Developing an Environmental Impact Assessment model for nearshore wave energy devices

Maria Apolonia, Ana Silva, and Teresa Simas

Abstract— **There is an increasing recognition of the importance of stablishing standards for environmental monitoring applied to the wave energy industry to understand the potential impacts of a device in early stages of its development. The fact that wave energy projects have unique characteristics, different from any other marine projects, results in a lack of methodological approaches for environmental and socio-economic impacts evaluation. This paper proposes a tool for Environmental Impact Assessment (EIA), including a Socioeconomic Impact Analysis (SEIA) for nearshore wave energy projects. An Adaptive Management (AM) approach is adopted to manage the project impacts regarding mitigation measures' adaptation and monitoring plan review. This tool is intended to work as a recommended practice guide for regulators and managers to apply in nearshore wave energy devices and sets the basis for the development of a decision-making tool on the delineation of best monitoring activities schedule and planning which will later be validated through its application on the MegaRoller device final design, an oscillating wave surge converter (OWSC) technology.**

Keywords— **Environmental Impact Assessment, Nearshore wave energy devices, Socioeconomic Impact Analysis.**

I. Introduction

ENVIRONMENTAL Impact Assessment (EIA) is a stepwise approach that ensures that the environmental implications of a certain action are considered before decision making in a given project. It is an instrument already implemented in several countries' legislation and it usually integrates projects' consenting process. However, there is a significant variation in EIA procedures which is directly linked with legal, policy and institutional frameworks in different countries. The SOWFIA project [1] carried out a review on the licensing procedures which showed the EIA process for ocean energy in Europe still lacks a streamlined framework and concludes that only through increasing knowledge can the EIA process be more specifically adapted to ocean energy developments. The consenting of offshore renewable energy is often considered the main non-technical barrier to the development of the sector as there are several uncertainties related to the potential environmental impacts of emerging technologies. Based on this, the RiCORE[2] project established a risk-based approach to consenting where the level of survey requirement is based on the environmental sensitivity of the site, the risk profile of the technology and the scale of the proposed project.

The fact that wave energy projects have unique characteristics, different from any other marine projects, results in a lack of methodological approaches for environmental and socio-economic impacts evaluation. The existing information focus mainly on environmental results for prototype or small array projects and, in many cases, the small scale of these projects doesn't justify the need for a full EIA process. EQUIMAR[3] project has proposed guidance to the process of environmental impact assessment although assuming the early stage of development of the technology linked to a high level of uncertainty.

A new model for EIA and monitoring is therefore strongly needed for wave energy projects. This report proposes an environmental and socioeconomic impact assessment model to work as a guideline for regulators and managers in nearshore devices, adopting an Adaptive Management (AM) approach. The model presented here is based on an exhaustive literature review regarding environmental effects of nearshore installations to comprehensively address stressors, receptors and effects of this kind of structures and the model is organised considering biological, physical and socioeconomic effects. Mitigation measures as well as monitoring protocols and the starting point for the

ID number: 1266 / Conference track: Environmental impact and appraisal.

This work is part of a project receiving funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 763959.

M. Apolonia is with WavEC Offshore Renewables, R. Dom Jeronimo Osorio n11, 1400-119 Lisboa, Portugal (e-mail: maria.apolonia@wavec.org).

A. Silva was with WavEC Offshore Renewables, R. Dom Jeronimo Osorio n11, 1400-119 Lisboa, Portugal (e-mail: ana.silve@gmail.com).

T. Simas is with WavEC Offshore Renewables, R. Dom Jeronimo Osorio n11, 1400-119 Lisboa, Portugal (e-mail: teresa@wavec.org).

[2] http://ricore-project.eu/
[3] http://www.equimar.org/

delineation of monitoring activities, usually applied to the most relevant impacts (classified from negligible to major), have also been reviewed and summarised to inform further model application. The EIA model for

effects' evaluation and prioritization of a specific project is then proposed, which is linked to a stepwise approach for the selection of appropriate mitigation and monitoring protocols. Final remarks are added to prepare the EIA model application to MegaRoller – an Oscillating Wave surge Converter (OWSC) - final design.

