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# Environmental Impact Assessment: Gathering experiences from wave energy test centres in Europe

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## 6 **Environmental Impact Assessment: gathering** 7 **experiences from wave energy test centres in Europe**

8

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## 33 **Abstract**

34 The wave energy industry is an emerging sector and a new user of maritime space that has  
35 potential to contribute significantly to the EU renewable energy goals. International and  
36 national regulatory frameworks necessitate Environmental Impact Assessments (EIA) that  
37 provide important data to inform development consent decisions. Here we have evaluated  
38 experience related to the assessment programmes at EU wave energy test centres combined  
39 with knowledge gained from EIA produced for other similar renewable energy developments.  
40 From this we have identified key receptors of concern, as well as the type and magnitude of  
41 impacts which may be expected. The key environmental receptors of concern for wave energy  
42 EIA include the physical environment (e.g. morphology, waves and current) and flora and  
43 fauna<sup>1</sup> as represented by marine mammals, seabirds, benthos, fish and shellfish.

44 From a review of the EIAs performed at wave energy test centres, we identified several lessons  
45 regarding the wave energy EIA process. There is clear evidence that the receptors of primary

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<sup>1</sup> The term 'flora and fauna' is used in the Environmental Impact Assessment (EIA) Directive (2011/92/EU consolidated version) – Article 3. The newly amended EIA Directive (2014/52/EU) entered into force on 15 May 2014 and uses the term 'biodiversity' as opposed to flora and fauna.

46 interest are dependent on factors such as the local environmental characteristics, the  
47 presence/absence of protected species and the regulatory authority under which the EIA is  
48 performed. Furthermore, it is recommended that concerns relating to cumulative impacts,  
49 from an expanding level of wave energy development taking place in a background of growing  
50 utilisation of the marine environment, which are largely unknown at this early stage of the  
51 industry may be comprehensively addressed at the national level as part of a Strategic  
52 Environmental Assessment (EIA) and/or in Maritime Spatial Planning (MSP) and that it should  
53 be regularly reassessed.

54

55

## 56 **Keywords**

57 Wave energy; Europe; Test Centres; Environmental Impact Assessment; receptors;  
58 recommendations.

59

## 60 **1 Introduction**

61 The wave energy industry is an emerging sector and, in comparison with more established  
62 industries, is a new user of maritime space. The potential of wave energy to contribute  
63 towards EU renewable energy goals and climate change mitigation have long been discussed  
64 (Cruz, 2008; Falcão, 2008; Clément et al., 2002). However, technical and non-technical barriers  
65 still need to be overcome in order for wave energy to become an established energy source.

66 A particular non-technical barrier experienced across Europe by different device and site  
67 developers is the necessity of this new industry to abide by EU and national regulatory  
68 frameworks for planning and development consents. In particular, wave energy developers  
69 need to comply with the EU Environmental Impact Assessment (EIA) Directive and associated  
70 national legislation, which necessitates the collection and collation of environmental data in  
71 order to enable regulatory authorities to make an informed decision on the proposed project  
72 and its potential environmental impacts at an early stage.

73 In the EU, the EIA process is codified in Directive 2011/92/EU and amended by 2014/52/EU,  
74 which defines the framework for the EIA process. The Directive identifies the projects subject  
75 to mandatory EIA (Annex I), and those for which EIA can be requested at the discretion of the  
76 Member States (Annex II), whereby the national authorities have to decide whether or not an  
77 EIA is needed.

78 The EIA process requires developers to supply comprehensive environmental data relating to  
79 both baseline conditions and possible environmental impacts of device installation. Given the  
80 novelty of wave and tidal energy device deployments, many effects and impacts are unknown  
81 and have not been quantified as yet (Langhamer et al., 2010). This has resulted in a number of  
82 gaps in the information, data and knowledge available to regulatory authorities and  
83 developers. One significant problem constraining wave energy project development is  
84 definition of the scope of the EIA, e.g. what kinds of data are collected, the resolution required

85 for each type of data and the timescale of any subsequent monitoring programme (Muñoz  
86 Arjona et al., 2012). These uncertainties can have a substantial impact on the cost of a project  
87 whilst also possibly causing delays to the project's development.

88 Various studies have been conducted to evaluate the potential change in waves through an  
89 array of wave energy converters (WECs) based on wave propagation and simplified  
90 hydrodynamic models (e.g. Millar *et al.*, 2007; Smith *et al.*, 2012; Rusu and Guedes Soares,  
91 2013). Preliminary studies generally conclude that the change in significant wave height  
92 alongshore due to the presence of an array of wave energy devices is unlikely to exceed a few  
93 percent. The largest effects of absorption will be experienced immediately downstream of the  
94 array where wave energy, period and spreading are most likely to be modified. The combined  
95 effects of wave spreading and diffraction will then lead to reductions in these alterations as  
96 distance from the array increases so that the net effect on distant shorelines can be quite  
97 small. Smith *et al.* (2012) argue that the changes which will eventually be observed are likely to  
98 be overestimated by these simulations due to the high rates of device energy absorption  
99 generally assumed in the modelling.

