

European Thematic Network on Wave Energy

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Environmental Impact

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1 Introduction

1.1 The Wave Energy Network

This report presents results from Work Package 3.3 of the European Thematic Network on Wave Energy.

The Network has been funded by the European Commission with the purpose of coordinating collaboration between European countries in the wave energy sector and was launched in 2000 with 14 partners representing universities, consultancies and developers from 10 European countries.

The tasks address scientific, technical and economic aspects of wave energy conversion, and the work has been divided into seven main tasks, each with its own subtasks, objectives and deliverables:

Work Package 1 – Network Co-ordination & Support

Work Package 2 – Co-operation with the Power Industry

Work Package 3 – Social, Planning and Environmental Impact

Work Package 4 – Financing and Economic Issues

Work Package 5 – R&D Activities on Wave Energy Devices

Work Package 6 – Generic Technology Review and Support

Work package 7 – Promotion of Wave Energy

For further information regarding the Network, please visit its homepage: www.wave-energy.net.

1.2 Work Package 3.3 – Environmental Impacts

The objectives of Work Package 3.3 have been to identify the environmental impact from the expanded development of wave and tidal energy schemes and to create recommendations for their development. Furthermore the objectives have been to collate information regarding the potential impact that the environment could have on wave energy

devices (e.g. growth of mussels, corrosion). Finally, environmental benefits in terms of reduced emissions of pollutants should be determined.

The current draft report covers these objectives based on responses from network members and studies of selected references.

As can be seen from the list of references (p. 38) much information has been found from studies of offshore *wind* energy, and the information in this draft report is in many cases based on a similar study from the EU Concerted Action on Wave Energy in Europe, dealing with “Environmental Impacts” [i].

In addition, Tom Thorpe’s reports (AEA Technology) on Work Package 3 [ii] and Work Package 4 [iii] of the Wave Energy Network have been very useful and many passages have been included, and Pat Mc Cullen (ESB International) has improved the report with his comments that have been included in this final edition.

Finally, results from the environmental scoping study for the Marine Energy Test Centre on Orkney have been included as Appendix 2, presenting a valuable overview of potential impacts during construction and operation of the test centre.

1.3 Background

In November 2000 a questionnaire was distributed to the network members, but only 4 members responded. These responses are attached to this report in Section 8, below.

As to why the response was so limited, some features of wave energy might give a partial explanation.

Firstly, it is not really meaningful to speak of wave energy in singular, as wave energy is currently pursuing a vast number of widely different technology trails, which means that the assessment of environmental impact, apart from being location dependent, to a large degree can be expected to be technology dependent as well. This can be seen from the responses received and is also illustrated in the Environmental Scoping for the Orkney Marine Energy Test Centre, where it is emphasized that “the full EIA required to support licence applications for the establishment of the test facilities will not necessarily be able to

predict all the specific impacts relating to each separate device that may be tested. It is therefore recommended that an ‘environmental approval procedure’ be developed, which will ensure that prior to deployment of each device, an assessment of device specific environmental impacts be undertaken and management or mitigation measures implemented where necessary.”[iv]

Secondly, there are only very limited practical deployment experiences available. Even within offshore wind power, a similar study [i] concluded that the available knowledge on a number of environmental impacts was sparse. For wave power it appears to be almost non-existent, and estimations of the environmental and social perceptions will largely have to be based on experiences from comparable industries.

On this background we have decided to utilise the experiences from offshore wind power. Obviously the environmental impacts may in some cases be quite different for wave power compared to wind power, and therefore inputs from other network members have been included with reference to specific device types. Nevertheless, we hope that this report may shed some light on the issues involved, and also prove as a good recommendation for the potential environmental barriers facing wave and tidal energy in the future.

We have chosen to define wave energy as multi-unit applications of a size rendering the projects within the scope of the EC Council Directive 85/337/EEC [v] amended in Directive 97/11/EC [vi], stating the minimum requirements to Environmental Impact Assessment for large construction projects. In the near future wave power appears to be bound to single-unit plants, which are likely to be too small for EIA requirements to apply. Nevertheless, excepting island applications, the future of wave power must be in projects of a size comparable to offshore wind if large-scale commercial penetration is to be achieved, and for these projects an EIA will be required.

Finally we have limited our study in the sense that only direct potential impacts from wave energy schemes offshore, near-shore and onshore have been included in this report. This means that additional expected impacts from e.g. necessary reinforcement of the grid onshore, like overhead power lines, are not presented.

2 Environmental Impact.

2.1 *Environmental Impact Assessment*

In theory, the siting of wave energy schemes can potentially avoid many of the perceived environmental impacts that have arisen with the rapid expansion of some on- and offshore technologies. However, with only a few schemes having been built to date, there is little evidence to substantiate this view, and offshore developments do generate additional impacts associated with the marine environment. If wave energy is to fulfil its potential as part of an integrated energy system, then a full and accurate assessment of its environmental benefits and burdens needs to be undertaken [ii].

Within the EU, an Environmental Impact Assessment¹ (EIA) must be carried out before public approval for larger projects can be granted. The minimum requirements of the EIA are specified in the EC Council Directive 85/337/EEC [v] amended in Directive 97/11/EC [vi].

The directives require that private and public projects, which are likely to have significant effects on the environment, must be subject to an assessment of their potential effects on the environment before they can be allowed to proceed.

An EIA shall identify, describe and assess the direct and indirect effects of a project on the following factors:

- human beings, fauna and flora
- soil, water, air, climate and the landscape
- material assets and the cultural heritage
- the interaction between these factors mentioned

The directives lay down rules for the EIA procedure, which includes a requirement for public participation: the results are to be made public, and the views of the public taken into

¹ The term “Environmental Impact Assessment” (EIA) covers the procedure that fulfils the assessment requirements of Directive 97/11/EC. In many countries, e.g. in the UK, the environmental information

consideration in the consenting procedure (for more information regarding this subject, please refer to the section on Public Acceptance).

As is the case for wind energy the individual member states shall determine, either through a case-by-case examination or through thresholds or criteria set by the member state, whether wave power projects shall be made subject to an assessment. In this way member states may exempt a specific project from the provisions in the directives.

2.2 Strategic Environmental Assessment

The SEA Directive (2001/42/EC 1, [vii]), which must be transposed to national laws by July 2004, and which has already been used by the UK government regarding 3 strategic offshore wind development sites [ix], supplements the environmental impact assessment system on the assessment of the effects of certain plans and programmes on the environment.

As this Directive is quite new and as the SEA report and statement will assist developers to prepare cost-effective EIAs for individual offshore renewable projects, it is presented in details below:

The objective of the Directive is to help integrate the environment into the preparation and adoption of plans and programmes liable to have significant effects on the environment, by subjecting them to a prior environmental assessment at the planning stage.

The Directive applies to plans and programmes prepared and adopted by a competent authority or prepared by a competent authority; it also applies to amendments to such plans and programmes. Other plans and programmes which set the framework for future development consent of projects will be subject to environmental assessment if an examination shows that they are liable to have significant effects on the environment.

Before the adoption of a plan or programme or its submission to the legislative process, the competent authority of the relevant Member State is required to carry out an environmental assessment and, after consulting the competent environmental authorities, to prepare an environmental report setting out:

- the contents of the plan or programme and its main objectives;

provided by the developer is presented in the form of an Environmental Impact Statement (EIS), which may

- the environmental characteristics of any area likely to be significantly affected by the plan or programme;
- any existing environmental problems which are relevant to the plan or programme;
- the national, Community or international environmental protection objectives which are relevant to the plan or programme in question;
- the likely environmental effects of implementing the plan or programme;
- the measures envisaged to prevent, reduce and offset any significant adverse effects on the environment;
- the envisaged monitoring measures.

The report must also include a non-technical summary of this information.

The draft plan or programme and the environmental report must then be made available to the authorities responsible for the environment and to the public, who should be able to express their views before the plan or programme is adopted or submitted to the legislative process. Furthermore, neighbour countries must be informed and consulted if it is considered that the plan or programme is liable to have transboundary environmental effects.

The environmental report, the opinions expressed by the relevant authorities and the public and the results of any transboundary consultations must be taken into account by the competent authority during the preparation of the plan or programme and before it is adopted.

When a plan or programme is adopted, the Member State responsible will inform all of the parties concerned regarding the plan or programme as adopted including a statement summarising how environmental considerations have been integrated, the environmental report, the opinions and the results of consultations, the reasons for choosing the plan or programme as adopted and the planned monitoring measures. ([viii], for more information regarding the adoption of the SEA Directive in UK, see [ix])

General conclusions:

then be described as the final product of an EIA. In this report only the term EIA will be used.

Developers of wave power farms must carry out an EIA on the specific project, with the purpose of providing information about the possible impacts on the environment from the time of installation until the dismantling of the farm.

The EIAs from individual wave energy projects will contain much valuable information regarding the effects from wave energy on the environment, but due to the fact that the experiences with wave power are currently very small, the literature on environmental impacts is lacking. However the experiences from offshore wind can be expected to produce relevant references for a number of the potentially significant impacts, which also apply to some of the wave power plants.

The SEA directive, requiring strategic environmental assessments and consultations at an early stage of certain plans and programmes, may assist ocean energy developers in carrying out the EIA.

2.3 Biological Impacts.

Responses from a questionnaire distributed in the Network indicate that visual and noise impacts from shore based devices are likely to be the most potential environmental impact. A number of other potential impacts were identified, but in general they were concluded to be technically solvable, simply adding to the costs of the projects. Whether or not the above conclusion is the result of the main operational experiences with shore bound devices is hard to judge, but it appears to be a fact that a precise evaluation of the environmental impacts associated with different types of wave energy converters cannot be performed with the current low level of operational experiences available. However, the lessons from offshore wind power clearly indicate that the documentation of environmental impacts will be an important issue for wave power as well, when the technologies reach large-scale commercial development.