A. General aspects

EIA usually follows 7 main stages: i) Screening; ii) Scoping; iii) Baseline characterisation; iv) Impact analysis; v) Mitigation measures; vi) Public involvement and vii) Monitoring.

Screening is the first step of the EIA process and consists on deciding on whether an EIA is required. If this stage leads to the conclusion that an EIA is required, the next stage is the scoping phase. This stage identifies the issues that are likely to be of most importance during the EIA so that the study focuses on the significant aspects and avoids time consuming activities. Baseline characterization gives information about the reference conditions of the site where the project will take place, on an environmental and socioeconomic level, and are the basis to predict potential impacts. The identification and prediction of impacts contribute for the delineation of mitigation measures. The mitigation process refers to methods of action that need to be taken to prevent, minimize and compensate for the predicted adverse effects of the project or to enhance its positive effects. Finally, a monitoring plan should be drawn for all project phases (from preparation to decommissioning) considering all the information obtained in the previous steps. Monitoring an effect or an impact means that the monitoring plan must be designed to measure change against some baseline condition or management objective. It is a key step to validate and change initial EIA findings. Public involvement throughout the whole process ensures all stakeholders are actively participating in the EIA process and contributing to decision making.

Since the scoping is done in an early stage of the project, mitigation measures can be further studied and be used as an input to design choices and operational procedures and logistics that lead to a reduction in the environmental impact of the project.

One of the approaches that have been proposed for the impacts assessment of wave energy projects is the identification of stressors which refer to any single characteristic or activity of an ocean energy project, and receptors, defined as the ecosystem elements that may be affected by a stressor [2]. During the identification of potential impacts, the effects of such stressors on the receptors are then quantified based on experience related with similar projects or simply based on expert knowledge regarding the sensitivity of the site and project characteristics.

AM is an iterative process that promotes decision-making, which can be adjusted in the face of uncertainties as outcomes from management and other events become better understood [3]. This learn-based management approach is applied in the present study manage project impacts in terms of mitigation measures' adaptation and monitoring plan review.

TABLE I
KEY EFFECTS ON MARINE NEARSHORE ACTIVITIES

Sector	Key Effects
Fisheries	Overfishing, change of population's dynamics, seabed disruption, water quality damage
Navigation	Chemical pollution, noise disturbance, loss of habitat
Aquaculture	Biological, organic and chemical pollution, habitat change, over-exploitation of marine resources
Seawalls	Change of hydrodynamic system and sediment transport, loss of habitat, potential habitat assemblages
Offshore wind and wave energy	Changes of the hydrodynamic system and sediment transport, loss of habitat, interactions with benthic communities and surface animals

B. Marine nearshore areas – sensitivity and main activities

The nearshore environment is generally defined as the area encompassing the transition from subtidal marine habitats to associated upland systems. Within the marine system, the nearshore subsystem extends from the landward limit of the Marine System to the 30 meters depth contour. This limit represents an ecologically significant depth to which water column and benthic processes are strongly coupled in the nearshore subsystem. [4]. These dynamic zones have changing biological, chemical and geological features and contain highly productive ecosystems.

The assessment of the sensitivity is important to understand the natural variability of the environment, as well as its vulnerabilities to given pressures, so that a prediction of potential impacts can be listed. The sensitivity analysis should therefore consider both environmental (biological and physical) factors and the socioeconomic aspects specific to a site. As per the biological factors, these areas provide a variety of ecosystems services e.g. nursery grounds for a wide variety of marine invertebrates and fishes and important feeding habitats for high trophic level pelagic predators [5]. Regarding the ecosystem physical characteristics of coastal zones, hydrodynamic processes are the driving force of sediment transport and evolution of the seabed [6]. These coastal processes include erosion, transport and deposition of sediments, essential for long shore drift material and ultimately beach morphology [7]. Any disturbance on the seabed may increase sediment

