

Blue Growth

Scenarios and Drivers for Sustainable Growth from the Oceans, Seas and Coasts

Maritime Sub-Function Profile Report 3.3
"Ocean Renewable Energy Sources"

Call for tenders No. MARE/2010/01

Client: European Commission, DG MARE

Rotterdam/Utrecht/Brussels, 13 September 2012

Wc



Contents

Contents	3
Summary description	4
1 State of Play	5
1.1 Description and value chain	5
1.2 Description of the current structures	8
1.3 Regulatory environment	9
1.4 Strengths and weaknesses for the sub-function	11
2 Research and technology	13
2.1 Research projects	13
2.2 Technological developments	13
2.3 Patent applications	17
3 Future developments	19
3.1 External drivers and key factors affecting the performance of the cluster	19
3.2 Assessment of response capacity and commercialisation potential	21
3.3 Most likely future developments	22
3.4 Impacts, synergies and tensions	23
4 Role of policy	27
4.1 Policy and political relevance	27
4.2 Domains for EU policy	27
Annex 1 Bibliography	31
Annex 2 Stakeholder catalogue	33
Annex 3 Case studies	35
Case 1: Paimpol-Brehat site, Brittany, France	35
Case 2: EMEC Test centre	36
Annex 4 Overview of most relevant research projects	39
Annex 5 Table of cross-links and synergies	40

Summary description

Energy from our oceans and seas can be produced with a broad range of technologies. This report will in particular look at wave, tidal, OTEC (Ocean Thermal Energy Conversion) and osmotic energy, here grouped under the term 'ocean renewable energy'. The report will not look into offshore wind energy nor into biofuels applications (e.g. algae). Those two technologies are covered in the function profiles on offshore wind and algae growth.

Several factors are encouraging the development of these technologies: various types of EU and national policies, a desire to become less dependent on imports of fossil fuels, the level and volatility of the prices of fossil fuels and an increase in energy demand.

The ocean energy industry is still at an early stage of development. However, increasing political support, high resource potential and possible synergies with other maritime industries are raising the industry prospects for growth. In this global competition, European companies are preparing themselves to lead the world in tidal and wave energy in particular – with the UK at the forefront of developments, and to a lesser extent Norway, Denmark and Ireland. All these sources are based on a wide range of technologies and at the same time, Though most are still in the demonstration and pilot project phase, some are preparing the steps towards commercial application.

The domains in which a clear role for EU policy initiatives have been identified are:

- development of an integrated policy framework;
- skills development, securing qualified personnel;
- support and coordination of Research, Development & Demonstration;
- creating a stable ocean energy market.

1 State of Play

1.1 Description and value chain

Ocean renewable energy consists of a package of four different offshore energy segments:

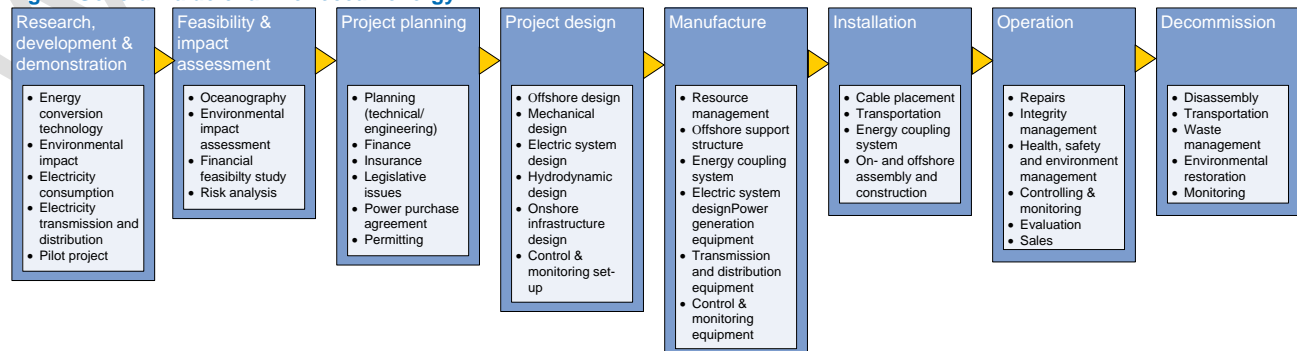
- Tidal energy. electricity that is generated using the energy stored in the tidal movement of water. The tidal movement contains two types of potential energy: the potential energy related to the continuous change of the water level during the tidal cycle (*tidal range energy*), and the kinetic energy in the currents caused by the tides (*tidal current energy*).
- Wave energy is electricity that is generated using the energy stored in the waves in oceans and seas, which are generated by wind.
- Osmotic energy is based on the salinity gradient between salt and fresh water. Technology cannot yet be considered proven; the segment is not yet in its commercialisation stage. Problems to be solved are in the field of prevention of fouling and pre-treatment;
- OTEC (Ocean Thermal Energy Conversion) is based on the thermodynamic potential between the warmer upper water layer and the colder deeper water layer.

In the long term, ocean energy has the potential to satisfy 15% of the European electricity demand (European Ocean Energy Association, 2010) and in some countries, such as the UK, wave and tidal resources can even provide up to 20% of national demand.

For the wave and tidal sector, a large number of devices are under development across Europe. So far, no particular design has emerged as clear front runner for large scale commercial development. The various technologies are at different stages of development with some prototypes currently being tested at full scale and commercial projects expected in the near future. For OTEC and osmotic power, a limited number of projects are currently being developed with again no clear technological development in sight.

In the value chain below, all relevant elements and activities in the whole sector of ocean energy are depicted. The value chain as portrayed here, roughly coincides with the stages that the installation of an ocean energy project goes through. However, a value chain is aiming at creating insight in all activities and types of employment that is associated – both directly and indirectly – with all elements in an industry or sector.

Fig. 1. General value chain for ocean energy



1.1.1 Wave energy

Ocean waves harbour vast amounts of energy. The size of the waves is determined by the wind (speed, period and fetch), bathymetry of the seafloor (which can focus or disperse the energy of the waves) and currents. Waves have the potential to provide a completely sustainable source of energy which can be captured and converted into electricity by wave energy converter machines.

For Europe, extensive research has been undertaken. The IEA-RTD (2011) estimates the potential wave energy capacity to be in the region of 320 GW. The potential wave energy capacity for the North-Eastern Atlantic including the North Sea has been estimated to be about 290 GW. The deep water capacity of the European coast of the Mediterranean Sea has been assumed to be in the order of 30 GW.

Research and development is focusing on some inherent problems to be tackled in the conversion of the movement of the water particles into electrical energy.

- In order to maximise energy conversion efficiency, the device has to be well adjusted to the most common range of periods of waves.
- For techniques that require a dominant wave direction, it is also important that they are placed in locations with a relatively constant main wave direction.
- The construction must be built very robustly, so that the heaviest storms cannot cause any damage. Because storm conditions do not match the optimal range, energy production under such circumstances is less favourable.

Wave energy is still facing R&D challenges to be overcome before commercialisation comes into view. Technologies are not yet proven. Research is looking to cut down installation and operating costs. Several pioneering players have built up a prominent position over the past 10-15 years, while new entrants are arriving today indicating the segment is entering the market phase (introduction).

An up-to-date report on wave energy is the Waveplam project (Waveplam, 2011). It covers the state of the art of available technologies, particularly those that have performed sea trials. In addition, the development strategy they have followed – including non-technical barriers – have been included as well. The report also contains a list of existing and proposed best practices to overcome the identified barriers. For example, best sites for ocean energy are often located in remote areas where the availability of the grid capacity can be a constraint, requiring additional installations such as transformer stations and grid connection points. This could make this type of energy extraction relatively costly compared to the amounts of energy that can be gained.

1.1.2 Tidal energy

Tidal range energy

With tidal range energy, a water level difference is created by restricting the water flow in or out of a storage basin. Dams or barriers usually form the boundary of these storage basins. The turbines that extract the potential energy are placed in the barrier that encloses the storage basin. The storage basin can be a natural part of the water system, such as an estuary or an inland sea arm, or can be man-made. Tidal range is the only technology with long-term proven viability, but we

consider the environmental implications of any new schemes to be prohibitive, at least in the European seas.

Tidal current energy

The other way of extracting energy from tides is to use the tidal current energy directly. Energy in currents can be harvested by free-flow driven turbines. The devices are placed directly “in-stream” and generate energy from the flow of water. There are a number of different technologies for extracting energy from marine currents, including horizontal and vertical-axis turbines, as well as others such as venturitis and oscillating foils (IEA, 2010). For the European potential tidal current capacity the IEA (2011) estimated a figure of 14 GW. Tidal current has proven to be technically feasible but costs are still too high to compete with other (renewable) energy sources. It is at the threshold of introduction.

1.1.3 Osmotic energy

Osmotic energy is a source of energy that can be won by the difference in salt concentration between seawater and fresh water. In areas where fresh and salt water meet, salinity gradients are present. These salinity gradients can be turned into energy. The steepness of the salinity gradient is a key factor here. This excludes estuaria, because of the long range over which fresh water and sea water are mixed. Favourable locations are those with a steep gradient, such as barrier dams and the fjords in Norway.

The potential of this source is estimated at 0.7 MW per m³/s discharge of fresh water. In the Netherlands (with the Rhine as major source), this would result in a production of 60 TWh (Deltares 2010). Statkraft's studies indicate that the theoretical potential for osmotic power in Europe amounts to some 180 TWh per year (Statkraft, 2011).

