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Based on Classification of the used Technology

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A method for EIA scoping of wave energy converters—based on classification of the used technology

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ABSTRACT

During the first decade of the 21st Century the World faces spread concern for global warming caused by rise of green house gasses produced mainly by combustion of fossil fuels. Under this latest spin all renewable energies run parallel in order to achieve sustainable development. Among them wave energy has an unequivocal potential and technology is ready to enter the market and contribute to the renewable energy sector. Yet, frameworks and regulations for wave energy development are not fully ready, experiencing a setback caused by lack of understanding of the interaction of the technologies and marine environment, lack of coordination from the competent Authorities regulating device deployment and conflicts of maritime areas utilization. The EIA within the consent process is central in the realization of full scale devices and often is the meeting point for technology, politics and public. This paper presents the development of a classification of wave energy converters that is based on the different impact the technologies are expected to have on the environment. This innovative classification can be used in order to simplify the scoping process for developers and authorities.

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1. Introduction

Wave Energy Converters (WECs) have been undergoing a significant development since the oil crisis in the 1970s, and have been subject to extensive studies. The technologies have been optimized, extensively tested and pilot wave energy projects have been realized. The knowledge and experiences gained lead to a development status that is ready for the market. The growth and interest in expanding the wave energy sector are based on its potential estimated to be up to 10 TW. Depending on what is considered to be exploitable, this covers from 15% to 66% of the total world energy consumption referred to 2006 (Engineering Committee on Oceanic Resources — Working Group on Wave Energy Conversion, 2003; Cruz et al., 2008).

WECs vary in technological concept and design. A total of 96 companies and energy concepts worldwide are listed by European Marine Equipment Council (EMEC) today; more than 56% of the WECs are located in Europe. Forty-nine different wave energy concepts are under development today only within Europe (Fig. 1). In order to gain permit from the related planning authorities to place a full scale WEC at a specific site, an Environmental Impact Assessment (EIA) is an administrative procedure that a project will usually have to pass (Zubiate et al., 2005). As WECs deployed in full scale is an early practice, only few EIAs of WECs have been carried out. It is argued by the developers, that only minor environmental impacts can be expected by deployment of WECs, and that most impacts are associated with the installation and decommissioning phase. (Sørensen and Russel, 2008). Never the less a European Directive requires that the European countries at least conduct an initial EIA screening to investigate whether or not a WEC is mandatory to conduct a full EIA.

Today Environmental Impact Assessments have been carried out for the following wave energy devices:

- AquaBuOY based on the deployment September 2007, Oregon, US (Weinstein et al., 2007) (Fig. 2).
- Wave Dragon 1:4½ prototype deployed by 2003 in Nissum Bredning, Denmark (Hansen et al., 2003) (Fig. 2).
- Wave Dragon based on the expected deployment off the west coast of Wales, UK by 2010 (Russell and Wave, 2007).

The deployment of the AWS west of Portugal in 2005 (Beirão at al. 2007) was established without any accessible EIA. So was the case with the deployment of Pelamis in Portugal, 2008 (Fig. 2) and a number of prototype shoreline devices of the OWC kind that have already been constructed and operated with varying degrees of success over the last 30 years around the World.

Further information on EIA exists for:

- The EMEC test center in Orkney, UK.
- The Wave Hub project north of Cornwall, UK established in 2008 (Harrington and Andina-Pendás 2007).

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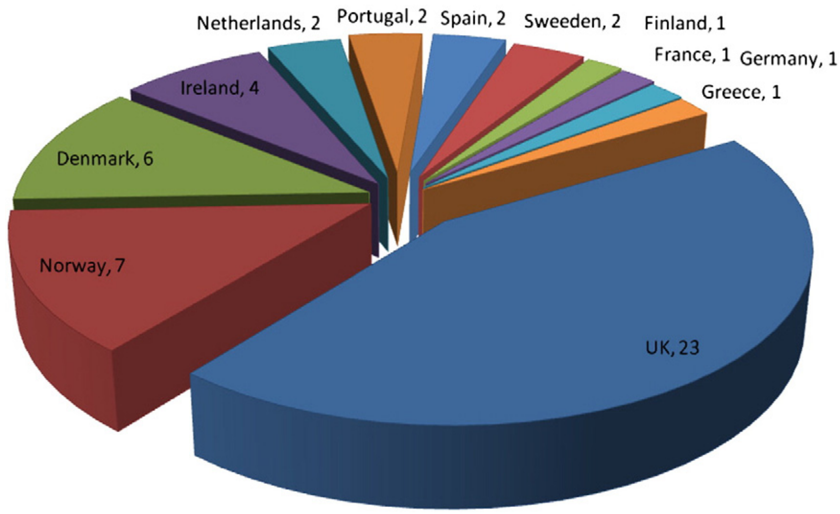

Fig. 1. Number of wave energy technologies developed per Country in Europe. Total is 52, with 3 technologies being in collaboration between 2 countries, for a total of 49 different concepts in EU.

The EMEC test center has been created for the purpose of testing full scale grid connected prototype devices in a limited amount of time (Fig. 3). Being a test site, the devices are not required to be subjects of full EIAs, but an Environmental Statement demonstrating that the developers are aware of the issues and potential environmental impacts of their devices. Wave Hub is an innovative demonstration site for wave energy generation located in the South West of England, north coast of Cornwall (Harrington and Andina-Pendás, 2007). It consists of an offshore electrical "socket" to connect arrays of wave energy converters to the national grid via under-sea cables (Fig. 3).

In European EIA systems, the involvement of the public, as well as the competent authority and other responsible government agencies, is an integral part of the process. Normally it is the competent authorities together with the developer of the project and his consultants in cooperation that carry out the first two steps of an EIA, namely the *screening* and the *scoping,* and sets the plan for the following process (Kørnøv et al., 2007). The organization and quality of the communication between the developer and the authorities depend on the national legislation in the actual country as well as on the administrative body. As implementation of full scale WECs is still at an early stage, the planning authorities in the European context have in general not a specific frame or body in place to handle the applications. This increases the risk that conflicts arise from the communication and thereby the risk that there will be a lack of coordination among developer, consenting bodies, authorities and statutory consultees (Kørnøv et al., 2007; Cashmore, 2004). In the worst case scenario this may translate into a delay that may eventually jeopardize the outcome of the project. At the present time Denmark is the only European country that has an administrative body in place to coordinate the planning and implementation of offshore wind and WECs: the Danish Energy Agency. Before 2009 the Danish Energy Agency allowed the deployment of 4 wave energy converters as demonstration plants and prototypes: (Wave Dragon, Wave Star, Wave Plane and Poseidon Organ) with very smooth procedures demonstrating an efficient frame work: for the development projects EIA screenings were carried out with the conclusion that it was not necessary to conduct EIAs for the projects. The conclusion was submitted for consulting to the statutory consultees who gave 3 positive responses, for which the project could then continue its implementation with no more environmental investigations. For one of the four demonstration projects the affected municipality asked for investigation of the impact of a specific duck species, and when this was conducted and showed that the ducks would not be impacted, no further investigations were demanded and no EIA was carried out. In the UK an administrative body similar to the Danish is under construction. At European level so far activities in the maritime environment have been managed by separate policies but the EU is rapidly calling for more integrated approach with a maritime spatial planning. Offshore energy production, including wave energy, seats within the list of main activities to be coordinated. The program also foresees coordination between Member States that will lead to less bulky procedures and lower administrative costs.