100 There are both potential positive and negative impacts of wave energy developments on  
101 cetaceans (Witt et al., 2012), and a number of reviews have assessed the potential impacts of  
102 MRE infrastructure on marine mammals (Lucke et al., 2006; Madsen et al., 2006; Simmonds  
103 and Brown 2010; Witt et al., 2012, Inger et al., 2009, Truebano et al., 2013). The main  
104 perceived risks are collision/entanglement, displacement, electromagnetic fields, noise and  
105 cumulative effects. Nonetheless, studies are still scarce and potential impacts have been  
106 largely hypothesised. There is also a high level of uncertainty regarding whether the  
107 documented responses may lead to impacts at the population level (MacLean et al 2014).

108 In recent years, sound from human activities such as shipping, seismic surveys and seabed  
109 drilling have increased the ambient noise level in certain areas (Hildebrand, 2004). Many

110 marine species use sound for communication, navigation, finding prey and evading predators  
111 (see e.g. Richardson et al. 1995) and different species detect and emit sound over a broad  
112 range of frequencies and amplitudes. Because of their dependence on sound, it is possible that  
113 the additional noise added to the underwater environment from the construction and  
114 operation of marine renewable energy devices and farms could have an effect on these  
115 underwater species.

116 Potential environmental impacts of ocean energy have already been identified in a number of  
117 papers and reports (e.g. Inger et al., 2009; Langhamer et al., 2010; Kadiri et al., 2012; Frid et  
118 al., 2012). However, the quantification of the real effects of technologies on the marine  
119 environment are site specific and still need to be assessed during device operation through the  
120 implementation of monitoring programmes. This paper is based on work carried out during the  
121 EU IEE-funded project Streamlining of Ocean Wave Farm Impact Assessment (SOWFIA) and  
122 aims to examine the EIA experience gathered at wave energy test centres across Europe. Key  
123 receptors are identified as well as principal findings from the test centres in order to help  
124 reduce uncertainties and facilitate the performance of EIAs of wave energy projects. Socio-  
125 economic factors are not considered in detail here, but are discussed by Simas et al. (2013).  
126 The term receptors is used to define individual components of the environment likely to be  
127 affected by the development, including flora, fauna, soil, water, air, climatic factors, and  
128 material assets such as the architectural and archaeological heritage, landscape and the  
129 interrelationship between these factors.

## 130 **2 EIA for wave energy test centres in Europe**

### 131 **2.1 Study sites**

132 Six European wave energy tests centres were considered in the SOWFIA project: AMETS in  
133 Ireland (Cahill, 2013), BIMEP in Spain (Marqués et al., 2008), Lysekil in Sweden (Parwal et al.

134 2015), Ocean Plug – Pilot Zone in Portugal (Huertas-Olivares et al., 2007), SEM-REV in France  
135 (Mousslim et al., 2009) and Wave Hub in the UK (Harrington and Andina-Pendás, 2008).

136 FIG. 1 NEAR HERE

## 137 **2.2 Data assimilation**

138 Data gathered from monitoring activities in each test centre have been uploaded to a Data  
139 Management Platform (DMP), an interactive tool designed and developed for the inter-  
140 comparison, benchmarking and analysis of the data collected. The analysis presented in this  
141 paper is based on data from monitoring activities at the six test centres listed above, but the  
142 DMP was also populated with some data available from other European test centres, e.g. the  
143 European Marine Energy Centre (EMEC) in Scotland and the Galway Bay Test Site in Ireland  
144 (Magagna et al., 2012). Data were divided into three main categories:

- 145 • Studies on physical factors (e.g. geomorphology, hydrodynamics and water quality);
- 146 • Studies on biological factors (e.g. benthos, marine mammals, fish and seabirds);
- 147 • Socio-economic information (e.g. relevant stakeholders for each test centre and  
148 information on the impacts of the proposed installation on local communities, data  
149 not considered in this paper).

150 These categories provide a broad envelope for monitoring of the eleven descriptors of Good  
151 Environmental Status (GES) of marine waters included in the Marine Strategy Framework  
152 Directive (MSFD) (JRC, 2011). The context for the type of information that has been reviewed  
153 for each category and test centre is summarised below, including the relevant potential effects  
154 of wave energy farms on the marine environment.