In “The Concerted Action on Offshore Wind Energy in Europe” [1] the following biological issues were indicated as being potentially problematic:

- Collision of birds with turbines
- Ousting off birds from their traditional feeding/roosting grounds
- Unknown effect of low frequency noise emissions on fish life and sea mammals
- Impacts on fish larvae
- Disturbances of seabed and fauna during construction and operation.

Whereas birds are undoubtedly the biological impact perceived most important for wind power, fish, sea mammals, and potential pollution associated with ship collisions are probably the impacts that will attract the most interest for wave power.

Only a few case studies of the impact on fish, birds, sea mammals and flora have been carried out in connection with the offshore wind farms already established, either as part of the Environmental Impact Assessments or as individual studies. This knowledge has not yet been compiled in a systematic manner, which results in the fact that the biological impacts and mechanisms involved are still associated with significant uncertainties.

The experience from studies on environmental aspects from offshore wind farms in Denmark and UK are collated on a national level:

- in Denmark the monitoring studies are being closely followed by an international expert group, and reports in English from these studies can be found on the internet, e.g.: www.hornsrev.dk and www.nystedhavmoellepark.dk
- the British studies are administered by a steering group known as COWRIE (Collaborative Offshore Wind Research into the Environment), including members from the industry, authorities and NGOs. The group is chaired by the Crown Estate and reports will be available from: www.offshorewindfarms.co.uk.

2.3.1 Sea Mammals

The effect from wave energy converters on sea mammals is considered relevant but not prohibitive by the wave net respondents.

An assessment of the local mammal population, e.g. seals, whales and dolphins, is however needed in the EIA, and if the specific site is situated in the vicinity of colonies (e.g. grey-seal) this question may become crucial in relation to the approval of the project. This was the case for the Swedish Bockstigen offshore wind power project, where a Before-After-Impact-Study was carried out before construction, during construction and two years after start of operation, showing that wind turbines did not affect the seals in any respect [x].

At the moment a Danish project is underway by SEAS, where the movements of radio-tagged seals are followed as part of a larger seal surveillance program in relation to the

construction of the Nysted/Rødsand wind farm where the population of seals is significant. One of the preliminary conclusions from this study is that seals are very mobile, and move over great distances in their ordinary lives [xi]. This means that disturbances during the construction phase can be expected to be only temporary, as seals will move back when their habitat is restored to normal conditions.

An issue which was deemed important for offshore wind power, and is likely to be so for wave energy as well, is low frequency underwater sound or electromagnetic field effects on cetaceans and seals.

Expected impacts:

- loss of habitat due to disturbance through noise emission from wave energy devices and from construction and maintenance vessels (or helicopters). The disturbance during the construction phase is expected to be only temporary, whereas disturbance from wave energy devices and maintenance vessels might have long-term effects. Although some disturbance of feeding patterns and social behaviour is possible, overall, these effects are likely to be insignificant; evidence from drilling activity for a geological survey at a offshore wind farm site in Sweden did not appear to disturb seal colonies 2 km away [xii].
For the Nysted/Rødsand Offshore Wind Farm it has been estimated, based on measurements from the Vindeby and Bockstigen offshore farms, that the submarine noise will at most be audible to marine mammals at a distance of up to 20 metres from the foundations [xiii].
The noise impact can be expected to vary considerably between different wave energy device types.
- vibrations in the infra sound area that could affect the animals' sonar system, making it more difficult to retrieve food. (On the other hand, when fishery - with trawling equipment - is restricted in the vicinity of the wave power plants, feeding possibilities might improve.)
- potential influence from low frequency sound emission and electromagnetic fields in cables. (However, calculations of magnetic fields from submarine cables dug down one metre under the seabed show that the magnetic field on the seabed above the cable will be smaller than the geomagnetic field.² Therefore no impacts are expected if the cables are properly buried.)

² The geomagnetic field is the constant magnetic field surrounding the earth

- Finally, there may be some risks to marine mammals arising from impacts from the operation of some schemes (e.g. hitting the blades of a turbine). However, most mammals do avoid dangerous moving underwater objects (e.g. ship hulls and propellers) [ii].

General conclusions:

- More studies are needed to evaluate the effect from noise and magnetic fields, and the visual impact on mammals.
- Before-After-Impact-Studies, including seismic surveys and monitoring of underwater noise levels, and studies on noise reception of sea mammals must be carried out where large projects are contemplated.
- When planning commercial wave energy projects, specific protection areas for sea mammals must be avoided,³ and duration and quantity of noise must be minimised during construction (especially at sensitive time periods) and operation. Submarine cables must be properly buried or shielded.

2.3.2 Fish

Only a few studies deal with the subject of the impact from offshore wind farms on fish, as the existing wind farms are erected in areas with no or very few fish. No studies have, to our knowledge, yet been performed in relation to wave power.

A Swedish study of the first offshore wind power project in the world outside Nordersund, Blekinge (Sweden), showed that there was no negative impact on fish from the 220 kW turbine – the fish population within 400 m from the turbine increased, however the fishermen caught less fish when the turbine was in operation, leading to a conflict of interest [xiv].

Expected impacts:

- Some positive effects on fish stocks can be expected to the extent that wave energy farms prohibit fishing with trawling equipment while improving habitat as breeding and resting grounds for fishery species. The exclusion of fishing will in some cases

³ For further information, please see Report on Work Package 2.2: “Conflicts of Interest”.

lead to conflicts, expectedly short term, with the fishing industry, see “Conflicts of interest”, draft report on Work Package 3.3.

- Foundations tend to serve as artificial reefs within the local ecosystem. Evidence indicates that this reefing effect does not produce a significant increase in fish production but serves to aggregate fish more densely [xv]. This is backed up by operational experience - studies at the Tunø Knob wind-farm have shown codfish numbers have increased around foundations [xvi].

Potentially negative effects are:

- effects of noise emission and vibrations on fish life both in the construction phase and after installation, which may lead to loss of habitat. Maintenance vessels may also have a negative impact, but compared to the “usual” impact from fishing boats and other ships this can be considered as a minor impact.
- Changes in sedimentation and turbidity⁴ of water may impact on fish and fish larvae. This is predominantly a temporary effect during construction. Evidence from fish surveys before and after construction for Danish offshore wind farms have not shown any reduction in fish species [xvi]. However, these effects may be more important in fish breeding areas or shallow areas, which juvenile fish tend to inhabit and some care may be needed in these areas, such as avoiding breeding seasons. For cables, some guide to the potential level of impact can be taken from the laying of natural gas pipelines. Laying of such pipelines causes a disturbance corridor of around 5 metres [xvii], with effects from suspended sediment levels affecting organisms of to 50 metres away. However this is regarded as a temporary impact as the area rapidly re-colonises following completion. (It should be borne in mind that at some locations the effect of naturally occurring storm events may routinely outweigh these temporary impacts).
- electric and magnetic fields around the cables may influence fish and fish breeding, but no research results have yet been found published on these issues, although seabed cables have existed during the last 80 years. This may be seen as an indication of the fact that sea cables have only little or no impact on marine life, but information on the impacts, if measurable, from the many existing seabed cables can be gained from monitoring studies. The cables connecting wave energy converters, substations and the grid will tend to be buried to avoid potential damage, for example from anchors or fishing activity [ii].

⁴ Turbidity is the degree of cloudiness or opacity of the seawater due to disturbed sediment.

General conclusions

As the effect of noise, vibrations and magnetic fields on fish is relatively unknown, studies and surveys may be needed before, during and after construction. Projects should seek to minimise the effect of structures and cabling on existing stocks, their food sources and spawning activity, e.g. by shielding and burying cables appropriately in order to minimise electro-magnetic impacts on fish.

2.3.3 Seabed and Benthos

In general the disturbance of seabed, and thereby of benthic communities,⁵ will primarily take place during the construction (and dismantling) phase, but for most types of wave and tidal energy converters this will be limited in scope and period, e.g. deployment of mooring systems, sinking or submersion of bottom mounted plant if used, cable laying etc. This means that for most devices the potential impacts seem likely to be significantly less than for an offshore wind power farm of similar size.

All offshore construction activity will affect the transparency of water and the local bottom sediment. Drilling, trenching, pile-driving or dredging operations during foundation placement and cable-laying will lead to increased loading of suspended solids, which can affect benthic organisms. Similarly, the reinstatement of the trench around the cable or foundation base results in burial of existing habitats for a few metres either side of the structure. Benthic organisms are particularly vulnerable, though impacts are small [ii].

Expected impacts:

- loss of habitat and individuals due to construction activities. However, the disturbance of the seabed from sedimentation during the construction phase only seems to be temporary.
- footprint of cables, maintenance vessels, electromagnetic radiation and noise may reduce abundance and diversity of seabed life somewhat.

⁵ benthic communities: communities living on the sea bed, also known as “Benthos”. (“Benthos” originally means “seabed” in Greek)

- bottom mounted structures tend to act as natural reefs and introduce fauna, however these artificial hard substrates may cause some changes to the biotope structure with consequences regarding benthos and subsequent food chain that are as yet unclear.
- the absence of fishing and shipping (except for maintenance vessels) will have a positive local effect on fauna and seabed

General conclusions:

The quality and quantity of possible impacts on seabed and benthos are not well known, calling for monitoring of specific project sites, both as part of the EIA and as generic studies. When designing large wave power projects, maintaining or improving habitat for local species of importance should be considered.