It is Authors' belief that a new classification based on the expected environmental impact of the devices will make it easier for developers and authorities to carry out the scoping of this type of projects. Indeed, the high variety of existing wave energy technologies challenges the understanding of the issues involved in the process therefore preventing a slim and efficient consenting process that is desirable

Fig. 2. From the left: Pelamis Portugal, Wave Dragon Nissum Bredning, DK, AquaBuOY Oregon, US.

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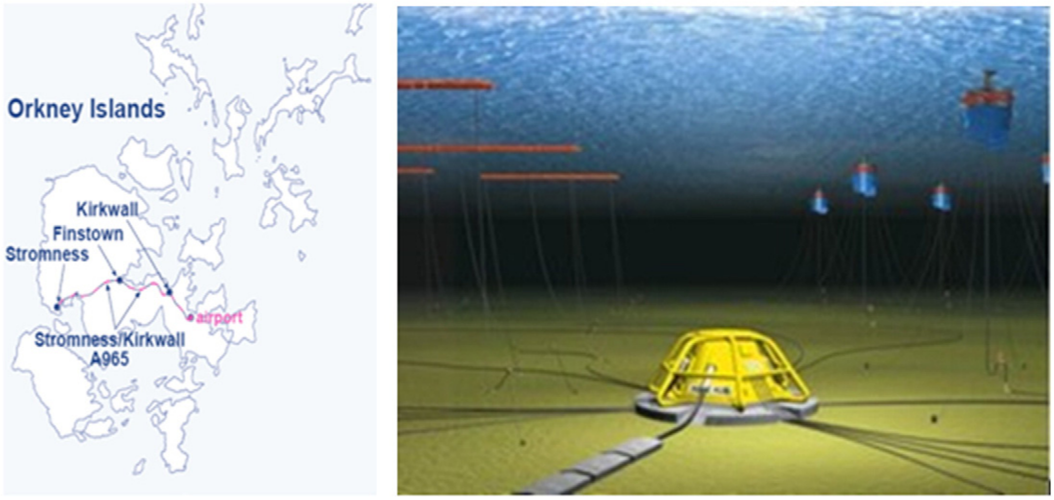

Fig. 3. On the left, EMEC facility location. On the right, offshore underwater electrical "socket" of the Wave Hub Project.

for a renewable energy project. As the focus of this paper is on the technical aspect of EIA regarding the delimitation and the coverage of EIAs in relation to ocean energy devices, the first two steps, Screening and Scoping of the EIA process, are of main interest.

2. Methods and materials

To identify which receptors are important to EIA of WECs, this paper takes its point of departure in the legislative context. The first part of this paper, Section 3, investigates the demands to EIA with focus on WECs within the EU. The related EU directive which is the basic EIA frame for all European Countries, is presented and the demands to the content of EIAs are described with special focus on the first two steps of the process where the scope and content of EIA is decided upon. Section 4 also looks into the state of the art on identification of environmental parameters in relation to WECs. The most detailed material regarding environmental impacts of WECs today is based on the EMEC guidelines for EIA of WECs. The EMEC results are used to set up an impact matrix for the screening and scoping of WECs. This part of the analysis is based on EU legislation and EIA educational materials as well as on existing reports and papers of EIAs of WECs. Other relevant reference material partially presented in this paper comes from the work under development within the EU-funded projects EquiMar (7FP, 2008–2011, under grant agreement no. FP721338). The next part of the paper, Section 5, is presenting an analysis of technological differences of WECs and related potential environmental impacts. The existing technologies within the EU are scanned in relation to 4 plus 1 criterions:

1) Distance from shore (onshore, intermediate, offshore)
2) Stability elements (simple moorings, complex moorings, gravity foundations, piles)
3) Obstruction to water column (little, some, very)
4) Power takeoff
5) Obstruction to the sea surface in case of wave farms (only mentioned).

In relation to these criterions it is identified how the technological differences affect the likelihood of environmental impacts. Based on the expected similar impact of the converters on the environment, a classification of WECs is presented. This is done by comparing the technology with the impact matrix based on the EMEC Guidance in Section 3. Finally, in Section 6, a comparative analysis is conducted between the expected environmental impacts derived from the classification against the results from the EIA of WECs that has been conducted at the present time (Wave Dragon Wales and AquaBuOY Oregon). Based on the comparative analysis, it is concluded that a table underlining the principal areas of concern for different groups of technologies as presented, makes it possible to simplify the scoping procedure and to provide an easier understanding of the technologies to the authorities.

3. EU directive on EIA

EIA is an environmental management instrument implemented worldwide. EIA was introduced in The Council of the European Union, 1985 via the directive: "Council Directive 85/337/EEC—on the assessment of the effects of certain public and private projects on the environment" (85/332/EEC) and later with an amending directive in 1997 (97/11/EEC). The European Directive describes the aim of EIA as: "…providing the competent authorities with relevant information to enable them to take a decision on a specific project in full knowledge of the projects likely significant impact on the environment…" This way EIA's function includes two fundamental aspects, one is technical and regards the question of how to make the best description and assessment of different impacts. The other aspect regards the question of how to make the EIA inform and influence decision making (Kørnøv et al., 2007). EIA often functions as a "framework for negotiation and compromise" and it plays an important role in the consenting process of a lot of projects (Cashmore, 2004). The Directive covers the provision for 25 countries counting among others Denmark and United Kingdom. These two countries have implemented EIA into their national legislation systems (Kørnøv et al., 2007). As earlier mentioned in this paper, several wave energy projects in Europe are facing the stage of realization where they are to deploy in large or full scale. WECs in full scale are expected to be subjects of EIA. A full EIA process based on the Directive includes the steps shown in Fig. 4. The arrows illustrate how the EIA process is iterative.

