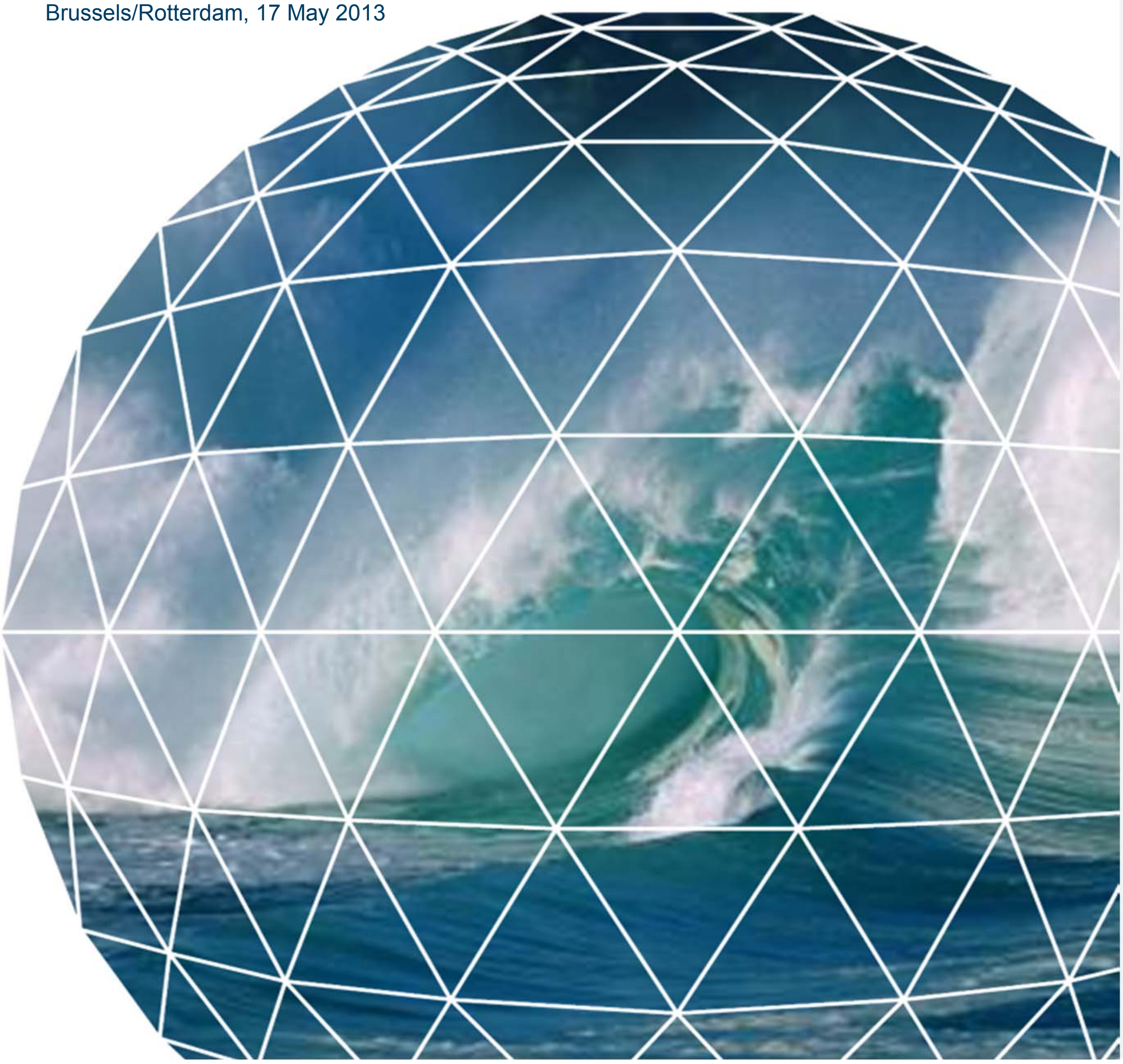
Study in support of Impact Assessment work for Ocean Energy

Final Report

FWC MARE/2012/06 – SC C1/2012/01

Client: EC DG Maritime Affairs and Fisheries

Brussels/Rotterdam, 17 May 2013



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Interim Report

FWC MARE/2012/06 – SC C1/2012/01

Client: EC DG Maritime Affairs and Fisheries

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ECORYS

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Preface

Our oceans and seas have the potential to play an important role in Europe's future energy generation. At present Ocean Energy is still in its infant stage, although some specific ocean energy technologies are now taking their first (pre)commercial steps. The political attention for Ocean Energy is rapidly growing. The current immature development of Ocean Energy creates a number of specific hurdles in its commercial introduction, similar to other renewable energy technologies which had to go through the same stage, such as offshore wind energy.

This report analyses the potential future development of ocean energy, the key challenges it is facing and its potential impact. It is meant to support the impact assessment on Ocean Energy which has been prepared by DG MARE.

The study has been carried out by an independent team. It should be noted that this report represents the views of the consultant, which do not necessarily coincide with those of the Commission.

Brussels/Rotterdam /Utrecht/London, May 2013

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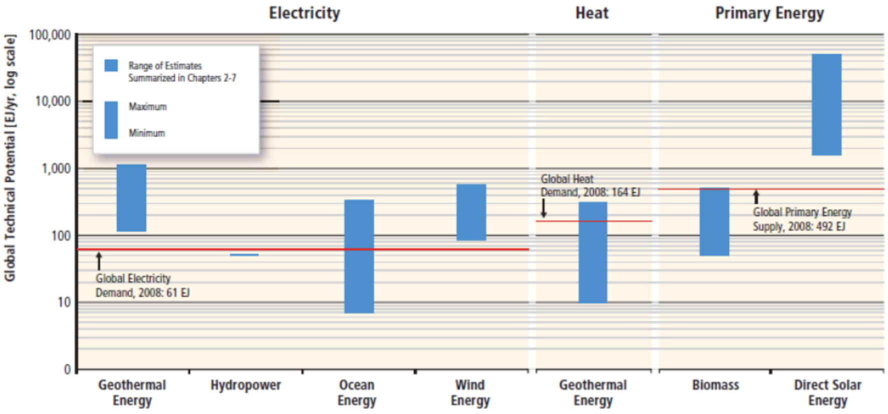
1 Introduction

1.1 Background

Energy from our oceans and seas can be generated with a broad range of technologies. Ocean Energy ("OE"[1]) encompasses the generation of energy from wave, barrages for tidal range, tidal streams, Ocean Thermal Energy Conversion (OTEC) and osmotic (salinity gradients) energy[2]. Although offshore wind energy is also generated at sea, it is not included under the definition of OE, but as part of the broader category of marine energy.

Given the relatively early state of technology development, the estimates of theoretical potential for OE technologies vary greatly (see figure 1.1). However, on the basis of existing scientific and expert assessment, the potential of OE is considered to be significant[3].

Figure 1.1 Global technical potential ranges of renewable energy sources



Range of Estimates of Global Technical Potentials

	Geothermal Energy	Hydropower	Ocean Energy	Wind Energy	Geothermal Energy	Biomass	Direct Solar Energy
Max (in EJ/yr)	1109	52	331	580	312	500	49837
Min (in EJ/yr)	118	50	7	85	10	50	1575

Source: IPCC (2011): Special report on renewable energy sources and climate change mitigation 2011

OE, with the exception of tidal barrages, is still at its demonstration and pilot project phase, but promising first steps towards commercial application are currently on-going. 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 for a leading role in tidal and wave energy in particular – with the UK at the forefront of developments, and to a lesser extent Norway, Denmark, France and Ireland. In addition, a potential for OE exists in other countries such as Portugal, Spain and the outermost regions. Other parts of Europe may also benefit from increased OE generation by supplying equipment and components to the OE industry sector.

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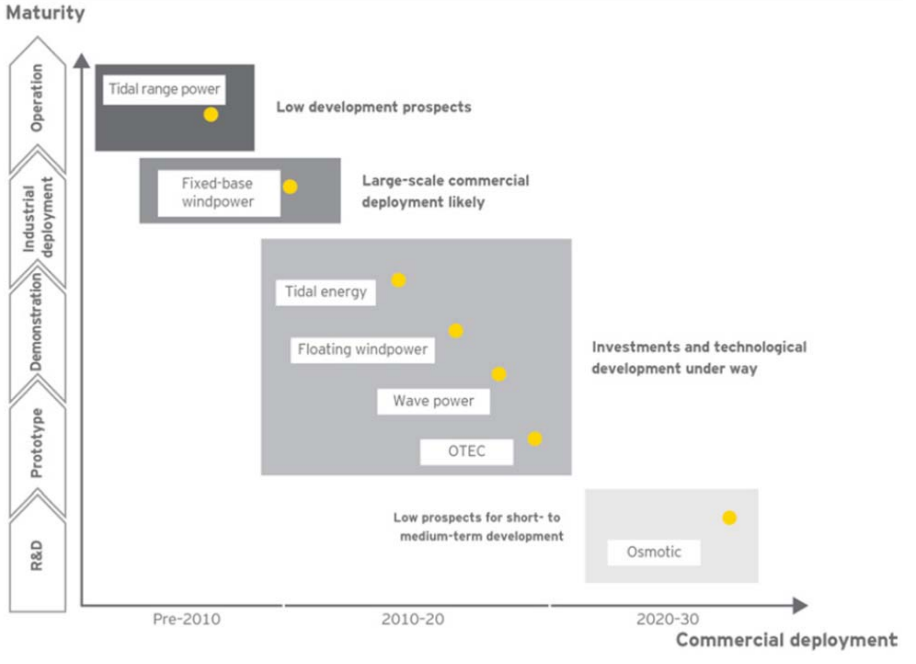
[1] "OE" is used throughout the study as the abbreviation for Ocean Energy

[2] See Blue growth study (Ecorys 2012), Maritime Sub-Function Profile Report "Ocean Renewable Energy Sources"

[3] For example the International Energy Agency (IEA) estimates that the global electricity generation from OE might reach up to 552 TW/h by 2050 in their optimistic scenario (Energy technology perspectives 2010). As comparison, the total annual electricity production in the EU27 is currently approximately 3,000 TWh.

Figure 1.2 OE maturity and development perspectives



Source: Ernst & Young 2012[4]

As illustrated by the figure above, all OE technologies are in their pilot and demonstration phase with the exception of the tidal ranges barrages. Osmotic power and OTEC technologies are also further away than tidal and wave in their path to commercialisation.

Several factors are encouraging the development of these technologies, including various types of EU and national policies in support of an accelerated uptake of renewable energy sources, a desire to become less dependent on imports of fossil fuels, the high level and volatility of the prices of fossil fuels, the increase in energy demand and a trend towards decentralised power generation. However, the development of OE will not take place automatically as a number of key bottlenecks exist that hamper the uptake of ocean renewable energy as being demonstrated in the existing body of literature on OE. This was also confirmed by a public consultation that was carried out by DG MARE in the period between mid-June-mid September 2012[5].

1.2 Purpose of this study

Against the above background the Commission has recognized the potential of OE and intends to support the appropriate conditions to stimulate the market take up of this promising energy source. To assess the best way forward the Commission launched an Impact Assessment to identify and assess different policy options that exists towards the introduction of OE.

The current study supports this Impact Assessment by describing various scenarios of possible future market uptakes of OE and assesses the economic, social and environmental implications that a development under these scenarios will have. It focuses on the introduction of wave and tidal energy which are seen as the most mature technologies within OE, although energy production

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[4] Ernst & Young (2012), Renewable energy country attractiveness indices. May 2012 Issue 33

[5] http://ec.europa.eu/dgs/maritimeaffairs_fisheries/consultations/ocean_energy/index_en.htm

driven by differences in temperature (OTEC) or salinity gradients (osmotic energy) can also become relevant on a longer timeframe.

1.3 Structure of the report

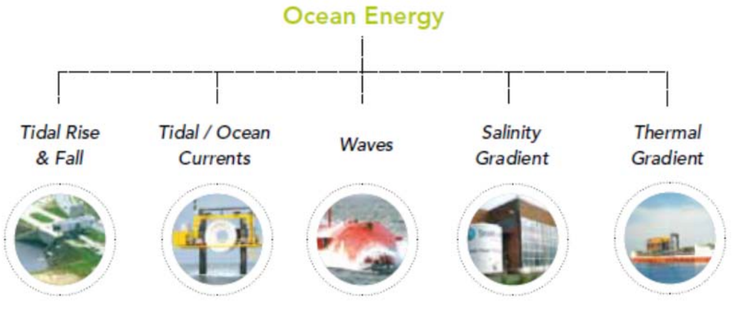
In this study we assess various scenarios for future development of Ocean Energy. First describe the state of play of Ocean Energy in chapter 2. Chapter 3 describes three scenarios for possible future development of Ocean Energy.. In chapter 4 we assess the economic, environmental and social impacts that each of these scenarios will have. Chapter 5 summarizes the findings of the study.

2 State of play

2.1 Main technologies

Oceans cover more than 70% of the earth's surface and are the world's largest solar collectors; they contain thermal energy from the sun and produce mechanical energy from tides and waves. There are a number of basic mechanisms to tap the ocean for its energy. We can use the ocean's waves; we can use the ocean's high and low tides; we can harness underwater currents; or we can use temperature differences in the water. Finally we can use the salinity gradient when the salt ocean water meets fresh river waters[6] [7].

Figure 2.1 Main types of OE



Source: Annual report of the IEA Implementing agreement on Ocean energy systems

Tidal Power

The tides are cyclic variations in the level of seas and oceans. All coastal areas experience two high tides and two low tides over a period of slightly more than 24 hours. Tidal power is a form of hydropower. There are two different means to harness tidal energy: the first is to exploit the cyclic rise and fall of the sea level using *barrages* and the second is to harness local tidal *currents*.

Tidal stream generators harness energy from currents generally in the same way as wind turbines. Because the density of water is more than 800 times the density of air, a single generator can provide a significant amount of power at low tidal flow velocities (compared to wind speed). Some tidal generators can be built into the structures of (existing) bridges, dams or flood control mechanisms, reducing the civil engineering costs[8].

The working principal of tidal barrage power (or tidal range) is that an estuary or bay with a large natural tidal range is artificially enclosed with a barrier. Barrages are essentially dams across the full width of a tidal estuary. Electricity is generated by allowing water to flow from one side of the barrage to the other, going through low-head turbines which activate a generator. Alternatively, the turbines can be used as pumps to pump extra water into the basin behind the barrage during periods of low electricity demand. This water can then be released when the demand on the system is at its greatest level, thus allowing the tidal plant to function with some of the characteristics of a "pumped storage" hydroelectric facility[9].

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[6] US Department of Energy. http://www.eere.energy.gov/basics/renewable_energy/ocean.html

[7] Global Energy Network Institute (2009). 'OE technologies for renewable energy generation'

[8] Twidell, J. & T. Weir (2007). 'Renewable energy resources – second edition'. Taylor & Francis, Canada.

[9] OE Council. http://www.oceanenergycouncil.com/index.php/Tidal-Energy/Tidal-Energy.html

History of tidal energy and its current status

The earliest occurrences of tidal power utilisation date from the Middle Ages, or even from Roman times[10]. But it was only in the 19th century that the process of using falling water and spinning turbines to generate electricity was introduced in the U.S. and Europe. Since 1966, the 240 MW ‘La Rance’ electricity generation system operates at an estuary into the Gulf of St Malo in Brittany, France, thereby proving the technical feasibility of this technology at large scale[11].

Box 1 La Rance Barrage – The world’s first tidal power station

In November 1966 the world’s first tidal power station opened on the estuary of the Rance River, in Brittany, France. 24 turbines were installed with a capacity of 240 MW. Its annual output is about 600 GWh.

Being a pilot project the costs were rather high, but they have been now recovered and electricity production costs are even lower than of nuclear power generation (1.8c per kWh vs 2.5c kWh for nuclear). Furthermore the power plant is a local attraction. Since 1966 about 70.000 people have visited the station.

Source: [*http://www.wyretidalenergy.com/tidal-barrage/la-rance-barrage*](http://www.wyretidalenergy.com/tidal-barrage/la-rance-barrage)

Whereas tidal range technologies have a longer history, tidal stream technology is not yet mature. No standard technology has yet emerged and a large variety of designs is currently piloted and experimented, with some close to large scale deployment. However, no commercial production facilities have been built yet . Several prototypes look promising, but they have not operated commercially for extended periods to establish performances and rates of return on investments[12].