In the field of osmotic energy, important players are Statkraft in Norway and Redstack/Wetsus in the Netherlands. Statkraft is planning to install the first MW capacity in 2014 - this date has not been postponed over the past two years. The technology can be considered as proven, though it is not yet in a commercial stage. Problems to be solved are in the field of prevention of fouling and pre-treatment. Redstack/Wetsus are planning an osmotic power pilot in the Afsluitdijk barrier dam, the Netherlands.

An interesting development is the combination of osmotic power with desalination plants. Minerals are removed from the water, which then becomes usable for drinking water and irrigation. Simultaneously, electricity is generated, thereby killing two birds with one stone. The brine flow that is discharged by desalination plants provides a potential source of energy due to the high salinity gradient between the brine and the receiving waters. Research on these possibilities is carried out under the FP7-project REAPOWER

1.1.4 Ocean thermal energy conversion

The heat stored in oceans and seas can be used to generate electricity. This technique is called Ocean Thermal Energy Conversion (hereafter: OTEC). Basically, OTEC is driven on a thermodynamic potential between the warmer upper water layer and the colder deeper water layer. The larger the difference between the two layers, the better OTEC works. Regions with the largest temperature difference are found in the tropical coastal areas, where the upper layers can reach average temperatures of 25°C, and the layers at 1 kilometre depth or more have a temperature of 4°C. Obviously, such regions are not present in Europe. That does not mean, however, that the EU cannot employ this technique elsewhere (Sorensen and Weinstein, 2008).

OTEC are in an early phase of development, but several demonstration projects have been realised the last decades. Examples can be found in Hawaii, Brazil, the Caribbean, West coast of Africa and Japan.

1.2 Description of the current structures

There is an increasingly active industry evolving around ocean energy, both in terms of technical development and in commercial planning. Most activities are taking place in Europe, USA, Canada, Australia and South Korea. Europe is leading the way in the development of technologies for wave and tidal current devices in particular.

There is no significant activity in South America, Africa, Russia, Asia and China, although the latter two have potential wave and tidal resources. Asia, with its increased energy demand, holds an enormous market potential for ocean energy projects.

The United Kingdom, and more specifically Scotland, has a significant lead over other countries in developing the ocean energy potential. Ocean energy resources are being recognised and required technologies are being developed. There is an active licensing program on-going by the Crown Estate to prepare for the installation of commercial scale arrays ranging from 10 to 200 MW.

Globally, the highest energy potential can be found in wave energy conversion (WEC). However, so far most progress has been made in tidal applications. Whilst the developers in the WEC field are looking for working solutions, the Tidal Energy Conversion (TEC) solutions are seemingly already looking to cut down installed & operating costs in preparation for the first small array solutions. It is noted, however, that long term reliability and performance has not yet been demonstrated.

Both in tidal and in wave energy, there have been a number of pioneering players who have built up a prominent position over the last 10 to 15 years. Examples of such companies, which have large devices operating offshore, are Marine Current Turbines (tidal, UK), Hammerfest Strom (tidal, Norway) and Pelamis Wave Power (wave, UK). An overview of recent initiatives and related technologies is presented in chapter 2.2.1.

After this initial phase a group of technology developers in the field of wave and tidal energy came into existence. They received specific attention, support and funding from the key industry players in the (hydro) power generation market (such as Alstom Power, Siemens, ABB, Andritz Hydro, Voith Hydro, Bosch Rexroth and Rolls Royce). Through this industrial support and available expertise, these new technology developers are catching up quickly and making significant progress. These companies are progressing to install their first large scale devices within the coming two years.

Various European developers and utilities are present in the UK and are preparing or executing commercial scale demonstration tests. The European Marine Energy Centre (EMEC) Ltd is the most prominent test facility in the world with readily available test berths for both tidal and wave testing. At various other locations in Europe, testing sites or prototype projects are being developed. For example, two tidal mini-array projects with a combined total of 2.5 MW are planned in the Netherlands, involving the Wave Rotor technology (3x500 kW) and the Tocardo turbine (6x150kW). EDF is planning to install a small array (4-6 MW) of Open Hydro tidal turbines off the coast in Brittany, France. Both Portugal and Spain are promoting and planning test facilities for wave energy devices. Outside Europe, the Bay of Fundy in Canada is the most prominent location for tidal energy projects. See also the overview in chapter 2.2.1.

According to the IEA, around 1 TWh of electricity was generated by tidal and wave energy technologies in 2010 (IEA, 2011). This contribution remains marginal in comparison with the total EU electricity demand of 3325 TWh or against the estimated potential for wave energy. In 2010, the total installed capacity of ocean energy is 3.4 MW (Renewable UK, 2011).

In the field of *tidal range energy*, despite considerable concept development and investigations into both tidal barrages and tidal lagoons in the UK, no scheme has yet been constructed there. The few 'on the ground' examples that do exist are from elsewhere in the world (see table 1), including La Rance (France) and Annapolis Royal (Bay of Fundy in Canada). A few much smaller schemes also exist in Russia (Kislaya Guba) and China (Jiangxia), although information about these is scarce. At present, a tidal barrage project with a 254 MW capacity plant is under construction in Korea (IEA, 2010).

Table 1. Some characteristics of tidal energy schemes (after Royal Haskoning, 2009 and IEA, 2011)

Country	Location	Installed Power (MW)
France	La Rance	240
Russia	Kislaya Guba	0.4
Canada	Annapolis	18
China	Jiangxia	3.9
S. Korea	Sihwa	254 (under construction)

1.3 Regulatory environment

1.3.1 European objectives

European energy policy has pushed forward the agenda on sustainability, competitiveness and security of supply the last decade. All those efforts were translated in 2008 and 2009 into legislation aiming at achieving major changes in energy supply and energy use in Europe, in particular the commitment to deliver the '20-20-20' targets on greenhouse gas emissions, renewable energy and energy savings. The '20-20-20' targets are:

- A reduction of greenhouse gas emissions by 20%;
- An increase in the share of renewable energy to 20% of the energy mix; and
- An improvement of 20% in energy efficiency.

In order to achieve these goals, the EU has set out some priorities and action points for this strategy. The main five priorities of the strategy focus on:

1. ensure a well-functioning energy market
2. improve the interconnection of energy networks
3. enhance energy supply security
4. promote the use of renewable energy
5. increase energy efficiency

1.3.2 European legislation

The most relevant measures regarding ocean energy are (EC, 2011):

- Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (EC, 2009).

- Regulation (EC) No 663/2009 of the European Parliament and of the Council of 13 July 2009 establishing a programme to aid economic recovery by granting Community financial assistance to projects in the field of energy. (EC, 2009)
- Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC (EC, 2009).
- Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 concerning greenhouse gas emission trading systems. This Directive states that at least 50% of the proceeds from the auctioning of allowances should be used amongst others, to develop renewable energies (to achieve the 20% renewable energies target by 2020). In addition, it states that: *“to accelerate the demonstration of the first commercial facilities and of innovative renewable energy technologies, allowances should be set aside from the new entrants reserve to provide a guaranteed reward for the first such facilities in the Union for tonnes of CO₂ stored or avoided on a sufficient scale, provided an agreement on knowledge-sharing is in place.”*
- Further relevant European legislation is the European Water Framework Directive and the European Fisheries Directive, EU Marine Strategy and the European Habitat and Birds Directive (Natura 2000).

The Renewable Energy Directive (Directive 2009/28/EC on the promotion of the use of energy from renewable sources) established for the first time binding targets at Member State level, both for the overall share of renewable energy and the share of renewable energy in transport. It also established framework conditions that will ensure that these objectives are achieved in an efficient and sustainable way. The first round of reporting from Member States under the Directive (the "forecast documents" of December 2009) showed that collectively Member States should over-achieve the share of 20 % renewable energy in 2020 required by the Directive. More recently, the development of National Renewable Energy Action Plans of the member states have included plans for wave, tidal and ocean energy Beurskens and Hekkenberg (2011). Their findings for countries (with data above zero production) are summarised in Table 2. According to these data, strong growth is expected in the period 2015-2020. Especially the UK has ambitious goals.

Table 2. Projected tidal, wave and ocean energy electricity generation in GWh for the period 2005-2020 (after Beurskens and Hekkenberg, 2011).

	Projected electricity generation in GWh			
	2005 (real)	2010	2015	2020
Ireland	0	0	0	230
Spain	0	0	0	220
France	535	500	789	1150
Italy	0	0	1	5
Portugal	0	1	75	437
United Kingdom	n.a.	2	10	3950

1.3.3 European funding

Ocean energy, as it is a renewable energy technology, can receive funding from a diverse set of programmes from the EU. All these programmes pursue different objectives, demonstration, or removal of barriers. They are listed in the table below.

Table 3. Different European ocean energy funding programmes (Ecofys, 2011).

