns induced by MRE projects are reported based on a classification scheme identifying stressors, receptors, effects and impacts. Although the potential effects of stressors on most receptors are identified, there are large knowledge gaps regarding the corresponding (positive and negative) impacts. In that context, the development of offshore MRE requires the implementation of fit-for-purpose monitoring activities aimed at environmental protection and knowledge development. Taking European legislation as an example, it is suggested to adopt standardized monitoring protocols for the enhanced usage and utility of environmental indicators. Towards this objective, the use of the FoR approach is advocated since it provides guidance for the definition and use of coherent set of environmental state indicators. After a description of this framework, various examples of applications are provided considering a virtual MRE project located in European waters. Finally, some conclusions and recommendations are provided for the successful implementation of the FoR approach and for future studies.

1. Introduction

Offshore winds, waves and currents have a large potential for long-term electricity generation worldwide (Pelc and Fujita, 2002; Thresher and Musial, 2010). The wind industry is leading the way, whilst devices to harvest offshore wave and current energy are still under development (Sutherland et al., 2008; Inger et al., 2009; Bedard et al., 2010). Offshore wind energy is harvested by turbines rotating about a horizontal axis, which are derived from the well-established technology used on land. Nowadays, commercial offshore wind turbines have seafloor foundations, the most common ones being monopiles driven into the bed, gravity-based foundations, tripod foundations and jacket foundations. However, with wind parks moving towards deeper water, various types of floating foundations are being developed (Butterfield et al., 2007; Main(e) International Consulting, 2012). For waves, the technology is relatively immature and no commercial design has emerged yet amongst the very large variety of existing concepts (see Drew et al., 2009; Bald et al., 2010). Regarding currents, the most significant technology offshore consists of rotating devices on horizontal axes (similar to wind turbines), even though other designs including vertical axes are also considered (see O'Rourke et al., 2010; Polagye et al., 2011).

As wind energy projects are moving further offshore, they are also increasing in size (see EWEA, 2012). The worlds largest (in surface area) Marine Renewable Energy (MRE) project currently operating offshore is the Greater Gabbard (southern North Sea), covering 146 km^2 with a nominal capacity of 504 MW; it should be soon exceeded by the 1000 MW London array project (230 km^2 surface area) which is currently being developed in two phases (Phase 1: 175 turbines over 121 km^2 generating 630 MW is fully operating since April 2013). The future of both wave and tidal

Acronyms: BACI, Before-After Control-Impact; DPSIR, Drivers-Pressures-Status-Impacts-Response; EIA, Environmental Impact Assessment; EMF, Electro-Magnetic Fields; EMP, Environmental Management Plan; ES, Environmental Statement; ESI, Environmental State Indicators; FoR, Frame of Reference; MRE, Marine Renewable Energy; PDCA, Plan-Do-Check-Act; QSC, Quantitative State Concept.

* Corresponding author.
E-mail address: egarel@ualg.pt (E. Garel).

http://dx.doi.org/10.1016/j.jenvman.2014.02.037
0301-4797/

energy converters is also to cover such large areas including hundreds of devices (see Johnson et al., 2012). In addition, the offshore energy industry is considering large-scale (i.e., area $> 10\ km^2$, at least) multi-platform projects combining various MRE devices (e.g., wind turbines and wave converters) or activities (e.g., energy conversion and aquaculture), in order to increase the utilisation factor per site and the overall revenue. That effort is testified by the relatively large number of recent EU-funded projects related to this domain (e.g., MARINA; MERMAID; ORECA; TROPOS; H2OCEAN).

Multi-platform or not, MRE projects are also expected to cumulate at specific locations offshore because of grid and land access considerations, together with site-specificity regarding the resource (especially for waves and currents). In the Irish Sea, for example, three wind farms are currently operating within a radius of less than 20 km (Walney, Barrow and Ormonde, covering an area of 73 km^2, 10 km^2 and 8.7 km^2, respectively) and a fourth very large one is proposed (West Duddon, 66 km^2). The development of these large-scale projects, and their addition to other anthropogenic activities offshore, is accompanied by environmental concerns (Pelc and Fujita, 2002; Gill, 2005; Michel et al., 2007; Sutherland et al., 2008; Inger et al., 2009; Masden et al., 2010; Simas et al., 2010; Wilhelmsson et al., 2010; Shields et al., 2011).