Advantages and challenges

An advantage of tidal power is that tides are more predictable than wind energy and solar power. Also, the tidal basins provide energy storage, hence extending power generation times and being available for storage of other power sources. However, there are also a number of challenges. As with wind power, the selection of a good location is critical; tidal stream systems need to be located in areas with fast currents where natural flows are concentrated between obstructions, such as at the entrances to bays and rivers, around rocky points, headlands, or between islands or other land masses. Furthermore, for tidal energy to be harnessed, the difference between high and low tides must be more than 7 meters in order to be economically feasible[13]. There are about 40 sites on earth with tidal ranges which match these criteria. Moreover there are also environmental points of

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[10] EU OEA (undated) 'Oceans of energy'. The first patent to harness power from waves was issued in France in 1799. See e.g., Ewen Callaway, "Energy: To Catch a Wave", 2007. http://www.nature.com/news/2007/071107/full/450156a.html.

[11] Twidell, J. & T. Weir (2007). ‘Renewable energy resources – second edition’. Taylor & Francis, Canada.

[12] Global Energy Network Institute (2009). ‘OE technologies for renewable energy generation’

[13] Ocean Energy Council. http://www.oceanenergycouncil.com/index.php/Tidal-Energy/Tidal-Energy.html

concern. Tidal range power plants that dam estuaries can impede sea life migration and the silt that builds up behind such facilities can affect local ecosystems that rely on the ebb and the flow of tides[14].

Wave energy

Waves are caused by the wind blowing over the surface of the ocean. As long as the waves travel slower than the wind speed just above the waves, there is an energy transfer from the wind to the waves. Power plants can transform the wave energy into electricity by extracting the energy directly from surface waves or from pressuring fluctuations below the surface.

Offshore systems are located in deep water, typically of more than 40 meters. Mechanisms use the motion of the waves to power a pump that creates electricity. Other offshore devices use hoses connected to floats that ride the waves. The rise and fall of the float stretches and relaxes the hose, which pressurizes the water, which, in turn, rotates a turbine. Built along shorelines, onshore wave power systems extract the energy of breaking waves[15].

History of wave energy technology

Also wave-power generation is currently in its development stage and not yet a widely employed commercial technology. At present, the majority of current proven applications are found in very small scale autonomous systems are used for marine warning lights on buoys and much larger devices for grid power generation[16]. The possibility of generating electrical power from deep water waves has been recognised for many years and the first known patent to use energy from ocean waves was filed in Paris in 1799. There have been attempts to use the power of the waves since at least 1890. In 1909 a wave power system was used in California for harbour lighting. A renewed interest in wave energy was fuelled by the oil crisis in 1973, but the low oil prices of the 1980s reduced the willingness to fund its further development. Recently, the interest is growing again .

Advantages and challenges

An advantage of wave energy is that production is much smoother and more consistent than wind or solar, resulting in higher overall capacity factors. Also, capturing and conversion mechanism may help to protect the shoreline. Nevertheless, there are also some challenges to overcome.. As for tidal energy, there is a potential impact on marine environment, although the noise and visible impact of each design varies greatly. Also, because wave patterns are irregular in amplitude, phase and direction, it is difficult to design devices to extract power efficiently over the wide range of variables. Next to this, there is always some probability of extreme storms or hurricanes which implies that structures of wave power plants have to withstand approximately 100 times the power intensity to which they are normally matched. This is expensive and will probably reduce normal efficiency of power extraction[17].

Ocean Thermal Energy Conversion

Ocean Thermal Energy Conversion (OTEC), also known as thermal gradient power, is limited to tropical regions, because it uses the temperature difference between cooler deep and warmer shallow or surface ocean waters to run a heat engine and generate electricity. To work properly, a temperature difference of 20-25 ^{o}C or more is desirable. Compared to technologies such as wave energy, the energy available from OTEC is much higher, but the thermal efficiency is very low; the theoretical maximum efficiency is 6 or 7%. Next to this, the extraction of energy is difficult and

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[14] Global Energy Network Institute (2009). 'Ocean energy technologies for renewable energy generation'

[15] US Department of Energy. http://www.eere.energy.gov/basics/renewable_energy/wave_energy.html

[16] Twidell, J. & T. Weir (2007). 'Renewable energy resources – second edition'. Taylor & Francis, Canada.

[17] Twidell, J. & T. Weir (2007). 'Renewable energy resources – second edition'. Taylor & Francis, Canada

expensive, mainly due to the required pumping material. So although OTEC has the potential to provide constant, base load electricity generation, there are also apparent challenges to overcome.

Salinity gradient power

Salinity gradient power (also known as osmotic power) is the energy available from the difference in the salt concentration between seawater and fresh river (or lake) water. Although the Netherlands and Norway are working on developing this technology in pilot plants, the current main problem is the high cost of the required membranes.

Because the latter two forms of OE are only in their early stages of development or not widely applicable in Europe, only limited attention will be paid to them in this report and the focus lies on wave and tidal energy. This should not be interpreted as a prejudgement on their likely potential in a longer time perspective.

2.2 Main players

EU countries with high potential for OE deployment are located along the Atlantic and the North Sea. In particular, the UK, Ireland, Portugal, Spain, France and the Netherlands are active in the field. The current leading country on an international basis is the UK with large testing sites in Scotland. Countries outside the EU with high potential and growing activity in the sector are Canada, the US, Japan, China and Australia. While until the recent past, the main individual players were universities, other research institutions and entrepreneurial SMEs, now larger industrial players (both in terms of technical development and in commercial planning) are entering the field[18].

As mentioned earlier, France built the first tidal power barrage in the 1960s but undisputedly the current leading country for the new generation of wave and tidal OE technology is the UK. The UK has more wave and tidal stream devices installed than the rest of the world combined with hundreds of MWs in the pipeline. Regarding test and demonstration sites, Europe has developed a network of sites where private and public actors are working on new technologies across various sea environments. The following figure shows existing testing facilities for OE in Europe.

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[18] Ecorys et al. (2012): Blue Growth subfunction report on Ocean Renewable Energy Sources p.8

Figure 2.2 European testing facilities for OE

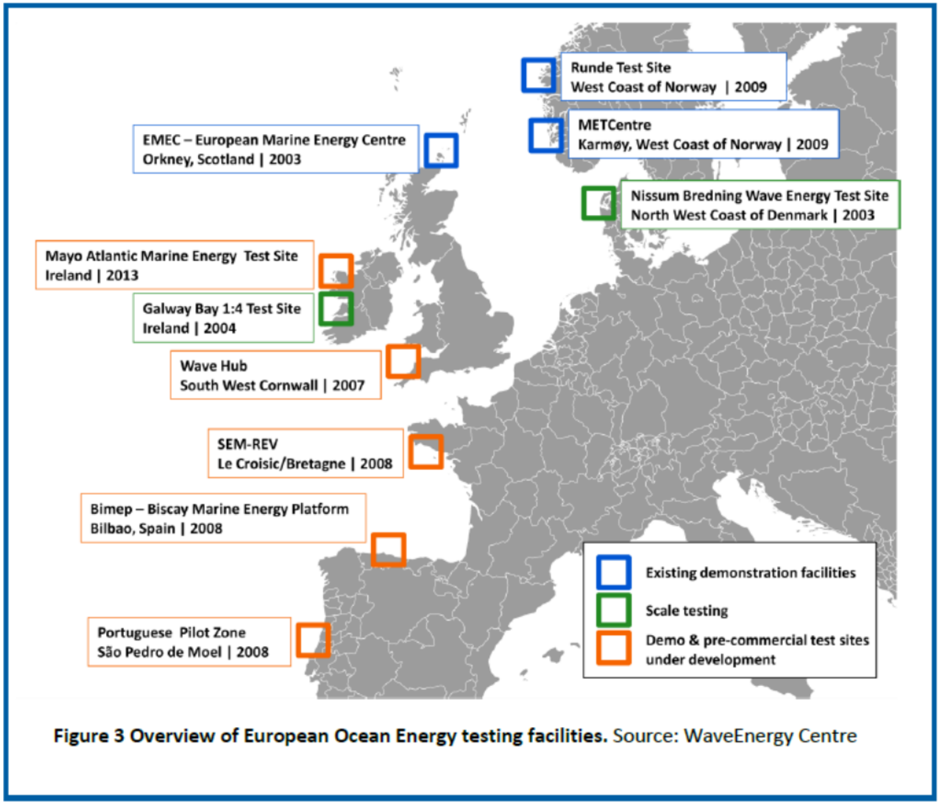

Figure 3 Overview of European Ocean Energy testing facilities. Source: WaveEnergy Centre

Source: EU OEA (2012) Position Paper Towards European industrial leadership in OE in 2020

Orkney, Scotland, hosts one of the largest facilities in the world where different devices are tested for several clients. Current clients are: Andritz Hydro Hammerfest, Aquamarine Power, Atlantis Resources Corporation, Scotrenewables Tidal Power Ltd, ScottishPower Renewables, Seatricity, bluewater, E-on, Kawasaki, Tidal Generation, Vattenfall, Voith, openhydro tidal technology and Wello[19].

This also shows that, whereas previously mainly SMEs and research organisations where involved in the development of OE, a number of large European utility companies and major industrial players are stepping in, not only in countries where the highest OE potential exists, but also in major inland EU Members States where technology providers for OE installations are located such as Germany and Austria.

Currently, over 100 different ocean energy technologies are under development in more than 30 countries[20]. Due to this intensive research activity a second generation of OE technology is expected to emerge in the coming years. Many authors note the parallels between OE and wind in the1980s and in particular offshore-wind in the 1990s[21]. This implies that with the necessary policy support the technology can become important contributor in shaping the role of ocean energy in Europe’s future energy mix.

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[19] http://www.emec.org.uk/about-us/our-sites/

[20] IEA-OES (2009)

[21] Esteban, M. and Leary, D. 'Current developments and future prospects of offshore wind and OE', Applied Energy, Vol. 90 (2012)

2.3 Current and planned deployment

The interest in OE technologies has increased strongly in the last decade, driven by the high energy demand and costs and the success of other renewables such as wind energy.

Despite the growing interest in the sector, actual investments are still limited, accounting for less than 2% of all investments in renewable energy[22]. Although tidal technology is already more advanced than wave, large testing wave power plants are currently getting installed across the EU. Overall the capacity for wave and tidal stream in the EU was at about 8 MW around 2011, with another 5.6 MW under installation(see table 2.1)[23]. At the end of 2012 the reported capacity increased to up to 10 MW[24]..

Table 2.1 Actual and planned OE deployment (figure marked with * are under installation) in 2011

Country	Wave energy	Tidal stream	Tidal range	Salinity
United Kingdom	2MW + 2.4MW*	4.8MW + 1.7MW*		
France			240MW	
Portugal	400kW + 300 kW*			
Spain	296kW + 225kW*			
Denmark	250kW			
Sweden	150kW + 1000kW*			
Norway		300kW		4kW
Total	**3.1 MW + 3.9 MW***	**5.1 MW + 1.7 MW***	**240 MW**	**4kW**

Source: IEA OES (2011), pg. 122, and EU-OEA (2012) modified by Ecorys

In addition to the already planned installations, some of the Member States national renewable energy plans include a further expansion of OE. Mainly the UK has planned significant advances to increase the installed capacity of OE until 2020 – the projects announced in the course of the first OE leasing round by the British Crown Estate alone account for 1,900 of the approximately 1,940 MW scheduled to be installed until 2020 throughout Europe. Only a few relatively small projects have been announced outside the UK[25].

The UK has also been most active in delivering government support to the development of OE, although more countries offer some sort of support[26]. Often support for OE is part of a general renewables support scheme which does not take into account the different technological status of OE. Government support is particularly critical at very early stages of development of new technologies to bridge the funding gap between fundamental research (by research institutes/universities) and market deployment provided by private players.

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[22] Ernst and Young country attractive index May 2012

[23] This number excludes the French La Rance tidal barrage as it is a technology from the 1960s and is therefore no indication for future developments in the sector.

[24] European Ocean Energy (2013): Industry Vision Paper

[25] Thaleman and Bard (2012)

[26] OES-IA (2009) 'Annual report'

Box 2 OE Teams compete for 10 Million pounds Scotland Prize

For the purpose of boosting efforts in Scotland to develop viable environmentally friendly ocean power systems, the Scottish government offers a 10 million pounds prize (about 11.8 million euro) for the most successful project. There were four companies which deploy test devices in northern Scotland who competed for this Saltire Prize which was announced in 2008.

As Scotland possesses about 25 percent of Europe's estimated tidal energy potential and 10 percent of Europe's wave energy potential, a development boost in Scotland might have spill over effects on other European regions.

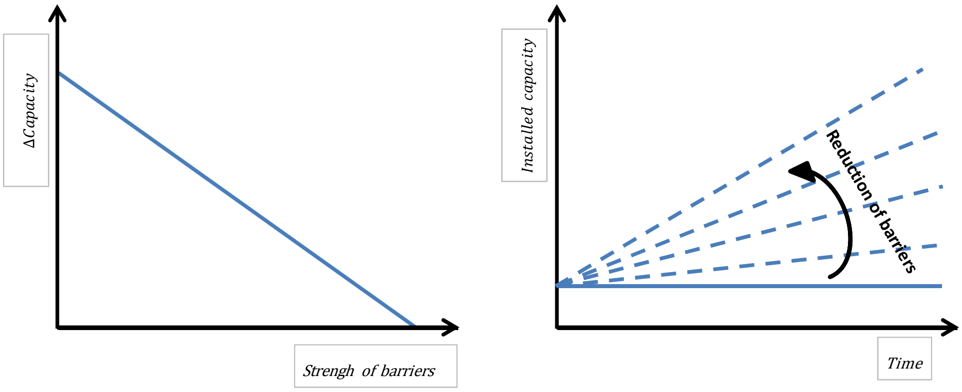
Sources: Photograph by Pelamis Wave Power (http://news.nationalgeographic.com/news/energy/2012/09/120907-scotland-wave-energy-saltire-prize/)

2.4 Challenges for development of Ocean Energy

Whereas the potential for OE is widely recognized, a number of barriers exist towards a wide scale introduction and commercialisation. These are to a large extent related to the early development stages of the technology. Given the current stage of development and the absence of appropriate market prices that reflect the environmental benefits of renewable energy generations in reducing greenhouse gas emissions, a clear rationale exists for government intervention to overcome these market distortions.

In an efficient market there are no barriers to entry for new technologies/players. This means that if they bring enough benefits to the consumer in comparison to existing products/services, they will enter the market and capture market shares. As fully efficient markets rarely exist, market analysis will seek to identify potential barriers which hamper commercialisation of new technologies and attempt to reduce them. The theoretical concept is illustrated in the figures below.

Figure 2.2 Relation of capacity and barriers



Source: Ecorys

There is an expected relation between the strength of barriers and the growth of a market (left figure above). In the worst case, these barriers are so strong that no further growth can be expected. In such a situation the installed capacity remains the same as it was in the original position. The other extreme would be no barriers at all, which leads to the highest possible growth rates of capacity. The maximum growth rate depends on the potential of the technology and other external factors. Hence, the more barriers are reduced, the higher the capacity increase can be and the higher the installed capacity is to a certain point in time.

Moving from the theoretical concept to the reality of OE, a number of barriers can be identified that hamper capacity increases in the OE sector. We have identified five main barriers for a commercialisation of OE. These barriers are related to the early stage of development or to contextual issues. Although some of these barrier are unique to OE, due to the fact it involves offshore energy generation, some of these barriers are similar to the barriers that other forms of renewable energy were facing looking back a decade or two. In the following sections the key barriers are further elaborated.

Fragmented technology development

OEis not one single technology. OE consists of four main groups of technologies: Tidal, Wave, Osmotic/salinity gradient and OTEC, which in turn encompass different designs and technologies.

Within the four technology groups, the number of systems being tested per technology is high. Tidal and wave energy systems, which are more mature than OTEC and osmotic energy, in particular show a wide spread of different technologies. This is understandable, given the current stage of development of OE. To a certain extent it can even be seen as an advantage to have many competing technologies as this might lead to a faster improvement and a broader choice of potential “winners”, but at the same time it hampers standardisation and upscaling (with a direct impact on cost reduction of technologies) within OE. It also creates a blurred image of OE towards potential investors causing a higher risk profile. This also puts OE at present at a disadvantage towards more developed forms of renewable energy sources and can create a hurdle in their future market uptake.[27]

Still high installation and operating costs compared to other renewables

Tidal and wave technologies are highly capital intensive, although,in general, investment costs of tidal energy plants are considered to be somewhat lower than wave energy. This is mainly caused by the fact that they must be installed, tested and operated under harsh sea conditions[28] These high capital costs and the long construction periods are at present a major barrier for investment in the technology. Moreover, compared to on-shore renewables, where access is relatively easy and down-times are relatively short, the operation and maintenance costs of offshore renewables are relatively high.