In general the subject of cables needs to be further investigated in relation to impacts due to physical size and electromagnetism, and the area around the cables may be included in the fishery exclusion zone. Existing seabed cables in position for some years between mainland and islands may serve as useful models.

2.3.4 Hydrography and coastal processes

Wave energy converters may have a variety of effects on the wave climate, patterns of vertical mixing, tidal propagation and residual drift currents. The most pronounced effect is likely to be on the wave regime. A decrease in incident wave energy could influence the nature of the shore and shallow sub-tidal area and the communities of plants and animals they support [iii].

Impacts on sea currents and hydrography may occur for large wave energy projects, where a significant portion of the wave energy is captured or reflected. Obviously this impact is largely dependent of the area covered and draught of the wave energy converters and distance to shore. Fixed structures such as the OSPREY are more likely to alter the wave climate than floating devices.

Impacts may be positive as well as negative, depending on project lay-out and location. Positive impacts may occur in the form of reduced coastal erosion levels from wave energy capture and reflections from large-scale wave energy schemes. Such impacts are however expected to be local.

Expected impacts:

- permanent changes in sediment structure may rise from changed water flow behind the wave energy converter, as it captures or reflects significant amounts of the wave energy
- changes to the wave regime along the shoreline could change the composition of the shoreline.

Detailed modelling may be necessary depending on size of project, proximity to shore, shallowness of water and general sensitivity of local hydrography or sea currents

General conclusions:

For some wave energy schemes potentially significant impacts on sea currents can be expected. Hydrological modelling and before-after studies are therefore likely to be included in the EIA for large projects.

2.3.5 Birds

Whereas birds are one of the most significant issues within wind power this is less likely to be so for wave power. As wave energy converters generally do not elevate much above sea level, and have no rotors moving in the air, actual and publicly perceived impacts are expected to be rather low. However, as the bird protection groups are generally strongly organised, it is advisable to avoid placing large wave energy projects in the vicinity of important bird areas.⁶ As important bird areas are often located in shallow water with low wave heights, many of these areas will not be of interest for the development of wave energy.

Potential impacts:

- ousting birds from their traditional feeding/roosting grounds due to physical changes of habitat

The possible impacts will depend on the following parameters:

- construction work: the impacts on birds during the construction phase are only expected to be temporary and limited. However, the choice and timing of

⁶ See report on Work Package 2.2

construction method may be of importance as high noise levels can potentially disturb both breeding and staging birds.

- feeding conditions: as the sub-surface part of the wave energy converter may prove to be a good living environment for small fish, mussels etc, this tends to attract bird colonies, feeding from this new fauna. If fishing, as expected, is to be forbidden within the wave power farms, the farm area may serve as feeding ground for birds, thereby improving feeding conditions and minimizing the ousting of birds from their traditional feeding/roosting grounds. It is for the same reason important that the wave energy device is designed in a way where no physical damage to animals will occur. It is also likely that birds may use converters for roosting and preening if the structural configuration allows this.
- noise/movements during operation: Noise may influence the impact on birds through ousting from the vicinity of the converter.

2.4 Effects from accidents

The effects on the environment due to accidents are to be taken seriously, as for instance a collision with an oil tanker may in worst-case cause severe damage regarding fauna and flora, water quality, coastline etc. It should however also be noted that in some cases wave and tidal energy farms may prevent accidents from happening, if the offshore renewable energy converters are located in waters where the collision risk is already high, e.g. due to reefs. Properly marked wave energy converters will then more clearly warn ships against the risk of collision than was the case before the devices were installed.

Collision risk analyses will be carried out as part of the EIA, but so far it seems to be quite difficult to develop reliable risk models – as can be expected, taking the lack of experience with collisions of this kind into consideration.⁷ Moreover, the effects of potential oil pollution for e.g. birds have not been estimated in e.g. the Danish EIAs for offshore wind farms.

Expected impacts:

⁷ For instance, the risk analyses regarding the Nysted/Rødsand and Horns Rev offshore wind projects were not immediately accepted by the developers, as the figures were based on the assumption that a ship entering the farm area would unavoidably cause a collision. A revised risk analysis has therefore been carried out for the two projects.

Accidental impacts on the environment may originate from collision between ship (e.g. maintenance vessel) or, theoretically, a low-flying aircraft (e.g. maintenance helicopter) and structure or substation, or from damage to submarine cable caused by anchoring, colliding or sinking ship, by trawling equipment or during construction.⁸

The effect of such accidents may be a pollution of the environment caused by substances from the offshore installation (converter/cable) or substances from the colliding ship or aircraft. The exact consequences of a collision are dependent on many parameters, such as type of ship/helicopter, collision angle, speed of colliding vehicle and the type of wave energy converter.

If larger ships, such as oil tankers, collide with a wave energy converter (WEC), in many cases it is to be expected that only the WEC will be seriously damaged. In other words, a ship collision does not necessarily mean leakage of huge amounts of harmful substances. Moreover, if a leakage of polluting substance is actually the result of the collision, the degree of impact on the environment will vary in relation to weather (temperature, wind speed) and of course the nature of the polluting substances.

The most possible polluting substance in these cases is regarded to be oil:

- oil spillage deriving from the WEC is not an issue of major concern, as the WECs will often contain only small amounts of oil, if any.
- the diesel oil inside a potential substation is neither regarded as being a major source of risk, as the oil amount is limited and the diesel oil will relatively easily evaporate. However, to minimise risks of leakage, substations should be constructed with double walls.
- damage on submarine cables may cause release of mineral oil isolating the cable, if this type of cable is chosen. In a worst-case-scenario at Horns Rev [xviii], the maximum oil leakage amount would be 4,200 l. Although this is a relatively small amount, and although the risk of such accidents has been calculated to be very low (one every 32,000 years), mitigation measures such as protection of the cable (by trenching if possible) and prohibition against fishing within the area of the farm and around the

⁸ During the construction of the Middelgrunden Offshore Wind Farm, the submarine cables were damaged three times, however without environmental impacts as the cables did not contain oil as isolating material.

cable are therefore highly recommendable. Moreover, the pressure inside the cable is to be monitored continuously in order to take immediate action in case of leakage.

- the most critical impact on environment regarding oil pollution would be caused by oil from ships. Diesel oil from fishing boats and maintenance vessels is not regarded as seriously as oil from larger ships, because diesel oil will evaporate to a relatively high degree compared to bunker oil. According to [xviii] the most critical event would be the pollution resulting from a collision with an oil tanker, as this collision could result in the leakage of considerable amounts of light oil or bunker oil. The bunker oil is the more destructive due to its low evaporation rate. The consequences of such a collision call for development of special emergency procedures with a short reaction time for each large offshore farm.

General conclusions:

As the consequences of collisions may be very serious, mitigating measures are called for in order to minimise collision risks, such as: proper marking of farm/WECs, protection of cables and development of special emergency procedures. However it should be noted that the collision frequency is relatively low and that a collision would not necessarily result in severe environmental damage.⁹

2.5 Visual Effect.

The visual impact will depend on, among others:

- the distance offshore
- the height of the device above sea level
- the weather conditions, and
- the height above sea level of the viewpoint

Wave energy converters are not expected to have a visual impact comparable to wind turbines due to their limited height. Nevertheless, coastal areas are often considered important for recreational purposes, making visual intrusion a potentially high-profile political issue, especially for on-shore and near-shore wave energy schemes.

⁹ For Horns Rev, the revised calculations resulted in a ship collision risk of 1 collision every 641 years.

In the UK, for example, over a third of its coastline is designated for its scenic or natural beauty, and as one in three people in the UK lives within a distance of 10km from the coastline [xix], and as public opposition and concerns are generally related to visual effects [xx], the visual aspects are of very high importance.

In a UK/Irish Guide to Best Practice in Seascape Assessment [xxii] a distance of 15 km is suggested as the maximum limit of visual significance along the coast in relation to offshore wind turbines.

Given the limited number of wave energy converters currently deployed, it is hard to quantify the magnitude of visual impacts from wave and tidal energy devices, but it is expected to be very location dependent and only becoming an issue of increasing importance when devices are deployed in larger numbers.

The visibility from shore will also depend on the requirements regarding marking lights and painting – marking lights will be mandatory in order to avoid ship collision. Therefore marking requirements (such as those of IALA [xxi]) and their effects regarding visual impacts should be known as early as possible in the planning phase. For shore based devices the siting and design is of utmost importance. A good example of how this can be done is given by the LIMPET project, which is practically invisible until one is relatively close to the device.

As the visual impact is a matter of the viewer's taste, it must be expected that there will always be some public resistance, especially for near-coast projects, but even the visual impact from offshore projects invisible from the shore may experience resistance when intrusively visible from ships, boats and ferry lines. An open and careful planning process with detailed visualizations and intensive dialogues with the local public may result in less public resistance.

2.5.1 Experience from wind power visualizations

In the case of wind power, Swedish investigations indicate that visualizations can cause problems with acceptance because pictures do not present the true visual impact of wind turbines on a landscape [xx]. Neither do they present their functional contribution. People construe the depicted wind turbines not as a source of renewable energy but as a new element in the landscape that will diminish its scenic value. On the other hand

visualizations undeniably have some value in accelerating social adjustment by providing an idea of what planned developments will look like. Inevitably, however, these pictures never truly depict the experience of an active wind turbine, although they are a great aid.