### 155 **2.2.1 Physical factors**

156 Coastal processes involve erosion, transportation and deposition of sediments controlled by  
157 the hydrodynamic pattern in a given coastal area. The removal of energy from the marine



158 environment due to the presence of wave energy devices has been identified as a potential  
159 negative effect of this group of technologies. Changes in the wave energy may influence the  
160 transport of gases, nutrients and food for some species and interfere with the distribution of  
161 others with dispersive juvenile stages reliant on transport by currents (e.g. Nowell and Jumars,  
162 1984; Koehl, 1996; Abelson and Denny, 1997; Gaines et al., 2003; Gaylord, 2008). Furthermore,  
163 the long shore transport of material (and thus the sites where sediment accumulates or  
164 erodes) is dependent on the size and direction of incoming waves. Thus, by reducing waves in  
165 general and particularly those from a specific direction (i.e. downstream of the device), long  
166 shore drift of material and ultimately beach morphology, shallow water bathymetry and  
167 substrata may be altered (Defeo et al., 2009; Shields et al., 2011). Theoretical models of wave  
168 energy farms consisting of 270 devices, with about 200 MW total installed power and moored  
169 in 50 to 70 m water depth off the coast of Portugal, indicated that the significant wave height  
170 at the 10 m depth contour may be reduced by 5 cm, when considering a monthly mean  
171 significant wave height range of 1.3 to 2.9 m. The research also found that the relative  
172 percentage of wave energy removal by the devices will be greatest during the summer (Palha  
173 et al., 2010).

174 In terms of the vessels and equipment used to install and remove wave energy test centres'  
175 infrastructure and wave energy converters, the principal types of substances that pose a risk to  
176 water quality are fuels, lubricants and coolants (used in hydraulic fluids and painting of  
177 devices). Furthermore the seabed disturbance during test centre construction and device  
178 installation (e.g. cable burial and installation of mooring systems) may increase sediment  
179 suspension and water column turbidity decreasing light penetration and interfering with  
180 primary production (e.g. phytoplankton, algae, seagrasses, kelp).

181 **2.2.2 Biological factors**

182 As mentioned above, wave energy devices have the potential to impact marine mammals, and  
183 possible adverse impacts might include collision, entanglement, entrapment, noise, habitat  
184 disturbance and electromagnetic fields as described by Cada et al. (2007), Dolman et al. (2007),  
185 Ortega-Ortiz and Lagerquist (2008). In addition, installation of wave energy developments in  
186 the marine environment will bring new sources of noise, and this may interfere with marine  
187 mammal species that use sound for communication, navigation, foraging and evading  
188 predators (e.g. Richardson et al., 1995; Patrício et al., 2009; Croxall, 1987).

189 The diversity of seabird species utilising European marine, coastal and offshore habitats is  
190 considerable. It is expressed in many forms, including feeding method (from deep diving  
191 species, like gannets, to surface foragers such as petrels), preferred flight heights, migratory  
192 period and selected routes, young rearing behaviour, selection of mates and foraging distances  
193 from breeding colonies (Croxall, 1987, Scott et al., 2014).

194 Due to the lack of information and data, impacts of wave energy devices on seabirds are  
195 mostly extrapolated from those observed in offshore wind farms (McCluskie et al., 2012 ),  
196 although wind and wave energy technologies represent quite different physical stressors  
197 (Langton et al., 2011; Lindeboom et al., 2011). Suggested effects included (negative and  
198 positive) are disturbance (e.g. noise, interference with foraging due to water turbidity increase  
199 during installation), collision, barrier effects to migration, habitat modification (which can  
200 include new roosting and foraging sites), loss and entrapment (Wilson et al., 2007; Witt et al.,  
201 2012; Cruz and Simas, 2012, Grecian et al., 2010). Clearly there are noteworthy differences  
202 between the potential impacts on birds of offshore wind farms and wave energy farms.

203 Collision risks with offshore wind farms, tall static towers or large blades with high tip speed,  
204 cannot be compared to collision risks with wave-energy devices, with different structures  
205 under water and no or only slowly moving parts, but there are also likely to be degrees of  
206 similarity. For example, the effects of disturbance during installation, habitat modification,

207 barrier and displacement effects are likely to show similarities for offshore wind and wave  
208 energy farms, as may future cumulative effects due to the factors mentioned here.

209 Benthos is the community of organisms which live on, in, or near the seabed. In temperate  
210 waters, the intertidal and subtidal hard bottom benthic communities frequently colonise up to  
211 100% of the area of available substratum (Pohle and Thomas, 1997). The benthos is usually a  
212 major consideration in biodiversity conservation since its study helps the understanding of  
213 changes in biological diversity caused by natural or anthropogenic factors. The hydrodynamic  
214 regime, in combination with sediment source, determines the characteristics of seabed  
215 sediment distribution and this ultimately determines a significant part of the broad scale  
216 community patterns observed (Judd, 2012), and so any change in hydrodynamics due to the  
217 presence of wave energy devices may impact benthic communities.