Significant cost reductions in the magnitude of 50 to 75% will be needed to reach a competitive level with other renewable energies (see section 4.2). The current levelised cost of electricity generation from tidal energy is estimated at about €0.25 per kWh, whereas the cost of electricity generation from wave devices is around €0.37per kWh. This compares to a levelised costs for offshore wind of €0.18 per kWh.[29]

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[27] EU OEA 'Position Paper', undated

[28] UK Marine action plan 2010

[29] Carbon Trust (2011) in JRC draft report, Accelerating marine energy (July 2011)

Access to grid infrastructure needs to be established

OE technologies face important challenges regarding their access to the grid infrastructure. This need to be addressed for the technologies to become competitive.. OE potential is located in relatively peripheral regions and islands, with small or limited upgrading capability. Those locations are very often characterised by a low population density and therefore low electricity demand causing limited incentives for grid players to invest. In addition, building and operating grids in the waters is an additional challenge for grid operators. Finally, grid connections will have to be granted in conjunction with other users of the sea and in full respect with environmental legislation. The peripheral location also may hamper the development, because of limited access to suitable ports for launch and maintenance.[30]

Administrative & regulatory issues

Complex and multiple administrative procedures can make investments difficult or even impossible. The 2012 IEA-OES report states that many countries have relatively complicated administrative procedures regarding OE. In many cases, it is not even clear who in the administration is responsible for OE. To a large extent this is obviously related to the limited experience with respect to OE as the number of applications is still limited and only recently increasing[31].

Some EU Member States are working already towards simplifying their procedures, for example, by designating "one-stop-shops" or “dedicated consenting authorities” to deal more effectively with consenting processes (e.g. in Scotland and Denmark)[32]. Also, test sites (e.g. EMEC in Scotland and AMETS in Ireland) are sometimes treated differently in the sense that they are “pre-consented”. This means that developers, using the site to test their devices, do not have to go through the full consenting process themselves[33].

Uncertainties of environmental impacts

Environmental impacts of OE projects are assessed in the development, installation and operation, but also decommissioning stage of OE installations. Given the limited experience with OE so far they are at this moment often estimated and benchmarked based on the experience of other maritime and offshore technologies such as offshore wind.[34] The uncertainty about environmental impacts might constrain the future development of the technologies even though first projects tend to show that environmental risks from OE technologies appear to be relatively modest (although differences exist regarding the different technologies).

The current uncertainties regarding environmental impacts increase the risk profile of these operations adding a premium to financing, but they also have an impact on administrative procedures, in particular when OE installations are planned in environmentally sensitive areas.

On the positive side, OE just like other renewable energy sources, emits no or limited CO_2 during operation.

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[30] Waveplam (2009): Del. 2.2: Non-technological Barriers to Wave Energy Implementation

[31] O’Hagan (2012): A review of international consenting regimes for marine renewables: are we moving towards better practice?

[32] Ibid.

[33] Ibid.

[34] Langhamer et al. (2010) 'Wave power—Sustainable energy or environmentally costly? A review withspecial emphasis on linear wave energy converters Renewable and Sustainable Energy Reviews', 14 (2010) 1329–1335, BOEhlert and Gill (2010) 'Environmental and Ecological Effects of Ocean Renewable Energy Development: a Current Analysis, Oceanography, vol. 23/2.

3 Future market uptake scenarios

The potential of OE in Europe is promising. Some authors indicate that the total capacity that can be technically achieved amounts to 280 TWh per year[35]. Different Member States and regions, primarily alongside the Atlantic and North Sea shores and outermost regions [36] [37] [38], have identified OE technologies to play an significant role in their future energy mix.

Not all potential may be realised due to non-technical characteristics such as financial viability or the lack of supportive policies, such as production incentives[39]. Due to the fact that the technology is still at a development stage it is hard to predict market uptake.

Three market uptake scenarios

In this chapter we elaborate three possible scenarios for OE market uptake, which are built around a different set of underlying assumptions. These scenarios are:

- Scenario 1: Baseline Scenario
- 2: Intensified Coordination
- Scenario 3: Strong Stimulus

For the short term (period until 2020) the market uptake under these scenarios is expected to be similar, as this is mainly influenced by actions and decisions already taken. This short term development is based on the most recent estimates regarding the installed capacity of OE. These follow the OE contributions within the National Renewable Action Plan as defined by the 2009 Directive[40].

The medium to longer term developments (period 2020-2035) build where possible on existing scenarios.[41] They also take notice of the historic development that took place in comparable sectors (notably offshore wind) to strengthen the evidence base. After Beyond 2035, uncertainties surrounding the development of OE (e.g. changing government policies, energy price developments etc.) and other factors such as technological development are too large to make reliable forecasts

The scenarios are possible future paths rather than forecasts[42]. Data should thus be interpreted with care. In addition, implications have been assessed in a qualitative manner where data limitations exist or implications are of a more intangible nature.

In the following sections, first we describe the baseline scenario. This can be considered as a business as usual scenario. Next we describe the “Strong Stimulus scenario” which can be seen as the most optimistic scenario as it implies strong actions taken to support OE. Scenario 2 ”Intensified Coordination” scenario, takes a middle position between between scenario 1 and scenario 3. This

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[35] Scruggs and Jacob; Cornett cited in Esteban & Leary (2012) Current development and future prospects of offshore wind and OE.

[36] OE Roadmap - http://www.seai.ie/Renewables/Ocean_Energy_Roadmap.pdf

[37] UK Marine Energy Action plan 2010

[38] Les energies marines renouvelables http://wwz.ifremer.fr/institut/content/download/39242/536346/file/Ifremer_synthese-etude-prospective-EnRM.pdf

[39] ORECCA European Offshore Renewable Energy Map, September 2011.

[40] Article 4 of **Directive 2009**/28/EC on **Renewable Energy** requires Member States to submit **national renewable energy Action Plans** by 30 June 2010.

[41] IEA World Energy Outlook 2012

[42] See also SEC(2011)1565/2 Impact Assessment accompanying the Energy Roadmap 2050.

scenario is assessed from a relative perspective and will only be described after scenario 3. Based on the resulting OE installed capacity in the scenarios the economic, social and environmental implications of each scenario are assessed in Chapter 4.

3.1 Scenario 1 – baseline scenario

Scenario narrative

Under the baseline scenario, the OE sector would continue its uneven path of development. It continues to be eclipsed by more advanced and competitive renewable energy sectors as well as by new and cheaper sources of fossil fuels (such as shale gas). As a consequence, the potential of the carbon-free OE to make a substantial contribution towards achieving the EU's ambitious 2050 decarbonisation objective would be curtailed.

In this scenario the OE share in the renewable energy mix will remain relatively small as well as its contribution to growing electricity demand. As a consequence, cost reductions and learning rates will be limited. The horizon for on-stream feasible and cost-effective OE will continue to be long term (2050) rather than medium term (2030).

Infrastructure improvements such as grid connections will continue at their current rate and will not take OE into consideration because there is no viable deployment to warrant factoring OE into the equation.

Development of OE installed capacity

As described in chapter 2, the currently installed capacity of modern wave and tidal installations amounts to approximately 10 MW[43].

For the development up to 2035 the business as usual scenario follows the reference scenario which has been adopted for the Energy Roadmap 2050 of the European Commission[44], updated with the most recent developments and the latest policies on energy efficiency, energy taxation and infrastructure adopted or planned after March 2010[45]. In this scenario installed capacity increases from its current level to 1.6 GW in 2020 and to 4.3 GW in 2035[46]. This is slightly more pessimistic than what is stated in the latest IEA World Energy Outlook which foresees and installed capacity of 6 GW in 2035[47] under their "Current Policy Scenario".

Capacity factor / load factor

In order to estimate electricity generation resulting from the installed capacity, assumptions must be made about the capacity factors of OE technologies. Capacity factor can be defined as the ratio of the actual output of a power plant over a period of time and its potential output if it had operated at full capacity the entire time. To calculate the capacity factor, we take the total amount of energy the plant produced during a period of time and divide this by the amount of energy the plant would have produced at full capacity. Various factors affect the value of capacity factors such as service maintenance, technical failures, regulatory requirement or pricing conditions. In addition, renewable plants are based on variable input (solar, wind, water) affecting the value of the capacity factor.

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[43] IAE OES (2011), with another 5.7MW under construction. This excludes the old tidal barrages that was built in La Rance France in 1966 and has a capacity of 240 MW.

[44] SEC(2011)1565 Impact Assessment accompanying the Energy Roadmap 2050.

[45] SEC (2011)1565. In the impact assessment this scenario is called the Current Policy Initiatives (CPI) scenario

[46] SEC(2011)1565, p 67. For wave and tidal the heading "other renewables (tidal etc.)" is used.

[47] Corresponding with an electricity generation of 20 TWh. See IEA (2012) World Energy Outlook 2012. For 2030 they assess a total installed capacity of 2 GW.

According to two UK studies, wave and tidal technologies may be able to provide capacity factors between 20-45%[48] depending on the technology and site. However, for the case of tidal barrages the load factor is much lower, typically around 23%[49]. It is claimed, however, that modern OE devices are able to achieve much higher capacity factors than tidal barrages, in the range of 40–50% for tidal flows, and also around the figure of 40% for wave[50]. JRC used in the 2012 draft version of its report on OE capacity factors around 35%. Another study used a capacity factor of 27%[51].

Give the wide range of estimates, we believe that these figures should be treated with caution, as there is yet no definitive evidence for them. Therefore, we have used a low and higher capacity factor (25% and 35%) for different calculations in this study.

For the short term, i.e. the period up to 2020, the Energy Roadmap 2050 reference scenario is updated with recent plans from the Member States which were published in their national renewable energy action plans (NREAP)[52]. By 2020, seven countries plan to have OE plants operating (UK, France, Portugal, Ireland, Spain, the Netherlands and Italy). In 2020, the installed capacity of these plants is projected to reach 2,243 MW, representing 0.5% of the total installed electricity capacity in the EU-27[53]. In particular, the UK has very ambitious plans set out for tidal and wave. This projection up to 2020 is in line with other literature sources that point to a strong growth of OE over the coming years[54].

Table 3.1 OE: installed capacity and generation potential in 2020

Country	Installed capacity (MW)	Generation Potential (MWh)
Ireland	75	230
Spain	100	220
France	380	1150
Italy	3	5
Netherlands	135	514
Portugal	250	437
UK	1300	3950
Total	**2243**	**6506**

Source: JRC (draft 2012)

The following figure shows the resulting development of OE installed capacity for electricity generation in the EU until the year 2035 in scenario 1 ´Baseline

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[48] European Commission, JRC/SETIS “Technology Map 2011’ EUR 24979 EN

[49] Breeze PA. Power generation technologies; 2005. ISBN 0750663138,9780750663137.

[50] New Zealand Electricity Commission. An appraisal of new and renewable generation technologies as transmission upgrade alternatives; 2005.

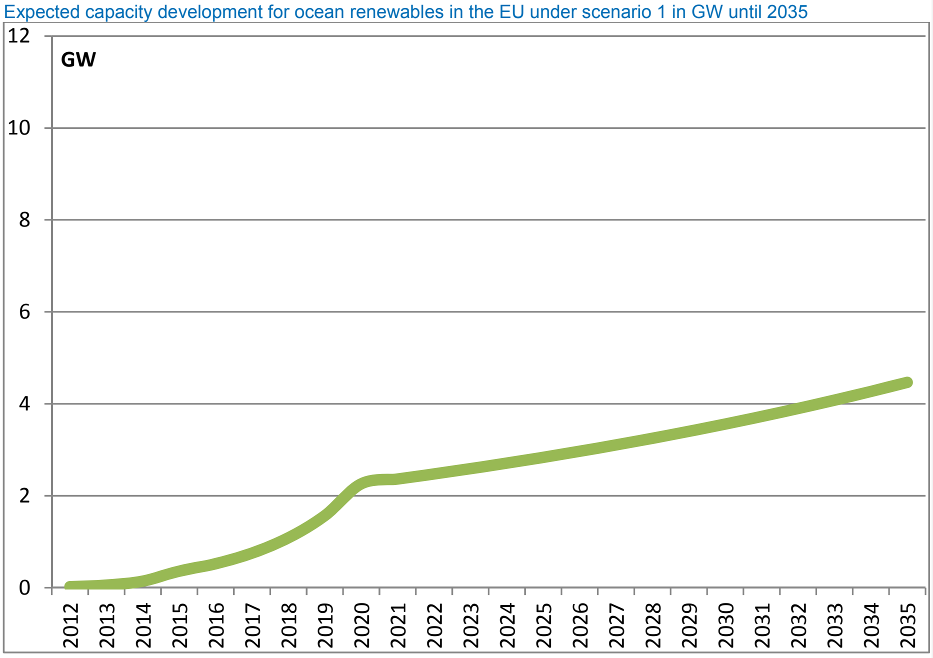
[51] Esteban, M. and Leary, D. 'Current developments and future prospects of offshore wind and OE', Applied Energy, Vol. 90 (2012)

[52] Article 4 of Directive 2009/28/EC on Renewable Energy requires Member States to submit national renewable energy Action Plans by 30 June 2010. http://ec.europa.eu/energy/renewables/action_plan_en.htm

[53] JRC (2012): "Draft report ‘Short overview of marine energy technologies and their European potential"

[54] See Blue Growth Study, DG MARE, 2012, Marine Energy in the UK State of the Industry Report, RenewableUK, March 2012, Implementing Agreement on OE Systems, IEA, 2010 (www.iea-oceans.orgwww.iea-oceans.org), The World Wave and Tidal Market Report 2011-2015, Douglas-Westwood, 2010.

Figure 3.1 Expected capacity development for ocean renewables in the EU under scenario 1 in GW until 2035



Data source: Ecorys, based on JRC (draft 2012) and EC, Energy Roadmap 2050 (2011)

3.2 Scenario 3 – Strong Stimulus

Introduction

Under this scenario OE installed capacity is assumed to follow the scenario “High RES” (scenario 4) from the European Commission 2050 Roadmap. In this scenario current and future measures are aimed at a maximum renewable energy penetration. Hence the “Strong Stimulus” scenario implies the policy and technology assumptions that underlie the High RES scenario of the European Commission Roadmap are being implemented.

As OE is often seen to follow a comparable development path as (offshore) wind energy, this scenario has also been placed in the light of the past development of offshore wind energy.

In the following sections we first elaborate the scenario narrative, followed by an analysis of the historical development of offshore wind and the similarities and limitations when comparing this to OE. Finally the expected market uptake under this scenario is described.

Scenario narrative

Under scenario 3 a number of structural actions are envisaged that structurally drive the market uptake for OE.

Based on the experiences gained with the current first generation of wave and tidal energy installations and increased access to finance for new installations learning curves will lead to significant cost reductions (see section 4.2). Learning from first generation of OE installation will be actively pursued across and between individual countries. Under this scenario, a new generation of full-scale OE conversion devices will have been installed in real operating conditions and lessons learnt from large scale demonstration programmes. Manufacturing processes for OE devices will be developing, automated and optimised with knowledge transfer from, and industrial cooperation with, other sectors, primarily offshore wind and offshore oil and gas but also with marine operations and shipbuilding industry.

This scenario is seen in the context of a favourable overall environment towards renewable energy sources. As the sector continues its development from the pre-commercial stage to full commercialisation, it will be able to take advantage of lessons learnt in the developmentof offshore wind industry, in particular in the field of infrastructure, supply chain, grid connection, authorisation procedures and understanding of the environmental impacts, thus creating clear synergies.

The example of offshore wind energy

As indicated earlier the development of offshore wind is often seen as being exemplary for the future development of OE. In this section we describe the historic development of offshore wind.

The deployment of offshore wind power can be considered to have happened in two phases to date. The first phase involved a series of small demonstration projects generally constructed in sheltered shallow waters from 1995 to 2000. The second phase was a time of projects which still had a demonstration role, but which were of an increasingly commercial nature and were deployed in more technically demanding situations between 2000 and 2004. In the year 2000, seven mostly small-scale demonstration projects were operational. By 2004, the industry had developed 15 projects many of them large-scale and fully commercial[55].