Programme	Finance instruments	Geographical scope	Budget allocated in 2009 (for RES)	Start date – end date	Type of projects
Intelligent Energy Europe (IEE)	Grant support	Member States, Norway, Iceland, Liechtenstein and Croatia	€ 19 million	2007 - undecided	Capacity building
European Local Energy Assistance (ELENA; part of IEE)	Grant support	Member States, Norway, Iceland, Liechtenstein and Croatia	€ 15 million	2009 - undecided	Technical assistance and project development
Seventh Framework Programme Energy (FP7)	Grant support	Member States	€ 150 million	2007-2013	RD&D
EU Recovery Programme	Grant support	Member States	€ 565 million	2009-2013	Investments in installations
Entrepreneurship and Innovation Programme (EIP)	Venture capital and guarantees	Member States, Norway, Iceland, Liechtenstein and candidate countries for EU enlargement	€ 72 million	2007-2013	Early and expansion stage companies

1.4 Strengths and weaknesses for the sub-function

- Strengths of this sub-function in a global perspective
 - High theoretical ocean energy capacity potential
 - Many opportunities for synergy with the experienced offshore value chain as industry is likely to be developed around existing offshore wind deployment facilities. This could drive port upgrades, manufacturing yard expansion and requires skilled labour and engineering services.
 - Lack of dominant players on the ocean energy market, providing niche market opportunities
 - The energy sources of this sub-function are reliable and predictable sources
 - Strong position of Europe in wave and tidal energy technologies
 - Tidal range technology is relatively readily deliverable through use of 'conventional' maritime engineering construction methods and use of core, proven, turbine technology similar to that used in hydropower schemes.
- Weaknesses of this sub-function in a global perspective
 - Many technologies are investigated but have yet to be commercialised. Innovation is still required to develop commercial-scale technologies and the associated infrastructure to deploy them
 - High cost price (in terms of EUR/kWh as compared with alternative (renewable) electricity sources)
 - Most of the environmental impacts of the technologies are not fully known, with the exception of tidal barrages.
- Constraints
 - Financing is the biggest barrier to the deployment of ocean energy projects. The costs of ocean energy projects remain high and uncertain

- Ocean energy is still highly dependent on favourable feed-in tariffs or green certificates
- Regulatory framework, permitting processes and liability issues
- Lack of infrastructure and transmission/distribution capacity. The best sites for ocean technology are located in remote areas where the availability of the grid capacity is generally a constraint
- Lack of availability of resource data, such as competing uses, (future) electricity demand, infrastructure development
- Lack of public awareness
- Geographical constraints on application of technologies: OTEC needs a high temperature difference, osmosis needs a steep gradient from fresh to salt water, wave energy needs high and uniform wave patterns, tidal energy needs strong tidal currents.
- Tidal barrages can cause strong environmental impacts. The main issues that have caused concern on previous schemes are relatively common and include changes in geomorphology and processes, impacts on patterns and rates of sedimentation and erosion, transport and accretion, thereby changing the morphology of the system. In turn, impacts on flora and fauna are expected (e.g. Studies of the Severn estuary)

2 Research and technology

2.1 Research projects

One of the main supports has been provided by the research framework programme. In the past 20 years, 42 projects have been supported in the framework of the energy research programmes. The allocated support is about €60 million (roughly €30 million for research and €30 million for pre-commercial demonstration projects). Annex 4 provides an overview of the most relevant FP6- and FP7-projects related to ocean renewable energy.

Ocean/tidal currents energy devices of nominal capacity of 5 MW could be supported under the NER 300 initiative established by Commission Decision 2010/670/EC and managed jointly by the European Commission, the European Investment Bank and Member States.

2.2 Technological developments

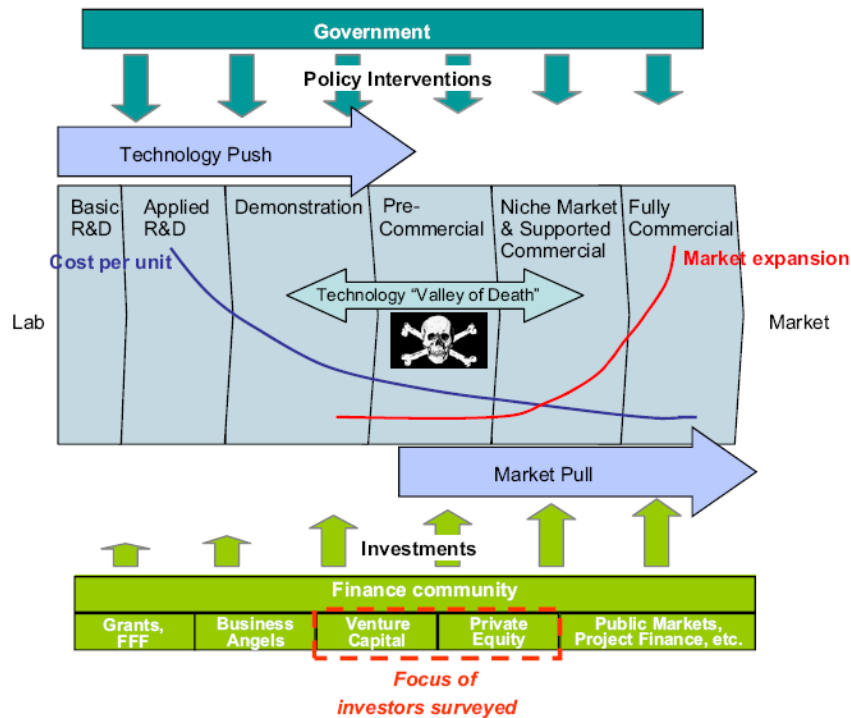
2.2.1 Wave and Tidal Energy

EMEC has identified six main types of wave energy converters: attenuators, point absorbers, oscillating wave surge converters, oscillating water columns, overtopping devices, others (Renewables UK, 2011). For background information we refer to the overview in the same publication of these technologies, some examples of devices developed or tested, and of the companies involved. Also IEA-RETD (2011) provides an overview of relevant technologies.

Leading technologies in the field of tidal current energy (IEA-RETD, 2011; IEA-OES, 2009) are horizontal axis turbines, vertical axis turbines and alternating hydrofoils.

The current state of the industry is that a number of technologies has progressed significantly at relatively high expense. It requires between 20 and 40 million € to reach the development of the first 1 MW demonstration project. To progress from smaller scale proven prototypes to commercial projects, the technology needs to be demonstrated at large scale for a prolonged duration of time. This is the most crucial phase for technology developers when bringing their device to the market. Most developers are now in this so called "Valley of Death" phase (see Figure 2).

Fig. 2. The innovation chain and the technology 'valley of death'



Source: Grubb, 2004

Although Fig.2 is very illustrative for the situation in the ocean energy sector, an important difference is the role of venture capital. Most leading technology developers are well beyond requiring venture capital investment, as the majority of investors in full-scale demonstrator and pre-commercial projects are utilities and OEM – eg SSE, Scottish Power, Vattenfall, International Power GDF Suez, EON, ABB, Rolls Royce, Siemens, Alstom etc.

Within the tidal energy market, some key players are moving to this next level. Market leader and tidal energy pioneer Marine Current Turbines is moving from venture capital funding and is being readied for sale to larger corporations. This step follows a 10-year development whereby the technology was demonstrated and the path to new array projects has been paved through licences with UC Crown estate and partnerships. Considering that new larger array projects will require significant investments and the funding of these projects cannot yet be on a non-recourse project finance, the leading company will require a very strong balance sheet.

In terms of technology and project developments, there are similarities with offshore wind power, where the core technology is developed to a smaller unit scale and an array of such devices are installed to provide the large project production. For tidal energy devices, the rated power capacity in the medium term seems to lie between 0.5 to 1.0 MW per device at a current speed of 2.5 m/s. An offshore array of such devices will then lead to large scale production in the 50-200 MW region. Initially, however, smaller commercial demonstration arrays between 10-20 MW are expected.

For Tidal developments, based on counts in RenewableUK (2011), consensus seems to be developing that rotary turbine technology will be the way forward, mostly horizontal axis turbines and a fewer developments using vertical axis turbines. A large number of technologies have been prototype-tested and are being scaled up to the demonstrators with approximately 1.0 MW of installed capacity. As the concepts have successfully been proven, the emphasis is now on reducing costs and increasing the performance reliability.

The development of wave energy converters, however, is focussing still on proving that the principles of operation are working and robust. There is also a larger variety of wave technologies being developed than we see in tidal development. There are hundreds of ocean energy conversion concepts under development and only a few dozen have reached the stage of prototype-proven designs. Only a very few have made the leap towards full scale demonstration at this stage. It is expected that the number of full scale demonstration units will double in the coming 2 to 3 years. From this select group of developers, however, only a few have yet successfully demonstrated that the technology works reliably for a prolonged period of time (see table below). Pelamis Wave Power is making most progress as they have sold two so called 'P2'-units of 750 kW to E.On and Scottish and Southern Energy, which are operating at the EMEC test site.

Table 4. Tidal Energy Conversion – Key players

Name	Device	Size Installed	Status
Marine Current Turbines	SeaGen U/S	2x600 kW	Working since 2008
Hammerfest Strom	HS-1000	500 kW 1 MW	Working since 2004 Working since 2011
Atlantis Resources	AK-1000	1 MW	Going through Accelerated lifecycle testing at NaREC's 3MW tidal turbine testing facility
Voith Hydro, Renetec	Voith Siemens Hydro Tidal	1MW	Installed at EMEC 2012
Rolls Royce	TGL	500 kW 1 MW	Working since 2010 Installation Summer 2012

Table 5. Wave Energy Conversion – Key players

Name	Device	Size	Status
Pelamis Aqua Power	Pelamis P2	750 kW	1 st working at EMEC, 2 nd working at EMEC
Aquamarine Power	Oyster 800	800 kW	Working at EMEC 350 kW device decommissioned
Carnegie	CETO buoy	200 kW	Testing
Wello	Penguin	600 kW	Installed at EMEC 2012
AWS	AWS-II	300 kW	Installed at Loch Ness, Scotland
Fred Olsen	Bolt	250 kW	Installed at FabTest, Cornwall

2.2.2 Osmotic energy

Basically, there are four main techniques that convert salinity gradients into electricity:

1. Reversed electrodialysis (Dlugolecki, P. et al., 2009)
2. Pressure-retarded osmosis (Thorsena and Holt, 2009)
3. Equilibrium vapour pressure usage (Olsson et al., 1979)
4. Electricity generation by means of a capacitor (Brogioli, 2009)

From our research, we conclude that the first two techniques are studied the most and are currently being (pre-)commercially developed and demonstrated. Based on this conclusion, we assume that these techniques are most likely to grow the strongest the coming decade and we therefore limit our focus on Reversed electrodialysis and Pressure-retarded osmosis.