TABLE II
EXAMPLES STRESSORS

Development Phase	Stressor
Preparation	Dredging activities Sampling Vessel noise
Construction	Vessel and equipment presence Drilling activities noise
Operation	WEC's physical presence Electromagnetic Fields (EMFs)
Decommissioning	Vessel and equipment presence Drilling activities noise
All phases	Chemical and oil pollution Drifting/sinking equipment Need for manpower and services

suspension and water column turbidity, decreasing light penetration and interfering with primary production.

Marine and particularly coastal ecosystems provide a wide range of services to human society including supporting, regulating, recreational and provisioning services [8], which is the reason why coastal regions are usually more densely urbanized and have a more developed economy than inland regions [9].

Besides navigation and fisheries, a range of other economic activities are currently competing for the use of the nearshore areas around, calling for the increasing need to manage these waters more coherently through Marine Spatial Planning (MSP). MSP reduces conflicts between sectors, creates synergies between different activities and protects the environment through early identification of impact and opportunities for multiple use of space. The effects of the main nearshore installations and activities are identified in Table I.

II. STRESSORS, RECEPTORS AND EFFECTS

An exhaustive literature survey was carried out to identify and evaluate the main effects of nearshore installations on the receiving environment based on stressors and receptors, focusing mainly on wave energy developments. Data were organised, and stressors were identified considering four project development phases: preparation, construction, operation and decommissioning. A fifth row was added to include common stressors across all development phases such as accidental events. The interaction between stressors and receptors was crossed, resulting in three Summary Impact matrices of key effects at biological (shown as an example in Appendix A), physical and socioeconomic levels. Key impacts were obtained by evaluating each key effect based on a ranking classification criteria adapted from EMEC guidelines [10]. This ranking comprises 6 levels of magnitude of impact (see Appendix A, for classification of environmental aspects), from 'negligible' to 'major', including 'positive' and 'no interaction'.

Since stressors may differ between the three matrices, examples of stressors associated with activities arising from each development phase are shown in Table II. The chosen receptors in this model can be consulted in Table IV.

III. MITIGATION MEASURES AND MONITORING ACTIVITIES

Monitoring is an important step of the EIA process to follow up the effects of impacts as well as to monitor mitigation measures efficiency. The interpretation and evaluation of the outcomes from monitoring results will support the elaboration of a new mitigation plan that will better adjust the environmental system and the goals set forth by the AM process. The identification of the relevant parameters for impacts and mitigation measures follow up through monitoring is then key to optimize the environmental management system. Table IV compiles several parameters usually measured during monitoring activities to evaluate wave energy effects across all phases of the project development and for the impacts classified in the literature as negligible, minor, moderate and major.

IV. THE EIA MODEL

The proposed EIA model consists on the identification and evaluation of potential impacts of wave energy devices, building on the summary impact matrices and the identified monitoring parameters. This method is intended to be a guide for managers and regulators on the identification and prediction of the most significant environmental and socioeconomic impacts of a project, definition of mitigation measures and planning of monitoring protocols and techniques. The method is to be applied on a case-by-case basis i.e. considering the project specific characteristics and site environmental conditions.

The EIA model is based on the identification and evaluation of the potential impacts of wave energy devices using the summary impact matrices. From here, a set of parameters and a set of mitigation measures taken from literature was then linked to the all relevant receptors. At the end, a decision tree method for the identification of the most appropriate monitoring techniques and protocols was delineated based on the parameters the user chooses for each receptor. The final output of the model is a set of monitoring plans for all the relevant receptors identified per development phase.