In 2001 the 50.5 MW of installed offshore capacity represented 1% of total new European wind capacity added in that year. In 2010, 883 MW were installed offshore representing 9.5% of the wind capacity added in Europe in that year[56]. The European Wind Energy Association (EWEA) has identified 141 GW of offshore wind projects in European waters – either operational, under construction, consented, in the consenting phase or proposed by project developers or in government proposed development zones. This 141 GW shows tremendous developer interest. With 26 GW already operational, under construction or consented, solid progress has been made towards 40 GW of offshore wind capacity by 2020. EWEA’s expectation is that 150 GW of offshore wind power will be operational by 2030. Offshore wind energy is currently most developed amongst the North Sea countries with the United Kingdom having a large share (45% of total installed capacity in Europe, mid 2011). By 2020 it is expected that 18 European countries will have developed offshore capacity[57].

The accelerated uptake was strongly influenced by strong political drivers for the deployment of renewable energy in many countries which were built on the twin pillars of climate change objectives and energy security. In addition industrial development, export potential and employment opportunities associated with renewable energy are seen as a primary motivation for promoting renewable energy development.

The following figure shows the historical development of offshore wind from 2000 until 2012 with indicated important policy actions in the EU and UK/DE (as these are the two most important markets for offshore wind in the upcoming future) which led to stronger growth rates in the segment.

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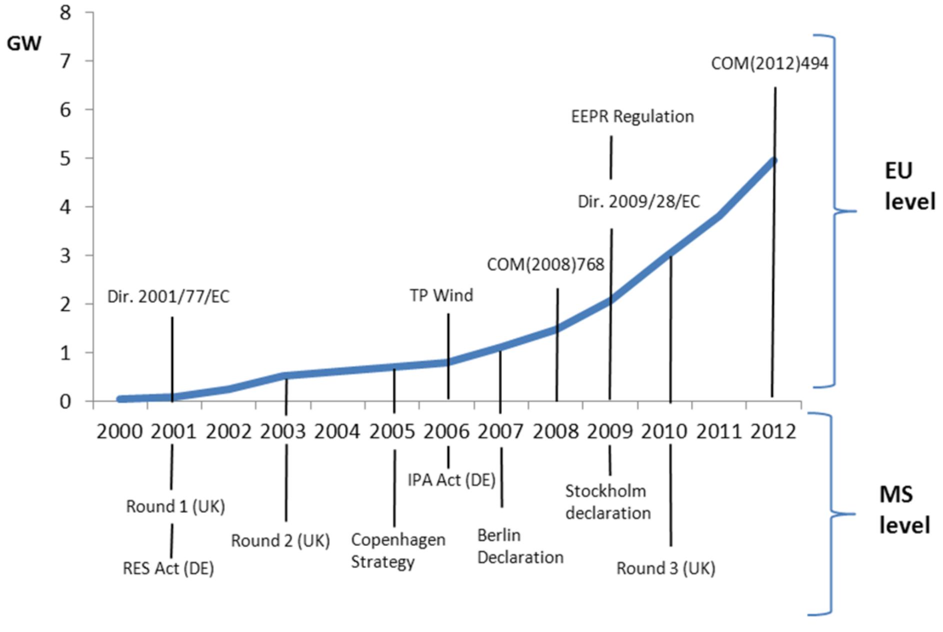
[55] IAE – Offshore wind experiences (2005).

[56] EWEA - Wind in our Sails (2011).

[57] EWEA – Wind in our Sails (2011)

Figure 3.2 Historic development of offshore wind with indicated policy actions



Source: Ecorys

Different authors argue that OE is comparable to offshore wind in its early stages of development. A recent study argues that the current situation in OE technology is comparable to the position of offshore wind in the beginning of the 1990s[58]. If the historical development of offshore wind is plotted on OE we can see that it could be expected to take off dramatically after 2025 reaching roughly 23 GW in 2035.

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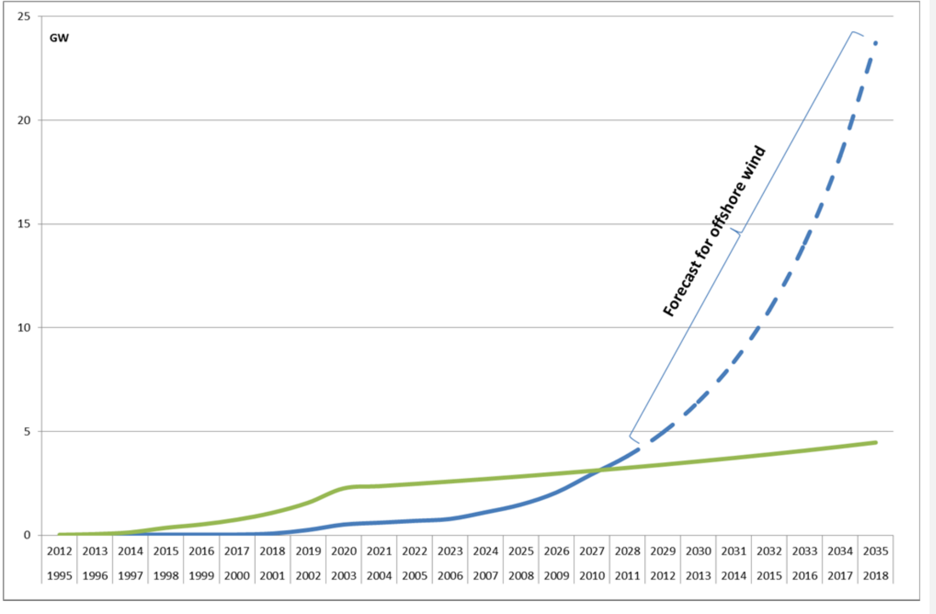
[58] Esteban, Miguel and Leary, David (2012): “Current developments and future prospects of offshore wind and OE”, In Applied Energy (90) 2012. They argue that the year 2008 of OE is comparable to the year 1991 in offshore wind.

Figure 3.3 Historical development of offshore wind (blue line) plotted on the development of OE (Green line = Scenario 1 Baseline scenario. The situation for OE in 2008 is assumed equal to offshore wind energy in 1991.)



Source: Ecorys based on Esteban & Leary (2012)

Limitations in comparing OE with offshore wind

Comparing with offshore wind makes sense as offshore wind and OE (in particular tidal and wave) share similarities regarding technology (use of structural materials (steel, concrete) and components and unit generation capacities), installation & operation techniques, regulatory environment (Maritime Spatial Planning, environmental legislation) and offer potential synergies (infrastructures, supply chains, environmental impacts).

However, modelling the development of OE based on offshore wind deployment only presents limitations. OE and offshore wind are developed in a different environment (different political and economic context, different set of stakeholders (e.g. Member States and coastal regions)). Furthermore, OE does not have (in contrast to wind energy) a successful parent technology (wind onshore).

The political energy climate at the end of the 1990s was strongly affected by emerging climate and renewable energy policies reflected in the adoption of a directive in 2001 and several Member States initiatives. The broad economic and financing climate was clearly more favourable then to emerging renewable energy technologies than it is now. For example at the beginning of the on-shore (and in Denmark off-shore) wind energy development was stimulated by Member State specific environmental targets and combined with general EU targets and environmental directives[59].This triggered the broad development of renewable energy technologies with onshore wind as a promising technology first of the class at the time. Offshore wind benefitted from the successful penetration of onshore wind across Europe with its proven technologies, increasing involvement of industrial players (e.g. utilities) relayed by innovative regional industrial development (e.g. Northern Germany and Denmark). Currently, the 2020 renewable energy targets and policy will, due to several circumstances (e.g. lack of financing, declining public support), be more likely

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[59] E.g. the EU-SEA Directive 2001/42/EC in which reasonable alternatives need to be identified for activities with a significant environmental impact.See http://offshorewind.net/Other_Pages/Links%20Library/Offshore%20Wind%20Experiences.pdf

target technologies that deliver faster and more renewable energy in the marketplace such as wind, solar and to some extent offshore wind.

Therefore, scenario 3 is inspired but not modelled on offshore wind because of the differences that present, in our opinion, additional barriers to the development of OE compared to offshore wind. The historical development of wind energy does evidence however that a strong development of OE may be expected in the coming two decades, provided that the right environment is created, even though the expected market development is likely to be slower than the offshore wind..

OE installed capacity

As mentioned earlier, scenario 3 “Strong Stimulus” follows the “High RES” scenario from the EC Energy Roadmap 2050[60]. By doing so we consistency with the Baseline scenario is ensured regarding more general assumption (on e.g. economic growth) which underlie both scenarios. In the “High RES” High RES scenario cumulative GHG emissions are expected to fall by long-term achievements, which would bring CO2 emissions to fall by 85% compared to 1990 levels. A strong stimulus of renewable energy in general is expected under this scenario. Support for Ocean Energy follows this general pattern. Scenario 3 can therefore only be credible if a strong stimulus from the public and private sector (combining hard and soft policy measures) will be set to accelerate the market uptake of OE from 2020 to 2035.

The development according to the “High RES” scenario from the EC Energy Roadmap 2050, is updated with the most recent forecasts for the developments until 2020.

The following figure reflects the expected development of OE installed capacity in the EU until 2035 under scenario 1 (the Baseline scenario) and scenario 3 (Strong Stimulus). Under scenario 3 installed OE capacity is expected to increase to 10.5 GW in 2035[61].

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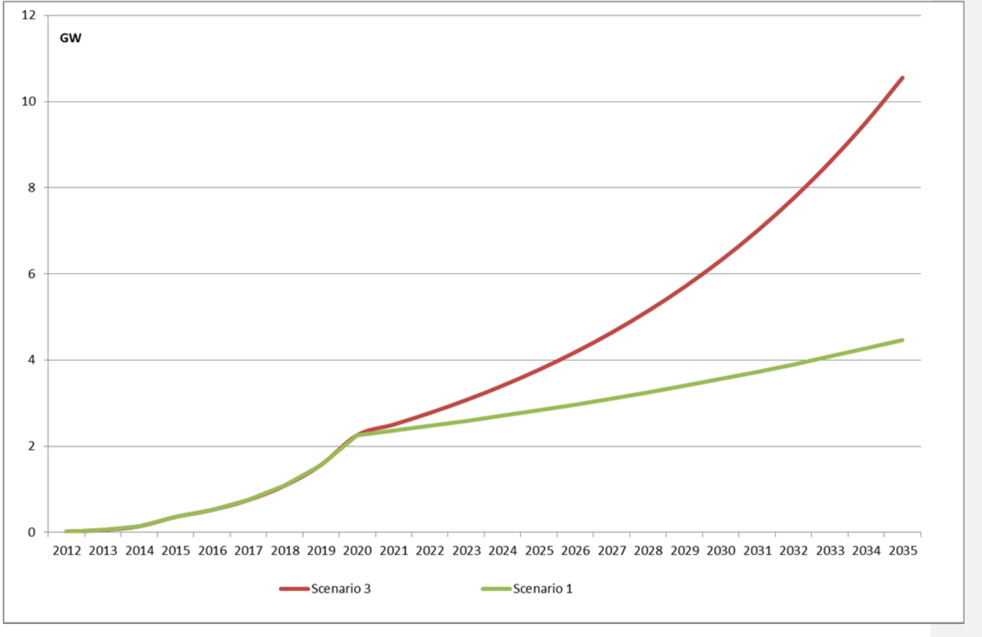
[60] SEC(2011)1565 Impact Assessment accompanying the Energy Roadmap 2050

[61] This is clearly lower than the mirrored offshore wind development path described earlier, but also slightly more conservative than the strong RES scenario adopted by IEA in their latest World Energy Outlook (the 450 ppm scenario which assumes the adoption of policies that put the world on a pathway that is consistent with having a 50% chance of limiting the global increase of average temperature to 2 degrees Ceclius in the long term) Under this scenario installed capacity in the European Union is expected to grow to 14 GW in 2035. For consistency reasons we rather adopt the EC High RES scenario as explained earlier.

Figure 3.4 OE installed capacity scenario 1 and scenario 3



Source: Ecorys based on EC (2011)

3.3 Scenario 2 - intensified coordination

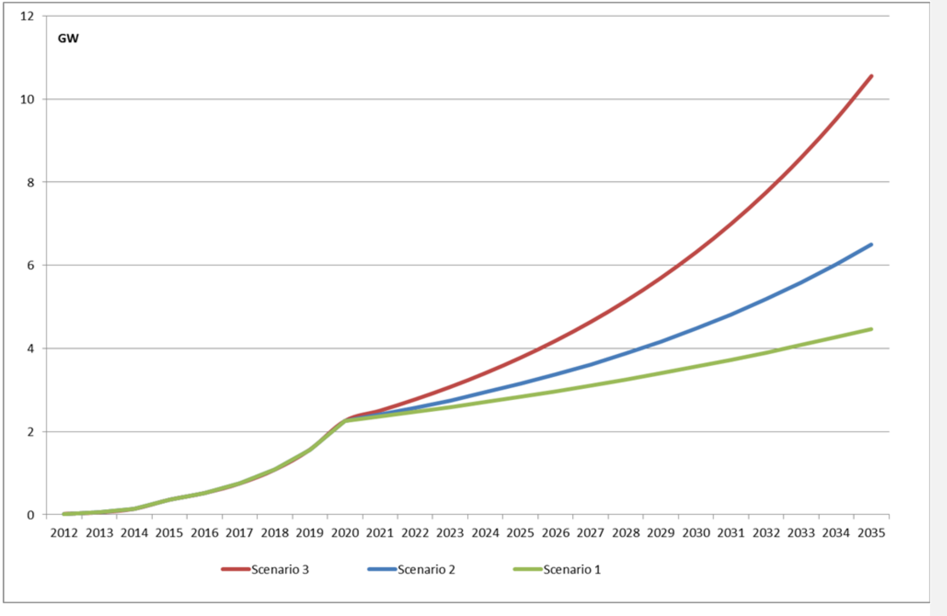
Scenario narrative

This scenario implies an “intensified coordination” among industry and Member States. This stronger coordination and cooperation supports a higher market uptake than the baseline scenario 1. However the market uptake is expected to be significantly lower than in the strong stimulus scenario 3 as it depends stronger on softer measures. Under this more “friendly” climate towards OE, the exchange of information and best practices in OE accelerate the capacity increase. The actual market uptake of this scenario depends very strongly on the willingness of individual partners to cooperate and share and is much less certain than in scenario 3.

OE installed capacity

Scenario 2 can be considered an intermediate scenario in which conditions are more supportive than in scenario 1 but less strong than in scenario 3. As such, its implications are less tangible in terms of market uptake than scenario 3. We have used a market uptake level which is placed at one-third of the difference in development between scenario 1 and 3. In 2035 this would mean an installed capacity of 6.4 GW.

Figure 3.5 OE installed capacity in scenario 2, in comparison with scenario 1 and scenario 3



Source: Ecorys

4 Economic, environmental and social implications of the scenarios

4.1 Introduction

Different market uptake scenarios will have different implications on economic parameters (e.g. production costs or added value of the sector), environment (e.g. as emissions) and social factors (e.g. employment). In this chapter we assess the economic, environmental and social impacts for each of the scenarios, based on available information from literature, where possible validated through a limited number of interviews and expert judgements.

The following indicators are included under the economic, environmental and social impacts.

Category	Implications
Economic	Cost reductions
	Competitive position of the EU industry
	Wider economic impacts –gross value added and supply chains
	Other impacts- benefits of energy diversification
	Administrative costs
Environmental	Biological, physical and chemical
	Greenhouse gas reductions
Social	Employment
	Public acceptance

Source: Ecorys

4.2 Economic effects

4.2.1 Future cost reductions

As explained in section 2.4~~2.4~~ the current high costs of OE are one of the most important barriers for the development of wave and tidal technology. Recent estimates place the current costs of the order of 400 - 470€/MWh for wave and 240 - 350€/MWh for tidal[62], much higher than wind costs (offshore 160 - 210€/ MWh and onshore 60 - 105€/MWh[63]). Significant cost reductions for OE in the magnitude of 50 to 75% will have to be delivered for those technologies to become competitive with alternative options.

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At present, the uncertainties about final costs and risks of OE devices are large, due to the very early stages of development. Accelerating the market uptake under scenario 2 and 3 will contribute to further cost reductions due to learning effects and scale advantages as illustrated by the cost reductions in solar and wind in particular. Future costs developments in this section are assessed using both investments costs and levelised cost of energy (LCoE)

Methodology

There are two main methods to determine the costs development of OE technologies: investment costs per unit of installed power (€/kW) and levelised Cost of Energy (LCoE) (€/kWh). Investment

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[62] LCIG Technology Innovation Needs Assessment (TINA) Marine Energy Summary Report, August 2012

[63] Renewable Energy technology cost series, IRENA, issue 5/5, Wind power, June 2012

costs (€/kW) mainly focus on the development of a technology and relate mainly to capital costs. The LCoE is a calculation of the cost of generating electricity at the point of connection to a load or electricity grid. It includes the initial capital, discount rate, fuel, as well as the fixed and variable costs of maintenance and operation, and maintenance.