The evaluation of environmental effects in the offshore realm is a difficult task, because the marine environment is a highly complex system where physical, chemical and biological properties interact at several spatial and temporal scales. Although being ambiguously defined (Heink and Kowarik, 2010), “environmental indicators” generally reduce the complexity of a problem, or of a large number of parameters, to a smaller number of key-parameters that enable the description or quantification of the status and trends of (entire or partial) ecosystems. As such, indicators may facilitate management decisions as they provide the necessary information for decision-makers about where, when and how to act (Gubbay, 2004; Davidson et al., 2007). They are also useful for the communication of overall progress on stated goals and benchmarks.

During the last decade, indicators have been increasingly developed, including for the marine environment (Davies et al., 2001; Gubbay, 2004), and used at global (e.g., World Bank, United Nation, Organization for Economic Co-operation and Development), regional (e.g., European Environment Agency), national and local levels, as well as in the private sector. For example, environmental indicators are commonly used by the offshore oil and gas industry to assess the impact of exploitation on the benthic ecology and water quality (e.g., Olsgard and Gray, 1995; Andrade and Renaud, 2011).

Indicators are commonly defined and organized in frameworks that facilitate their understanding and interpretation ensuring at the same time the appropriate match between end-users and scientists (Gabrielsen and Bosch, 2003; Gubbay, 2004). Frameworks can also help to understand the inter-relations between various indicators (Stegnestam, 1999). Several environmental frameworks have been proposed, depending on the application and scale of the problem considered. For example, the Drivers-Pressures-Status-Impacts-Response (DPSIR) model provides an overall approach for analysing environmental issues, generally with regards to sustainable development (Borja et al., 2006). This framework is useful as a descriptive method reporting the environmental impacts of a particular sector through the use of indicators; as such, it is largely used to report indicators set at national levels and is able to provide a link between the socio-economic aspects of an activity and the induced environmental changes. DPSIR may be therefore well-adapted for the strategic development of the offshore MRE industry (Elliott, 2002). However, this type of framework might not be relevant – or difficult to implement – if the focus is on environmental monitoring of specific projects, where guidance is required to select specific indicators. In this case, other prescriptive

Table 1
Potential effects of stressors (top row) upon receptors (far left column), associated to offshore MRE devices. For simplicity, the stressor “cumulative impacts” and the receptor “ecosystem interactions” are not included. Environmental effects and main potential impacts are discussed in more detail in Subsection 2.3.

	Physical presence of device	Dynamics	Release of chemicals	Generation of sound	Electro-magnetic fields
Physical environment	Artificial reef	Scouring Seabed disruption Hydrodynamic changes Aerodynamic changes Sediment dynamic changes			
Marine mammals and turtles	Collision potential Aggregation effect Obstruction of migratory route			Hearing injuries Site avoidance Stress increase Acoustic masking	Behavioural change
Pelagic habitat and communities	Collision potential Artificial reef Aggregation effect No take zone Steppingstone effect	Hydrodynamic changes Aerodynamic changes Pressure effects near rotating devices		Hearing injuries Site avoidance Stress increase Acoustic masking	Behavioural change
Benthic habitat and communities	Artificial reef No take zone Steppingstone effect Flora and fauna impact by moorings	Scouring Seabed disruption Hydrodynamic changes Aerodynamic changes Sediment dynamic changes	Pollution from dredging	Acoustic masking	Behavioural change Sediment temperature increase
Marine birds	Collision potential Aggregation effect Obstruction of migratory route			Site avoidance	
Water quality	Artificial reef Light reduction Sediment re-suspension by moorings	Seabed disruption Hydrodynamic changes Aerodynamic changes Sediment dynamic changes	Leaching Spilling Pollution from dredging Pollution from maintenance		