3.1. Screening and scoping

The screening is the first stage in the process of EIA. There are different ways of conducting screenings. In the EU directive an inclusive list of projects where EIAs are mandatory is given in Annex I. Projects where EIA can be mandatory depending on the size and significance of the environmental impacts are listed in Annex II (97/11/EEC). Projects listed in Annex II should undergo further screening to assess whether or not the project will impact significantly on the environment, and if yes, a full EIA will be required. Annex II includes among others wave energy constructions as the following is listed:

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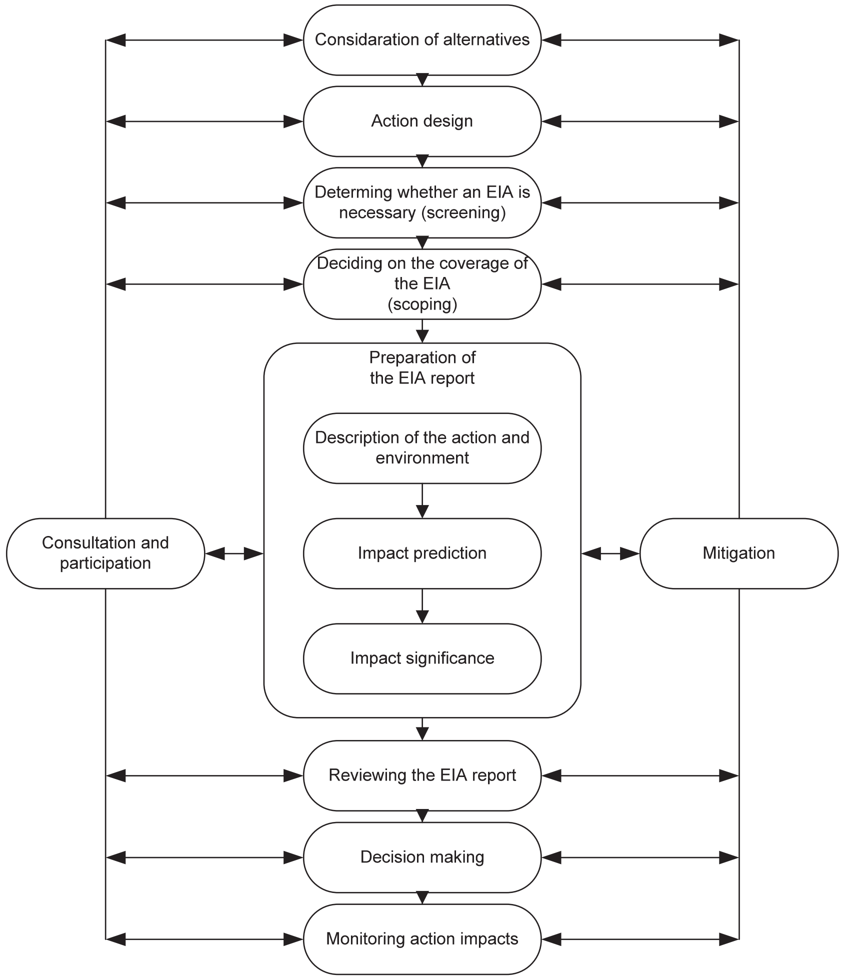

Fig. 4. The environmental impact assessment process (after Wood 2003 p.7).

"Energy industry" and "Industrial installations for the production of electricity, steam and hot water" (97/11/EEC). Usually the screening is conducted by the related authorities when a developer or company is applying for a site permit for a specific project (Kørnøv et al., 2007). If the screening process leads to the conclusion that an EIA should be carried out, the next step in the process is to decide which receptors are important to include in the EIA and at what level of details they should be assessed. This is the scoping phase. In short, the object of scoping is to identify as:

1. the appropriate time and space boundaries of the EIA study
2. the information necessary for decision-making and
3. the important issues to be considered in an EIA
4. the significant effects and factors to be studied in detail

The EU Directive defines a broad concept of the environment and points at the following groups of environmental receptors to be investigated in relation to the scoping of the assessments: human beings, fauna and flora, soil, water, air, climate and the landscape, material goods and the cultural heritage and the interaction between these factors (97/11/EEC). There are different methods for scoping. The EU Commission made guidelines for scoping (EU-Commission 2001) including general checklists or impact matrixes. Also existing environmental statements of relevance for the specific action, consultation of (environmental) authorities, NGOs, the public and consultants and experts are ways of approaching the scoping of a project. The scoping process itself can vary in scope, complexity and time taken. A method used to identify parts 3 and 4, as described above, is the Impact Matrix method, where the rows represent the environmental receptors and the columns represent the stressing activities (stressors). This method will be applied to wave energy projects. The cells of the matrix then express the potential for disturbance of the entity on the rows from the activity in the column. A matrix created following the EMEC Guidance has been realized. This summarizes all the activities and entities that may interact in case of WECs.

4. Development of an impact matrix from the EMEC EIA guidance

EMEC presented a very detailed list of information that developers must provide with respective key impact issues associated with different aspects of the device (EMEC EIA Guidance for WECs).

The proposed criteria to assess the environmental impact of wave energy converters is based on the exposure, defined as "the contact or co-occurrence of a stressor with a receptor", and the effects describing the ability of a stressor to cause adverse consequences. The criteria for the EIA can hence be presented as a combination of exposure and effects as major, moderate, minor, negligible, no impact and positive impact (Table 1). The effect on the environment of the device must be accessed for installation, operation and maintenance and decommission phases. Also, the assessment of accidental events must be taken into account (Table 2).

Based on the huge variety of existing WECs it appears obvious that the environmental effects of WECs are strongly dependent on the technology in addition to the location of the project. A summary of receptors and activities potentially involved in the deployment of WECs is reported from the EquiMar project (7FP, 2008–2011).

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Table 1
Summary of EMEC environmental impact assessment guidelines for WECs.

	Ecological effects	Socio-economic effects
Major	Degradation to the quality or availability of habitats and/or wildlife with recovery taking more than 2 years (e.g. *widespread seabed excavations, erosion*)	Change to commercial activity leading to a loss of income or opportunity beyond normal business variability/risk potential short term effect upon public health/wellbeing, real risk of injury (e.g. *loss of important fishery area, dive site, creation of seabed or floating debris*)
Moderate	Change in habitats or species beyond natural variability with recovery potentially within 2 years (e.g. *seabed excavations in a small area*)	Change to commercial activity leading to a loss of income or opportunity within normal business variability/risk Possible but unlikely effect upon public health/well-being. Remote risk of injury (e.g. *small exclusion area away from or small part of actively used areas*)
Minor	Change in habitats or species which can be seen and measured but is at same scale as natural variability (e.g. *low level noise from devices*)	Possible nuisance to other activities and some minor influence on income or opportunity. Nuisance but no harm to public (e.g. *short term congestion at harbors*)
Negligible	Change in habitats or species within scope of existing variability and difficult to measure or observe (e.g. *localized avoidance of structures by wildlife*)	Noticed by, but not a nuisance to other commercial activities. Noticed by but no effects upon the health and well-being of the public (e.g. *additional shipping at sea*)
No interaction	None	None
Positive	An enhancement of ecosystem or popular parameter (e.g. *enhance biodiversity, save in CO2 emissions*)	Benefits to local community (e.g. *contract to use local skills and expertise on a project*)

4.1. Alteration in water column patterns

Effect on currents and waves: The impacts on currents and waves are strongly dependent on technology and location of the projects with maximum effects closest to the installation and near the shoreline (Boehlert et al., 2008). Sediment Dynamics: Disturbance on sediment dynamics can occur during operation as a consequence of modification on water circulation, i.e. in current velocities or wave heights but also directly during installation or decommission. The effects which occurred during installation are usually temporary and their significance is proportional to the amount and type of bottom substrate disturbed.