The benefits of using visualizations are connected to a person's professional training and their previous experience with wind turbines. If people can understand the rationale behind certain designs or if they can recognize some benefits in relation to other wave power locations, visualizations can work well to create a positive dialogue. In this context it is important to understand that a 'picture' can both suppress the benefits of wave energy devices and camouflage some of the visual effects. Hence, visualizations must always be accompanied by detailed explanations. Furthermore, wave energy converters are not only experienced by seeing them, but also through hearing and feeling their presence, and the use of "virtual reality" should be useful in this regard.

General conclusions:

The general conclusion is that visual impact of energy plants has a very high profile in the public awareness, and that this high awareness might apply for wave energy projects as well – especially shore-based and near-shore plants. At the current level of commercial impact from wave energy, visual impacts do not appear to possess a significant barrier, but the issue might pose a barrier for specific locations, especially when large-scale future wave power farms are projected. The experience with offshore wind power clearly indicates that there is strong public concern for this issue, even concerning offshore wind power farms, which are, from the shore, barely visible to the naked eye.

Experience from existing offshore wind farms indicates that the following recommendations of relevance for wave power can lead to reduced public resistance:

- The devices should in general be placed as far away from the coast as possible, and in particular proximity to recreational areas and/or areas of great scenic value should be avoided
- the planning process must be very open and careful, and if the farm is visible from land, the effect on the environment and economy (e.g. tourism) of the coastal area must be assessed
- farm formation, number and size of wave energy converters and cumulative effects should be thoroughly and openly analysed and discussed before a decision is taken

- early local involvement in the planning phase is essential and community involvement in ownership of the wave farm will be beneficial when the technology has been proven.

2.6 Noise and vibration effects

Noise from wave energy converters arises from e.g. the movement of mechanical parts (aerodynamic noise), and the transmission of power and momentum in the conversion system (mechanical noise from gearboxes). Furthermore, mechanical noise may arise from some control equipment.

The degree of noise effects is primarily dependent upon the level and character of the noise emitted, the distance from the plants to potential sensitive receivers, wind directions and background noise levels. For wave energy converters the noise emission levels can in general be expected to increase in parallel with the background noise level (breaking waves). Nevertheless noise may be a significant issue, especially for shore based devices.

2.6.1 Airborne noise

It is expected that airborne noise could have the following impacts:

- ousting of birds
- loss of habitat for marine mammals
- decrease in public acceptance if noise from the wave energy converter is audible to humans from the shore

Concerning noise it appears that wind power has received a reputation for being noisy, which, together with the fact that noise propagates much easier over the sea than over land, is reflected in the public attitude towards wind power, including offshore wind. This reputation is somewhat unjustified, as current wind turbines are not very noisy. The reputation therefore seems to be a public perception based on experiences with early turbines, which could be noisy. The lesson to be learned for wave power therefore appears to be that noise effects are to be handled carefully for early prototypes as the public perception of the noise impact may not change significantly when mature technologies with lowered noise emissions are available.

During construction, airborne noise from construction work (vessels, blasting etc.) is expected to affect birds and marine mammals (ousting), but as the effects are of limited duration, the impacts are expected only to be temporary. However, sensitive time periods like breeding or nursery periods should be avoided if the construction site is placed near important biological areas – this may be in conflict with the intentions of the developers to establish wave power plants when stormy weather is least probable.

2.6.2 Underwater noise and vibrations

During construction, underwater noise may have a detrimental effect on marine mammals, fish and benthos. However, the effect is temporary, but sensitive time periods should be avoided – in the case of fish larvae, construction work at sensitive periods may result in a very high fish mortality rate.

During operation, noise from wave energy converters can be transmitted into the water in two ways: the noise either enters the water via the air as airborne sound, or the noise is transmitted into the water as structural noise. The frequency and level of underwater noise is thereby determined to a certain degree by the way the wave energy converter is constructed.

Underwater noise from wave energy converters must of course exceed the level of underwater background noise (ambient noise, especially from ships) in order to have any impacts on marine fauna.

The effects on marine life from vibrations of the turbines are rather unknown. Noise frequencies and magnitudes are likely to show considerable variations among different technologies, but noise measurement data on wave energy converters are currently not publicly available.

Only measurements and post construction impact studies will reveal if underwater noise will really affect marine mammals.

General conclusions:

The general conclusion is that for *wind* turbines airborne noise impact has a high profile where public awareness is concerned, but that this is derived from previous generations of

wind turbines and not to the technical realities of today. This perception may however become associated with *wave* energy converters also, especially if the early generation plants have significant noise impacts. Demonstrating that noise from wave energy converters is insignificant is therefore important for the future of wave power. It must be remembered that noise may travel large distances over open water surfaces.

Regarding underwater noise and vibrations, the effects on marine animals, fish and benthos need assessment in generic studies and in a site-specific manner, because the extent of these effects is relatively unknown. The experience gained from small pilot projects will be important in this regard.

2.7 Decommissioning

The issue of decommissioning is a potentially great problem for offshore developments.

National (see for instance [ix]) and international laws of the sea require total removal of offshore structures (installed after February 1999) when they reach the end of their operating lifetimes. Partial removal will not be allowed for such installations.

Not only will the requirements regarding decommissioning increase costs, the removal of offshore installations will also cause marine disturbance, and consequently decommissioning work should not take place during sensitive periods in order to minimize impacts on environment due to e.g. noise, vibrations, and sediment disturbance.

However the effects are expected to be temporary, as the environment will return to its pre-development status with time [ii].

2.8 Emissions

Unlike conventional fossil fuel technologies, wave energy produces no greenhouse gases or other atmospheric pollutants whilst generating electricity. However, emissions do arise from other stages in its life cycle (i.e. during the chain of processes required to manufacture, transport, construct and install the wave energy plant and transmission equipment).

For wave energy technologies, the typical stages of the life cycle are:

- Resource extraction;
- Resource transportation;
- Materials processing;
- Component manufacture;
- Component transportation;
- Plant construction;
- Plant operation;
- Decommissioning;
- Product disposal.

Ideally, each of the life cycle stages listed above should be considered, in order to evaluate the total emissions from the life cycle of the technology. However, an exact analysis of every stage is neither possible nor necessary. The emissions of most of the major air pollutants (particularly carbon dioxide, sulphur dioxide, oxides of nitrogen and particulates) are expected to be broadly proportional to energy use. Therefore, the most important life cycle stages for atmospheric emissions are those with the highest energy use. Detailed studies of the main renewable energy technologies have been carried out using this approach within the ExternE study (e.g. [xxiv]) and elsewhere in the literature. This has shown that, for most renewables:

- The emissions released during the manufacture of the materials are the most important;
- Energy use in all of the transportation stages is likely to be negligible; energy use in freight transport is typically only 1 MJ/t/km for rail [xxv] and in road transport is typically 3 MJ/t/km;
- Energy use in the extraction of the primary materials used in construction (e.g. limestone and aggregates) or in components (e.g. iron ore and copper ore) is typically an order of magnitude lower than energy use in their primary processing;
- Energy use in the construction, decommissioning and disposal processes is also likely to be at least an order of magnitude lower than for material manufacturing.

In assessing the energy use and emissions for technologies, data relating to realistic sites and technologies should be used, in recognition of the fact that these factors are important in determining the magnitude of some emissions. Emissions associated with the

manufacture of materials and components are dependent (to some extent) on industrial practices, the generation mix and pollution control regime in the country of manufacture.

The above evaluation has been carried out for a range of technologies [xxvi], [xxvii], and the results for some renewables and wave energy are shown in Table 1, where the resulting emissions from typical examples of offshore renewable energy technologies are compared with the emissions arising from the average mix of generating technologies in the UK [xxviii].

It is evident that wave energy (and the other renewables) can offer significant reductions in the omissions of gaseous pollutants when compared to fossil-fuel based generation [iii], [ii]¹⁰.

Although power produced in the UK 2002 involves less greenhouse emissions, especially because there has been a major shift from coal to gas powered generation since the early 1990s [xxxi], the result, that wave energy produced power emissions are negligible compared to the UK mix, will still be valid.

Pollutant	Tidal Current (g/kWh)	Wave (g/kWh)	Wind (g/kWh)	Average UK Mix (g/kWh) (1993)
CO ₂	12	14 - 22	12	654
SO ₂	0.08	0.12 – 0.19	0.09	7.8
NO _x	0.03	.05 - .08	0.03	2.2

Table 1 Life-Cycle Emissions from Offshore Renewables

General conclusions:

The general conclusion is therefore that although emissions arise from different stages of a wave energy device's life cycle, this amount is negligible and more than outweighed by the

¹⁰ T.W Thorpe is the true author of this whole section on "Emissions".

saved emissions from power production, stressing the fact that wave energy is an environment friendly energy (see section 4 below).

3 Impacts from Environment on Wave Energy Converters

The potential impact from environment on wave energy schemes will be highly dependent on the type of WEC and its location – onshore, near-shore or offshore.

Below the most important expected potential impacts are presented, based on responses from Network members to a questionnaire that was sent out concerning this topic (see App. 1).

Sensitivity to sea currents

For offshore systems currents should not be a problem, providing the survivability is good, which of course is an essential precondition. Shoreline devices may be sensitive to orthogonal currents which break up wave patterns.

Sensitivity to wind

This subject should not become a barrier, as aerodynamic behaviour of floating structures can be considered during design. However the subject of wind needs consideration at all stages where site investigation, construction operation, maintenance, human access and risk analysis is concerned.

Sensitivity to marine growth

The subject of marine growth is an important area for research, both regarding marine growth inside the turbines and regarding marine growth in general. The systems will have to be treated and maintained in order to avoid the expected reduced efficiency over time.