Reversed electrodialysis

Reversed electrodialysis works on the same principle as a common salt battery. Anion and cation exchange membranes are stacked alternately together between an anode and a cathode. The spaces between the membranes are filled alternately with fresh water and seawater. This results in a chemical salinity gradient, forming an electric potential. Via redox-reactions, electrons flow from the anode to the cathode, creating an electrical current which can be connected to the power grid (Turek and Bandura, 2006; Post, 2009).

Pressure-retarded osmosis

Pressure-retarded osmosis works by means of a semi-permeable membrane, through which water passes but in which salt is retained. Because there is a chemical potential between solutions with a different salt gradient, fresh water will mix with the salt seawater. If the seawater is contained in a pressure chamber, the pressure will increase further. This excess of pressure can be employed to generate electricity via a turbine (Achilla et al., 2009).

Company profile: Statkraft

Statkraft was the first energy company to implement power production from salinity gradients. The plant, located at Tofte outside Oslo, opened in 2009, and will demonstrate the operational feasibility of osmotic power. Another osmotic power prototype plant was opened in Japan 2010 and a prototype plant for reversed electro dialysis is soon to go online in The Netherlands. Statkraft is working with industry experts and technology suppliers globally to create real industrial progress and help realize this potential. Since 2008 Statkraft has organised annual Osmosis Membrane Summits, in order to share solutions and help scale up the production of osmotic membranes. The next big milestone is the decision to build a pilot plant between 1 and 2 MW. The investment decision is planned for 2013. Furthermore, the goal is to build a full scale demonstration plant of 25 MW within 2020.

2.2.3 Ocean Thermal Energy Conversion (OTEC)

Although there are many different systems, three main OTEC technologies can be distinguished:

1. Open cycle OTEC (Nihous et al., 1990)
2. Closed cycle OTEC (Wu, 1990)
3. Hybrid systems (Vega, 1992)

Open cycle OTEC

In an open cycle OTEC system, seawater is used directly. The relatively warm surface water is guided in a low pressure container where it evaporates. The created steam drives a turbine connected to an electric generator, thereby converting kinetic energy into electricity. Subsequently, the steam is condensed to a liquid form again by mixing it with cold water from the deep water layers.

Closed cycle OTEC

In a closed cycle OTEC system, the seawater is used indirectly via a low-boiling medium. The warmer surface water is pumped through a heat exchanger, vaporising the medium. Subsequently, the vapour drives a turbine connected to an electric generator, generating electricity. Then, the vaporised medium condenses via another heat exchanger, which is cooled by deep seawater. Typical low-boiling mediums are ammonia and propane.

Hybrid systems

In a hybrid system, open and closed cycle OTEC systems are combined. Similar to the open cycle system, warm surface water is guided in a low pressure container and evaporates. The steam

vaporises a low-boiling medium via a heat exchanger in its turn – as in a closed cycle system – and generating electricity through a turbine.

OTEC project DCNS

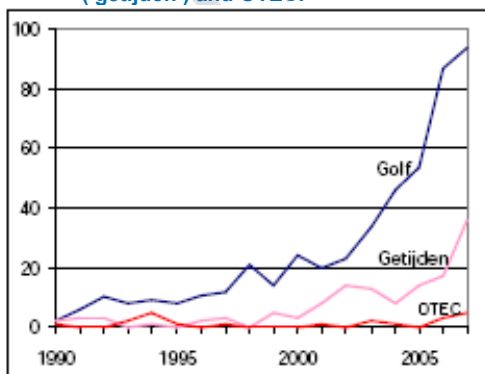
Information gathered from: <http://en.dcnsgroup.com/energy/marine-renewable-energy/ocean-thermal-energy/>

“Ocean thermal energy conversion is one of three marine renewable energy technologies that DCNS is actively developing. Before validating the technology and its promising applications in tropical zones heavily dependent on fossil fuels, DCNS plans to produce a pilot plant. DCNS and the Réunion Island regional council signed an initial R&D agreement in April 2009 to study the feasibility of installing an OTEC pilot plant on the island, a French overseas department in the Indian Ocean. In October 2009, the partners signed a second agreement to study the pilot plant’s integration with existing generating capacity. The aims of this second agreement include the mitigation of the technological risks identified in phase 1, notably the reliability and cost of the intake pipe that will bring cold water from the deep. The challenge is to design, fabricate, install and operate for at least 30 years a 1,000-metre pipe between 5 and 10 metres in diameter. The second agreement also paves the way for setting up a pilot plant at a location on the coast, effectively a full-scale model of an OTEC plant. The pilot plant will be set up and tested at DCNS’s Nantes-Indret centre in western France then shipped to Réunion Island and re-assembled on the university campus at Saint-Pierre for a further round of studies.”

2.3 Patent applications

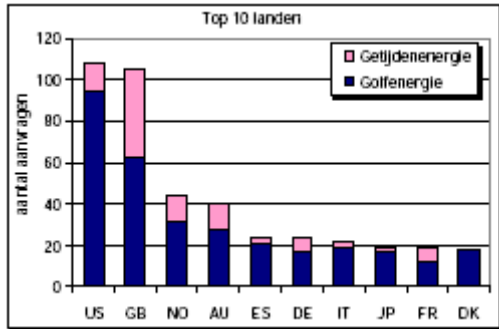
According to Octrooicentrum Nederland (2009), the number of patent applications per year in the field of tidal and wave energy has increased more than tenfold in the period from 1990 to 2007 and from ca. 10 international applications per year in 1990 to over a 100 in 2007. Most of these increases, are related to wave energy. The USA and UK are the most active countries, followed by Norway and Australia.

Fig. 3. Number of international patent applications per year for wave energy ('golf'), tidal energy ('getijden') and OTEC.



Source: Octrooicentrum Nederland, 2009

Fig 4. Number of international applications for tidal ('getijdenenergie') and wave energy ('golfenergie') per nationality of applicant



Source: Octroicentrum Nederland, 2009.

In the field of OTEC-installations, the number of patent applications is relatively constant at one or several applications per year, although over the past few years there seems to be a slight increase. The USA and Japan are leading in this field. OTEC not only lags behind wave and tidal energy, but also behind patent applications on all fields of technology.

3 Future developments

3.1 External drivers and key factors affecting the performance of the cluster

3.1.1 External drivers

Level and volatility of fossil fuel price

Fossil fuels are currently dominant in the European energy mix. The cost of electricity is, amongst others, derived from the cost of the energy sources that generate the electricity. Currently, the cost of ocean energy is higher than the cost of fossil fuels. So, everything else considered equal, utilities have a preference for fossil fuel based electricity over ocean energy. But if the fossil fuel price increases – which is likely to happen – than this preference can change over time.

This conclusion is supported by many interviewees, who confirm that the fossil fuel price is among the most important external drivers for the development of the ocean energy sector. Because the fossil fuel price is rather volatile, it is hard to place this driver in a time-frame. There are other factors influencing the relation between fossil fuel price and investments in renewable energies, such as risk profiles, subsidies and taxes, policy stability, vested interests, green image, etc. Because of these many factors, the interviewees could not set a certain price or tipping point where the preference would fall on ocean energy. The interviewees agree, however, that increasing fossil fuel prices offer an opportunity for the ocean energy sector, because they contribute to the public debate about renewables and encourage the utilities to switch to cleaner technologies.

Development of a European legislative framework

The ocean energy sector, as with most renewable energy sources, is dependent on a strong stable legislative framework. Important are stable funding and subsidy schemes, aiming at R&D and installation of ocean energy technologies. Also strict climate policies, such as the Emission Trading Scheme (ETS) and the binding renewable energy targets under the renewable energy Directive, are necessary for the development of the ocean energy.

Three interviewees have mentioned that so far, wave, tidal and osmotic energy have not received the political attention they deserve. One interviewee argued that the acknowledgement by the EU of the potential of osmotic energy would be an important driver for the development of this energy source. Public awareness and valuation of renewable energy will result in easier funding of projects and earlier abandonment of fossil and nuclear fuels.

Development of a national and regional framework

Over the last few years, a number of EU Member States have put in place attractive financial incentives, in terms of both revenue support and capital grants, and have developed world-class testing facilities for ocean energy. In addition, several regions around Europe launched their regional ocean renewable energy strategies, for example in Bretagne, Basque Country and Scotland)^{1 2}. See also the case studies. Some interviewees discussed that certain national policies targeting ocean energy are too unstable – often in terms of funding or subsidy availability. Therefore, investors are reluctant to invest in them. As 'shining example' we mention here the report recently released by the UK House of Commons, 'The future of marine renewables', which is warmly welcomed by the sector and promises to lead to the stable, favourable conditions required.

Development of competitive position with other renewable energy sources

According to two stakeholders, ocean energy does not only compete with fossil fuel based electricity, but also with other renewable energy sources. The more established and developed renewable energy sources such as wind energy and photovoltaic power pose a threat to the ocean energy sector, because they are favoured by utilities. The authors challenge this conclusion, because these technologies are in very different stages of the product life cycle.

Development of competitive position with nuclear power – Changing perception on the various technologies

As a result of the recent disaster at the Fukushima power plant, and the oil spill in the Gulf of Mexico, public awareness is increasing on the risks of various energy technologies. There is no clear indication on what the impacts of those recent events will be on the future energy mix and the impacts on ocean energy in particular. However, the decision from Germany to anticipate the end of nuclear energy will most likely provide stimulus for renewable energy.