4.2. Interference with benthic habitats

It occurs during installation and decommission as direct result of disturbance of anchoring of the construction vessels, digging and refilling the trenches of the power cables and installation of permanent anchors, pilings or other mooring systems. When installation is completed, disturbed areas are supposed to re-colonize by the same organisms assuming that the substrate and habitats are restored to a similar state but uncertainties from indirect impact of alteration in water circulation may be more extensive and long-lasting.

4.3. Artificial reef effects

The extensive and rapid colonization of ocean energy structures by macro-benthic communities has also been established, particularly on the device foundations installed in coastal sandy areas. It is important to determine if this change is beneficial or not for the existing local conditions. The offshore energy units should be regarded as artificial reefs and as such its design can play a critical role in species establishment. The influence of foundation surface orientation of an epibenthic colonization was also examined and observations of the use by fish and crustaceans were carried out during three years (Langhamer and Wilhelmsson, 2009).

4.4. Water quality interference

When talking about chemical effects of wave energy devices it is important to distinguish between spills as a source of chemical, low probability but high impact, versus continuous release of chemicals, for example in fouling paints. The rapid and heavy growth of marine fouling of wave energy devices is considered of particular concern. There are currently only three options to deal with marine fouling: use of antifouling coatings, in situ cleaning using high pressure jet spray by divers or remotely operated vehicles and removal of the device from the water surface for cleaning on site or onshore and reapplication of antifouling coatings. Nowadays the use of tri-butyl tin compounds on coatings has been proposed to phase out, and research has been carried out to develop less toxic antifouling coatings (Michel et al. 2007). Chemicals can move over a large area, depending on the site circulation pattern. Although this type of effects are, like others, strongly site-specific, information is needed on the toxic compounds to be used, potential amounts that could be released, responses of the biological receptors and the fate of contaminants.

4.5. Noise disturbance

Construction, operation and decommission of large mechanical structures will inevitably produce sound that may disturb or even cause physical damage to wildlife in the vicinity. It is worth to mention that for some devices the noise can be of disturbance for the local communities.

The construction phase is of particular concern if pile driving is required. The effects of pile driving operations on fish have received little attention (Hawkins, 2006), but ongoing work is being conducted by CEFAS and Cranfield University funded by COWRIE. Early work that demonstrated that the rise and decay time is very important and that a combination of rapid rise and decay (~1 ms) and a sound pressure of ~229 dB re to 1 μPa are required to be lethal (Wardle et al., 2001) and it is unlikely that piling operations will cause mortalities directly.

Noise disturbance on marine mammals: physical/physiological effects may include hearing threshold shifts and auditory damage. Behavioral responses, including fright, avoidance and changes in behavior and vocalization patterns have been observed in baleen whales, odontocetes and pinnipeds; in some cases at a range of tens or hundreds of kilometers from loud industrial noises. There are important gaps in our knowledge. For example, the characteristics of the sound signature of these new and developing technologies are poorly known and how they propagate at different ranges and depths are poorly understood. Work is needed to estimate safe levels of exposure for different marine mammal species.

Noise disturbance on fish: even if physiological damage is unlikely to be caused by construction of marine renewable energy devices, behavior may be disturbed. Many species of fish use sound both for communication and for detecting prey and predators. There could, however, be physiological damage, either temporary or permanent that

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Table 2
Example of stressors and activities in general impact matrix of WECs.

Receptor / Activity	Geology and geomorphology	Sediment distribution and movement	Hydrography and hydrographic processes	Landscape and seascape	Atmosphere	Coastal spices	Water column spices	Seabed spices	Sea bird	Commercial sea and harbor uses	Local economy	Recreation and communities	Archeology
Installation													
Mooring/foundation system													
Electric transmission infrastructure													
Vessel presence													
Operation and maintenance													
Mooring/foundation system													
Electric transmission infrastructure													
WE device presence													
Heating and cooling system													
Chemical coating													
Noise emissions													
Vibrations													
Light													
Decommission													
Vessel presence													
Mooring/foundation removal													
Electric transmission infrastructure removal													
Accidental events													
Oil spill													
Sinking													
Uncontrolled floating													
Collision													

could seriously affect subsequent survival (Blaxter and Hoss, 1979; Hoss and Blaxter, 1982).

4.6. Electromagnetic fields

As the offshore renewable energies have been developing and maturing, it became clear that the most practical way to transport the energy produced is to wire it to land through underwater cables. However, cables are also expected to link devices between themselves and possibly a common hub, depending on the park design. Therefore a significant proportion of seabeds in offshore parks is expected to have the presence of cables. The Electromagnetic Field (EMF) is a broader term that includes the Electric Field (E Field), measured in μV/m, which is usually contained within the cable insulation and the magnetic (B-Field) measured in μTeslas which is detectable on the outside of the cable. In turn, the B-field can create an Induced Electrical Field (iE Field) when conductive animals move through it. Some marine species have the ability to detect and some use EMF fields for orientation and detection of other animals (predator–prey interactions) (Murray, 1974).

The offshore wind industry in the UK has been funding important environmental work through the Collaborative Offshore Wind Research into the Environment (COWRIE) including a comprehensive study on EMF fields. The COWRIE 1.5 report concluded that an interaction between electro-sensitive species and the EMF fields caused by offshore wind cables is likely to occur. However it is very hard, with current data, to estimate if there can be a species or an ecological impact from EMF.

4.7. Interference with marine animal movements and migrations

Device dependent, especially dependent on the size of the installation. Disturbance and collision are considered the most concerned issues but also the permanent loss of habitat due to displacement (avoidance), barrier effects (e.g. fragmentation effects on units of the ecological habitat network such as breeding or feeding areas) and increased consumption of energy reserves during migration due to avoidance reactions, are to be taken into account. Construction of large industrial scale generation systems could potentially disrupt the movement patterns of marine wildlife.

4.8. Socio-economic issues: public opinion, acceptance and participation

Opinion studies conducted in Europe and United States indicate that the public is generally supportive of developing alternative energy sources specifically onshore and offshore wind energy (Coyle, 2007; Ladenburg, 2006 and Dong Energy, Vattenfall, Danish Energy Authority and the Danish Forest and Nature Agency, 2006). A review on public acceptance of offshore wind energy in Denmark and United Kingdom indicates some fairly strong trends in public opinion which can be resumed in the following topics (Michel et al., 2007):

1) The public is in favor of offshore wind energy also in the region where they reside;
2) Visual impacts appear to be the primary issue of public concern;
3) Offshore wind park development appears to gain public approval as the community is exposed to operational projects;
4) Early local input to the planning process is critical to gain public acceptance.

Although there is uncertainty on the public support for wave power, it should be reasonable to assume that similar conclusions would be obtained for wave energy installations.