218 The construction and operation of wave energy farms could affect fish and result in changes to  
219 their abundance and distribution close to a wave farm. Such changes can have implications on  
220 fishing activities which need to be assessed (e.g. Simas et al., 2013). The potential impacts  
221 from the development of offshore wave farms on fish include: collision mortality (generally  
222 low risk depending on the technology employed), physical habitat modification, acoustic  
223 trauma and barrier effects due to electromagnetic effects (EMF). Positive benefits may include  
224 structures forming artificial reefs (ARs) and/or fish aggregating devices (FADs) for pelagic fish  
225 (Langhamer et al., 2009).

### 226 **2.2.3 Socio-economic factors**

227 In general the main socio-economic activities identified in the vicinity of the wave energy test  
228 centres under study are fishing, navigation and tourism. Industry is also referred to in some  
229 reports as an important socio-economic activity but impacts of wave energy deployment on it  
230 are all considered positive in terms of sector development in the region and job creation.

231 Socio-economic factors are not considered further here, but are discussed by Simas et al.  
232 (2013).

### 233 **2.3 Review of Environmental Impact Assessment reports**

234 A detailed review of the EIA reports to assess the perceived magnitudes of the impacts on  
235 environmental receptors included in each EIA report for each wave energy test centre were  
236 reported by Simas, et al. (2013). Following on from this we have attempted to homogenise the  
237 perceived magnitudes of these impacts by adopting the following classification across all EIAs:

- 238 • Compatible impact: impact that can recover immediately after cessation of the activity  
239 and that does not need any protective measure(s);
- 240 • Moderate impact: impact that can recover without any protective or corrective  
241 intensive practices and where restoring the initial environmental conditions takes  
242 some time;
- 243 • Severe impact: impact that needs some adequate protective and corrective measures  
244 to restore the initial environmental conditions, which requires significant time;
- 245 • Critical impact: impact whose magnitude is above the acceptable threshold. It  
246 produces permanent impairment of the environmental conditions.

## 247 **3 Comparison of EIA for wave energy test centres in Europe**

248 Table 1 shows the type of monitoring studies carried out in each wave energy test centre  
249 under study. It can be seen that the benthos is the most common EIA component and is  
250 characterised in all test centres, followed by hydrodynamics and marine mammals, which have  
251 been studied in five test centres.

252 TABLE 1 NEAR HERE

253 Although common components are identified among test centres' EIAs, a large variance in the  
254 evaluation of potential impacts is evident. Table 2 highlights the variation in evaluation of  
255 impacts between test centres. This depends on a complex combination of factors, discussed  
256 further below, including: the environmental conditions at each site, the presence of protected  
257 species and habitats and the location of each site relative to protected areas. It should be  
258 emphasised that these are potential impacts identified in the test centre EIAs before  
259 deployment of any devices and are not observed impacts. The different evaluations of  
260 potential impact at each site is partly due to different approaches in consenting authorities as  
261 well as site specific biological and/or socio-economic characteristics between the included  
262 countries and the test centres.

263 Furthermore, the consenting process may have differences even within a country and these  
264 processes are likely to evolve as the industry develops. For example, when Uppsala University  
265 applied for permits and consent for the Lysekil project (Parwal et al. 2015), the Swedish  
266 Environmental Law was still quite new and there was provision for small projects to be  
267 developed without the need to undertake an extensive EIA. The team at Uppsala University  
268 were able to agree with the authorities, based on best knowledge, on which pre-construction  
269 and post-construction studies would be valuable and should be undertaken (Haikonen et al.,  
270 2013, Langhamer et al., 2009). However, the provision for small projects changed by the time  
271 the application was made for the ten year consent to be extended in 2013, and in this case, a  
272 full scale EIA was required with specified studies as included in Table 1.

273 TABLE 2 NEAR HERE

274 In Ireland, in the EIA for the AMETS test centre (Cahill, 2013), the receptors considered for the  
275 physical environment were water quality and groundwater, physical processes, air quality and  
276 climate. The impacts on water quality and groundwater were considered to be moderate  
277 because the main effects are expected from suspended sediments during cable burial and

278 anchoring operations; the impact on the physical processes was taken as compatible because  
279 it is expected that the impact of wave energy converters when deployed at the test area would  
280 be insignificant in comparison to the natural processes occurring; the impact on the air quality  
281 and climate was deemed compatible both in the national context and in the immediate  
282 receptor area.