To calculate the LCoE, a set of parameters has to be defined, such as efficiency improvements, the capacity factor, the interest rate (a proxy for assessing riskiness of the technology), the expected lifetime of the technology, O&M costs etc. Therefore, final results of those calculations depend very much on the set of initial assumptions made. Unlike other energy technologies, there is a limited evidence based or industry experience for the different parameters for OE. Different assumptions can change the outcome of the LCoE by 50% or more[64].

As a result of the uncertainties on costs and risk profiles of OE technologies the findings of the calculations should be used with care.

Learning curve

In order to determine the future cost reductions of OE, the concept of a learning curve is used. A learning curve is a graphical representation of the changing rate of learning for a given product or technology. A learning curve expresses the decrease in costs of a product or technology by a constant fraction with each doubling of the total number of units produced[65]. Because a learning curve displays the relation between costs and production (in this case the total installed capacity in the EU) and not time, the market uptake scenarios of the previous chapter will be used to link installed capacity to time.

The data for future installed OE capacity reflect a combination of both tidal and wave energy. No separate projections are available. Hence, in this report, we make no distinction between the pace of cost reduction in tidal and wave energy, although in reality this does not have to be the case.

The shape of the learning curve is based on the likely extent of cost reduction and the range of learning rate by a combination of literature review and experiences from other industries such as wind. The pace of development (the steepness of the learning curve), however, does depend on the learning rate of the product or technology. Scientific literature states that a learning rate ranging from 0% to 20% should be used and that the cost of small, modular products tends to decrease more rapidly than the cost of large, non-modular units or plants[66]. Tidal and wave energy technology cannot be considered very small and modular so the upper range up to 20% is unlikely. The learning rate for investment costs is lower than the learning rate of the costs of generated electricity (which also includes efficiency improvements and reduction of O&M costs)[67]. Experiences and literature for the development of the investment costs of offshore wind, range from 2,5 - 10%[68].

We believe that a learning rate of 5-10% is considered realistic for OE. In view of the different scenarios, we believe that a learning rate approaching 10% is more likely in the context of the

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[64] Black % Veatch 'Levelized Cost of Energy Calculation' Presentation to be found at: http://www.efchina.org/csepupfiles/report/20112844913435.70772110666485.pdf/Levelized%20Cost%20of%20Energy%20Calculation_BV_EN.pdf

[65] K. Blok 'Introduction to energy analysis'. Techne Press, Amsterdam. 2007.

[66] L. Neij 'Cost development of future technologies for power generation – A study based on experience curves and complementary bottom-up assessments. Energy Policy 36 (2008) 2200-2211..

[67] L. Neij 'Cost development of future technologies for power generation – A study based on experience curves and complementary bottom-up assessments. Energy Policy 36 (2008) 2200-2211..

[68] UK Energy Research Centre 'Great Expectations: the cost of offshore wind in the UK waters – understanding the past and projecting the future (2010). Report to be found at: *www.ukerc.ac.**uk**/support/tiki-download_file.php?fileId=1164*

higher uptake scenarios 2 and 3 which will have a higher focus on R&D leading to a higher learning curve. In scenario 1, the learning rate is assumed to be around 5%.

Box 4.1 The shape of the learning curve

When plotting unit costs over installed capacity, the shape of the learning curve is convex, with the costs logarithmically decreasing. However when plotting the unit investment costs against time, the curve becomes linear due to the exponential character of the capacity increase over time. The formula and parameters used to establish the learning curve are explained in Annex A.

In order to calculate the Levelised Cost of Electricity, the parameter values as adopted in the recent draft JRC (2012) report[69] have been used. This makes a comparison between the developments of the LCoE of tidal and wave energy and that of other (fossil) energy technologies mentioned in the same report possible.

Timeline for cost-reduction

Costs are a function of the capacity installed and operated. Unfortunately, until now, no commercial wave or tidal stream installation has been built. Evidence of costs and performance hence comes from large-scale prototypes but those costs might be overestimating the cost of commercial projects[70].

Therefore, the application of learning curves, as explained above, needs to be based on a realistic commercial starting base. In 2020 a volume of 2.2 GW of OE capacity is expected to be installed in European waters (see chapter 3). By 2020, we assume that the process of lowering costs due to learning experiences can be applied from that basis because of the commercial nature of the projects being installed. Hence we start to apply a learning rate after 2020 only.. The 2020 investment costs data are taken from Joint Research Centre (draft 2012): ‘Short overview of marine energy technologies and their European potential’.

Resulting cost decreases

Investment costs

Implications of the scenarios on investment costs for wave energy are assessed on the basis of the market uptake scenarios and the learning curves as presented above. The result is given in figure 4.1 and 4.2 below.

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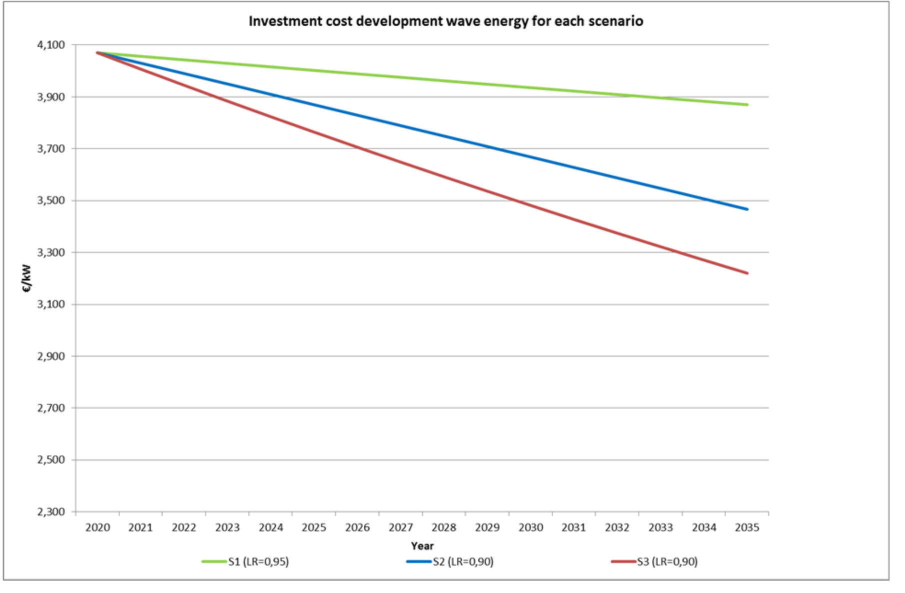
[69] *Joint Research Centre (2012) ‘Short overview of marine energy technologies and their European potential’.*

[70] Carbon Trust (2006), Future marine energy - Results of the Marine Energy Challenge: Cost competitiveness and growth of wave and tidal stream energy)

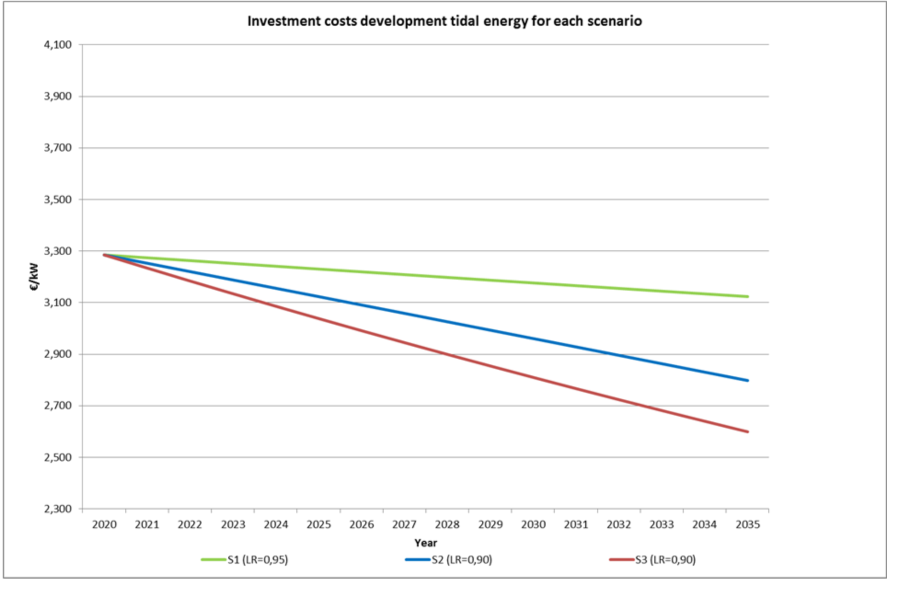
Figure 4.1 Cost development of wave energy in each scenario



Source: Ecorys

For **wave energy** in scenario 1, the investment costs of wave energy will drop from about 4.100 €/kW in 2020 to 3.870 €/kW in 2035 using a learning rate of 0.95. This means that the doubling of total installed capacity in the 2020-2035 period will lead to a decrease of 5% in investment costs. In scenario 2, investment costs of wave energy drop from 4.070 €/kW in 2020 to 3,466 €/kW assuming a higher learning rate of 10% (LR=0,90). This means a reduction of costs of about 15% in 15 years time. In scenario 3, which includes the strongest growth of OE capacity installed, the investment costs of wave energy drop from 4,070 €/kW in 2020 to 3,220 €/kW, applying a learning rate of 10%. This means a reduction of costs of about 20% in 15 years time.

Figure 4.2 Cost development of tidal energy in each scenario



Source: Ecorys

For **tidal energy**, in scenario 1, investment costs reduce from about from 3,285 €/kW in 2020 to 3,123 €/kW. Also in this case, it means that by 2035, the total costs have decreased by almost 5%. In scenario 2, the investment costs of tidal energy will decrease about 15%, from 3,285 €/kW in 2020 to 2,798 €/kW, applying a learning rate of 10%. In scenario 3, with the fastest market uptake due to the implied measures put in place under this scenario, investment costs decrease by 20%, coming from 3,285 €/kW in 2020 going to 2,559 €/kW.

Levelised Costs of Energy

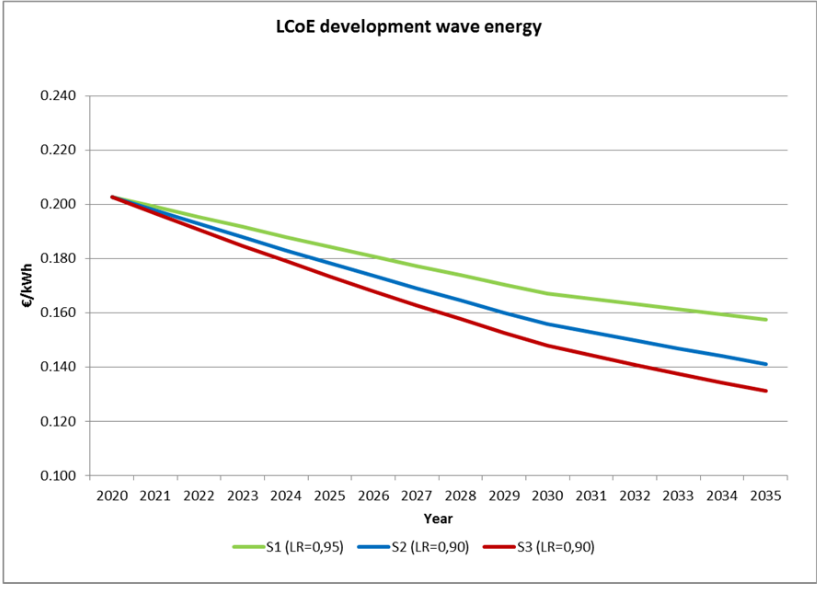
The Levelised Cost of Energy (LCoE) are calculated using a set of parameters including the investment cost, the interest rate, load factor, economic lifetime and the fixed and variable O&M costs (see Annex A).

The figures below illustrate the development of the Levelised Cost of Electricity of wave and tidal energy. The 2035 estimated costs range from 0.16 to 0.13 euros per kW/h in the case of wave, and 0.13 to 0.1 for tidal depending on the scenarios and the learning rate.

Again, the results of these LCoE graphs have to be used and interpreted with care. The calculations involve setting different parameters, each one being subject to various assumptions. For example, discount rates or interest rates are assumed to decrease over time representing the maturing of the technology and the declining perpection of risks by the investors. Capacity factors are also subject to contrasting drivers, as you can assume that the best sites are taken first so increasing potentailly the electricity generation but in the same time, technology development should improve the future capacity factors. Finally, learning rates are also subject to debates oscillating between 5% to 15% in the literature.

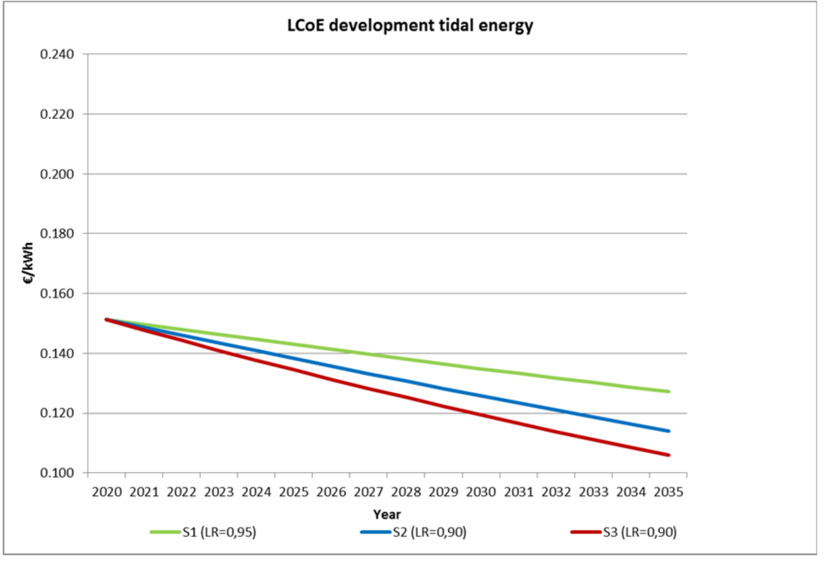
For the capacity factor, we have used a capacity factor of 25% for both technologies over the period. This capacity is slightly above JRC estimates (23%)[71] but below other estimates such as Black and Veatch[72] (35% for wave, 35% for tidal stream and 20% for tidal range).

Figure 4.3 Levelised Cost of Energy of wave energy in each scenario



Source: Ecorys

Figure 4.4 Levelised Costs of Energy of tidal energy



Source: Ecorys

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[71] JRC (draft 2012)

[72] Cost of and financial support for wave, tidal stream and tidal range generation in the UK, Black and Veatch Ernst and Young, October 2010

The figures above show a decrease of the levelised costs of wave energy from 0,203 €/kWh in 2020 to 0,157 – 0,131 €/kWh in 2035. For tidal energy, a development from 0,151 €/kWh in 2020 to 0,127-0,105 €/kWh can be observed.

Overview of cost developments in the different scenarios

An overview of the expected cost developments for tidal and wave energy under our scenarios is given in the following tables.