From a socio-economic point of view wave energy farms may induce negative attitudes and create conflicts with other activities due to space-use conflicts such as fisheries, subsistence fishing, marine recreational activities, proximity of designated conservation areas and other alternative energy facilities.

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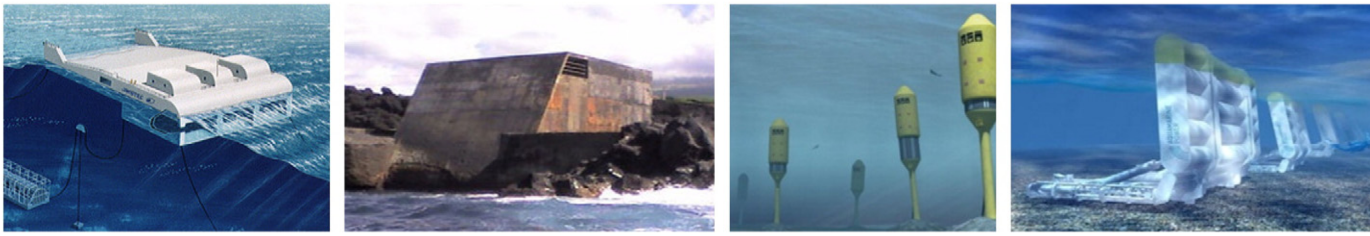

Fig. 5. From the left: Mighty Wale, Pico plant, wave Swing and Oyster.

5. Relevant parameters for EIA of wave energy converters

Different wave energy technologies have few things in common, one with the other, that can be listed as follows: electrical transmission infrastructure, electrical system, subsea conversion station/system and energy storage. Unless the device is onshore, these installations may be responsible for electromagnetic fields and for the impact on benthic habitats. Other common features are: shore connection, shore facilities and in most cases use of antifouling; the latter could be responsible for degradation of water quality. Impact assessment of possible degradation of benthonic habitats caused by laying submarine cables, disturbance of sensitive species exposed to electromagnetic fields and risk of degradation of water quality as a consequence of usage of antifouling must be completed for all the devices with exclusion only of onshore devices that do not use antifouling, such as onshore Oscillating Water Column devices (OWC) or Sea wave Slot cone Generator (SSG) (Margheritini et al., 2008).

The traditional classification of wave energy converters based on working principles (overtopping devices, point absorbers and oscillating water columns), location (shoreline, near shore, and offshore) or orientation to the main wave direction (terminators, attenuators, and buoys) fails to address the relevant parameters related to environmental issues and can be misleading if used to assess the environmental impact of the different technologies. For example, two oscillating water columns may use different stability elements: the Mighty Whale (Japan 1998, Fig. 5) is a floating structure moored to the sea bed while the Pico plant (Pico, Azores 1999, Fig. 5) is an onshore device with gravity foundation. Pelamis and Archimides Wave Swing (Fig. 5) are both designed to be installed in deep waters but while the first one is emerging from the surface, the second is several meters submerged. In the same way, the Oyster (Fig. 5) and Wave Dragon are both terminators but the first one is a submerged wave activated body while the second is a floating overtopping device.

In the variety of locations, shapes, sizes and working principles that the wave energy sector presents at this stage it is difficult to identify common guidelines for the different technologies. Nevertheless it is possible to clearly recognize five parameters relevant for the EIA of WECs. These parameters are described in the following paragraphs. The assessment tables presented in the next paragraphs are to be considered a simplification and conservative with respect to the final impact assessment. The tables should be used by developers, authorities and stakeholders as primary indication or fast consultation on relevant issues for the EIA of a specific technology once the basic information on the installation is known.

6. *D*: distance from shore

It is possible to classify the devices by location (Fig. 6):

I. Onshore devices. All the devices installed on land, in harbors or any device installed within the swash and surf zone.
II. Intermediate water devices. All the devices installed further than the surfzone or in any case within 5 km from land.
III. Offshore devices. All the devices installed further than 5 km from land.

The *D* parameter has direct consequences on the following receptors:

- Local communities (visual impact and recreational use of the sea).
- Coastal processes such as current velocities, wave heights, sediment dynamics and coastal species.
- Navigation and fishery.

It is possible to state that the major impacts for local communities occur for onshore devices as they are directly exposed to the different

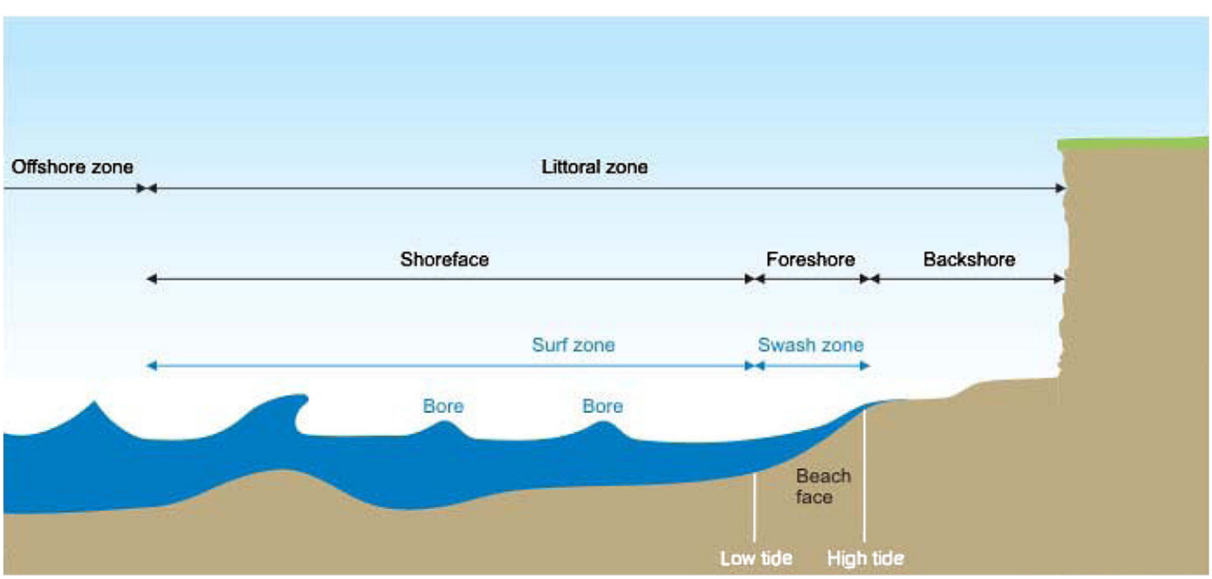

Fig. 6. Illustration from the Division of Nearshore Research (http://lighthouse.tamucc.edu/Main/HomePage).

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Table 3
Assessment table based on distance from shore.