TABLE IV
MONITORING PARAMETERS FOR CHOSEN RECEPTORS

Factor	Receptor	Parameters
Physical	Hydrodynamic System	Wave climate (height, period, mean direction and directional spreading), currents (speed, direction and velocity profile along the water column), turbulence, bathymetry
	Water Column	Turbidity levels, temperature, salinity, water depth, Chlorophyll *a*, dissolved oxygen levels, nutrients and contaminants content
	Seabed	Sediment composition and granulometry, sediment transport, contaminants content
	Shoreline	Erosion/deposition patterns, shoreline morphology
Biological	Benthic Community	Species composition and abundance, distribution, density, diversity and dominance structure and percentage of coverage, presence of invasive species
	Fish & Turtles Marine Mammals Birds	Species composition (and presence/absence only for marine mammals) and abundance, distribution, density and diversity
Socioeconomic	Local Communities	Number of direct and indirect jobs created (quantifying highly specialized ones), level of public acceptance, identification of relevant stakeholders, quantification of GHG emissions avoided
	Archaeological Sites	Archaeological site identification
	Landscape & Seascape	Visual perception/impact
	Economic Activities	Overlap with other marine uses (marine spatial planning analysis), number of new businesses created, identification of relevant stakeholders

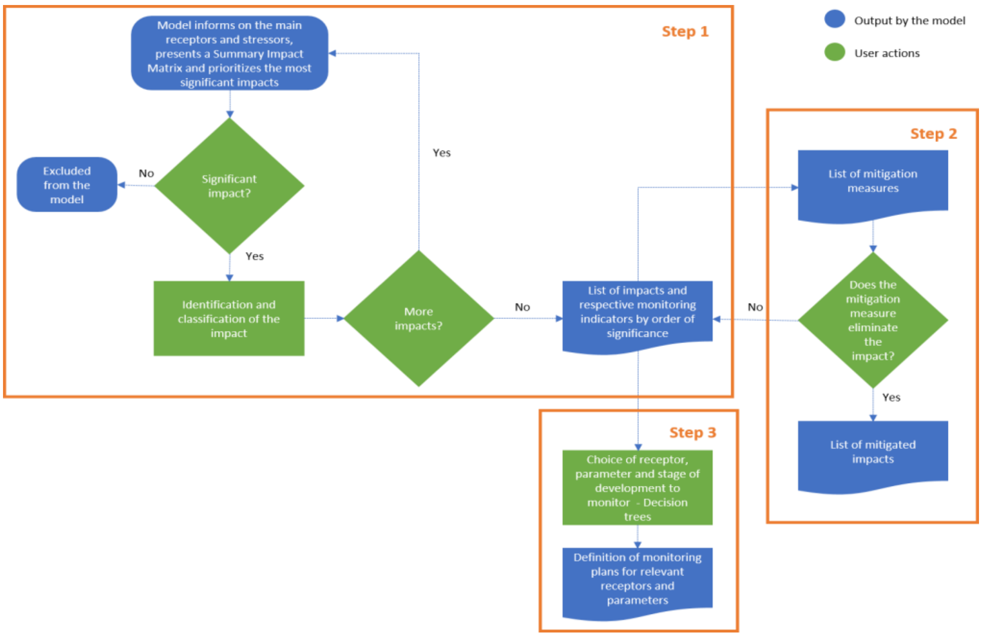

Fig.1. Flowchart of the proposed model.

To reduce environmental and socioeconomic potential effects and adjust the assessment during the EIA process, an AM procedure is adopted in this model to consider changes in the project impacts and their respective mitigation measures' as well as the adaptation of the monitoring plan, according to monitoring results. The selected monitoring techniques aim to assess the impacts magnitude classification and monitor the effectiveness of implemented mitigation measures, to update, if required, the impacts' magnitude classification, define a new set of mitigation measures and help adapting the monitoring plan. The flowchart in Fig.1 summarizes the methodology of the proposed model.