Table 4.1 Wave energy investment costs development

Wave energy investment costs	Scenario 1 (€/kW)	Scenario 2 (€/kW)	Scenario 2 / Scenario 1	Scenario 3 (€/kW)	Scenario 3 / Scenario 1	Scenario 3 / Scenario 2
2020	4.070	4.070		4.070		
2035 (LR=0,95)	3.870					
2035 (LR=0,90)		3.466	90%	3.220	88%	93%

Source: Ecorys

Table 4.2 Wave energy LCoE development

Wave energy LCOE	Scenario 1 (€/kWh)	Scenario 2 (€/kWh)	Scenario 2 / Scenario 1	Scenario 3 (€/kWh)	Scenario 3 / Scenario 1	Scenario 3 / Scenario 2
2020	0,208	0,208		0,208		
2035 (LR=0,95)	0,157					
2035 (LR=0,90)		0.141	90%	0,131	88%	93%

Source: Ecorys

Table 4.3 Tidal energy investment costs development

Tidal energy investment costs	Scenario 1 (€/kW)	Scenario 2 (€/kW)	Scenario 2 / Scenario 1	Scenario 3 (€/kW)	Scenario 3 / Scenario 1	Scenario 3 / Scenario 2
2020	3.285	3.285		3.285		
2035 (LR=0,95)	3.123					
2035 (LR=0,90)		2.798	90%	2.599	88%	93%

Source: Ecorys

Table 4.4 Tidal energy LCoE development

Wave energy LCOE	Scenario 1 (€/kWh)	Scenario 2 (€/kWh)	Scenario 2 / Scenario 1	Scenario 3 (€/kWh)	Scenario 3 / Scenario 1	Scenario 3 / Scenario 2
2020	0,151	0,151		0,151		
2035 (LR=0,95)	0,127					
2035 (LR=0,90)		0,114	90%	0,106	88%	93%

Source: Ecorys

OE compared to other energy technologies

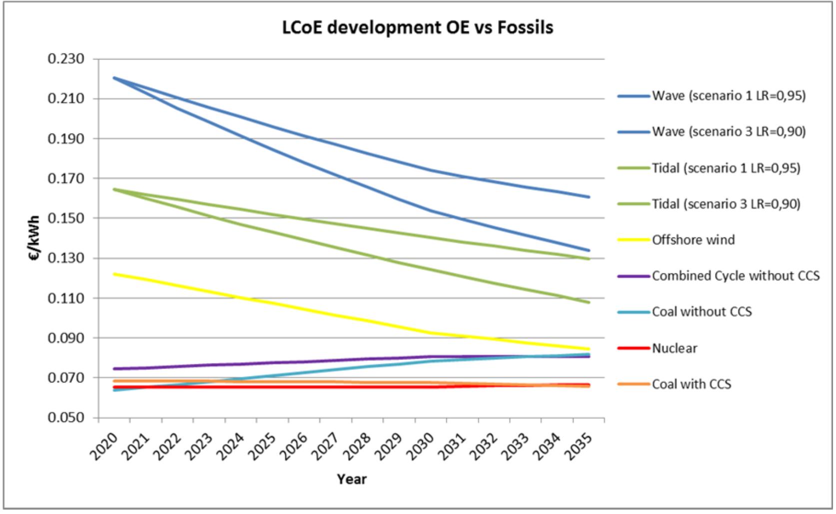
The tables and figures in the previous section show that the investment costs of wave and tidal energy will be around 2.599-3.631 €/kW in 2035 and the LCOE will lie in the range of 0,106-0,127 €/kWh for tidal energy and 0,131-0,157 €/kWh for wave energy. It is interesting to compare these figures to those of other energy technologies. **Table 4.5**~~Table 4.5~~ presents the data for LCOE for a selection of energy generation technologies.

Table 4.5 Estimated investment costs non-OE technologies in 2030

	LCOE (€/kWh)
Offshore wind	0,093
Coal with CCS	0,068
Coal without CCS	0,079
Combined cycle without CCS	0,081
Nuclear energy	0,066

Source: EWEA (2011) 'Pure Power – Wind energy targets for 2020 and 2030 (offshore wind) and Joint Research Centre (draft 2012) 'Short overview of marine energy technologies and their European potential' (other technologies).

Figure 4.5 LCoE development OE versus fossil technologies



Source Ecorys based on Joint Research Centre (draft 2012

OE sources are expected to remain costlier than other energy technologies by 2020. However significant costs reduction will be realised bringing the levelised costs of OE closer to other energy sources. Still by the year 2035 the costs of OE will be above the level of conventional energy sources. However the costs of OE are declining more rapidly over time than those of fossil energy technologies, meaning that if this development continues beyond 2035, OE will continue to narrow down their gap with other renewable technologies.

Concluding, we can say that A number of conclusions can be derived from the calculation of LCoE of Ocean Energy in comparison with fossil fuels::

- The levelised costs of some fossil technologies are expected to increase, for instance coal without CCS and combined cycle without CCS.
- The levelised costs of renewable energy declines. In all of our scenarios, LCoE of tidal and wave also decline but in some cases wave and tidal decline slower than offshore wind (scenario 1 with LR=0.95). As a result, the continuation in scenario 1 will not lead to a sufficient decline of wave and tidal to competitive level with offshore wind in the long term.
- In scenario 3 (LR=0.9), in particular, wave and tidal LCOE are expected to decline faster and narrow their gap with alternative options such as offshore wind and some fossil fuels options combined cycle without CCS and coal without CCS.

Although no definitive conclusion can be drawn from the calculations on when and how fast OE can be cost competitive with other forms of energy generation, it can be said that under scenario 3 an acceleration of the LCOE reduction will result in narrowing the gap between wave and tidal with other alternatives such as offshore wind in the period up to 2035.

The above results can be contrasted with other research findings. A recent study conducted by Esteban and Leary[73] presents different conclusions. The authors argue that the possibility exists that wave and tidal energy become cost competitive around 2021, with a LCOE of around 0,06 €/kWh, using different learning rate that decreases linearly between 0,75 and 0,95.

4.2.2 Competitive position of the EU in OE

Given its stage of development established dominant players, supply chains and mature technologies do not yet exist in OE technology. Nevertheless, several experts believe that, despite representing only a small portion of the current renewable energy market, ocean renewables are progressively getting close to patented commercialization[74]. In fact, for the wave and tidal sector, a large number of devices are being tested and developed across Europe, the US and, more recently, Asia. According to the European OE Association, "*Europe is well positioned to lead the world in harvesting OE*", which makes it a likely centre for pre-commercial and early commercial deployment[75].

This section provides an overview of the competitive position of the EU in OE vis-à-vis other global players. First, we present Europe's expected future position in terms of installed capacity and power generated in comparison to worldwide developments. Second, we will observe how the EU possesses a strong research basis when it comes to OE, as mirrored in the share of publications issued within the EU borders. A different scenario will be observed for patents, in which some strong EU players exist in parallel with an increased activity of non-EU companies. Finally, the

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[73] Current developments and future prospects of offshore wind and OEMiguelenergy Miguel Esteban a,⇑, David Leary b,1 in applied Energy, August 2011

[74] See e.g. M. Messinger, R. Almon (2009), *Making Waves on the OE Patent Landscape*, Clean Tech Law and Business, available http://www.sternekessler.com/media/pnc/3/media.1053.pdf

[75] European OE Association (2010) *Oceans of energy.European OE Roadmap 2010-2050,* available http://www.eu-OEa.com/wp-content/uploads/2012/02/EUOEA-Roadmap.pdf

presentation of the OE policy ambitions of some key countries will give us an idea of where the competition is currently coming from.

To review the developments in Europe and other major regions in the world an overview of the expected installed capacity in 2020, 2030 and 2035 in these regions as projected by IEA in their Current Policies scenario[76] is presented in table 4.6. This deviates from the scenarios used in our study but gives a good insight in the expected relative development of Europe vis-à-vis other regions.

Table 4.6 OE electricity generation and installed capacity according to IEA Current Policies scenario[77]

	Electricity Generation (TWh)			Electrical Capacity (GW)		
	2020	2030	2035	2020	2030	2035
European Union	**2**	**7**	**20**	**0**	**2**	**6**
United States	-	1	3	-	0	1
OECD Americas*	0	2	5	0	0	1
China	-	1	2	-	0	0
Japan	-	0	1	-	0	0
OECD AsiaOceania**	2	3	5	0	1	1
World	**3**	**13**	**32**	**1**	**3**	**8**
Share of EU	**66%**	**54%**	**62%**	**-**	**66%**	**75%**

* including Canada, Chile, Mexico and United States

** including Australia, Japan, Korea and New Zealand

According to the projections of the IEA current policies scenario (which only considers the effects of already enacted policies), throughout 2020 and 2030 the EU will preserve its leadership position, both concerning the electricity generation and the installed capacity. In fact, as compared to the rest of the world, by 2035 around 60% of the global electricity generation and 75% of the electrical capacity will be found in the European Union. This scenario gives an indication of the uptake that OE might have in the near future, as well as of the leading role the EU will continue to play in the near future.

A different picture can be observed in IEA's high growth "450 scenario", as shown **Table 4.7**~~Table 4.7~~ below.

Table 4.7 OE electricity generation and installed capacity according to IEA 450 scenario[78]

Region	Electricity Generation (TWh)			Electrical Capacity (GW)		
European Union	**2**	**20**	**50**	**1**	**6**	**14**
United States	1	5	6	0	1	1
OECD Americas*	1	7	10	0	2	2
China	-	1	2	-	0	1
Japan	-	2	6	-	0	2

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[76] In this section IEA scenarios are used to use a comparable source instead of EU 2050 Energy Roadmap scenarios

[77] The IEA Current Policies scenario only projects the effects of those government policies that have been enacted by mid-2012, without considering any potential or likely future policy action. For more information, see IEA World Energy Outlook 2012.

[78] The IEA 450 scenario is rather positive, since it assumes that future energy policies will be adopted consistently with having around a 50% chance of limiting the global increase in average temperature to 2° C in the long term, compared with pre-industrial levels. For more information, see the IEA World Energy Outlook 2012.

OECD AsiaOceania**	3	9	15	1	2	4
World	**6**	**38**	**82**	**2**	**10**	**22**
Share of EU	**33%**	**53%**	**61%**	**50%**	**60%**	**64%**

* including Canada, Chile, Mexico and United States

** including Australia, Japan, Korea and New Zealand

Within this positive scenario developed by the IEA both EU capacity and capacity installed elsewhere will grow more rapidly than in the Current Policies scenario of the IEA, and by 2035 the European Union will concentrate more than half of the electricity generation and electrical capacity coming from ocean renewable energy. In this setup the European Union appears as the strategic continent in which most of the available ocean renewable energy is developed and commercialised, with respectively 61% of the electricity generation and 64% of the installed capacity. It can however be noticed how in this scenario other regional players such as Canada, the US, Japan, Korea and Australia are progressively catching up and significantly improving their electrical output and installed capacity in a relatively short period of time.

Ocean Energy: a growing scientific interest

Publications

The potential of the sector is mirrored in the progression of the number of OE publications and patents over the last decade, which provides a clear sign of how universities and companies are inquiring about and experimenting different solutions as well as approaches to best develop ocean technologies and move towards their industrial uptake.

Table 4.8 Development of scientific publications (2001-2010)

Publications	**Number**	**Number**	**Number**	**Increase in %**	**Increase in %**	**% of total**	**% of total**
Year	***2001***	***2006***	***2010***	***2001-2010***	***2006-2010***	***2001***	***2011***
Ocean Energy	143	257	392	274%	153%	11%	8%

Source: Ecorys (2012) Blue Growth report

In the context of renewable energies, science provides the basic scientific insights and responds to the fundamental challenges – may they be scientific, engineering or socio-economic – that will inevitably arise in the process of demonstrating and deploying new technologies[79]. For these reasons, the observation of the geographical origin of publications can help us understand in which regions of the world a greater scientific effort is deployed so to enhance the development of ocean renewable energies. The below table indicates that, between 2001 and 2010, 44% of the marine energy-related publications have been released in the European Union.

Table 4.9 Share of EU in total publications (2001-2010)

Publications	**EU**	**non-EU**	**Total**	**% EU**	**%non-EU**
Ocean Energy	6418	8048	14466	44%	56%

Source: Ecorys (2012) Blue Growth report

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[79] International Scientific Panel for Renewable Energies (2009) *Research and Development on Renewable Energies. A Global Report on Photovoltaic and Wind Energy*, available http://www.icsu.org/publications/reports-and-reviews/ispre-photovoltaic wind/ISPRE_Photovoltaic_and_Wind.pdf

Patents

If scientific research constitutes one milestone towards the development of successful technologies, patenting enables to secure technology inventions, while representing one fundamental step between research institutions and the private industry.

Table 4.10 Development of patents (2001-2010)

Patents	Number	Number	Number	Increase in %	Increase in %	% of total	% of total
Year	***2001***	***2006***	***2010***	***2001 -2010***	***2006 -2010***	***2001***	***2011***
Ocean Energy	110	166	730	664%	440%	6%	15%

Source: Ecorys (2012) Blue Growth report

As the above graph suggests, the amount of patents relating to ocean renewables has been constantly growing. Between 2001 and 2010, the number of OE-related patents has grown with 664%, higher than any other marine sector assessed in the Blue Growth study. This gives us an indication of the perceived potential of the sector, as well as the dynamics put in the testing and improvement attempts of OE technologies.

Table 4.11 Share of EU in total patents (2001-2010)

Patents	EU	Non-EU	Total	% EU	% Non-EU
Ocean Renewable Energy	769	3117	3886	19,8%	80,2%

Source: Ecorys (2012) Blue Growth report

However, when looking at the regional distribution of patents, we can observe how the European Union, despite being particularly active when it comes to scientific publications, has been home to only 20% of the inventions patented between 2001 and 2010. Most of the inventions have been taken place outside EU borders, suggesting that Europe as a whole might have a gap to fill between the academic world and the OE industrial sector.

Table 4.12 Top-20 number of inventions (patents) in the field of OE per country (2001-2010)

Priority countries[80]	Inventions (patents)
China	631
Patent Co-operation Treaty[81]	596
United States of America	526
Japan	425
Republic of Korea	403
United Kingdom	259
Germany	241
European Patent Office[82]	109

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[80] A priority country is the country where the invention was invented.

[81] The Patent Co-operation Treaty is an international treaty, administered by the World Intellectual Property Organization (WIPO). The treaty allows to acquire patent protection for an invention simultaneously in each of the 140 member countries.

[82] The European Patent Office is one of the two bodies that, together with the Administrative Council, build up the European Patent Organization, an intergovernmental organization created in 1977. The organization currently counts 38 countries, with the mission to grant European Patents in accordance with the European Patent Convention.

Priority countries[80]	Inventions (patents)
Australia	92
Russian Federation	84
Spain	82
Norway	71
France	62
Canada	54
Brazil	47
Sweden	24
Taiwan	22
Netherlands	20
Denmark	15
Romania	14

Source: Ecorys (2012) Blue Growth report

Whereas the previous paragraph provides evidence in the data concerning the patent country of origin, the above table presents an overview of the twenty best performing countries in which renewable energy-related inventions have been patented between 2001 and 2010. In particular China, the U.S., Japan and Korea have seen active patent activity in securing technology and research efforts. At this moment this places them as the current leading countries in the development of new marine energy technologies and well beyond EU leaders like the United Kingdom and Germany. As the UK is ahead of other countries in terms of the development of capacity, activity of key players is apparently also concentrated there which is reflected by the ranking of patents, whereas Germany may likely be ranked high because of its strong base in the high tech marine equipment manufacturing sector.

Furthermore, data also allows recording the technology improvements performed by other countries like Australia, Canada and Russia, which are progressively catching up with their international competitors. If however we take figures for all European countries and the European Patent Office together, Europe would firmly rank first with 826 patents (if we disregard double counting and overlaps between countries and the EPO).

It should be noted that patent registration data mainly indicates where patenting takes place. Although in many cases this will have a direct relation with the country of origin of the assignees (the organisations applying for a patent) this is not by definition the case. In particular in countries where the market is expected to grow, foreign companies can be expected to apply for a patent in that country. Therefore also an analysis is made of the leading assignees.

Table 4.13 Ranking of top 20 patent assignees – leading companies (2001-2010)

TOP ASSIGNEES	TOTAL	COUNTRY
OCEAN POWER TECHNOLOGIES INC	19	U.S.A
VOITH PAPER PATENT GMBH	17	GERMANY
LOCKHEED MARTIN CORP	16	U.S.A
UNIV ZHEJIANG	16	CHINA
BOSCH GMBH	15	GERMANY
HYUNDAI	13	SOUTH KOREA

TOP ASSIGNEES	TOTAL	COUNTRY
KOREA OCEAN RES&DEV INST	12	SOUTH KOREA
CHINESE ACADEMY OF SCIENCES	10	CHINA
HITACHI	10	JAPAN
MITSUBISHI GROUP OF COMPANIES	10	JAPAN
ROLLS-ROYCE PLC	10	U.K.
INHA IND PARTNERSHIP INST	9	SOUTH KOREA
INNO&POWER INC	8	SOUTH KOREA
SINGLE BUOY MOORINGS	8	THE NETHERLANDS
TOSHIBA	8	JAPAN
ATLANTIS RESOURCES CORP PTE LTD	7	SINGAPORE/U.K.
OPENHYDRO IP LTD	7	IRELAND
SAMSUNG	7	SOUTH KOREA
SIEMENS	7	GERMANY
UNIV HEHAI	7	CHINA

Source: Ecorys (2012) Blue Growth report

The list of patent registrations by company presented above gives an indication of companies showing activity in ensuring a knowledge ownership base. Several companies mentioned are known for specific technologies or components supplied to both (renewable) energy sectors and other areas. Some of them can be considered component developers or operators rather than ocean renewable companies per se.

As we stated in the Blue Growth sub-function report on ocean renewables: "*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).*[83]" Furthermore we stated in the same report that "*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*." Some of these names also appear in the top-20 of patent holding companies presented above.