283 Within flora and fauna, the environmental receptors assessed at AMETS were marine  
284 mammals, seabirds and benthos. The impact on the marine mammals was classified as  
285 moderate because, although the construction phase is likely to be the most disruptive to  
286 marine mammals due to increased noise and boat traffic, they are expected to return to the  
287 area once construction has been completed. Operational impacts are not deemed to be  
288 significant. The potential impacts on seabirds, which came from physical disturbance, risk of  
289 collision and noise disturbance, are speculative and they are expected to be minimised so the  
290 cumulative impact was classified as moderate. The general effects of the development on  
291 benthos, due to increased sediment transportation, is unlikely to have any more effect than a  
292 natural storm. The greatest potential impact in this regard is due to the creation of an artificial  
293 reef, which can on one hand increase biodiversity in the area, but on the other may fragment  
294 benthic communities. Nonetheless the extent of this was expected to be small in the context  
295 of the total available habitat so the impact was classified as moderate.

296 In Spain, at the BIMEP test site (Marqués et al., 2008), the receptors assessed within the EIA  
297 regarding the physical environment were water quality, groundwater and physical processes.  
298 The impact on the water quality and groundwater was considered compatible because the  
299 possible damage caused to the water during the installation, functioning and decommissioning  
300 of the WECs is considered minimal; the impact on the physical processes was severe because  
301 the device moorings were not expected to be removed following the testing period, but  
302 instead would remain in place.

303 For the flora and fauna the descriptors considered by BIMEP were marine mammals, seabirds,  
304 fish/shellfish and benthos. The impact on the marine mammals was assessed as severe  
305 because of the vibrations and noise produced mainly during the installation and  
306 decommissioning of the WECs and cables and, to a lesser extent, during the operation of the  
307 WECs. The impact on the seabirds was moderate because the birds can be affected by noise  
308 and vibrations during the installation, operation and decommissioning of both cables and  
309 WECs. Potential impact on the fish and shellfish due to vibrations and noise of installation and  
310 decommissioning was classified as moderate as was the impact due to electromagnetic fields.  
311 Research has identified the biological significance of electromagnetic fields to certain marine  
312 species (Gill et al., 2012), and although there has been no documented evidence of significant  
313 behavioural effect on a species level from existing installations, this uncertainty has led the  
314 authors of the EIA report to judge the potential impact as moderate whereas at other sites it is  
315 considered compatible (Conley et al. 2012). BIMEP's EIA required an *in situ* analysis of the  
316 electromagnetic fields generated by the subsea cables to be carried out to try to assess the  
317 real impact. The EMF study at BIMEP includes: modelling of the cable and its electromagnetic  
318 fields; design of the appropriate sensors to determine the magnetic and electric fields;  
319 measuring the electromagnetic fields generated by the subsea cable when buried, when lying  
320 on the seabed, and generated by connection boxes and the connectors. The increase in  
321 suspended sediments in the water was deemed a moderate impact on benthos while the  
322 dragging of the mooring and/or the anchors was considered a severe impact.

323 The Swedish test site, Lysekil (Parwal et al. 2015), deemed the overall impact on the physical  
324 environment, including water quality, groundwater and physical processes, compatible  
325 because both the increased sedimentation and the bio-fouling effect around and nearby the  
326 WECs were considered to be localised and could be equated with other, similar and common  
327 natural occurrences. For the flora and fauna category, the impacts on marine mammals,

328 seabirds and benthos was considered compatible: in fact the Lysekil site and its surroundings  
329 do not host species of special interest or at least none that would be affected by the project.

330 At the Portuguese test centre Ocean Plug (Huertas-Olivares et al., 2007) only the flora and  
331 fauna sensitivities were assessed and the impacts were deemed severe on both marine  
332 mammal and seabirds because of the presence of endangered species which can possibly be  
333 affected by the deployment and operation of wave energy devices. This example highlights the  
334 dramatic effect that project siting can impart on the EIA process.

335 The EIA analysis carried out to assess the potential impacts at the French SEM-REV test centre  
336 (Mousslim et al., 2009) under the physical environment includes water quality, groundwater  
337 and physical process parameters. The impact on water quality and groundwater was moderate  
338 because the water quality alteration due to fluid industrial waste and turbidity was deemed  
339 moderate and temporary using conventional mitigation measures. The impact on the physical  
340 processes was compatible because the modification of sedimentary dynamics was deemed  
341 moderate to negligible due to the limited footprint of impacted area, the low number of  
342 anchors and the weak nature of local sediment transport. For the flora and fauna, the  
343 receptors considered were marine mammals, seabirds, fish and shellfish and benthos. The  
344 impact on marine mammals, seabirds and fish and shellfish has been classified as compatible  
345 because disturbance during installation and operation is considered negligible due to the short  
346 duration of the works and limited number of WECs to be tested. Noise and electromagnetic  
347 effects are given as moderate to minor/negligible assuming the use of suitable mitigation  
348 measures, such as cable burying. The impact on the benthos was compatible, because the  
349 destruction of benthic species and micro and macro algae on the submarine cable route and  
350 on the test site itself, has been classified as reversible and negligible.