The user should start with the prioritization of impacts (Step 1) by listing the most significant key effects and assign a level of impact to each of them according to EMEC guidelines and considering the project specific characteristics and baseline characterization. This stage is followed by the selection of mitigation measures (Step 2), in which the user should be able to distinguish which key impacts are fully eliminated through the implementation of a mitigation measure. The ones that don't, move further to the next step. Finally, the use of decision trees works as a decision-support tool for the identification of monitoring protocols/techniques (Step 3). The EIA model steps are detailed below.

C. Step 1: Impacts identification and evaluation

Step 1 consists of adapting the impacts classification presented in the summary impacts' matrices according to the project features and environmental sensitiveness of the site. This allows impacts prioritization, classifying them according to the EMEC's classification ranking for each phase of the project development, in a case by case analysis.

D. *Step 2: Mitigation measures listing*

Following the identification, evaluation and prioritization of the project key impacts, the list of mitigation measures needs to be identified to prevent, minimize and compensate for those negative effects of the project development. Different mitigation measures are needed depending on specific interactions of the project components with the environmental receptors. Step 2 of the EIA model consists in assigning mitigation measures to the impacts that have been prioritised under Step 1. A final matrix containing the stressors, receptors, impacts and selected mitigation measures is generated to inform Step 3 on the effectiveness of these measures follow up through monitoring.

E. *Step 3: Monitoring protocols planning*

The last step comprises the identification of the monitoring protocols and techniques to be carried out. A decision tree was developed to serve as decision-support tool, to help managers and regulators determining which monitoring techniques need to be included in the monitoring plan.

The monitoring framework developed in this report was adapted from the method developed by [11] and includes the use of the environmental parameters presented in Section III. To help the manager or regulator use this method, a decision tree was developed to set the

TABLE V
MONITORING TECHNIQUES/PROTOCOLS

Technique/Protocol	Code	Technique/Protocol	Code
Acoustic doppler current profiler (ADCP)	1	Radar observations (birds)	14
Active acoustic – sonars	2	ROVs, underwater cameras	15
Aerial photographs	3	Sampling collection and analysis techniques	16
Analytical methods (e.g. econometric models)	4	Satellite images	17
Conductivity, Temperature, Depth (CTD)	5	Secchi disk method	18
Desk based analysis	6	Sonar and LIDAR techniques	19
Dive surveys	7	Spectrophotometry, HPLC or fluorometry	20
Geographic Information Systems (GIS)	8	Telemetry tags	21
Hydrophones	9	Temperature sensors	22
In situ multiparametric probes	10	Turbidity meters	23
Observation surveys	11	Use of models	24
Participatory methods	12	Wave measure buoys	25
Passive acoustic – C-Pods	13	Winkler method and oxygen sensors	26

The receptor is		
	Hydrodynamic System	**Go to A**
	Water Column	**Go to B**
	Seabed	**Go to C**
	Shoreline	**Go to D**
(A)The parameter is	Wave climate	1, 25
	Currents	1
	Turbulence	1
	Bathymetry	2, 19
(B) The parameter is	Turbidity levels	18, 23
	Temperature, salinity and water depth	6, 10, 22
	Chlorophyll *a*	20
	Dissolved oxygen levels	10, 26
	Nutrient and contaminants content	10
(C) The parameter is	Sediment composition and granulometry	16
	Sediment transport	23
	Contaminants content	16
(D) The parameter is	Erosion/deposition patterns	3, 17, 24
	Shoreline morphology	3, 17, 24

The receptor is		
	Benthic Community	**Go to A**
	Fish & Turtles	**Go to B**
	Marine Mammals	**Go to C**
	Birds	**Go to D**
(A) The parameter is	Species Composition, Abundance and Density	7, 15, 16
	Species Distribution and % of coverage	7, 15
	Species Diversity and Dominance Structure	16
	Presence of invasive species	7, 15, 16
(B) The parameter is	Species Composition	6
	Species Abundance	2, 6, 15
	Species Distribution	6, 21
	Species Density	15
	Species Diversity	6, 15
(C) The parameter is	Species Composition/Diversity and presence/absence	11, 13, 15
	Species Abundance and Density	11, 15
	Species Distribution	11, 13, 15, 21
(D) The parameter is	Species Composition and Diversity	11
	Species Abundance and Density	11, 14
	Species Distribution	11, 14, 21