D parameter	Local communities	Coastal processes and coastal spices	Navigation and fishery
Onshore devices	Major	Major	Nil
Intermediate water devices	Moderate	Moderate	Major
Offshore devices	Negligible	Minor	Major

phases of the device lifetime. Major impacts related to coastal processes are also expected to occur for near shore devices (Boehlert et al., 2008) while the impact on navigation is nil. In the case of intermediate water devices, moderate impact can be expected for local communities and costal processes, while major impact can be expected for navigation. This is assuming any kind of interaction of the local communities with the device area. Nevertheless, intermediate waters tend to be busy with recreational and economical activities and because of this, major impacts cannot be excluded. For offshore devices negligible impacts are expected on local communities, while impacts on navigation can be major. The evaluation of the impact on coastal process must be further investigated, even though it seems reasonable to consider a minor-negligible impact as the majority of the available wave energy at a deep water offshore site can be lost naturally through frictional effects with the sea bed before it gets to the shoreline. Table 3 summarizes the above statements based on the exposure method for all the phases during the lifetime of the installation (installation, operation, and decommission).

7. *S*: stability elements

It has been stated that most impacts are associated with establishment and decommission phase of WECs. Considerable impact can be attributed to the installation of stability elements. Four elements can provide stability to WECs depending on the device. For floating devices, anchors/moorings that allow different degrees of movements are used. Mooring lines can be

I. simple mooring lines,
II. complex mooring lines.

In case of wave energy parks they can form intriguing underwater patterns (Fig. 7). Simple moorings are here considered the ones that see no more than 3 lines to and from the single device.

For bottom supported structures,

III. piles,
IV. gravity foundations.

The *S* parameter has direct influence in the following receptors:

- Benthonic habitats
- Geology
- Archaeology
- Water column species

Piling represents inevitably the most intrusive practice, considering also the noise during the installation phase and the permanent impact on benthonic habitats, geology and possibly archaeology. Here impact on water column species is considered to be limited to the installation phase and therefore minor.

Moorings are in general the less impacting practice presenting a negligible impact on geology but in case of complex mooring or wave farms and large scale installations the mooring lines may impact the water column species and even navigation. All the other impacts are considered to be minor and eventually temporary and related to installation and decommission.

Gravity foundations are considered to have moderate impact on the benthonic habitats and possibly archaeology, estimating potential recovery within 2 years from installation, while negligible impact is expected to occur on water column species. Moderate impact on geology has here been attributed to this practice as less intrusive than piling, but usually interesting in a bigger area than moorings or anchors. Table 4 presents the assessment of the technologies by categorization of the *S* parameter.

8. *z*/*d*: obstruction to water column

d being the water depth at location and *z* the draft of the wave energy device if floating or the extension from the sea bottom if bottom based (Folley et al. 2007), the $|z/d|$ parameter expresses the relative

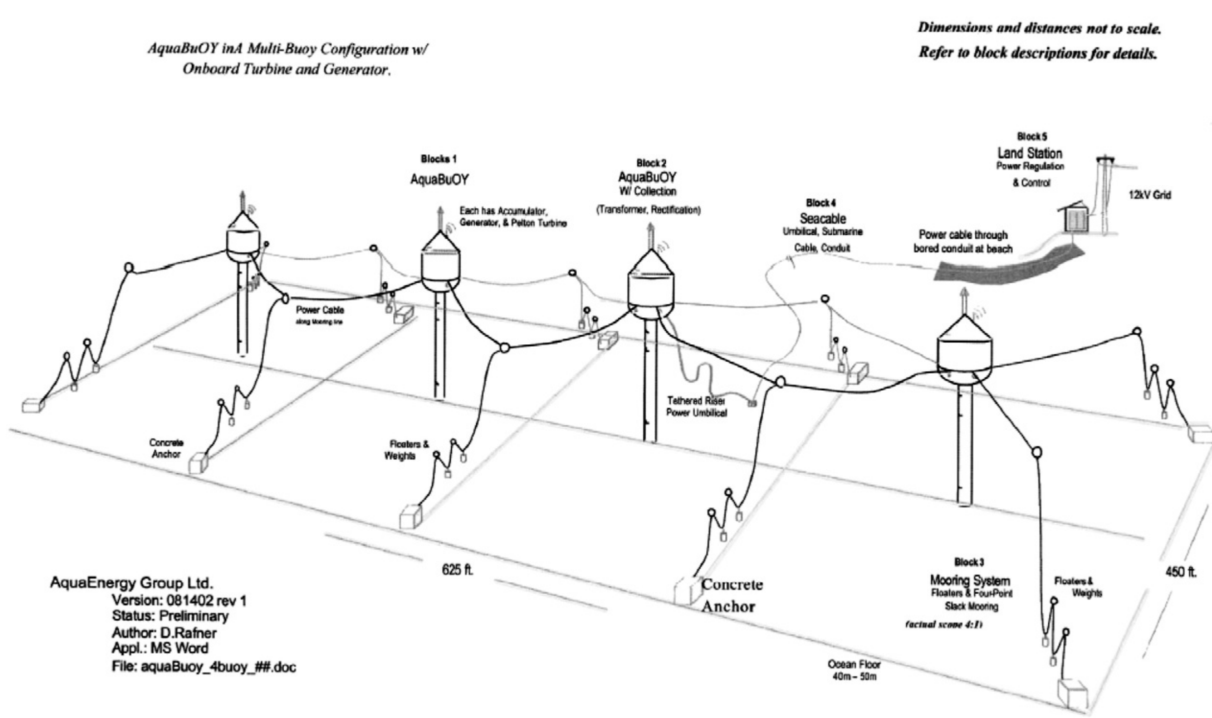

Fig. 7. AquaEnergy Group Ltd. AquaBuOY multi-buoy configuration, dimensions and distances not in scale.

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Table 4
Assessment table based on the type of stabilizing element.

S parameter	Benthonic habitats	Geology	Archaeology	Water column species
Simple moorings	Minor	Negligible	Minor	Minor
Complex moorings	Minor	Negligible	Minor	Moderate
Gravity foundations	Moderate	Moderate	Moderate	Negligible
Piles	Major	Major	Major	Minor

obstruction of the water column (vertical) by the device. z is positive for floating devices and negative for bottom based devices (Fig. 8). The absolute value of the obstruction parameter is included between 0 and 1, assuming it is never equal to 0 and equal to 1 for total obstruction of the water column. The water column being the habitat of most sea species as well as the area for propagation of currents and wave, and the presence of wave energy devices being a possible degradation of the natural conditions of this environment, it seems reasonable to introduce a factor that alerts to the restrictions that these receptors may run into.

This parameter is also directly related to the operation phase of the devices more than any other phase.

Depending on the z/d parameter, the WECs can be classified as follows:

I. Little obstructive, for $0<|z/d|\leq 0.1$
II. Obstructive, for $0.1<|z/d|\leq 0.3$
III. Very obstructive, for $|z/d|>0.3$

The z/d parameter has direct consequences on the following receptors:

- Water column species
- Costal processes
- Navigation and fishery
- Local communities (recreational activities)

It must be noticed that it is difficult to define the obstruction parameter for onshore devices so that we will assume that for those devices $z/d<0.1$. This seems reasonable, as onshore devices have relevant impact only on the above receptors listed also for the D parameter. It is clear that currents and waves propagate with different mechanisms at different depths and that it is relevant if the partial obstruction interests the lower or higher part of the water column. The impact on the environment with relation to the higher or lower obstruction of the water column is anticipated in the assessment table.