351 At Wave Hub in the UK (Harrington and Andina-Pendás, 2008), under the physical environment  
352 category, water quality, groundwater and physical processes were included. The EIA



353 documentation indicated that the impact of the site on water quality and groundwater was  
354 compatible. This is because the survey of water and sediment quality carried out to determine  
355 the baseline showed that no impact on water, soil or sediment quality will take place during  
356 construction, operation or decommissioning. The impact on the physical processes was  
357 compatible, because results of modelling showed that waves at the coast could be impacted  
358 by up to 13%, but more typically in the order of 5% (Smith et al., 2012), and a minimal impact  
359 due to changed sediment transport on beaches could be expected along the northern Cornish  
360 coast.

361 Considering flora and fauna, assessed receptors were marine mammals, seabirds, fish and  
362 shellfish and benthos. The impact on marine mammals was compatible, because the  
363 installation of WEC anchors or moorings is likely to involve either pile driving or seabed drilling  
364 for some types of WEC (Witt et al., 2012). The impact of construction noise on marine  
365 mammals was considered to be of minor adverse significance, the impact on the seabirds was  
366 compatible, because no significant impacts on all birds present at the site are expected if  
367 appropriate mitigation measures are employed. Regarding fish and shellfish the most  
368 frequently recorded sensitive species is the basking shark and the main impact of concern was  
369 the electromagnetic fields generated by cables which were considered unlikely to cause  
370 damage. Nonetheless, considering the sensitivity of the species, the impacts were deemed  
371 compatible. The impact on the benthos was compatible because any disturbance to intertidal  
372 seabed communities from installation and decommissioning of the cable was considered to  
373 have minimal impact due to rapid re-colonisation of the surrounding seabed.

#### 374 **4 Discussion of similarities and differences observed**

375 This review of EIA in the six European wave energy test centres highlights some clear  
376 differences and inconsistency among test centres. It should be noted that the EIA reports are  
377 analysed to assess perceived impacts on receptors and are not 'real' impacts. Evaluations of

378 the severity of potential impacts given in the EIAs varies between different test centres partly  
379 due to different approaches in consenting authorities as well as biological/socio-economic  
380 differences. One observation evident from the review is the pronounced role that the  
381 presence of protected species plays in the EIA process. In the case of the Ocean Plug test  
382 centre, the presence of endangered species led to the potential impact on receptors (marine  
383 mammals and seabirds) being assessed as severe, whereas in all other test centres critically  
384 endangered species were not deemed present and the potential impact on marine mammals  
385 and seabirds was assessed as moderate or compatible.

386 Another aspect is the variability of sensitivity to various receptors under different regulatory  
387 regimes. Five of the seven selected receptors were not assessed in at least one centre and not  
388 one test centre assessed all of the receptors in its EIA. Another aspect highlighted in this  
389 review is that the potential impacts identified in the EIAs for essentially similar projects are  
390 different and shown to be dependent on the local environmental/political/regulatory  
391 landscape. This is demonstrated by the fact that six test centres, which may host the same  
392 device types, exhibit impact magnitudes for the same receptors ranging from compatible to  
393 severe. Potential impacts on air quality, climate, water quality and groundwater are uniformly  
394 perceived as having the lowest magnitude followed by physical processes. With one exception,  
395 potential impacts from EMF were not considered significant across the test centres. This  
396 classification usually exempts these impacts from the monitoring plan after deployment. In  
397 cases where cumulative impacts of several devices for a given component are important, their  
398 absence from the monitoring program may compromise the learning process for upscaling of  
399 impacts regarding large scale developments.

400 Key environmental receptors of potential concern for wave energy EIA are considered in this  
401 work. These receptors fall into one of two categories: the physical environment (waves and

402 currents, coastal morphology) and flora and fauna, particularly benthos and marine mammals  
403 (Conley et al. 2012).

404 As regards hydrodynamics (waves and currents), the existing understanding is that arrays of  
405 wave energy devices will lead to alterations in the energy level and spectral nature of incident  
406 waves in the lee of such arrays but that these effects will diminish with distance from the  
407 arrays. Preliminary studies suggest that a magnitude of change of no more than 10% can be  
408 expected.