Evasion technologies, which are available e.g. within the ship industry, must be neutral to environment (marine fauna and flora, quality of water) according to the International Convention on the Control of Harmful Anti-Fouling Systems, developed by IMO's (International Maritime Organization's) Marine Environment Committee [xxix].

As offshore oil and gas installations provide attachment surfaces for a variety of algae and invertebrates, so wave energy converters would be colonised by fouling organisms. The

species recruited to these sites would depend on the species communities within the vicinity of the device, distance offshore, water depth and clarity, prevailing weather conditions and position relative to coastal currents and the speed of those currents [xxx]. There would be a seasonal factor involved in the build up of this community with the main build up of fouling extending from about April to November.

It is inevitable that anti-fouling measures would be necessary where, for instance, attached organisms cause changes in corrosion and fatigue behaviour, hinder inspection and maintenance, etc. Fouling prevention measures specific to wave energy converters have yet to be developed, but could include the use of anti-fouling paints or direct injection of biocides. Fouling of sea water conduits at coastal power stations has been controlled by injection or electrolytic generation of chlorine. Due to the effects of dilution it is not clear if the use of this measure at a more open sea location might be environmentally harmful. Certainly chronic impacts may result if the chlorine was allowed to react to form chlorinated organics which tend to bio accumulate and persist in the environment, although this would appear to be unlikely in open waters. There are numerous options for the removal of marine fouling, each of which has its relative merits. None of these pose any significant environmental problem although some (e.g. high-pressure jets) could be hazardous to the user [iii].

Sensitivity to material deposits (soil, debris)

As intrusion of material deposits between moving parts, into turbines (air- or water), flow channels etc. might cause malfunction/destruction of a device, the sensitivity of a WEC to material deposits is an important issue.

For instance, shoreline devices could be vulnerable to floating seaweed, jelly-fish, trash and may be partly blocked by storm movement of deposits. Offshore and near shore devices are expected to be less affected, however this is to a high degree depending on the individual design.

For example concerning the floating offshore WEC, Wave Dragon, the device may be expected to collect considerable amounts of garbage in the reservoir with its wide gap between two wave reflectors. Although cleaning technologies are available from hydro power plants, special precautions need to be taken in order to avoid reduced efficiency e.g. if access to turbines is blocked by debris (or, in theory: marine mammals) in the grid trash rack serving as protection in front of the turbines.

Risk of corrosion problems

By using standard offshore technology risks and effects can be calculated, and if the devices are built according to offshore norms corrosion problems can be avoided. Corrosion problems are not regarded as a technical barrier as problems can be solved - prevention measures will simply add to costs.

General conclusions:

It is not expected that impact from environment on wave energy devices will constitute a barrier for the large-scale development of wave energy, providing survivability aspects have been solved. However, as the experience is limited, information regarding this subject gained from studies of individual demonstration projects in the near future should be collated and made available for the wave energy community. It must however be remembered that this type of experience will to a very high degree be both location and device specific.

4 Environmental Benefits of Wave Energy

The most important environmental benefits of wave energy are similar to other renewables:

- the avoidance of pollutant gasses, and
- the preservations of raw materials like gas and coal

Secondary benefits of wave energy such as lowered risk of pollution due to accidents with e.g. oil tankers - because less oil needs to be transported - have not been included and will not be important before the use of wave energy in particular (and renewable energy sources in general) has reached higher levels than today.¹¹

Environmental benefits should be clearly stated in the Environmental Impact Assessment and the emphasizing of these *positive* environmental impacts is crucial in relation to the public and political acceptance of wave energy.

4.1 Avoided Emissions

The benefits to the environment from using wave power are mainly by reducing atmospheric pollution. As well as a significant reduction in CO₂, other pollutants are also reduced; SO₂, NO_x, CO, Methane and Particulates.

In Denmark it is estimated that for each produced kWh wind power, the following emissions are avoided from an ordinary coal fired power plant:

CO ₂ :	810 g/kWh
SO ₂ :	1.5 g/kWh
NO _x :	1.4 g/kWh

The actual saving in emissions depends to a large extent on the mix of types of power generation for an individual country or region and the type of plant replaced. It is apparent

¹¹ The share total EU energy consumption provided by renewables was around 6% in 1999, and the renewable share of EU electricity consumption 13%. The EU indicative targets for 2010 are 12% respectively 22,1% [xxxii]

that any calculations on emissions savings must look realistically at the type of power generation likely to be replaced, and not just assume that the most polluting will be shut down [i].

For the UK, evaluations regarding avoided emissions have been carried out for a range of technologies [xxvi], [xxvii] and the results for some renewables and wave energy are shown in Figure 1-Figure 3 below.

In order to compare with the range of possible fossil fuel stations, three different fossil fuel technologies were chosen:

- Combined cycle gas turbines (CCGT).
- Modern coal plant (i.e. pulverised fuel with flue gas desulphurisation - PF+FGD).
- The UK generating mix 1993 [xxvii].

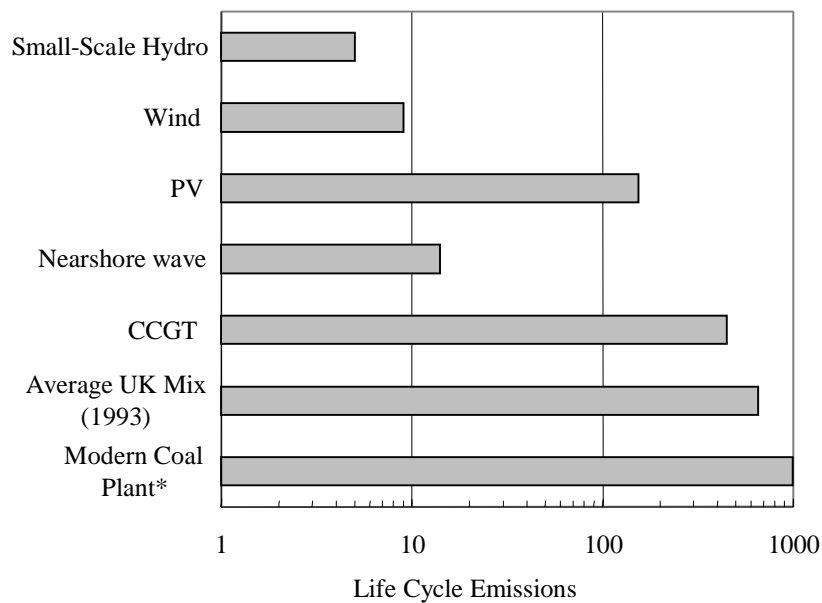


Figure 1 **Comparison of Life Cycle Emissions of CO₂**

Key. * = coal plant with flue gas desulphurisation and low NO_x burners.

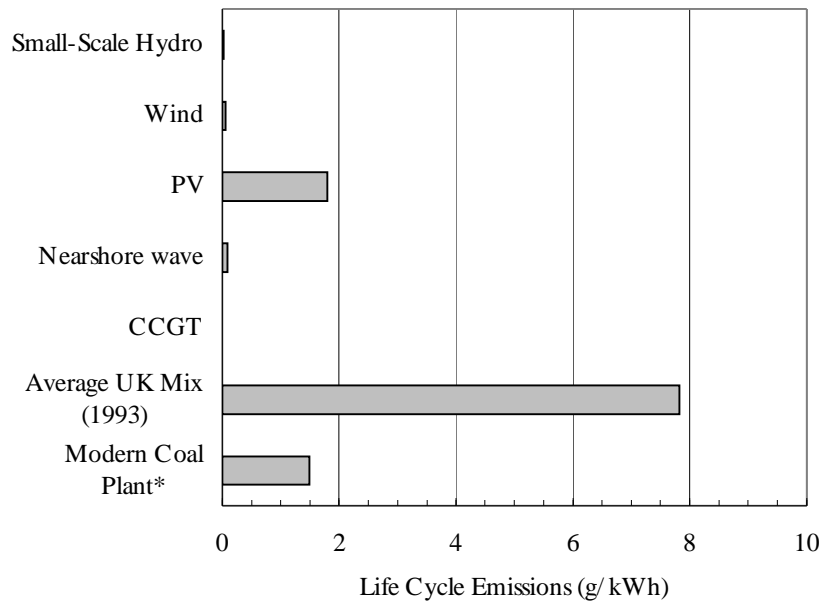


Figure 2 Comparison of Life Cycle Emissions of SO₂

Key. * = coal plant with flue gas desulphurisation and low NO_x burners.

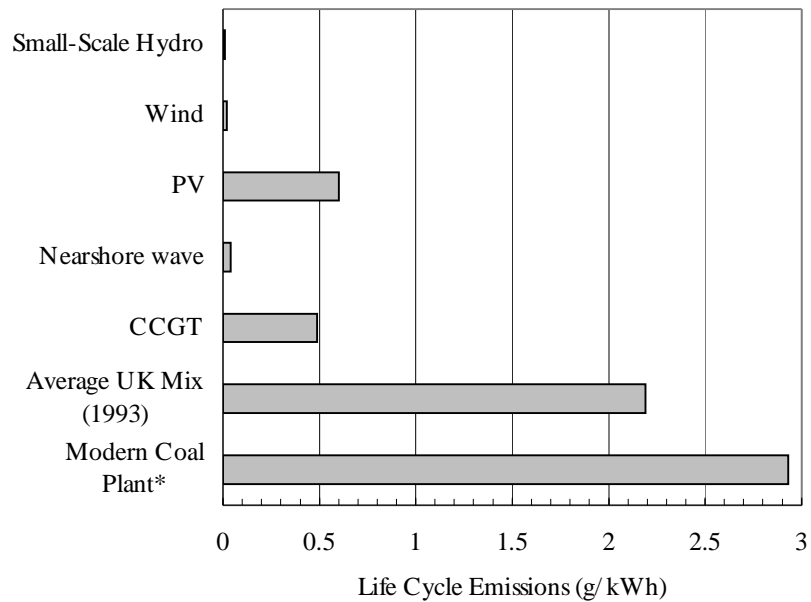


Figure 3 Comparison of Life Cycle Emissions of NO_x

Key. * = coal plant with flue gas desulphurisation and low NO_x burners.