The major impacts occur for very obstructive devices. Water column species, from marine mammals to fish are likely to be seriously affected by the presence of the devices, especially considering parks installations. Behaviors such as avoidance or permanent loss of habitat are of major concern. Considering that such installations are suitable mainly for offshore locations, the impact on coastal processes and local communities is considered moderate, but major for fishery and navigation.

For obstructive devices, also considered suitable only for offshore installations, the effect on local communities is also moderate but minor on coastal processes, taking into account a smaller water column obstruction. The expected effect on navigation and fishery is moderate or major for bottom based and floating structures respectively.

For bottom based little obstructive devices, the impact on the listed sensitive receptors is minor or negligible. For floating little obstructive devices, impact on navigation is major but on coastal processes, water column species and local communities, impact is minor or negligible. The last statements for little obstructive devices are valid for offshore devices. The results of the classification on the assessment are presented in Table 5.

9. *w*/*a*: obstruction to sea surface

It is important to remember that the final goal of the sector is to realize wave energy farms and extract bigger quantities of energy. In this prospective the EIA must take into account impacts related to its extension, like conflict of utilization of the sea resources with other sectors, the hydrodynamic processes, sediment distribution and movement, routes of large sea species, such as mammal.

z/d being a parameter that refers to two dimensional conditions, it seems important to mention the introduction of another parameter relevant for wave energy farms involving installation of a number of devices. a being the total area occupied by the WE farm and w the sum of the areas (above view) of the structures, the parameter w/a expresses the horizontal obstruction of wave farm installations and implements the z/d parameter. This parameter is related only to offshore or intermediate devices, $w=0$ being for onshore devices. The parameter w/a is expected to have potential influence on the following receptors:

- Navigation and fishery
- Interference with marine animal movements
- Coastal processes
- Local communities

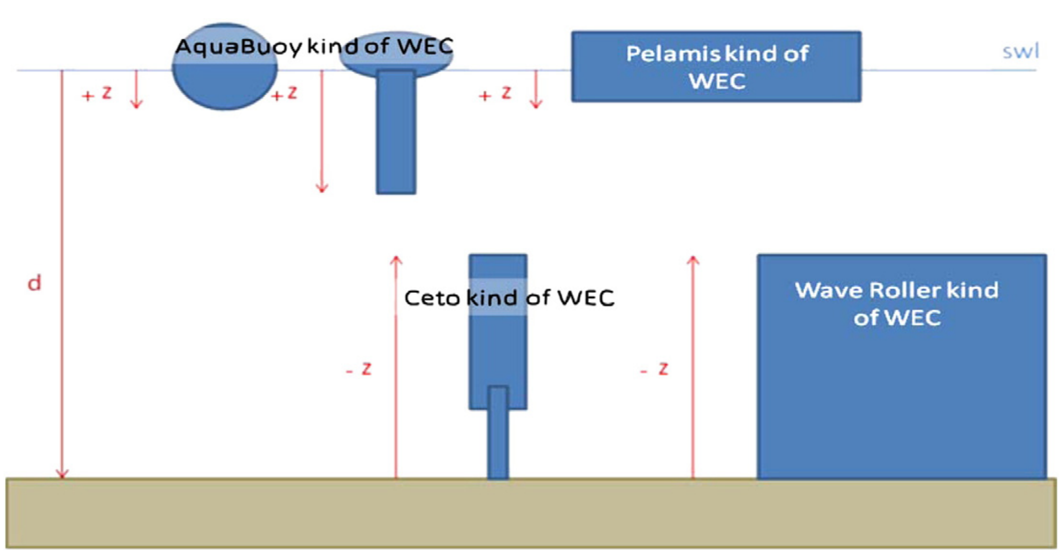

Fig. 8. Definition sketch for z for different kind of devices.

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Table 5
Assessment table based on the obstruction parameter.

z/*d* parameter	Water column spices	Navigation and fishery	Coastal processes local	Local communities
Little obstructive $z>0$	Minor	Major *	Minor **	Negligible**
Little obstructive $z<0$	Minor	Minor	Minor	Negligible
Obstructive $z>0$	Moderate	Major	Minor	Moderate
Obstructive $z<0$	Moderate	Moderate	Minor	Moderate
Very obstructive $z>0$	Major	Major	Moderate	Moderate
Very obstructive $z<0$	Major	Major	Moderate	Moderate

*No interaction for onshore devices. **Major for onshore devices.

10. *P*: power takeoff system

The power take off systems in wave energy involve moving parts, either directly activated by wave motion (hydraulic ram, elastomeric hose pump and air turbines) or by wave energy potential (hydroelectric turbines) and a system to convert the mechanical energy into electricity (generators). The stage of conversion is obviously technology dependent and so is their expected impact on receptors; nevertheless the power take off system also allow some device classification (Drew et al., 2009).

The main disturbance to the environment, derived by the power take off of the devices, is caused by noise and accidental oil spillage.

In first attempt it is possible to address these issues to specific power takeoffs. Hydraulic ram, hydroelectric turbines and air turbines are noisy and especially air turbines can be of high disturbance for local communities. Hydraulic ram and elastomeric hose pump system may generate oil spillage as a consequence of malfunctioning. The underwater noise and the water quality interference being subjected to large uncertainties, no summarizing table of assessment of expected environmental impacts will be presented, but it is important to address the above mentioned issues and relevant baseline studies are conducted supported by appropriate monitoring programs.

11. Validation of assessment method

As already mentioned, because of the early stage of wave energy devices, not many technologies underwent a full EIA. In the following section the EIA of AquaBuOY and Wave Dragon is used to validate the assessment method presented in this paper. The validation is summarized and presented in Tables 6 and 7 (Weinstein et al., 2007 and Russell et al., 2007).

It emerges that the assessment method succeeds in addressing the relevant parameters for the environmental impact of WECs. Also the classification of devices depending on the introduced parameters correctly addresses the impact of the specific devices. The main discrepancies regard the minor and negligible impact on water column species and coastal processes claimed by AquaBuOY developer, while based on the assessment of this paper major and moderate impacts are expected. This may be due to the small installation that was assessed in the EIA report (4 devices) while the assessment in this article is made keeping the large farm installation in mind. The same goes for the expected impact on navigation of the Wave Dragon device.

12. Suggestion for the EIA process

No clear indication from the Authorities exists on what to provide for the EIA of wave energy devices, as for them it is difficult to spot common approaches to such an enormous variety of technologies. For this reason the risk is that WE companies are dragged into a time consuming and too expensive process for the EIA and Consents process that may kill the project and consequently the technology. The case of Wave Dragon is eloquent: the developer had to take care of communication to the public, Statutory Consultees and Consenting Bodies. The process has been prohibitively slow. Coordination of the interlocutor is required.