The receptor is		
	Local Communities	**Go to A**
	Archaeological Sites	**Go to B**
	Landscape and Seascape	**Go to C**
	Economic Activities	**Go to D**
(A)The parameter is	Number of direct and indirect jobs created	6
	Level of public acceptance	12
	Identification of relevant stakeholders	6, 12
	Quantification of GHG emissions avoided	4
(B) The parameter is	Archaeological site identification	8
(C) The parameter is	Visual perception/impact	6, 12
(D) The parameter is	Overlap with other marine uses	8
	Identification of relevant stakeholders	6, 12
	Number of new businesses created	6

Fig. 2. Decision trees for selection of monitoring activities.

most appropriate monitoring techniques (listed in Table V) in each stage of development. Three distinct decision trees were developed for the physical, biological (Fig. 2) and socioeconomic factors. The user is guided through these decision trees by answering a set of questions on the receptor, parameter and stage of development towards the monitoring protocols that determine the monitoring plan across all the receptors considered.

The monitoring methodology can change considerably depending on the stage of development being analysed regarding its schedule and planning. Thus, after the identification of the monitoring techniques and protocols per parameter and receptor, the model will provide information on the monitoring planning and schedule specific to each development phase considering the parameters monitoring spatial coverage, duration and frequency.

V. CONCLUSION

EIA processes and knowledge acquisition on the devices interaction with the marine environment represent crucial aspects when approaching consenting/permitting processes. Given the lack of EIAs for wave energy devices, and particularly for nearshore projects, it was difficult to gather all the information needed. Nevertheless, the data collected for the elaboration of this framework provides a means for deepening our knowledge of the potential environmental and socioeconomic impacts of nearshore wave energy projects, allowing regulators and managers for better decision-making. Finally, this report sets the basis for the development of a decision-making tool on the delineation of best monitoring activities schedule and scenarios to optimize time and costs, which will later be validated through its application to the final MegaRoller design.

APPENDIX A

TABLE A1
ENVIRONMENTAL ASPECTS CLASSIFICATION ADAPTED FROM EMEC GUIDELINES

Magnitude of Impact	Description
Major	Degradation to the quality or availability of habitats and/or wildlife with recovery taking more than 2 years
Moderate	Change in habitats or species beyond natural variability with good recovery potentially within 2 years
Minor	Change from baseline conditions measurable but within scale of natural variability
Negligible	Change in habitats or species within scope of existing variability and difficult to measure or observe
No Interaction	None
Positive	*An enhancement of ecosystem or popular parameter*