It can clearly be seen that wave energy (and other renewables) can offer significant reductions in the omissions of gaseous pollutants when compared to fossil-fuel based generation. The only exception to this is for CCGT, whose emissions of SO₂ are effectively zero [iii].

General conclusions:

As Wave Energy is a renewable energy that produces no greenhouse gases or other atmospheric pollutants while generating electricity, environmental benefits will arise from the avoidance of pollutant gasses and the preservations of raw materials like gas and coal.

The actual saving in emissions and preservations of raw materials will of course depend on the ability of wave energy to penetrate the energy market, and on the type of energy that is replaced by wave energy.

5 General conclusions

In summary, the environmental burdens of offshore energy schemes are likely to be low, provided developers show sensitivities with appropriate site selection and planning authorities control deployment in sensitive locations. Although the potential impact appears to be low, the lack of operational schemes means that further research into likely practicable impacts and mitigation strategies might be required.

The following conclusions and recommendations concerning future RTD-activities in most cases imply the construction of large-scale wave energy projects, as monitoring programs and Before-After-Impact-Studies carried out at specific sites often represent the only possible way to achieve exact knowledge or at least an improved understanding of the impacts from wave power, particularly on the environment.

However, the lessons learned within offshore wind power in the coming years will probably yield significant new insights, especially concerning the impacts on marine environment, social acceptance management and conflicts of interest, which can provide more guidance for the wave energy environment.

As the assessment of environmental impacts associated with wave power is made extremely difficult due to the lack of reference cases and impact studies, it is important that relevant information is systematically collected and disseminated early in the market penetration phase, in order to allow the non-important factors to be ruled out. It is therefore strongly recommended that a European working group is established securing effective transfer of practical experiences gained, when a representative number of devices have been installed.

5.1 Identification of problem areas

Potentially negative environmental impacts:

Mammals:

- loss of habitat due to
 - noise emissions
 - accidents
 - food chain changes
 - electromagnetic fields and vibrations, e.g. affecting the sonar system

Fish:

- impacts on fish and fish larvae from sedimentation/turbidity, underwater noise, vibrations and electromagnetic fields
- effects from unnatural reef (if any)

Fauna and Seabed

- changes in sediment structure
- direct loss from foundation and cable footprints
- impact on biotope from foundations/hard substrates and electromagnetic fields

Coastline

- impact on coastline due to current/sediment changes arising impacts on local currents/waves

Visual impact

- man-made intrusions in an otherwise structureless seascape, or – for onshore converters – in the coastal landscape.

Noise impact

- noise impacts from shore-based and near shore devices
- impact on birds, sea mammals and fish from underwater noise

Leakages

- Primarily associated with risk of ship collisions

5.2 Recommendations for RTD programmes

In general, it will be very important to collect information from different studies in order to cover the whole area, as different “narrow” site specific studies are carried out at the different projects: Baseline and impact studies from individual projects are to be disseminated and jointly appraised. Conclusions from local projects should be translated and all relevant existing material placed on a publicly accessible web-site

Environmental impacts:

Mammals:

- More studies are needed to evaluate the effect from noise and magnetic fields, and the visual impact on mammals. Before-After-Impact-Studies, including seismic surveys and monitoring of underwater noise levels, and generic studies on noise reception of sea mammals are called for.

Fish:

- As the effect of noise, vibrations and magnetic fields on fish is relatively unknown, studies and surveys must be carried out before, during and after construction: Site-specific and species-specific monitoring studies are necessary in order to investigate the effect on fish, e.g. investigate if marine structures may indeed serve as natural reefs, as indicated from previous studies of offshore wind power, the consequences thereof, and investigate the consequences on fish population/fishing possibilities when fishing (with net) is restricted within and in the vicinity of the wave energy converter(s).

Seabed

- The quality and quantity of possible impacts on seabed and benthos is not well known, calling for surveys of specific project sites, both as part of the EIA and as generic studies. How will the hard substrates and cable footprints/electromagnetic fields influence the base-line biotope? Investigations should seek to enhance habitat, e.g. by use of appropriate foundation design where seabed mounted devices are concerned.

Visual impact

- Research of computer simulation possibilities to test different farm layouts seen from different angles, levels and at different weather conditions in order to make visualisations comparable to real-life conditions, is recommended for large-scale

shore based and near-shore projects. Buoys and lanterns might be expected to be the most significant visual impact.

- Clear definitions of marking requirements

5.3 General recommendations

It is very important that mitigation strategies are developed for each wave energy project in order to avoid/minimise negative impacts on environment.

Fish, birds and mammals:

Identification and avoidance of sensitive areas

Avoidance of site works during sensitive time periods

Minimisation of noise levels during construction, operation and dismantling

Minimise effect of structures and cabling on fish stocks

Seabed, Benthos:

Minimize artificially induced sedimentations and turbidity

Hydrography, currents and coastal processes:

Analysis of local impacts on currents and wave climate. Potentially positive and negative effects on coastal erosion rates, if any, should also be carefully modelled in the pre-planning phase

Water quality:

Avoid use of pollutant chemicals when wave energy devices are protected against marine environment

Noise:

Secure low noise levels

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8 Appendix 1. Questionnaire Responses from Network Members

Country: Portugal Device type Offshore. Form filled out by: Teamwork Technology

[Sheet 2] Task 3. 3 Environmental Impact: To what extent can potential environmental impacts be expected to be a barrier to large-scale <i>Wave Energy Schemes</i> during planning, construction or installation?				
Topic	Importance	Main Conclusions	References	Available (Y/N)
	1=low 2=medium 3=high			
3.3.1 a Visual Impact	1	Depending on type of system, floating or submerged		
3.3.1 b Noise impact	1	As above, the acoustic noise is to be considered as serious to be studied		
3.3.1 c Birds	1	As above		
3.3.1 d Other wildlife (e.g. sea mammals)	2	As above, an environmental impact study must answer the question of influences on sealife.		
3.3.1 e Changes to seabed	2	In principle the changes will be minimum and local.		
3.3.1 f Disturbance of sea currents	2	As 3.3.1 e		
3.3.1 g coast erosion & material deposits	2	For offshore systems it will be very low and a local effect on material deposits		
3.3.1 h leakage of harmful substances	2	Depending on type of device		
3.3.1 i ESPOO convention (hearing of neighbour countries)	2	Is only important if the large scheme is close to the neighbouring country.		
3.3.1 Other impacts	2	Potential positive effects on underwater wild life is to be investigated.		

[Sheet 3] Task 3.3 Impact of the environment: Please specify expected impacts of environmental effects on the WEC's during planning, construction or installation in relation to the topics listed below:			
Topic	Importance		Main Conclusions
	Risk	Effect	
	1=low 2=medium 3=high		
3.3.2.a Sensitivity to sea currents	1	1	For offshore systems currents is not a problem
3.3.2.b Sensitivity to wind	1	1	Underwater system used by Teamwork
3.3.2.c Sensitivity to marine growth	2	2	System has to be treated and maintained
3.3.2.d Sensitivity to material deposits (soil)	2	2	Depending on geological situation of the location
3.3.2.e Sensitivity to material deposits (floating trash)	2	2	As above
3.3.2.f Risk of corrosion problems	1	1	By using standard offshore technology risks and effects can be calculated
3.3.2 g Other environmental impacts....	2	2	Acoustic noise can be a serious environmental problem

Country: Denmark**Device type (OS/NS/SH): OS Form filled out by: EMU**

[Sheet 2] Task 3.3 Environmental Impact: To what extent can potential environmental impacts be expected to be a barrier to large-scale *Wave Energy Schemes* during planning, construction or installation?

Topic	Importance	Main Conclusions
	1=low 2=medium 3=high	
3.3.1 a Visual Impact	1	Very dependent on distance to shore. Will probably not be considered important for far offshore locations.
3.3.1 b Noise impact	2	May require documentation, before public authority can be given.
3.3.1 c Birds	2	Will require considerable documentation and monitoring if close to bird restricted areas.
3.3.1 d Other wildlife (e.g. sea mammals)	3	To be discussed. Dependent on technology and location.
3.3.1 e Changes to seabed	1	Not important for offshore devices.
3.3.1 f Disturbance of sea currents	1	Not important for offshore devices.
3.3.1 g coast erosion & material deposits	1	Not important for offshore devices.
3.3.1 h leakage of harmful substances	3	May be a major issue, in relation to the risk of ship collisions. The WEC's themselves only carry insignificant harmful substances (diesel for emergency systems)
3.3.1 i ESPOO convention	3	Will be important for offshore locations, especially as the status of locations outside the national jurisdiction is currently undecided.
3.3.1 j Other Environmental impacts...	1	Influence from electric fields on fish breeding has been brought up. This area needs further research.