3.1.2 Key factors

Technological development

Many interviewees mentioned that the technological development of most ocean energy technologies must be improved in order to develop the sector further and to cause a true development of economics of scale. The main focus is on improving the energy conversion efficiency. For osmotic energy, for instance, research is predominantly aimed at improving membrane efficiency. For OTEC, more research on gaining electricity from a smaller temperature gradient is needed before the technology could be successfully employed in European waters. Technology development can to some degree be stimulated by national authorities and the EU, but also by the sector itself when combining research efforts.

Financing

In chapter 1, financing is identified as the most important constraint on the development of ocean energy. This is confirmed by the majority of the interviewees, although two observe that at this stage of pre-commercial activity, funding is not the most important bottleneck.

Developments in the coming decade will remain dependent on available support and funding. A mixture between public capital support through EU-funding and government grants plus the local revenue structures in the form of feed-in tariffs or other will be required to allow the industry to develop. The mix is therefore not the same in the various countries throughout Europe. The

¹ <http://www.pole-mer-bretagne.com/ressources-energetiques-marines.php>; <http://www.eve.es/web/Energias-Renovables/Energia-marina.aspx?lang=en-GB>; www.scotland.org/about/innovation-and.../renewables.html

² <http://www.scotland.org/features/item/renewable-energy-a-more-sustainable-future/>

industry will move to those countries where the combination of the energy resources and the financial incentive schemes are the best; at present this is the UK. The coming phase whereby the technology developers need to move towards the first commercial array projects will determine the success for this emerging industry.

Some interviewees see a stronger link between growth potential and feed-in tariffs than between growth potential and oil price.

Infrastructure

Many interviewees mentioned that a well developed infrastructure is an absolute necessity in order to facilitate the ocean energy sector. Infrastructure includes:

- On- and offshore power grid, with sufficient transmission and distribution capacity;
- Port and harbour facilities
- Specialised vessels for offshore construction, maintenance, cable laying, etc.

A distinction between technologies must be made. Osmotic energy plants are often located at river mouths. Such areas are mostly well developed already in terms of infrastructure. Conversely, most wave and tidal plants are located further from the coastline, where infrastructure can be less developed.

Because the sector is still in a pre-commercial state, infrastructure is momentarily not a limiting factor. However, more infrastructure is needed with the further development of the ocean energy sector.

As it is foreseen by all interviewees that ocean energy is likely to be developed in the North Sea and North East Atlantic, infrastructure should be developed in these regions to connect energy generation with energy use.

Others

Other key factors are related to existing barriers in health and safety, environmental and other sea users considerations, supply chain constraints and skills shortages. Though these are not the most pressing boundary conditions, these barriers must be overcome if the sector is to develop.

3.2 Assessment of response capacity and commercialisation potential

The market for wave and tidal energy conversion is in the transition from technology invention, development and testing towards pre-commercial demonstration projects, small arrays and servicing. It is envisaged that over the next 4 years up to 2015, the total cumulative expenditure will be in the range of € 850 million (Douglas-Westwood, 2010). Of great importance here is the involvement of major original equipment manufacturers, as well as the increasing interest and involvement of major energy utilities (RenewableUK, 2012).

Private funding comes from a variety of sources: utilities, industrial, financials and venture capital. A specific example is a publicly traded independent technology company. Carnegie from Australia raised 33 million euro to start-up the CETO wave energy conversion development through an Initial Private Offering. RenewableUK (2012) concludes that the attractiveness of the industry to investors is increasing, largely due to the government support in the UK and to several high profile demonstrations of commitment.

Research, Development and Demonstration (RD&D) activities performed directly by the private sector or financially supported or promoted by public funding are instrumental to the removal or mitigation of technical barriers. RD&D, by creating domestic intellectual capital, can also support green employment and the development of future industries. The importance of the support that can be provided by publicly funded RD&D activities is particularly relevant for the more immature technologies given the lower investment capacity of the private sector and longer timescales involved. Direct involvement and possibly co-investment from private companies into RD&D activities should be maximised.

Issues related to health and safety, environmental and other sea users considerations, supply chain constraints and skills shortages are important and have to be dealt with, mitigation measures can reduce their impact (IEA-RETD, p. 125, 2011).

Both the sector itself and neighbouring sectors must keep an open eye. National and EU authorities have instruments to facilitate, e.g. in licensing and permitting procedures.

3.3 Most likely future developments

In the near future, the worldwide yearly installed capacity is expected to double yearly. By the end of 2010, the total installed capacity of ocean energy was 3.4 MW. This capacity was envisaged to more than double to 7.8 MW in 2011 (RenewableUK, 2011). The actual installed capacity by the end of 2011 was 5.6 MW (RenewableUK, 2012), and although less than anticipated earlier, still indicating a very high growth rate. Of all installed devices, more than 80% of the capacity will be installed in the UK (IEA (2010) p.125). The outlook for 2012 is looking at around 11 MW of total installed capacity³. The collective ambition of the ocean energy developers is to have another 65 MW in small arrays installed by 2014-2015, provided sufficient government incentive programmes are in place⁴.

Douglas-Westwood (2010) have evaluated that in 2010 some € 37 million was spent globally on ocean energy developments, tenfold the amount of 2005. It is anticipated in the same study that the total amount of annual spending on ocean energy will increase another tenfold to the € 360 million range by 2015. The UK has advanced the most in terms of industry commitments and technology development. At present, the ocean energy sector in the UK employs some 800 permanent jobs. Carbon Trust in the UK sees a global market developing to € 45 billion annually by 2050. Under the most optimistic forecasts, about 240 GW of ocean capacity would be deployed globally by 2050, 75% of which would be made up of wave power and the rest tidal (ReCharge, 2011).

Arup was appointed by the Department of Energy and Climate Change (DECC) in October 2010 to look at the deployment potential and generation costs of renewable electricity technologies in the UK up to 2030 (Arup, 2011). The study has reiterated the data from previous work - that there is limited deployment by 2020, but up to 4000 MW of capacity by 2030 (in the medium forecast). Of these 4000 MW, 1700 MW are in wave energy, 1400 MW in tidal current energy, and 1000 MW in tidal range energy. Tidal current is seen as the most promising technology in the short term, however the costs and funding gaps have been re-confirmed as still challenging.

In the interviews, the following future perspectives are mentioned:

³ RenewableUK (2012), p.10

⁴ RenewableUK (2011)

- The roadmap of the OEA (Ocean Energy Association, 2010) provides a good, although according to the interviewee somewhat optimistic, overview of the medium and longer term development of the wave and tidal power sector
- The subfunction can develop and grow towards 2020. In the long term, wave energy will grow to be equal to off-shore wind energy.
For osmotic energy, no commercial plants exist yet. The first developments will be the construction of demonstration plants of 1-2 MW. The first commercial plant could start in ca 5 years.
For OTEC, a 10 MW plant is planned for 2015. The most promising perspective on the short term will be linking up to the commercialisation of SWAC (Sea Water Air Condition). On the mid and long term, OTEC can develop in combinations with various other technologies, and could eventually go off-shore.
- Off-shore developments will receive a boost, as more activities are undertaken at sea
- It is of key importance to look at the subfunction from a trans-national viewpoint. Optimal potential may be at some distance from demand. This emphasises the necessity of a super-grid infrastructure.
- With future developments as planned, there will be an emerging bottleneck in connecting the devices to a grid along the coast. Along the coasts, few grids are in place. As getting permissions alone takes 6 to 8 years, parties should start thinking about that now.

3.4 Impacts, synergies and tensions

At present, the ocean energy sector in the UK employs some 800 permanent jobs, and some expect that the ocean energy sector in the future can create around 10,000 fte by 2020 (RenewableUK, 2012 p.7) and up to 20,000 fte by 2035 (RenewableUK, 2011). Furthermore, the GVA to the UK economy will then be around 800 million pounds per annum (RenewableUK, 2011). No data are available for the whole of Europe, but the share of the UK may be estimated at some 80% of total EU employment, according to one of the interviewees. A critical note must be placed here; it is our view that these figures are probably somewhat optimistic. Since many factors and drivers affect the development of the sector, the number of jobs created or value added to the EU economy is largely unknown for the decades to come.

An qualitative overview of synergies and tensions between Ocean Renewable Energy and other subfunctions is presented in Annex 5.

There is a wide scope of activities required to bring ocean energy to the markets, which is best compared to the relatively young offshore wind and the offshore oil&gas industries, the latter having been developed over the last 70 years. There will be a significant potential for existing industries to provide services and goods to the ocean energy sector. This new market will attract keen interest from contractors and suppliers from the oil&gas sector as their activities may show a gradual decline in the coming decades.

The expertise available from this industry is valuable to the success of the ocean energy sector. Interest from experienced suppliers and contractors from these two industries to be involved and support the ocean energy business is gradually increasing. Various companies are starting to develop tailor-made services for the ocean energy sector. One such example is Bluewater Energy Services BV from the Netherlands, a global leading offshore mooring systems contractor, who has developed an open architecture floating foundation to which various contractors can mount their

turbine devices. Other such services related to component suppliers, offshore installation, operation & maintenance services, project management & engineering and system certification.