409 As regards noise impacts, limited measurements from deployed WECs confirm that the  
410 emitted noise is likely to be limited to frequencies below a few tens of kHz, that the signal  
411 strength varies with sea state and that the noise emitted would be detectable by some marine  
412 species.

413 The limited experience to date regarding the impact of MRE devices on marine mammals  
414 suggests that these animals may avoid such devices but further experience with different  
415 technologies in different settings is needed. Experience with nets and static (but slack) fishing  
416 gear indicates that entanglement is a potential issue although the risk associated with wave  
417 energy devices is likely to be much lower than with other MRE technologies, such as tidal  
418 turbines where collision is a potential issue. The risk is potentially aggravated by the increased  
419 availability of food arising from the potential FAD (fish aggregating devices) potential of WECs.  
420 Because of the highly mobile nature of marine mammals, cumulative effects from increasing  
421 MRE developments as well as other anthropogenic activities are of special concern and must  
422 be carefully considered in the planning stages of a new development.

423 WECs have a much smaller above-water profile than wind turbines, and so are likely to present  
424 a much lower collision risk to seabirds than offshore wind, but their considerable underwater  
425 structure may provide an enhanced collision or entrapment risk, particularly their moving

426 parts. The most likely direct impact of WECs on birds is displacement. Species that are  
427 restricted to foraging in specific habitats may be particularly vulnerable, but sensible site  
428 selection to avoid sensitive foraging areas will help mitigate possible population impacts.

429 The experience provided from test centre EIAs suggests that the effects of the deployment of  
430 wave energy converters on coastal processes and geology would be insignificant in comparison  
431 with the natural processes occurring at the sites. Similarly, seabed disturbance from  
432 construction is generally considered to be local, temporary and similar in magnitude to  
433 common natural occurrences in the marine environment. These are the main reasons why  
434 impacts on benthos are sometimes considered local and limited to the devices' footprint on  
435 the seabed (e.g. mooring and anchoring systems).

436 Wave energy developments have potential to exhibit the same advantages as fish aggregating  
437 devices, artificial reefs and no-take zones. At the Swedish Lysekil test centre, WECs were  
438 judged to exhibit clear features of artificial reefs (ARs), with expected positive effects. The  
439 ability to design the WECs actively to enhance this effect was successfully demonstrated.

## 440 **5 Conclusions**

441 The review of the EIA documents produced shows that the receptors of primary interest are  
442 dependent on factors such as the local environmental landscape, the presence/absence of  
443 protected species and the regulatory authority under which the EIA is requested. It should be  
444 emphasised that the environmental impacts discussed here are potential impacts identified in  
445 the test centre EIAs and are not observed impacts.

446 A matter of concern in the assessment of environmental impacts is the cumulative impact  
447 from an expanding level of wave energy development taking place against a background of  
448 growing use of the marine environment (Maclean et al 2014). While there is some room for  
449 developers to partially mitigate this impact in the early stages of project development, this is a

450 complex matter which is both technically and financially largely beyond the ability of any single  
451 developer to address adequately. For this reason, it is suggested that, although necessarily a  
452 component of individual project assessments, the issue of cumulative impacts should be  
453 comprehensively addressed strategically at the national level as part of SEA and/or in Maritime  
454 Spatial Planning and that it should be regularly reassessed.

455 It is clear that a large amount of scientific work is intrinsic to establishing the definitive effects  
456 and impacts of wave energy devices on the marine environment. Currently the majority of  
457 wave energy devices are deployed in dedicated test centres on a time limited and single unit  
458 basis. This limits the utility of the environmental information recorded and can result in effects  
459 and impacts being hypothesised only. To address this there is a need for a number of specific  
460 actions:

- 461 1. A dedicated research agenda for monitoring the environmental effects of devices on  
462 the marine environment and its communities;
- 463 2. Sharing of environmental data across disciplines and increased dissemination of EIA  
464 and related data so that knowledge of impacts can be developed;
- 465 3. Increased deployments of [multiple] devices in real sea conditions so that the  
466 hypothesised effects and impacts can be proved or disproved;
- 467 4. Standardised monitoring across test centres.

468 Whilst there will always be variation in the parameters considered during the EIA process, due  
469 to its site specific nature and cultural perception of risk, it would be advantageous to ensure  
470 consistency between methodologies used in measuring and monitoring environmental  
471 parameters. The existence of test centres should facilitate such an approach given the same  
472 devices are often tested in different test centres. Indeed, test centres have a key role to play

473 in providing environmental data and evidence on positive and negative impacts of early stage  
474 wave energy device deployments that will help inform future development of the industry.