No.	References	Content
1	EC Directives 85/337/EEC and 97/11/EEC	On documentation and monitoring of environmental impact from large public and private construction projects.
2	Energistyrelsen (1998): Retningslinier for udarbejdelse af miljøredegørelser for havmølleparker (Guidelines for environmental impact analyses for offshore wind power parks) Rambøll - Copenhagen (In Danish)	Implementation of the above directives for offshore wind power in Denmark
3	Sørensen et. al. (1999): VVM redegørelse for vindmøllepark på Middelgrunden (Environmental Impact Assessment of the Wind Farm Middelgrunden), Copenhagen Utility and Middelgrundens Vindmøllelaug - Copenhagen (In Danish, with English summary)	Case study. Environmental impact study for 40 MW offshore wind power park near Copenhagen.
4	Elsam (2000) Høring om Havvindmøllepark ved Rødsand (Hearing on offshore wind power park at Rødsand)	Case Study: Report on environmental Impact of an offshore wind power project prepared for the public hearing process. Available at http://www.ens.dk/nyt/Hoeringer/VindRoedsand/hoering_Roedsand.htm with English summary
5	Elsam & Eltra (2000): Høring om Havvindmøllepark på Horns Rev (Hearing on offshore wind power park at Horns Rev)	Case Study: Report on environmental Impact of an offshore wind power project prepared for the public hearing process. Available at http://www.ens.dk/nyt/Hoeringer/VindHornsRev/hoering.htm with English summary

Country: Denmark Case: Wave Dragon, North Sea 20 km offshore. Filled out by: EMU

[Sheet 3] Task 3.3 Impact of the environment: Please specify expected impacts of environmental effects on the WEC's during planning, construction or installation in relation to the topics listed below:			
Topic	Importance		Main Conclusions
	1=low 2=medium 3=high		
	Risk	Effect	
3.3.2.a Sensitivity to sea currents	2	1	Efficiency not very affected of the vessel not heading directly into the sea. Also good survivability. Risk of this situation uninvestigated
3.3.2.b Sensitivity to wind	1	1	The area for catching wind is small.
3.3.2.c Sensitivity to marine growth	2	2	Regarding marine growth inside the turbines, this issue is currently being tested. Regarding marine growth in general, evasion technologies are available within the ship industry, but may require that the device is towed to a shipyard every 5-10 years. This is still an important area for research.
3.3.2.d Sensitivity to material deposits (soil)	1	1	As a floating offshore vessel this will not be a problem
3.3.2.e Sensitivity to material deposits (floating trash)	3	2	With the wide gap between the wave reflectors, the device may be expected to collect considerable amounts of garbage in the reservoir. Cleaning technologies are available from hydro power plants.
3.3.2.f Risk of corrosion problems	1	3	Built according to offshore norms. Corrosion problems can be avoided.
3.3.2 g Other environmental impacts....	3	1	Lightning. Standard technologies are available.

Country: Greece

Form filled out by: CRES

[Sheet 2] Task 3.3 Environmental Impact: To what extent can potential environmental impacts be expected to be a barrier to large-scale <i>Wave Energy Schemes</i> during planning, construction or installation?				
Topic	Importance	Main Conclusions	References	Available (Y/N)
	1=low 2=medium 3=high			
3.3.1 a Visual Impact	3	Visual intrusion important near recreational and/or coastal settlements	1,2,3,5	
3.3.1 b Noise impact	3	Acoustic intrusion important near recreational and/or coastal settlements	1,2,3,5	
3.3.1 c Birds	1	Relevant mainly for air turbine-based systems		
3.3.1 d Other wildlife (e.g. sea mammals)	2	Specific protection areas for sea mammals (e.g. monachus-monachus seal in west Aegean Sea, sea turtles in Ionian Sea)	6	
3.3.1 e Changes to seabed	1			
3.3.1 f Disturbance of sea currents	1			
3.3.1 g coast erosion & material deposits	2	Possible effects of LS-WES on littoral processes; effects might be positive (coastal protection)	1,2,3,5	
3.3.1 h leakage of harmful substances	2	Mainly hydraulic fluids		
3.3.1 i ESPOO convention (hearing of neighbour countries)	2	Should not be relevant within 6 m – zone		

Country: Greece

Case:

Form filled out by: CRES

[Sheet 3] Task 3.3 Impact of the environment: Please specify expected impacts of environmental effects on the WEC's during planning, construction or installation in relation to the topics listed below:			
Topic	Importance		Main Conclusions
	Risk	Effect	
	1=low 2=medium 3=high		
3.3.2.a Sensitivity to sea currents	2	2	Effects might be positive, e.g. WEC alignment with incident wave direction
3.3.2.b Sensitivity to wind	2	2	Aerodynamic behaviour of floating structures should be considered during design
3.3.2.c Sensitivity to marine growth	?	?	
3.3.2.d Sensitivity to material deposits (soil)	2	2	Intrusion of material deposits between moving parts, into turbines (air- or water), flow channels etc. might cause malfunction/ destruction of a device
3.3.2.e Sensitivity to material deposits	2	2	
3.3.2.f Risk of corrosion problems	2-3	2-3	
No.	References		Content
1	Νόμος Αριθ. 2773, Εφημερίς της Κυβερνήσεως, Αρ. Φύλλου 286, 22/12/1999		Law governing energy production-distribution incl. RES
2	Νόμος Αριθ. 2601, Εφημερίς της Κυβερνήσεως, Αρ. Φύλλου 81, 15/4/1998		Law governing energy production-distribution incl. RES
3	Υπουργική Απόφαση. Δ6/Φ1/ΟΙΚ.8295/19.4.1995, Εφημερίς της Κυβερνήσεως, Αρ. Φύλλου 385, 10/5/1995		Council resolution governing energy production-distribution incl. RES
4	Αβούρη, Α., Β. κ.ά. «Η ελληνική νομοθεσία για το περιβάλλον», Αθήνα, ΤΕΕ, 1993, τόμ. 2, σ. 214-232		Greek legislation for environment
5	Δαγρές, Δ. (1981) «Μελέτη της νομοθεσίας περί αιγιαλού και παραλίας», ΤΕΠ ΜΕΛ-Μ727		Environmental legislation for shoreline
6	«Κατάλογος φυσικών προστατευόμενων περιοχών της Ελλάδας» (1992), Περ. Η Φύσις, τεύχ. 58, σελ. 23-25		Catalogue of natural protected areas in Greece

Country: Ireland**Form Filled out by: Pat Mc Cullen (ESBI)**

[Sheet 2] Task 3. 3 Environmental Impact: To what extent can potential environmental impacts be expected to be a barrier to large-scale <i>Wave Energy Schemes</i> during planning, construction or installation?			
Topic	Importance	Conclusions	Refs.
3.3.1 a Visual Impact	1(NS,OS)	Requirement to use high visibility anti collision colour for moored devices may increase perceived impact	(1) Y/Eng. (2) Y/Eng
3.3.1 b Noise impact	1(NS,OS) 2(SH)	Varies with location. Shore based units with Wells turbines likely to be most significant. Would be dealt with in EIS.	(1) Y/Eng
3.3.1 c Birds	1(NS,OS) 2(SH)	Probably not significant for floating devices. Could be significant for shoreline device if rear nesting habitat. Would be dealt with in EIS.	(1) Y/Eng
3.3.1 d Other wildlife (e.g. sea mammals)	2(NS,OS) 1(SH)	Special interest groups may demand reassurance re low frequency underwater sound or electromagnetic field effects on cetacean and seals.	(1) Y/Eng
3.3.1 e Changes to seabed	1-2	Probably limited apart from sea bed mounted submerged converters or shoreline converters	(1) Y/Eng
3.3.1 f Disturbance of sea currents	1-2	Problems unlikely except in shallow water.	(1) Y/Eng
3.3.1 g coast erosion & material deposits	2	Expectation would be for reduced erosion for NS, OS but possible local erosion at SH, validation required.	(1) Y/Eng
3.3.1 h leakage of harmful substances	2-3	Potential lubricant, hydraulic fluids loss should be controllable. Would be included in EIS and operational plans.	(1) Y/Eng
3.3.1 i ESPOO convention	1	Should not be significant along Irish Atlantic Coast.	

References

(1) Offshore Generating Stations: Note for Intending Developers. Dept. of Marine and Natural Resources (Dublin).

(2) International Association of Marine Aids to Navigation and Lighthouse Authorities Convention

Content

Primarily offshore wind but includes criteria applicable to wave and tidal converters.

Country: Ireland Cases: Form Filled out by: ESBI

[Sheet 3] Task 3.3 Impact of the environment: Please specify expected impacts of environmental effects on the WEC's during planning, construction or installation in relation to the topics listed below:				
Topic	Importance		Conclusions	Refs.
	Risk	Effect		
3.3.2.a Sensitivity to sea currents	2	2	Shoreline devices sensitive to orthogonal currents which break up wave patterns	(1)Y/Eng.
3.3.2.b Sensitivity to wind	2	2	Needs consideration at all stages where site investigation, construction operation, maintenance, human access, risk analysis is concerned.	(2) Y/Eng.
3.3.2.c Sensitivity to marine growth	2	2	Not yet clear, reduced efficiency over time expected and remedial action necessary.	
3.3.2.d Sensitivity to material deposits (soil)	2	2	Shoreline converter may be partly blocked by storm movement of deposits. Near shore, offshore device anchors and power cables influenced by bed types.	
3.3.2.e Sensitivity to material deposits (floating trash)	2	2	Shoreline devices may be vulnerable to floating seaweed, jelly-fish, trash. Offshore, near shore devices less so.	
3.3.2.f Risk of corrosion problems	3	2	Prevention measures - simply add to costs.	
3.3.2 g Other environmental impacts....	3	3	Wellbeing of power cable connection from floating devices critical.	
3.3.2 (h)	2	2	Unchallenged designations in areas of habitat, coastal zoning heritage and other special environmental reservations may rule out good sites.	