Work in Progress

Table 6: Impact matrix of the medium-term and longer-term developments

Function	Indicators	Bal- tic	North Sea	Medi- terr.	Black Sea	Atlan- tic	Arc- tic	Outer most
1. Economic impacts	market size, Wave	0	0	0	0	++	0	+
	market size, Tidal	0	0	0	0	++	0	+
	market size, OTEC	0	0	+	0	0	0	+
	market size, Osmotic	0	+	0	0	+	0	0
2. Employment impacts	fte direct employment	0	+	0	0	+	0	0
	fte value chain	0	+	+	+	++	0	+
3. Environmental impacts	reduction CO2		0		0	+		0
	geomorphology		0			0		
	fish		0			-		
	birds		0			0		
	mammals		0			0		
	soil disturbance		0			-		
4. Other impacts	competing claims on near-shore space		0			--		0
	competing claims on off-shore space		0			0		0

++ = Strong positive impact expected

+ = Considerable positive impact expected

0 = Negligible impact expected

- = Considerable negative impact expected

-- = Strong negative impact expected

The development of ocean energy sector is likely to start in the North East Atlantic Ocean.

Therefore, most of the impacts will be limited to that region. With the technological development, economies of scale, increasing fossil fuel prices and the sustainability requirements from the EC, other marine regions cannot be excluded in the long run.

Environmental Implications

Apart from the benefits to the environment by reducing the overall CO₂ production during electricity generation, devices in the water capturing tidal or wave power will have various possible impacts to the (local) environment. For example, there is the impact of the activity to install the devices on the seabed by driving in foundation piles and the influence on the morphological process of sediment transport along the seabed. There will also be an impact to the fish, their habitat and more in general on the local ecosystem. There might also be positive impacts on fish, especially if the area is excluded for fishing, thus providing refuges and artificial reef structures.

The assessment of the environmental impacts is a highly complex process, not only because of the medium where these projects are being developed but also due to the variety of devices and the different ways in which they interact with the surrounding environment. Only a few Environmental Impact Assessments (EIA) have been carried out and then only for small pilot plants. Continued monitoring of these pilot projects is required in order to fully understand the implications to the local environment. For tidal demonstration projects, it is concluded that the turbine technologies do not obstruct the fish from safely swimming through as the rotational speed of the turbines is low enough to permit their passage.

The EquiMar project (EquiMar, 2011), with more than 60 specialists from 11 countries participating is funded through the EU FP7 program. The results from the project confirm that the environmental impacts of ocean energy projects are not yet fully understood. The EquiMar project has defined a set of protocols on how best to assess the impact of such devices to the environment; see Ingram et al. (2011). The protocols will be used in the development of the new Marine Energy Standards currently being developed by the IEC technical committee 114. The EquiMar programme funding by FP7 was finalised in 2012.

Other initiatives are developed studying various aspects of the installation of tidal and wave devices. The SuperGen Marine Energy Research Consortium in Scotland, the RaceRocks initiative in Canada and in the USA the on-going research by the National Oceanic and Atmospheric Administration (NOAA, 2011).

Osmotic power facilities have only a small environmental impact. Because they are situated in places where fresh and seawater meet, the salinity gradient is not affected much. Moreover, the water is actually cleaned by the membrane.

Both literature and interviewees stress the importance of synergies with related functions and value chains. The synergies with the offshore sector were already mentioned. The relevance of this synergy is confirmed by several interviewees.

Royal Haskoning (2009) observed that the commercial viability of a tidal range scheme may be deemed greater if a wider range of functions and related economic benefits could be incorporated. Examples of such functions are infrastructure (improved transport networks), leisure and tourism, or flood control. Related observations that come forward from the interviews:

- combining OTEC with Sea Water Air Conditioning (SWAC);
- application of OTEC-technology in the production of LNG
- combining OTEC with production of drinking water and extraction of minerals

One of the interviewees urges the importance of searching for combinations, trying to solve multiple problems at once, e.g. combining OTEC on floating installations with reducing the problem of the plastic bulb in the oceans.

4 Role of policy

4.1 Policy and political relevance

The preceding section has identified a number of trends and barriers in relation to the development of ocean energy. There is a clear case to support ocean energy development because of the level of energy resource, the benefits to the economy, industry and employment, the low carbon emissions, and energy security.

However, the number of barriers and their intensity, the ocean energy industry need political support to overcome these challenges.

4.2 Domains for EU policy

Justification for EU action in the issues mentioned in par. 4.1 must be found in:

- linkage to at least one article of the Treaty
- insufficient achievement of the objectives by Member States
- better achievement of the objectives by the Community.

Without further investigation, these conditions are expected to be met. In the following, EU involvement is presented in policy domains. These domains are based on the information from interviews. This information was verified and supplemented mainly from the European Ocean Energy Roadmap 2010-2050 by the Ocean Energy Association (2011), unless otherwise stated.

European policy framework

A stable, predictable and encompassing policy framework for the emerging ocean energy sector is currently lacking. Key elements in such a framework consist of a stable funding policy, guaranteed grid access with sufficient transmission capacity, streamlined spatial planning and clear permitting procedures in which health, safety and environmental requirements are unambiguously stated.

In some cases, regulations from different policy fields are contradictory. In those cases an integrated European policy is needed.

The sea has no borders, although EU Member States have their own systems of seabed ownership and regulation. There is a requirement for a common understanding and application of existing EU environmental regulations to ensure that rules are applied consistently. This will allow project developers to predict with confidence whether a particular project can be undertaken in an environmentally acceptable manner.

Currently, regulatory authorities applied existing frameworks and permitting procedures for ocean energy projects. These frameworks and procedures are, however, tailored for more established uses of the sea, such as the oil and gas industry, fishing and shipping. Many interviewees mentioned that existing policies regarding marine spatial planning and permitting should be adapted to cope with the specific characteristics and requirements of the ocean energy sector.

It is important to collaborate with important stakeholders involved in this sector. Such stakeholders are TSOs, environment agencies, health and safety bodies and research centres. Moreover, cooperation with other uses of the marine environment minimises conflicts, as well as provides the potential to reap benefits from synergies between users of the sea.

The complex permitting procedures that are in place for ocean energy projects form a barrier to the further development of the sector. These procedures delay the deployment of a project, thereby increasing development costs and timescales. Options to lower this barrier can be done by looking at best practises in some Member States. Such best practises can be one-stop shopping procedures, streamlining applications procedures or pre-permitted areas with designations for ocean energy projects.

Skills

New requirements regarding employee qualifications in the areas of project management, national and international law, quality assurance, occupational health and safety, and technical English are evident in almost all sectors of the value-added chain. Deficits in the European market can be attributed to a lack of compatibility and transferability of national professional qualifications, certificates and standards. Work initiated by the International Electrotechnical Commission (IEC) Technical Committee 11418 on Marine Energy in 2007 will lead to the development of international standards for ocean energy systems. Work in progress on ocean energy systems includes: relevant terminology, design requirements, resource characterisation and its assessment, and the evaluation of performance of ocean energy converters in the open sea.

Research, Development and Demonstration (RD&D) support and coordination

The ocean energy sector is currently in a pre-commercial phase. More research, development and demonstration (RD&D) is needed so that technical barriers and inefficiencies can be decreased, technologies advance in their learning curve and economies of scale can develop. These effects will bring down the cost of energy derived from ocean sources, ultimately bringing the sector in a commercial state.

One of the most obvious roles that the EC can play is providing (financial) RD&D support. There are many different financial mechanisms to create RD&D incentives. Apart from the funds already mentioned in chapter 1, the EC could introduce public-private partnerships. Another way of stimulating RD&D is by postulating a common research agenda so that the RD&D is strategically focussed. A strategic research agenda for ocean energy should be developed to guide R&D efforts in the key areas of:

1. components and power take-off;
2. deployment and installation methods;
3. development of design, operation and maintenance tools; with an objective of technological advancement from R&D to demonstration, pre-commercial and, finally, to commercialisation.

As the body of knowledge on the impact of ocean energy on the marine environment is still very limited, it is important that existing and generated knowledge in different EU Member States is shared efficiently, so that research is not duplicated and best practices can be disseminated quickly. The scope of cooperation on environmental issues could be widened to include technologically-orientated aspects.

Collaborative efforts and increasing targeted EU and national funds are crucial for advancing ocean energy technology. Coordination between EU and national research programmes and between

various stakeholders, such as research institutes, universities, industry and consultancy firms, should be encouraged and supported.

Several EU Member States, including the UK, Ireland, Denmark, Sweden, Spain, Portugal and Germany, have conducted comprehensive research programmes on ocean energy. These initiatives will need to be integrated into the Europe-wide strategic research agenda and implemented through the European Industrial Initiative.

Ocean energy market

Creating and maintaining a stable ocean energy market is essential for the further development of the sector. The private sector should work closely together with the Member States and the European Commission, and jointly create a long term vision on how the market should look like.