Export opportunities of EU players

Several studies[84] [85] suggest that the important European domestic resources could provide opportunities in the EU and also export markets outside the EU. According to the Carbon Trust[86], the global market for marine energy could be worth up to 575 billion euro in the period 2010–50, reaching up to 50 billion euro/year by 2050. In this same report, Carbon Trust believes that this level of market level could potentially create over 68,000 UK jobs by 2050. The Carbon Trust report presents additional estimates of potential benefits for OE such as, the value of worldwide electricity revenues from wave and tidal stream projects could ultimately be between 75 billion euro/year and

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[83] Ecorys (2012), Blue Growth sub-function report Ocean Renewable Energy Sources.

[84] Channelling the Energy - A Way Forward for the UK Wave & Tidal Industry Towards 2020 October 2010

[85] Ocean energy roadmap – Sustainable Energy Authority Ireland

[86] Carbon Trust (2011) Accelerating Marine Energy report

237 billion euro/year[87]. Investments of over £500b (Euro 600 bn) would be necessary for wave energy to contribute 2000 TWh/year worldwide[88]. What is certain is that the expected cost reduction per installed capacity should open up new markets for supply in the EU and beyond the EU. These are likely in North America and in Asia as can be seen from the IEA global scenarios presented above.

Another indicator for potential European leadership can be found in the customer base of key research and test centres such as the European Marine Energy Centre (EMEC).

Box 6.1 The EMEC test centre

The European Marine Energy Centre (EMEC) is a marine test centre established in 2003 at the Orkney Islands north of Scotland, in an environment with both high wave conditions and high tidal ranges. The offshore facilities established include an under water grid connecting 14 offshore test beds to shore as well as two scale test sites, and were realised on the basis of some 30 mln GBP provided by various government layers within the UK and Scotland.

Since its start, a number of well-known devices have been tested, such as the first floating wave energy converter Pelamis and the hydro-electric Oyster.

Since EMEC is one of the largest test centres of its kind worldwide, and so far the only that offers facilities for both wave and tidal energy converters, it has attracted the interest of developers and investors from across the world. The current client base indicates the names of players currently active in the domain of tidal and wave energy technology. Furthermore it suggests that these parties already are or may become important players in the OE arena of the future. Among current clients we find companies such as:

- For wave energy:
  - Aquamarine Power (Scotland)
  - E.On (Germany)
  - Seatricity (UK)
  - Vattenfall (Sweden)
  - Wello Oy (Finland)
  - Pelamis wave power (UK)
  - AW Energy (Finland)
- For tidal energy
  - Andritz Hydro Hammerfest (Norway)
  - Atlantis Resources Corporation (UK)
  - Bluewater energy services (Netherlands)
  - Kawasaki Heavy Industries (Japan)
  - Open Hydro (Ireland)
  - Scotrenewables (UK)
  - Tidal Generation (UK, subsidiary of Rolls Royce)
  - Voith Hydro (Germany)

EMEC has also proactively sought cooperation beyond Europe by signing international collaboration agreements with Energy Association of Japan, Ocean University of China, Incheon Metropolitan City in South Korea, and latest with the National Taiwan Ocean University (NTOU) and the Industrial Technology Research Institute (ITRI) in Taiwan.

Source: www.emec.org.uk

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[87] Extracted from Future Marine Energy Results of the Marine Energy Challenge with original source ENTEC (2005)

[88] ETSU (1999), A Brief Review of Wave Energy.

OE within key countries’ policy programmes

Globally, according to CSIRO (2012)[89], promising sites for wave power are found not only in Europe (Atlantic coast) but also in the Americas, Australia and Southern Africa. The potential of tidal power outside Europe according to them is found in the Americas, Canada, China, and Russia. They state however that Europe leads when it comes to the development of technologies; Ireland, the UK and Portugal, but also Denmark and Sweden though these countries are not having large wave energy sources at their disposal. This being said, it seems evident that the OE development and deployment of activities is expanding to a growing extent outside the European continent[90]. It is therefore interesting to briefly present some of these countries’ policy plans for the development of marine renewable energy.

Apart from the current position of Europe worldwide in publications and patents and in terms of its share in installed capacity, the competitive position of the EU will also be influenced by ambitions and support policies pursued by other countries. It is therefore highly interesting to have a look at what other major key players have planned for the development of their OE sector.

China

According to the current 12th Five Year Plan (2011-2015), China’s OE capability is targeted to reach up to 50MW by the year 2015. Justified by growing consumption needs, a slowdown of Chinese nuclear development and fossil fuels reduction targets (The Climate Group, 2012)[91], the Chinese government has planned to develop several mechanisms to stimulate the overall ocean renewable energy drive. These include the bringing of tidal and wave technology to a mature level, implementing ocean demonstration projects in Chinese coastal areas and grid-off islands, as well as cultivating the cluster of the OE industry (ICOE 2012). These targets are supported by a wide set of legislation, in particular regulations on marine spatial planning system, and special funding mechanisms which, between 2010 and 2013, will bring financial support to OE for up to 600 million RMB (73 million Euros)[92]. From an overall point of view, the Chinese Government has put in place valuable instruments (both legal and financial) to pursue the development and move towards the commercialization phase of OE. However when compared to the European Union, China is still facing important challenges concerning the lack of expertise and experience both in technology and management[93].

Korea

The Republic of Korea has also recently emerged among the new main players in the OE sector, with R&D investments amounting to 13 million Euros in 2010[94]. Such financial support is planned to bring OE to contribute by 4.7% to the total supply of renewable energy by 2030, which amounts to 1.540 kTOE (OES-IA 2010)[95]. To do so, Korea foresees three distinctive phases for the development strategy of OE: phase 1 (2008-2012) has served to building a technologically independent basis; phase 2 (2013-2020) is due to verification and the technological advancement; phase 3 (2021-2030) will concentrate on the high-value industrialization (Japan-Korea Joint

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[89] CSIRO (2012), Ocean renewable energy: 2015-2050. An analysis of ocean energy in Australia. July 2012.

[90] European Ocean Energy Association (2011) Position Paper. Towards European Industrial Leadership in Ocean Energy in 2020, http://www.decc.gov.uk/assets/decc/11/meeting-energy-demand/wave-tidal/3610-position-paper-towards-euro-ind-leader.pdf

[91] The Climate Group (2011) *Renewable Energy Development Targets in China’s 12th Five Year Plan Adjusted Upwards, Briefing Note.*

[92] European Ocean Energy Association (2011).

[93] X. Dengwen (2012) *The Activities of Marine Renewable Energy in China*, ICOE 2012.

[94] K. Hong (2010) *Implementing Agreement on Ocean Energy Systems. Annual Report 2010*, available http://www.gse.it/en/company/internationalactivities/internationalorganizations/Documents/2010_Annual_Report.pdf

[95] Hong (2010).

Workshop on Ocean Renewable Energy 2012)[96]. Overall, Korea is investing specific resources in the diversification of device types, the expansion of demonstration projects and the involvement of organizations[97]. This is in line with the data presented in table 6.7, where the presence of Korean companies among the patent assignees is evident.

Japan

The 2010 available data illustrates that Japan is increasingly focusing on the potential of renewable energies. Solar and wind have received particular attention, while ocean renewables have been allocated an approximate total budget of 7.8 billion yen (67 mln EUR) for the years 2011 – 2015[98]. With a view to move towards the commercialization of OE devices, a plan called “OE Technological Development Research” was established in 2011. The plan lasts for 5 years and aims to promote ocean renewable energy research projects in Japan (OES-IA 2011). Overall, and according to the relative law enacted so far, research on OE focuses on feasibility studies, performance and economic improvement of the technologies used in exploiting the various types of OE[99]. It is remarked that Japan’s OE policy document was drafted prior to the Fukushima catastrophe which has result in an increased attention for energy sources to replace nuclear power production. One may expect that OE can benefit from this but so far no new policy indications were found.

Canada

According to the Canadian Marine Renewable Energy Technology Roadmap Steering Committee, Canada’s OE sector aims at becoming a leading player on the global stage by means of a strong focus on industrial development[100]. OE is planned to generate 250 MW by 2020 and 2000 MW by 2030 (ICOE 2012). Moreover, Canada plans to acquire leadership in technical solutions and services to provide value-added goods and services to 30% of the global industry by 2020 and 50% by 2050 (ICOE 2012). A strategic focus is given to cost and risks reduction, as well as to demonstrating the reliability of ocean renewable energy plants in operation[101]. Such vision includes the creation of shared infrastructure initiatives that can eliminate barriers, coordinated strategic research, feed-in tariffs to launch market driven projects, cross-sector technology and skills transfer, as well as the enhancement of engineering, procurement and construction capabilities (ICOE 2012).

United States of America[102]

Also the US is becoming increasing active in the field of Ocean Energy. Research and demonstration activities are stimulated under the Water Power Program of the Department of Energy (DOE). The main purpose of this programme is to advance the marine and hydrokenitic technology industry in the US. As in other countries ocean energy is still in its development stage and only demonstration and pilot installations are active. Various policy initiatives are undertaken to support and grow ocean energy. Apart from R&D support this includes an overall mapping of the resource base for wave and tidal energy in US coastal waters by DOE, the establishment of several federal (and state) incentives for renewables in general, and regulatory changes which facilitate the rise of ocean energy (including the establishment of a separate Bureau of Ocean Energy

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[96] K. Hong (2012) *Policy, Roadmap and Strategy of Ocean Energy R&D in Korea*, Japan-Korea Joint Workshop on Ocean Renewable Energy, available http://www.engan.esst.kyushu-u.ac.jp/~JapanKorea/material/Ocean_Energy_Overview(KHong).pdf

[97] Hong (2010).

[98] OES-IA (2011).

[99] OES-IA (2011).

[100] Marine Renewable Energy Technology Steering Committee (2011) *Charting the Course. Canada’s Marine Renewable Energy Technology Roadmap*, available http://www.marinerenewables.ca/wp-content/uploads/2012/09/MRE_Roadmap_e.pdf

[101] Marine Renewable Energy Technology Steering Committee (2011).

[102] Information based on OES-IA (2011)

management which function as the central window towards the development of offshore renewables). No formal target are yet expressed towards the share of ocean energy in the energy mix of the US.

Australia

The 2012 CSIRO report has confirmed Australia's great potential when it comes to OE, in particular wave energy. The increasing R&D and commercial OE activity is one of the consequences of the Government-mandated target of Australia's domestic energy to be produced from renewable sources by 2020[103]. On the one hand, government funded R&D is mainly addressed to universities and small spin-off companies that are focusing on a wide range of OE-related topics (OES 2012). On the other side, industry funded R&D is concentrating on 3 main areas, namely "public education initiatives, the preparation of a sectorial OE development strategy and building best practices for OE governance in Australia" (OES 2012). It however stems from both the CSIRO and the OES report that ocean renewable energy does not emerge as one of the key renewable energies for Australia, with projections predicting that no construction will develop as long as the nominal capacity factor will remain below around 0.4[104].

Conclusion on competitiveness

In the above section we have elaborated on the position of the EU industry vis-à-vis its global competitors on the basis of their R&D activities (measured by publications and patents registered) as well as their policy ambitions. This draws a mixed picture in which on the one hand EU players appear to have a leading role in terms of scientific research and new inventions whereas on the other hand the shift from inventions to patenting raises concern that others are better able to commercialise on new inventions than the EU.

The available publication data confirm the strong EU research basis, while the presence of German and UK companies among the top patent assignees proves that the EU has established relevant OE engineering and commercial activities. In fact, the existence of leading test centres within Europe attracts commercial players and provides a basis for developing devices with a European base. This is also seen from the list of companies active until date. Furthermore competitiveness for Europe not only comes from within the OE investors but also from supplier companies providing particular components. Here the sector appears to benefit from having leading suppliers based in Europe such as Rolls Royce, Voith or Siemens. Their size combined with the development environment available within Europe helps them also in exporting to elsewhere.

Nevertheless, if we consider the global scenario for OE, we can identify other global competitors (e.g. China, Canada, Korea), which have been developing growing OE policy ambitions, deploying great R&D efforts, while proving successful in moving further towards the commercialization of OE scientific findings.

In terms of market outlook, while scenarios from IEA suggest that the EU will maintain its leading role with regard to the share of capacity installed, the ambitions expressed in policy documents from various countries are challenging this position.

On a more global level, the development of a leading EU OE industry can serve an international market that is expected to expand dramatically in the next few years. For this reason, the link between the research agenda and the industry should be further strengthened, with a view to the commercialization of OE.

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[103] CSIRO (2012).

[104] CSIRO (2012).

EU competitiveness in the various scenarios

Increased market uptake may trigger more dedicated R&D activities and research effort, while vice versa this can help to further smoothen market uptake trends. Both science and industry can benefit from this. We thus expect stronger growth in stronger uptake scenarios. In scenario 3, with continuous leadership in terms of capacity in Europe, this will benefit the European supply industry as well, while in scenario 2, slower growth may provide more room for non-EU countries to gain ground and non-EU supplier industry to overtake part of the EU's leadership. Hence we have scored the EU competitiveness in the various scenarios as follows.

Table 4.14 Impacts on EU competitiveness by 2035 (with scenario 1 as the baseline)

	Scenario 1	Scenario 2	Scenario 3
Scientific publications and citations	0	+	++
Inventions registered (patents)	0	+	++
Market leadership of EU enterprises	0	0/+	++

Source: Ecorys

4.2.3 Wider economic effects: gross value added and supply chains

Precise economic benefits of developing OE in Europe are bound to be approximate because of the uncertainties about the long-term economic potential of OE, as well as the potential synergies with other existing maritime activities. As also described in the previous section the EU is well placed to leverage its skills/capabilities and experience in marine operations, maritime engineering offshore oil and gas, ship-building and power generation to accelerate progress in the OE sector and capture the economic value[105]. Whilst technologies are at early stages, support and investment in technology development should be seen as guaranteeing the option of OE for future years when cost reductions have occurred to an extent where the technologies are competitive, and technologies can be deployed in an industrial manner.

Gross Value Added

The assessment of the total gross value added (GVA) associated with OE builds on estimates regarding the employment which results under the three scenarios (see section 4.4~~4.4~~). Based on earlier studies[106] a value added of EUR 200,000 per job (fte-full time equivalent) is estimated as a maximum. Existing data for offshore wind point to a figure of EUR 185,000[107] indicating that this amount represents a plausible order of magnitude, since both sectors are relatively capital intensive sectors. When maturing, this figure might reduce, as some state that GVA in operational activities are generally lower than in high tech manufacturing (supply) sectors.

Based on the estimated effects of the scenarios on employment as presented in section 4.4 (7-14,000 jobs (in maintenance and construction) in 2035 in scenario 1 up to 21-41,000 (in maintenance and construction) in scenario 3), this implies additional GVA will amount to € 1.3-2.8 billion EUR by the year 2035 for scenario 1 rising to € 4-8 billion in scenario 3.

Table 4.15 Estimated GVA in 2035 (bn €)

	GVA (bn €)
Scenario 1	1.3 - 2.8
Scenario 2	2.3 – 3.6

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[105] Wave and Tidal Energy in the UK State of the industry report March 2011

[106] See Ecorys (2012), Blue Growth Study

[107] EUR 1.3 bn GVA / 7000 jobs

Scenario 3	4.2 – 8.2

Source: Ecorys

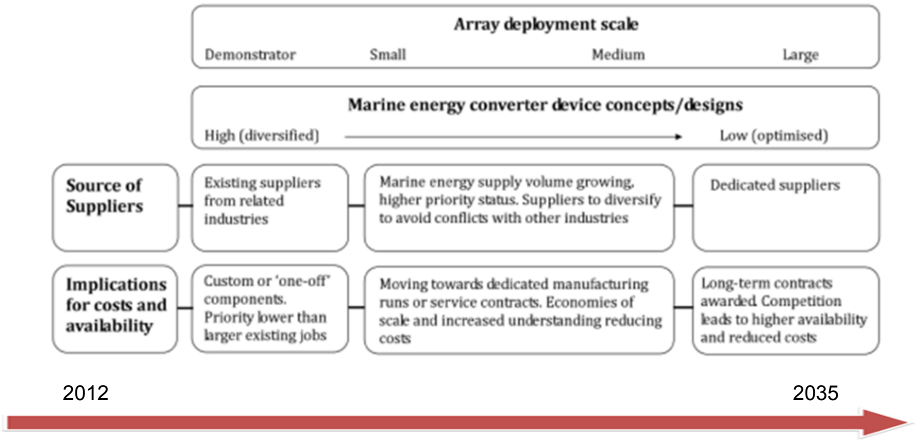
The above table 4.15 includes both the direct value added created in the manufacturing and the operation of OE and the indirect value added which is the result of the inter-linkages with other economic sectors.