As argued in the introduction, at European level there is not frame or body in place to handle the applications for wave energy deployment. This increases the risk that conflicts arise from the communication and thereby the risk that there will be a lack of coordination among developers, consenting bodies, authorities and

Table 6
Comparative analysis between the assessment of the AquaBuoY installation in Oregon derived from the classification presented in this paper (expected impacts) and the assessment presented by the developer (stated impacts).

AquaBuOY			
Classification		Expected impacts	Stated impacts
D: offshore device	☺	1. Negligible impact on local communities. 2. Minor impact on coastal processes. 3. Major impact on navigation.	1. Development of shore station represents a permanent visual impact of the project but because of dimensions and distance from shore of the buoys this impact will not be significant. 2. Negligible impact on coastal processes. 3. Fishing and navigation exclusion zone needs to be established.
S: complex mooring	☺	1. Minor impact on benthonic habitats. 2. Negligible impact on Geology. 3. Minor impact on archaeology. 4. Moderate impact in water column spices.	1. Negligible impact on benthonic spices. 2. No substantial changes in the bathymetry or temporary for deployment phase. 3.- 4. It is unknown if the mooring system may represent a point of entanglement for marine life especially for farms.
z/*d*: very obstructive, $z>0$	☺	1. Major impact on water column spices. 2. Major impact on navigation and fishery. 3. Moderate impact on costal processes. 4. Moderate impact on local communities.	1. Minor impact on water column spices. 2. Fishing and navigation exclusion zone needs to be established. 3. Negligible impact on costal processes. 4. No detrimental impact on recreational activities.
P: elastomeric hose pump system	☺	1. May generate oil spillage in case of malfunctioning.	1. The system does not use hazardous materials. As such project operation will not affect water quality.

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Table 7
Comparative analysis between the assessment of the Wave Dragon installation in Wales derived from the classification presented in this paper (expected impacts) and the assessment presented by the developer (stated impacts).

Wave dragon			
Classification		Expected impacts	Stated impacts
D: intermediate water device	☺	1. Moderate impact on local communities. 2. Moderate impact on coastal processes. 3. Major impact on navigation.	1. Moderate. 2. Minor because of short term effects. 3. Negligible.
S: complex mooring	☺	1. Minor impact on benthonic habitats. 2. Negligible impact on Geology. 3. Minor impact on archeology. 4. Moderate impact in water column spices.	1. Minor to moderate. 2. Not issue of concern. 3. Negligible effect. 4. Minor to moderate impact.
z/*d*: little obstructive, z>0	☺	1. Minor impact on benthonic habitats. 2. Negligible impact on Geology. 3. Minor impact on archeology. 4. Moderate impact in water column spices.	1. Minor to moderate. 2. Not issue of concern. 3. Negligible effect. 4. Minor to moderate impact.
z/*d*: little obstructive, *z*>0	☺	1. Minor impact on water column spices. 2. Major impact on navigation and fishery 3. Minor impact on costal processes. 4. Negligible impact on local communities.	1. Minor impact. 2. Minimal. 4. Minor and short term effects. 3. Negligible.
P: hydroelectric turbines	☺	1. Noise.	1. Minor significance.

statutory consultees. On the other hand, the presence of such a body in Denmark, represented by the Energy Agency, demonstrated to be beneficial to the process. It is then suggested that not the developer but a competent governmental body is in charge of the coordination among the consulters (Fig. 9). Companies in the market are relatively small, and so are the capitals available to run the business, relying on private investors, and funds from different R&D projects. Many, if not all the companies behind the different technologies present the same history: after 5–10 years of research and development, pilot plants and prototypes are being constructed. At this point the developers had spent at least 15 mill Euro in average (Kofoed et al., 2008).

13. Conclusions

Selection of relevant parameters for EIA of wave energy converters has been made. Those are:

1. *D* parameter, indicating the distance of the installation from shore.
2. *S* parameter, indicating the kind of element used for stabilizing the device.
3. *z*/*d* parameter, indicating the relative water column obstruction (vertical) caused by the presence of the device.
4. *w*/*a* parameter, indicating the relative horizontal obstruction of a wave energy farm.
5. *P* parameter, indicating the kind of power takeoff utilized in the installation.

Classifications of wave energy devices have been made for each parameter. It is possible to conduct the EIA of WECs by the presented classification. The impact assessment on receptors that are present in more than one table must be carefully considered as a result of interaction of different relevant parameters.

All the relevant receptors involved in WE are represented in the impact assessment tables and the expected impacts are quantified based on the classification. Beneficial impacts regard artificial reef effects, save in CO_2 emissions or improvement of local economy or local community life. For devices built on breakwater the improvement of the civil structure and its functions are also a beneficial impact. Those effects have not been listed as they are very project dependent or subjected to uncertainties, (see, for example, artificial reef effect paragraph).

Suggestion for the creation of a management body between the developers and the authorities responsible for the consent of wave energy deployment has been made arguing the relative benefits based on the Danish case.

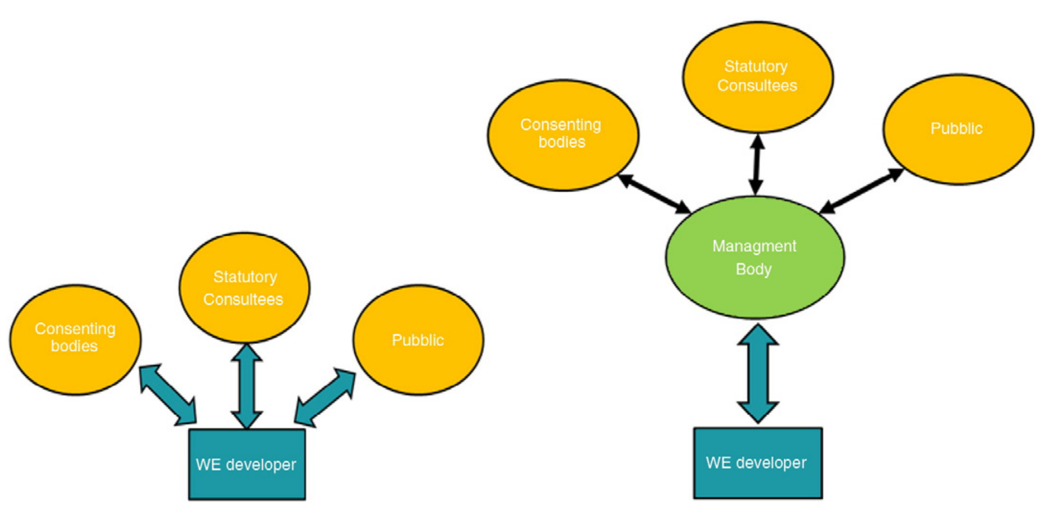

Fig. 9. Schematics of the existing (left) and suggested (right) structures for managing the applications for deployment of WECs.

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It is demonstrated that the above listed tools can improve the EIA process for WECs.

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