Work in Progress

Annex 1 Bibliography

- ABS Energy Research, 2009. The Ocean Energy Report, fourth edition
- Achilla, A. et al. (2009) Power generation with pressure retarded osmosis: An experimental and theoretical investigation. *Journal of Membrane Science* 343, pp. 42-52
- Arup, 2011. Review of the generation costs and deployment potential of renewable electricity technologies in the UK. Study Report, REP001, Final | June 2011.
http://www.decc.gov.uk/assets/decc/What%20we%20do/UK%20energy%20supply/Energy%20mix/Renewable%20energy/policy/renew_obs/1834-review-costs-potential-renewable-tech.pdf
- Beurskens, L.W.M. and M. Hekkenberg (2011) Renewable Energy Projections as published in the National Renewable Action Plans of the European Member States covering all 27 EU Member States. EEA/ECN report.
- Brogioli, D. (2009), Extracting renewable energy from a salinity difference using a capacitor. *Physical Review Letters* 103
- Deltares (2010), Renewable Energy from Water & Subsurface.
- Dlugolecki, P. et al. (2009) Practical potential of reverse electrodialysis as process for sustainable energy generation *Environmental Science & Technology* 43, pp 6888–6894
- Douglas-Westwood (2010) The world wave and tidal market report 2011-2015.
- EC (2009). Communication 519 final. Investing in the Development of Low Carbon Technologies (SET-Plan)
- EC (2010) Communication 639 final. Energy 2020 - A strategy for competitive, sustainable and secure energy.
- EC: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:en:PDF>
- EC: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:200:0031:0045:EN:PDF>
- EC: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:211:0055:0093:EN:PDF>
- Ecofys (2011) Financing Renewable Energy in the European Energy Market. Report for the EC, DG ENER
- Equimar project website - see www.equimar.org
- European Ocean Energy Association (2010) Oceans of Energy - European Ocean Energy Roadmap 2010-2050
- Grubb (2004), Technology Innovation and Climate Change Policies: An Overview of Issues and Options, *Keio Economic Studies*, Vol. 41, No. 2, pp. 103 - 132
- House of Commons, Energy and Climate Change Committee (2012) The future of marine renewables in the UK. HC1624, published Feb. 2012.
- IEA (2010) Implementing Agreement on Ocean Energy Systems (www.iea-oceans.org)
- IEA (2011) World Energy Outlook 2010. IEA-OECD annual report.
- IEA-OES (2009) Ocean Energy: Global technology development status. IEA-OES doc nr T0104
- IEA-RETD (2011) Accelerating the deployment of offshore renewable energy technologies, IEA-RETD report
- Ingram, D, G.Smith, C.Bittencourt-Ferreira and H.Smith (2011) Protocols for the equitable assessment of marine energy converters. EU Equimar FP7 project.

- Nihous, G.C. et al. (1990) Conceptual Design of an Open-Cycle OTEC Plant for the Production of Electricity and Fresh Water in a Pacific Island. *Ocean Energy Recovery*, pp. 207-216
- NOAA - NOAA Technical Memorandum NMFS F/SPO-116 – Environmental Effects of Tidal Energy Development. www.depts.washington.edu/nmrec
- Olsson, M. et al. (1979), Salinity gradient power – utilizing vapour-pressure differences. *Science* 206, pp. 452-454
- PMSS (2011) Marine Special Report 2011 (www.pmss.co.uk)
- Post, J.W. (2009), Blue Energy: Electricity production from salinity gradients by reverse electrodialysis. PhD thesis, pp. 224
- ReCharge newspaper (accessed on May 3, 2011) (www.rechargenews.com)
- RenewableUK (2011) State of the industry report (www.renewable-uk.com accessed on May 15, 2011)
- RenewableUK (2012) Marine Energy in the UK State of the Industry Report 2012 (March 2012)
- Royal Haskoning (2009) Tidal Energy - Lessons learnt from the United Kingdom and opportunities for the Netherlands.
- Sorensen, H.C. and Weinstein, A. (2008) Ocean Energy: Position paper for IPCC, pp. 8
- Thorsena, T. and Holt, T. (2009), The potential for power production from salinity gradients by pressure retarded osmosis. *Journal of Membrane Science* 335, pp. 103-110
- Turek, M. and Bandura, B. (2006), Renewable energy by reverse electrodialysis. *Desalination* 205, pp. 67-74
- Vega, L.A. (1992) Economics of Ocean Thermal Energy Conversion (OTEC). *Ocean Energy Recovery*, pp 152-181
- Waveplam, <http://www.waveplam.eu/page/> (accessed on June 22nd, 2011)
- Wu, C. (1990) Specific power optimization of closed-cycle OTEC plants. *Ocean Engineering* 17 pp. 307-314

Annex 2 Stakeholder catalogue

Interviewee	Organisation	City/country	Specific theme	Interviewer	Face to face, or telephone
Remi Blokker	Bluerise	Delft, Netherlands	RES - OTEC	Lija van Vliet	F2F
Kas Hemmes	Technical University Delft	Delft, Netherlands	RES - blue energy	Lija van Vliet	F2F
Nathalie Rousseau	European Ocean Energy Association	Brussels, Belgium	RES - all	Oscar Widerberg	F2F
Stein Erik Skilhage	Statkraft	Oslo, Norway	RES - Osmotic energy	Sil Boeve	Tel
Emmanuel Brochard	DCNS	Paris, France	RES - all	Lija van Vliet	Tel
Eoin Sweeney	Sustainable Energy Authority Ireland	Dublin, Ireland	RES - all	Sil Boeve	Tel
Roberto Lacal-Arantegui	JRC	Petten, Netherlands	RES wave and tidal	Sil Boeve	Tel
Sian George	Aquamarine Power	Edinburgh, Scotland	RES - all	Sil Boeve	Tel
François Lienard	IMI	Brussels, Belgium	RES - all	Henk Wolters	Tel
Oliver Wragg	RenewableUK	London, UK	RES - all	Lija van Vliet	Tel

Annex 3 Case studies

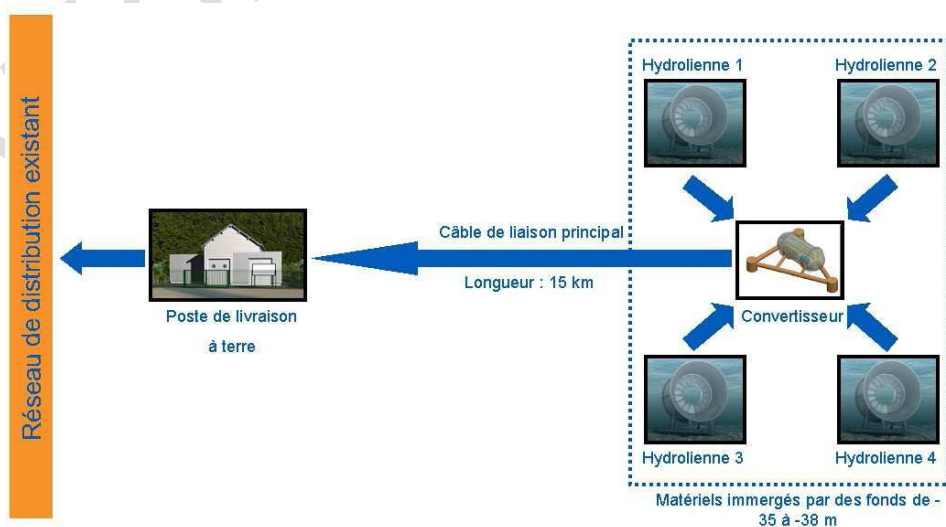
Case 1: Paimpol-Brehat site, Brittany, France

<http://energie.edf.com/hydraulique/energies-marines/carte-des-implantations-marines/parc-hydrolien-de-paimpol-brehat/presentation-51512.html>

The project was initiated in 2003 and has needed 4 years of research and development before being launched. The goal of the project, a first in France, is to test the administrative, technical, economic and environmental feasibility of the demonstration technologies. The main objective of the project is the production of electrical renewable energy. The project equally provides a start to reduced energy dependence of Brittany. The project consists of the installation of 4 hydroturbines at some 15 kilometers off the coast, at depths of 35 to 38 meters below mean sea level.



The tidal current lets the turbines rotate. This rotation is turned into an electrical current which is transformed sub-sea and then transported to the coast by means of a 15 km long cable (diameter 10 to 15 cm), and there connected to the grid.



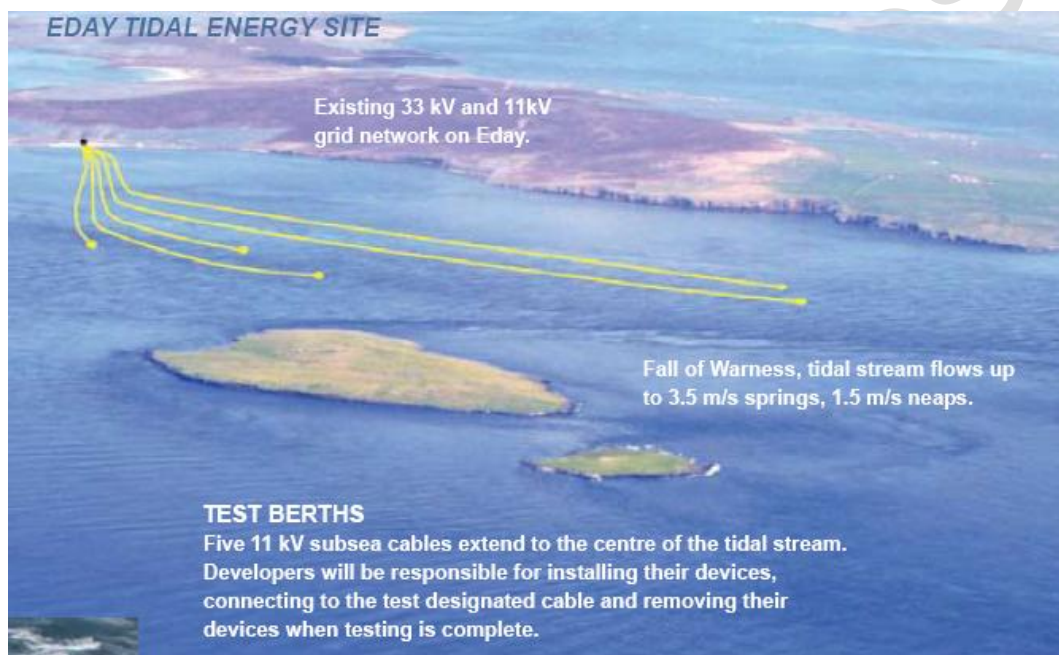
The site is scheduled to enter service by the end of the summer of 2012.