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639

640 **Tables**

641 Table 1 - Type of monitoring studies carried out in each wave energy test centre analysed.

	Test centres	AMETS	BIMEP	Lysekil	Ocean Plug	SEM REV	Wave Hub	Total
Receptors	Country	Ireland	Spain	Sweden	Portugal	France	UK	
Physical	Bathymetry			✓		✓	✓	3
	Geomorphology	✓			✓	✓	✓	4
	Hydrodynamics	✓	✓		✓	✓	✓	5
	Acoustics/Noise		✓	✓			✓	3
Biological	Benthos	✓	✓	✓	✓	✓	✓	6
	Fish & Shellfish		✓	✓			✓	3
	Plankton studies						✓	1
	Marine Mammals	✓	✓		✓		✓	4
	Sea birds	✓			✓		✓	3
Socio economic	Landscape/Visual	✓					✓	2
	Archaeology			✓			✓	2
	Navigation						✓	1
	Fisheries	✓			✓		✓	3
	Economics						✓	1
	Tourism						✓	1

642

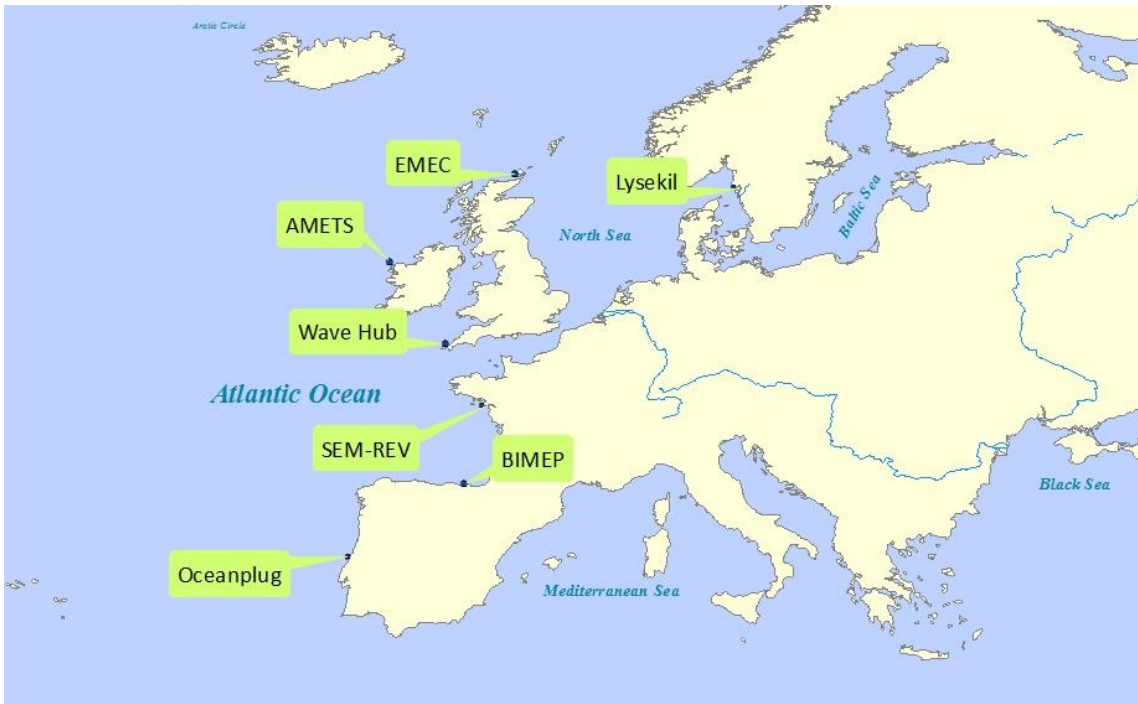
643

644 Table 2 - Impact magnitudes for different environmental receptors as reported in the EIAs of  
 645 each European test centre (Conley et al., 2012). Co: Compatible; M: Moderate; S: Severe; Cr:  
 646 Critical; N/A: Not Applicable.

Receptors		AMETS	BIMEP	LYSEKIL	OCEAN PLUG	SEM REV	WAVE HUB
Physical	Water quality and ground water	M	Co	Co	N/A	M	Co
	Physical processes	Co	S	Co	N/A	Co	Co
	Air quality and climate	Co	N/A	N/A	N/A	N/A	N/A
Biological	Marine mammals	M	S	Co	S	Co	Co
	Seabirds	M	M	Co	S	Co	Co
	Fish and shellfish	N/A	Noise: M	Co	N/A	Co	Co
			EMF: M				
	Benthos	M	Increased turbidity: M	Co	N/A	Co	Co
Anchors and moorings' dragging: S							

647

648 **Figures**



649

650 Fig. 1 - Location of the wave energy test centres in Europe.