References

(1) Prof. T. Whittaker, Queen's University Belfast,
(Personal Communication)

(2)Health & Safety at Work Act 1989 and
subsequent regulations

Content

Experience at Islay

9 Appendix 2 Information from Environmental Scoping Study, Orkney

Source: Highland and Islands Enterprise (2001): Environmental Scoping for a Proposed Marine Energy Test Centre, Stromness, Orkney

Table 2.1 Construction of wave test site

Sensitivity	Route sector	Offshore	Landfall	Onshore
Natural resource exploitation				
• Fisheries		Obstruction to local inshore fisheries (creeling and trawling depending on exact timing of construction).	Billia Croo popular beachcombing location.	Potential to interfere with catchment area of the Stromness drinking water supply (the 'water works') during overhead cable installation activities.
• Drinking water supply				
Farming		Area not considered likely for offshore fish farm development.	Use of farmland (fenced grazing) for drilling equipment and construction of building for switchgear equipment.	First section of cable will be installed underground, potentially across farmland. New overhead lines may be installed over farmland. Interference with farming activity and access.
• Fish				
• Agriculture				
Communication		Vessel presence during construction will be an obstruction to well defined navigational channel up the west coast of Mainland.	Increased public access to Billia Croo shoreline.	Interference with local traffic during cable installation along roadways/tracks. Additional traffic on single track roads. Existing tracks will be upgraded.
• Shipping	• Roads			
• Cables				
Natural habitats		Disturbance to seabed from anchoring and/or jack-up of construction vessels, cable connection points, spur manifold and cable installation. Discharge of drill muds and cuttings to seabed at breakthrough during directional drilling.	Small area of wetland located adjacent to the shore at Billia Croo (OS reference HY 102225).	Damage to moorland habitat during the installation of new overhead lines.
• Seabed habitats/communities				
• Onshore habitats/communities				
Wildlife		Disturbance (noise and physical presence) to local fish, seabirds, seal and cetaceans during construction (e.g. piling and drilling).	Potential for some birds to use areas in vicinity of landfall for nesting and feeding.	Installation of new overhead lines through area important for breeding moorland birds (see Conservation). Breeding birds in fields.
• Fish	• Birds			
• Mammals				

Table 2.1 (cont) Construction of wave test site

Sensitivity	Route sector	Offshore	Landfall	Onshore
Conservation value		Offshore test area located in National Scenic Area. Cetacean species protected under EU legislation may be susceptible to noise disturbance at close range.	Directional drilling avoids disturbance to geological/geomorphological features of the Stromness Heaths and Coast SSSI and cSAC. Landfall located in National Scenic Area.	Installation of new overhead lines through Brunt Hill site of local conservation importance for breeding moorland birds. New overhead lines located in National Scenic Area.
Tourism / recreation / local amenity		Sea area off Black Craig used for sea angling. Cliff walk and sea views popular with locals and visitors.	Presence of civil engineering works in view of local inhabitants and visitors to the area. Waste generation e.g. drill cuttings, construction waste, during construction activities.	Presence of overhead line construction works within local amenity areas (e.g. Brunt Hill, the Loons). Increased traffic levels, visual intrusion and noise during construction.
Cultural heritage		<i>Further investigation required to identify if any wrecks present – no charted wrecks.</i>	<i>Archaeological interest noted close to landfall.</i> The ‘naming stone’ (engraved stone with records going back over 3 centuries) is located at the north end of Billia Croo. Billia Croo quarry (OS reference HY 222106) of historical significance for fish fossils.	Archaeological interests noted close to/along proposed cable route. Visual impact from the installation of new overhead lines which will add a new feature to the local skyline.
Other economic interests		Potential positive effect to local economy if local services utilised during offshore construction (e.g. tugs, other vessels). Harbour congestion and presence of ‘unusual’ marine traffic (e.g. jack up rig) in Stromness and other locations in Scapa Flow.	Potential positive effect to local economy if local services utilised during construction of landfall facilities (e.g. building contractors).	Potential positive effect to local economy if local services utilised during overhead line installation (e.g. civil engineers, construction companies, electricians). Potential additional support to improved facilities in Stromness harbour.
Accidental risk		Release of oil based drilling mud and cuttings onto seabed habitat if breakthrough before oil based mud changed out. Floating debris if equipment lost to sea. Seabed debris hazard to fisheries.	Diesel spill, contamination of littoral habitat and shorebird feeding areas. Drilling mud spill. Spillage of drill cuttings during transportation. Uncontrolled drainage into wetland area.	Diesel spill, contamination of moorland habitat and catchment area for local drinking water supply. Run-off of turbid water into water supply during installation of the new overhead lines.

Table 2.2 Operation of wave test site (with devices present, including device installation, maintenance etc)

Sensitivity	Route sector	Offshore	Landfall	Onshore
Natural resource exploitation		<i>Exclusion of creeling and trawling fisheries from a defined sea area.</i>	None.	None.
<ul style="list-style-type: none"> • Fisheries • Drinking water supply 		Vessel obstruction to inshore fisheries during tow out and installation – likely to be regular occurrence as ‘testing’ devices.		
Farming		None.	Permanent loss of small area of farmland (fenced grazing) for the location of the switchgear building.	None.
<ul style="list-style-type: none"> • Fish • Agriculture 				
Communication		<i>Pre installation requirement for devices to be moored in Scapa Flow or at a suitable preparation/pier/work area.</i>	Increased traffic levels.	Increased traffic levels.
<ul style="list-style-type: none"> • Shipping • Cables 	<ul style="list-style-type: none"> • Roads 	Exclusion of shipping from a well defined navigational channel for vessels up the west coast of Orkney Mainland, includes exclusion from test defined area, device itself and vessels during tow out and installation.		
Natural habitats		Disturbance to seabed (e.g. anchors) when devices installed/removed for any maintenance etc.	Damage to wetland area at the back of the shore from any landfall activities.	Any maintenance requirements should be carried out in line with existing Scottish and Southern Energy procedures to minimise disturbance to moorland habitats.
<ul style="list-style-type: none"> • Seabed habitats/communities • Onshore habitats/communities 		Loss of wave energy (altered surf zone/water oscillation behind the devices) from the marine environment due to presence / operation of test devices may result in habitat and community modification (will vary between specific devices) but may experience changes in species density in inter tidal zone.		

Table 2.2 (cont) Operation of wave test site (with devices present, including device installation, maintenance etc)

Sensitivity	Route sector	Offshore	Landfall	Onshore
Natural habitats (cont.)		Pollution of water column from antifoulants, lubricants and hydraulic fluids.		
• Seabed habitats/communities				
• Onshore habitats/communities				
Wildlife		Disturbance (noise and physical presence) to local fish, seabird, seal and cetaceans populations as a result of device operation. Devices that break the sea surface may attract roosting birds and provide a seal haul out. May act as a positive reef effect for local fish populations.	None.	Any maintenance requirements should be carried out in line with existing Scottish and Southern Energy procedures to minimise disturbance to any sensitive species e.g. breeding birds.
• Fish				
• Birds				
• Mammals				
Conservation value		<i>Visibility of devices may impact sea views in National Scenic Area.</i> Cetacean species protected under EU legislation may be susceptible to noise disturbance at close range.	None.	None.
• Designated sites				
• Nominated species				
Tourism / recreation / local amenity		Exclusion of recreational users from a well defined navigational channel i.e. sea angling. Yachting activity likely to increase once Stromness marina established. Exclusion of dive charters from area with potential for scenic diving.	None.	If not a dedicated cable then potential for destabilisation of household electricity supplies along cable route.
• Activities				
• Aesthetics				
• Local inhabitants				
Cultural heritage		<i>Further investigation required to identify if any wrecks present – no charted wrecks.</i>	None.	None.
• Archaeological sites/interests				
• Historical interests				

Table 2.2 (cont) Operation of wave test site (with devices present, including device installation, maintenance etc)

Sensitivity	Route sector	Offshore	Landfall	Onshore
Other economic interests • Standard of living • Lifestyle		Provision of support services from local contractors and employment opportunities. Secondary business opportunities greater than when no devices are present e.g. promotion of marine energy systems.		
Accidental risk	Shipping collision risk. Leak of oils into marine environment. Potential use of explosives as a sinking mechanisms in emergency situation. Entanglement with fishing gear. In the event of failure in national grid connection there will be a requirement for a ‘sink’ for energy still being produced by devices (e.g. pump, heater) depending on sink type there could be a number of associated impacts e.g. heating of local seawater, pumping of seawater.	In the event of failure in national grid connection there will be a requirement for a ‘sink’ for energy still being produced by devices (e.g. pump, heater) depending on sink type there could be a number of associated impacts (e.g. additional building requirements).	Potential for increased incidence of road traffic incidents due to increased traffic levels. In the event of failure in national grid connection there will be a requirement for a ‘sink’ for energy still being produced by devices (e.g. pump, heater) depending on sink type there could be a number of associated impacts (e.g. additional facility requirements).	

Note: The potential impacts created by different devices must be highlighted. For example, terminator systems may alter the surf zone and natural water particle oscillations behind them to a greater extent than perhaps an attenuator or point absorber device (see Appendix 1) would, based on a single device in operation. Attenuators and point absorbers would perhaps only create a noticeable alternation to the surf zone and natural water particle oscillations behind them if they were closely grouped in a wave farm arrangement. Seabed mounted devices may cause considerable more disturbance to the seabed than floating systems. However the visual impact will be reduced if they are not surface piercing.