Biological Effects			Receptor							
			Benthic Communities		Fish & Turtles		Marine Mammals		Birds	
Development phase	Activity	Stressor	Key Effect	Mag	Key Effect	Mag	Key Effect	Mag	Key Effect	Mag
Preparation	Surveying	Sampling: coring, boring and grab sampling	Loss of biodiversity		NK		NK		NK	
		Noise from Vessels and sonar/seismic surveys	Disruption of behaviour; potential harm		Disruption of behaviour; potential harm		Disruption of behaviour; potential harm		Disruption of behaviour	
	Site preparation	Dredging Activities	Productivity reduction; loss of biodiversity; food web implications		Disruption of behaviour; food web implications		Disruption of behaviour; food web implications		Disruption of behaviour; food web implications	
Construction	Transport of wave device and support structures	Vessel activity; Presence of machinery/equipment	Disruption of behaviour		Disruption of behaviour		Disruption of behaviour		Disruption of behaviour	
		Noise from vessels	Disruption of behaviour; potential harm		Disruption of behaviour; potential harm		Disruption of behaviour; potential harm		Disruption of behaviour	
	Installation of wave device and support structures	Installation of WEC; Piling/drilling activities	Productivity reduction; Loss of Biodiversity; Food web implications		Disruption of behaviour; food web implications		Disruption of behaviour; food web implications		Disruption of behaviour	
		Noise from piling/drilling activities	Disruption of behaviour; Potential harm		Disruption of behaviour; potential harm		Disruption of behaviour; potential harm		Disruption of behaviour	
Operation	Device deployment	Physical presence of WEC device and structural components	Reef effects; Food web promotion; increase in productivity and biodiversity		Fish aggregation; food web promotion		Food web promotion		Food web promotion	
			Risk of harmful biofouling; Invasive species		Risk of collision, entanglement, entrapment		Risk of collision, entanglement, entrapment		Risk of collision, entanglement, entrapment	
		Noise generation	Disruption of behaviour; potential harm		Disruption of behaviour; potential harm		Disruption of behaviour; potential harm		Disruption of behaviour	
		EMFs	Disruption of behaviour		Disruption of behaviour		Disruption of behaviour		NK	
Accidental events	Chemical / oil / fuel spill	Chemical and oil pollution	Potential toxic response		Potential toxic response		Potential toxic response		Potential toxic response	
	Loss of equipment / structural components	Physical presence of sinking/floating equipment	Disruption of behaviour; potential harm through		Disruption of behaviour; potential harm through		Disruption of behaviour; potential harm through		Potential harm through ingestion/entanglem ent	
			ingestion/entanglemen t		ingestion/entanglemen t		ingestion/entangle ment			
Decommissioning	Removal of device and structural components	Vessel activity; Presence of machinery/equipment	Loss of biomass and biodiversity locally enhanced; food web implications		Disruption of behaviour; food web implications		Disruption of behaviour; food web implications		Disruption of behaviour; food web implications	
		Noise from vessels and removal	Disruption of behaviour; potential harm		Disruption of behaviour; potential harm		Disruption of behaviour; potential harm		Disruption of behaviour	

Fig. 1. Overview of the Summary Impact Matrix applied to biological effects.

ACKNOWLEDGEMENT

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 763959.

REFERENCES

[1] EU, "Streamlining of Ocean Wave Farms Impact Assessment (SOWFIA) project," 2018. [Online]. Available: https://www.plymouth.ac.uk/research/coast-engineering-research-group/sowfia-project.

[2] G. Iglesias, J. A. Tercero, T. Simas, I. Machado, and E. Cruz, "Environmental Effects," in *Wave and Tidal Energy*, 2018.

[3] L. Hanna *et al.*, "IEA Wind task 3.4 Technical Report - Results of IEA Wind Adaptive Management White Paper," 2016.

[4] FERC, "Environmental Assessment for Hydropower License - Reedsport OPT Wave Park Project," 2010.

[5] B. Ballachey *et al.*, "Variability within nearshore ecosystems of the Gulf of Alaska," 2015.

[6] S. Sawczyński and L. M. Kaczmarek, "Sediment Transport in the Coastal Zone," *Tech. Sci. 17(2), 2014, 165–180*, 2014.

[7] D. Greaves *et al.*, "Environmental Impact Assessment: Gathering experiences from wave energy test centres in Europe," *Int. J. Mar. Energy*, 2016.

[8] UNEP-WCMC, "Marine and coastal ecosystem services: valuation methods and their application," 2011.

[9] L. Yi *et al.*, "Impacts of human activities on coastal ecological environment during the rapid urbanization process in Shenzhen, China," *Ocean Coast. Manag.*, vol. 154, pp. 121–132, 2018.

[10] EMEC, "Guidance for Developers at EMEC Grid-Connected Sites: Supporting Environmental Documentation. Report by European Marine Energy Centre (EMEC)," 2013.

[11] E. J. Shumchenia *et al.*, "An Adaptive Framework for Selecting Environmental Monitoring Protocols to Support Ocean Renewable Energy Development," *Sci. World J.*, 2012.