The initiative has been embraced in the region with enthusiasm, rooted in:

- the expectation of a strong economic impulse by the local authorities;
- the expectation of a strong image for Brittany;
- an existing cluster of co-operating universities, developers and energy suppliers.

Case 2: EMEC Test centre

The European Marine Energy Centre (EMEC) in Orkney was established in 2003 and offers developers the opportunity to test full-scale grid-connected prototype wave and tidal stream devices. The centre operates two sites – a wave test facility and a tidal test facility – which have multiple berths that allow devices to be tested in the open sea. The berths have an existing connection to the onshore electricity network and facilities for technology and environmental monitoring.



There is currently strong demand for the existing cables and EMEC has seen growth through the Renewable Energy Strategy-sponsored projects, increasing the number of grid connected berths on site, from nine to twelve. This has also seen the creation of the 'scale sites' for both wave and tidal devices in Orkney. These are planned to be of interest to technologies where developers would prefer to deploy at a scale smaller than their planned commercial roll-out, or at full size, but in conditions that are less extreme than the full-scale sites. The increase in capacity has coincided with EMEC's transition to being fully self-funded through the rental and service fees it receives from its customers. EMEC's world-leading experience as the only marine energy UKAS accredited test site in the world, means that it is a strong contender to leverage value from its expertise. EMEC has already led the development of guidelines that have been taken forward to become international standards and continues to provide leadership.

EMEC has been set up by a grouping of public sector organisations following a recommendation by the House of Commons Science and Technology Committee in 2001. Funding to enable the establishment of EMEC's infrastructure and services to date is in the region of £30 million.



The Scottish Government
Highlands and Islands Enterprise
HIE Orkney
ORKNEY ISLANDS COUNCIL



Scottish Enterprise
DEPARTMENT OF ENERGY & CLIMATE CHANGE
CARBON TRUST
HIGHLANDS & ISLANDS PARTNERSHIP PROGRAMME
PROGRAM CO-ROBHA NA OADRHEALACHD IS NAH BHEAN
THIS PROGRAMME HAS BEEN PART-FINANCED BY THE EUROPEAN REGIONAL DEVELOPMENT FUND UNDER THE HIGHLANDS & ISLANDS OBJECTIVE 1 PARTNERSHIP PROGRAMME

Work in Progress

Annex 4 Overview of most relevant research projects

acronym	start date	funding programme	website	research area / short description
Aquagen	2011-01	FP7-SME	http://www.aquagen-project.eu/project-description.html	Development of cost-effective, water based power take-off system for ocean energy applications
Cores	2008-04	FP7-Energy	http://hmrc.ucc.ie/cores/	Components for ocean renewable energy systems
Equimar	2008-04	FP7-Energy	http://www.equimar.org	Equitable testing and evaluation of ocean energy extraction devices in terms of performance, cost and environmental impact
Hydroaction	2008-09	FP7-Energy	http://www.hydroaction.org/	Development and laboratory testing of improved action and matrix hydro turbines
Marina Platform	2010-01	FP7-Energy	http://www.marina-platform.info/	Deep off-shore multi-purpose renewable energy conversion platforms for wind/ocean energy conversion
Marinet	2011-04	FP7-Infrastructure	http://cordis.europa.eu/fetch?CALLER=FP7_PROJ_EN&ACTION=D&DOC=1&CAT=PROJ&QUERY=012ed25875f0:9eaf:79fa65b5&RCN=98372	Ocean renewables infrastructure network for emerging energy technologies
Orecca	2010-03	FP7-Energy	http://www.orecca.eu/web/guest;jsessionid=C6E7B0BFC5F9EAB53BA102C2B2AB0059	Coordination action on off-shore renewable energy conversion platforms
Pulse Stream 1200	2009-11	FP7-Energy	http://www.mapinfobase.eurocean.org/pdf/List.pdf?t=1307569260593&id=30133	Demonstration of innovative full size demonstration prototype tidal current generator
Reapower	2010-09	FP7-Energy	http://www.reapower.eu/index.php?option=com_content&view=article&id=2&Itemid=2	Reverse Electrodialysis Alternative Power Production
Standpoint	2009-11	FP7-Energy	http://cordis.europa.eu/fetch?CALLER=FP7_PROJ_EN&ACTION=D&DOC=1&CAT=PROJ&RCN=94488	Standardisation of point absorber wave energy convertors
Surge	2009-11	FP7-Energy	http://cordis.europa.eu/fetch?CALLER=FP7_PROJ_EN&ACTION=D&DOC=1&CAT=PROJ&RCN=92897	Simple underwater generation of renewable energy
Waveplam	2008	Intelligent Energy	http://www.waveplam.eu/page/	develop tools, establish methods and standards, and create conditions to speed up introduction of ocean energy onto the European renewable energy market.
Waveport	2010-02	FP7-Energy	http://cordis.europa.eu/fetch?CALLER=FP7_PROJ_EN&ACTION=D&RCN=94487	Demonstration of an innovative full size system for wave energy conversion
Wavetrain	2008-10	FP6-Mobility	http://www.wavetrain2.eu/	Initial training network for wave energy research professionals

Annex 5 Table of cross-links and synergies

Function affected	Sub-function	General	Baltic	North Sea	Mediterranean	Black Sea	Atlantic	Arctic	Oceania	Remarks
Affected										
1. Maritime transport and shipbuilding	1.1 Deepsea shipping	-	0	-	0	0	-	0	0	ocean energy devices may obstruct shipping lanes; as ocean energy focuses on the Atlantic, effects will be concentrated there
	1.2 Shortsea shipping (incl. RoRo)	-	0	--	0	0	--	0	0	id.
	1.3 Passenger ferry services	-	0	--	0	0	--	0	0	id.
	1.4 Inland waterway transport.	0	0	-	0	0	-	0	0	
2. Food, nutrition, health and ecosystem services	2.1 Catching fish for human consumption	+	0	+	0	0	+	0	0	platforms and infrastructure may offer opportunities for fishing. On the negative side, competition for space
	2.2 Catching fish for animal feeding	0	0	+	0	0	+	0	0	
	2.3 Growing aquatic products	0	0	0	0	0	0	0	0	
	2.4 High value use of marine resources (health, cosmetics, well-being, etc.)	0	0	0	0	0	0	0	0	

Function affected	Sub-function	General	Baltic	North Sea	Mediterranean	Black Sea	Atlantic	Arctic	Outermost	Remarks
	2.5 Agriculture on saline soils	0	0	0	0	0	0	0	0	
3. Energy and raw materials	3.1 Oil, gas and methane hydrates	+	+	+	+	+	+	+	+	Synergy is expected in off-shore know-how
	3.2 Offshore wind energy	+	+	+	+	+	+	+	+	Synergy is expected in off-shore know-how. Negative influence may occur in competition for research and stimulation funds
	3.3 Marine renewables (wave, tidal, OTEC, thermal, biofuels, etc.)	na	na	na	na	na	na	na	na	
	3.4 Carbon capture and storage	0	0	0	0	0	0	0	0	
	3.5 Aggregates mining (sand, gravel, etc.)	-	0	-	0	0	-	0	0	Negative influence in competition for space
	3.6 Mineral raw materials	0	0	-	0	0	-	0	0	
	3.7 Securing fresh water supply (desalination)	0	0	0	0	0	0	0	0	
4. Leisure, working and living	4.1 Coastline tourism	+	0	+	0	0	+	0	+	ocean energy devices may offer good opportunities for recreational fishing and swimming by providing platforms. OTEC, when combined with SWAC and drinking water supply, may boost recreation in outermost areas

Function affected	Sub-function	General	Baltic	North Sea	Mediterranean	Black Sea	Atlantic	Arctic	Other	Remarks
Affected										
	4.2 Yachting and marinas	0	0	0	0	0	0	0	0	
	4.3 Cruise including port cities	0	0	0	0	0	0	0	0	
	4.4 Working	+	0	+	+	0	+	+	+	Expected growth will offer jobs
	4.5 Living	0	0	0	0	0	0	0	0	
5. Coastal protection	5.1 Protection against flooding and erosion	0	0	0	0	0	0	0	0	Tidal range barriers may be combined with protection, but suitable areas are very limited and adverse environmental impacts are severe
	5.2 Preventing salt water intrusion and water quality protection	0	0	0	0	0	0	0	0	id
	5.3 Protection of habitats	0	0	0	0	0	0	0	0	
6. Maritime monitoring and surveillance	6.1 Traceability and security of goods supply chains	0	0	0	0	0	0	0	0	
	6.2 Prevent and protect against illegal movement of people and goods	0	0	0	0	0	0	0	0	
	6.3 Environmental monitoring	+	0	+	0	0	+	0	0	Developing ocean energy in a sustainable manner will call for additional monitoring activities to check and adapt. The other way round, development of ocean

Function affected	Sub-function	General	Baltic	North Sea	Mediterranean	Black Sea	Atlantic	Arctic	Other	Remarks
Affected										
										energy will profit from increased and integrated monitoring efforts, which will reduce monitoring efforts and uncertainties in projected scheme development.

Explanation:

++ = Strong positive impact on other subfunctions/sea basins expected

+ = Considerable positive impact on other subfunctions expected

0 = Negligible impact on other subfunctions/sea basins expected

- = Considerable negative impact on other subfunctions expected

-- = Strong negative impact on other subfunctions expected

Work in Progress

Work in Progress

P.O. Box 4175
3006 AD Rotterdam
The Netherlands

Watermanweg 44
3067 GG Rotterdam
The Netherlands

T +31 (0)10 453 88 00
F +31 (0)10 453 07 68
E netherlands@ecorys.com

W www.ecorys.nl

Sound analysis, inspiring ideas