Supply chains

To capture the full economic impact of OE for Europe viable supply chains must be built. As of today, the number of dedicated suppliers in OE remains limited due to the relatively small scale of the industry, its limited visibility and uncertain future growth. However, suppliers due to their size (e.g. Siemens, Voith) (see section on competitiveness) can develop their capabilities and change their existing products/services portfolios to supply the OE sector provided market grows in a similar fashion as solar and wind.

A recent FP7 study[108] assessed the present and future scenarios for a marine energy supply chains. According to the study, most of the major components (e.g. gearboxes, blades etc...) in the OE sector are customised (versus mass produced). As a result, costs are extremely high and lead times for building prototypes are long. Up to now, for cost minimisations purposes, most developers are trying to use existing (off-the-shelf) components either in a similar application or modified in some way (e.g. existing gear box modified sealing and material to resist corrosion) for their projects. This approach might not prove optimal but it allows operational experience to be gathered before dedicated OE components could be developed in an industrial manner. This mechanism is an underlying driver to explain the current high costs in OE and the possibility for further cost reductions once operations are scaled up (see also section on cost reduction).

Figure 4.6 Evolution of the marine energy supply chain



Source Equimar project - Deliverable D5.7 Assessment of the present status and future scenarios of the supply chain for marine energy arrays 2011

Over time, as OE matures it can be expected that supply chains become more standardised and products and components are sourced regionally or locally to save lead times and reduce costs[109]. This development is also supported by the development of a local, regional industry that grows on

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[108] Equimar - Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact

[109] SEAI 2012

the back of the development of local and regional OE installations and might lead to establishment of specific regional clusters of OE industrial and R&D activity. A similar development can be observed in offshore wind energy which is already in a more advanced state of development where specific industrial cluster have developed over time. This is also driven by conscious sourcing strategies of tier I companies, such as Vestas in offshore wind[110].

The higher the uptake of OE, the stronger the supply chain can be expected to develop. In particular under scenario 3, with a potential of 10.5 GW of power in the waters surrounding the EU in 2035, opportunities are created in this respect and it is expected to be possible to develop in size into an industry comparable to offshore wind today, growing in a controlled and swift manner whilst learning from and not repeating the mistakes made by larger existing industries. Like offshore wind, in OE Europe could benefit from a first mover advantage. The longer term potential may be even higher as also offshore wind today is still considered to be a relatively immature sector[111].

OE impacts on ports

Ports play an important role in the development of OE. Diverse facilities and services are hosted by key sea ports. During the construction phase, specialised vessels to construct offshore structures and install devices are required and ports are the key nodes of logistics in this process. After commissioning, regular maintenance or other operational services may be needed for which a home port is required that hosts specialised vessels, storage facilities and ancillary services.

The faster development of OE under certain scenarios will have implications for ports. As we have seen in the offshore wind energy sector, several ports have transferred into major hubs for servicing the construction process of offshore wind parks and continue to play a role in providing operational services, thus benefiting from the associated employment in and around the port.[112] Especially in scenarios where the growth of ocean renewable capacity will be fast and thus call for efficient and up-to-scale facilities at sites geographically located attractively vis-à-vis the offshore sites concerned.

Furthermore the development of OE will boost the demand for supplies from marine equipment manufacturers. With a leading position in the high value/high complexity segments of shipbuilding and offshore platform development, European based OEMs and developers will benefit from the increased demand for components and specialised ships.[113]

Synergies with other sectors

Apart from building supply chains future developments of the wave and tidal energy sector will be linked with developments in other sectors[114], such as offshore wind energy, oil and gas, hydropower, exploiting positive synergies in technology developments (e.g., components), infrastructure, supply chain and policies. There will be significant opportunities for co-location of technologies; for example for wave, tidal and offshore wind energy, utilizing common platforms for wave/wave or wind/tidal hybrid systems. Mutual learning processes, shared infrastructure and innovations from a shared supply chain will be of great benefit to the future expansion of both the OE sector and related sectors.

Industry cooperation initiatives can also pave the way for increased cross supply chain cooperation and knowledge sharing with other marine sectors. In this context one may look at initiatives previously taken in the shipbuilding sector which nowadays acts as a supplier and

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[110] SEAI 2012, p26

[111] Garrad Hassan in Wind in ours sails – EWEA, 2011

[112] See for example the case study on Oostende presented in the Blue Growth study (Ecorys, 2012).

[113] Ecorys (2012), Green growth opportunities in the EU shipbuilding sector. Final Report. 5 april 2012.

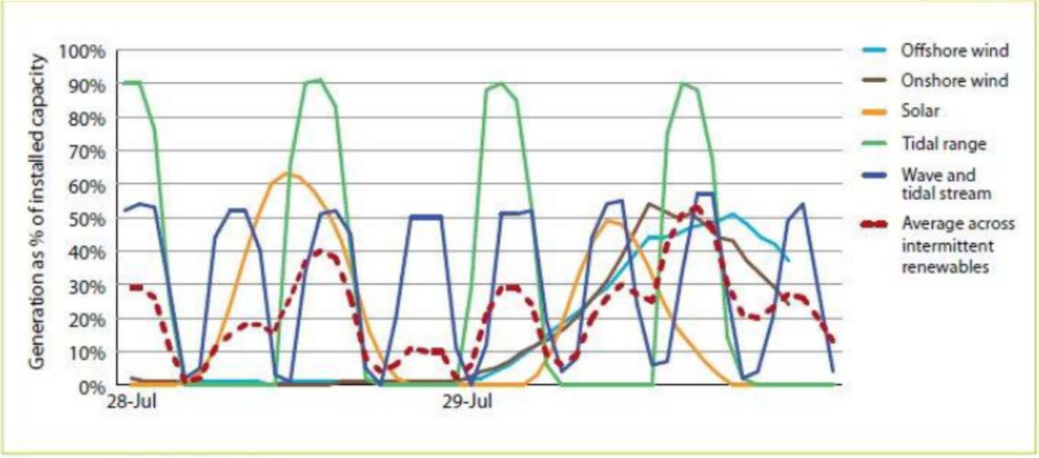
[114] See JRC (2012): "Draft report ‘Short overview of marine energy technologies and their European potential"

developer/innovator to many marine sectors including offshore energy (today particularly wind and oil & gas but providing potential to OE as well). The LeaderSHIP strategy developed sector wide contains a variety of action areas to enhance the competitiveness of the sector including R&D actions (also connected to the Waterborne Technology Platform), attention to IPR (which may become a concern in the future in the OE sector as the market matures and outsourcing will become practice), funding structures (industry - bank relations and standardised contracting approaches) and networking actions.

4.2.4 Other impacts – benefits of energy diversification

The introduction of OE will change the overall characteristics of the energy system bringing additional benefits. Early results and findings provided by the Electricity Market Reform Expert Group in the UK[115] showed that a key impact of diversifying the mix of renewable technologies is that it reduces the variability of the hourly aggregate output levels. Wave energy thus provides a means of moderating the variable output of wind generation and reducing the risk of long periods of low renewables output (see **Figure 4.7**~~Figure 4.7~~)[116]. The energy production of both wave and tidal energy is much less variable and more predictable than wind energy. As a result the required reserve capacity can be lower[117]. For the UK alone a reduced reserve and back-up facility resulting from a diversification of the energy mix with OE is expected to produce benefits in the order of magnitude of 300 million GBP per annum[118].Yet another benefit is that the lower variability of a diverse renewables supply reduces the risk of periods occurring in which total output from non-dispatchable sources exceeds total demand. This would lead to spilled energy supply and enable to match supply and demand in a more efficient way. The value of “spilled” energy which can be avoided as a result of diversifying the energy mix has been estimated by EMREG at roughly 200 million GBP per annum.

Figure 4.7 Variability of renewable energy generation technologies (over 2 illustrative days for 2030 mix)



Source: CCC analysis based on modelling by Poyry.

Note(s): Based on observed patterns 28-29 July 2006, scaled up to 2030 levels. Chart shows the generation that would be produced by the different renewable technologies (as a percentage of installed capacity) in the Poyry Very High scenario over a two-day period.

Source: EMREG (2012)

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[115] Reference

[116] in essence because it will regularly be out of phase with wind and tidal generation

[117] EMREG (2012)

[118] EMREG (2012)

Apart from a more stable energy supply the increased use of renewable energy (including OE) will reduce the need for fossil fuel imports. This will lead to additional benefits in the form of a lower dependency on imported fuels and decreased price volatility as a result of geopolitical instability.

4.2.5 Administrative costs

The administrative costs related to OE are strongly related to the observed administrative and regulatory bottlenecks that OE is facing (see section 2.4~~2.4~~). In examining the impact on administrative costs it is instructive to compare the experience of OE with offshore wind-power. To this end the recent *Wind barriers* report[119] found that there are shorter total and administrative lead times for offshore wind-power projects, compared to onshore projects (due mainly to a shorter waiting time for the necessary permits[120]. However, the total administrative costs (not including the administrative costs connected to grid connection) are comparatively much higher, at nearly 14% of total project costs. The authors of the report suggest that these are mainly due to the costs of EIA and note that ‘the offshore market, despite its growing capacity, is not yet fully developed. This causes insecurity as to the scope of the EIA, spatial planning, and answering new types of questions from environmental NGOs’.[121]

Similar observations can presumably therefore be applied to the OE sector, which is, relatively speaking, even less developed. Indeed the novelty of OE is quite likely to result in even larger administrative costs for OE projects due to the lack of familiarity of national administrations with the technology outside duly authorized test areas.

Interestingly the report goes on to call, as a policy objective, for the level of administrative costs to be reduced to 1.5% of project costs (for all wind-power developments). On the basis of the total costs of OE projects to date a more modest reduction in terms of administrative costs would still confer substantial savings.

The reduction of administrative costs is expected to be directly related to the reduction of administrative barriers and reduced uncertainty of environmental impacts, which is expected to reduce over time as experience and knowledge of OE increases. This implies that in higher uptake scenarios this process will accelerate due to the faster gaining of experience

4.3 Environmental impacts of OE

4.3.1 Introduction

Just like for any type of energy generation installations, setting up and operating a structure in an environment will lead to changes in the surrounding parameters of this environment. Offshore renewable energy from offshore wind is in this respect not different than the various OE technologies. These installations can cause changes in small and large-scale hydrodynamics around the structures, sea bed morphology, sediment transport and ecosystem functioning. It can also lead to changes in the ecotope, changes in species distribution and bio-productivity. In addition, some of the OE technologies may have specific impacts. For example, osmotic power (salinity gradient) installations change the composition of water by extensive filtering and/or reverse osmosis, and can thus have an effect on water quality and ecosystem.

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[119] European Wind Energy Association WindBarriers - Administrative and grid access barriers to wind power (July 2010) at page 33. http://www.windbarriers.eu/fileadmin/WB_docs/documents/WindBarriers_report.pdf

[120] Which can be explained by the fact that there are less actors involved with projects at sea and less potential conflicts arise.

[121] Although the authors go on to note that, conversely, offshore projects are much less at risk from law suits and social acceptance issues.

However, impacts on the environment may also be beneficial. The experiences of offshore wind development provide some interesting lessons. Offshore wind farms are generally prohibited areas for commercial fisheries and navigation, which can result in the development of relatively bio-productive and bio-diverse refuges around the foundations. It could be expected that similar to offshore wind parks, OE farms can have similar beneficial effects by providing hard structures and prohibiting disturbance by other users (e.g. fisheries), thereby serving as a protective refuge area for habitat, biodiversity or fisheries [122]

In this context, it is imperative to understand better the type and extent of the immediate and long-term impacts on the environment. Like offshore wind farms, if OE development deploys in a significant manner in large networks of installations expanding over vast areas of the seas, cumulative impacts of such developments would have to be better studied, understood and mitigated.

With extensive knowledge of large-scale and local hydrodynamics, morpho-dynamics, ecosystem functioning and spatial planning, site selection for installations can be optimized to result in maximum energetic yield, as well as in minimal negative effects on the surroundings. Early integration of environmental impacts in the development of OE technologies will optimise OE deployment in a sustainable manner avoiding delays and costs in later stages due to required mitigating measures or compensation measures[123].

Environmental legislation for OE

Over the last two decades, the EU and its Member States have developed a robust environmental legislation framework with the objectives to protect specific species and habitats and minimize impacts of plans or projects on the environment. More details are provided in annex C.

OE projects will be mostly affected by the EU Habitats and Species Directive (92/43/EEC), the Environmental Impact Assessment Directive (85/337/EEC) and the Wild Birds Directive (2009/147/EC).

Framework of Analysis

To better understand what impacts emerging OE technologies are likely to have on their environment, we have looked at the environmental impacts and the CO_2 balance for each of the OE technologies, wave, tidal barrage, tidal stream, osmotic and OTEC.

Due to the early stage of those technologies, the limited number of devices operating in their final environments, and the limited availability of environmental data, the type(s) and extent of specific impacts on OE are not well known at this time. Impact(s) on OE are likely to be of the same type(s) and magnitude as existing wind generation and other offshore renewable energy generation infrastructure.

Limitations / considerations regarding data on OE

A number of limitations and consideration should be considered regarding the assessment of environmental impacts of OE:

- Available data is very limited, mostly from single OE installations, usually pilot studies, not full-blown installations; only few commercially operating installations worldwide;
- No long term monitoring data is available (recent implementation);
- Data from pilots/installations is highly location-specific;

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[122] Inger et al. 2009

[123] Pelc and Fujita 2002, Boehlert and Gill 2010

- Focus is on environmental impacts that are typical and particular to OE technologies, i.e., not on standard/generic (minor) impacts that can be expected for most offshore and coastal developments (such as grid connections, mooring or base support). For assessment of cumulative impacts, such generic impacts should however be included in the overall analysis, along with effects of multiple installations (e.g., commercial power farms).
- Research is ongoing but not conclusive yet. There are several EU FP7 projects focused on OE development and related environmental impacts (e.g. Vectors, Mermaid, Equimar, SOWFIA...). They are detailed in annex C. No definitive conclusion can be drawn yet from those ongoing research efforts on the impacts of OE technologies on the environment.
- If pilot/field data is not available, reference will be made to literature on similar generic interactions of structures with the marine environment (e.g. wind turbines, desalinisation plants);

4.3.2 Biological, physical and chemical environmental impacts per technology

At present, there is a great need to better understand the potential effects or impacts of OE developments on the marine environment[124]. Several previous authors (e.g., Boehlert and Gill 2010, Shumchenia et al. 2012) differentiate between environmental effects and impacts; in this report we focus on potential significant major impacts that may be associated with particular types of OE technology, and or with marine environments.

Key findings are presented in the table below and in annex C. The table on the next page provides a general overview of potential and significant environmental impacts can be expected with implementation of a single OE installation. This does not address large-scale implementation (i.e. a farm) or cumulative impacts with other offshore users.

In the table impacts are categorized as follows:
- **unlikely** (negligible no significant impact),
- **potential** (slight or moderate impact, could require mitigation),
- **significant** (large, significant impact, such that design alternation, mitigation or compensation is required)

The subsequent sections describe per technology the environmental impacts in general terms, whereas more details are provided in.

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[124] Boehlert and Gill 2010, .Inger et al 2009, Gill 2005

Table 4.16 Overview of potential environmental impacts of implementation of single installations of five OE technologies

OE Technology Type	Life Cycle Stage	IMPACT											
		Biological					Physical						Chemical/WQ
		Primary Production	Connectivity	Species Mortality	Habitat Disturbance (incl. Benethic Habitat, Artifical Reef effect(s))	Behavioral Disturbance (e.g. avoidance behavior, collision, entangement)	Water Movement Residence Time Wave Climate Flow Tidal	Geomorphology Erosion Sedimentation Sediment Dynamics	Hydrology Salinity Temperature	Sound (Noise)	Electromagnetic Fields	Light Disturbance	pH O2 CO2 Nutrients Contaminants/ Hazardous Materials
Osmotic Gradient	Installation		🟨	🟨	🟨	🟨	🟨	🟨		🟨			🟨
	Operation & Main	🟨	🟨	🟨	🟨	🟨	🟨	🟥	🟥				🟥
	Decommission				🟨	🟨	🟨	🟨					🟨
Wave (Floating/Fixed)	Installation				🟥	🟥							🟨
	O&M		🟨				🟥	🟨		🟥			
	Decommission				🟨	🟨				🟥			🟨
Tidal (Flow)	Installation				🟥	🟥				🟨			🟨
	O&M						🟨			🟨		🟨	
	Decommission				🟨	🟨	🟨	🟨		🟨			🟨
Tidal (Barrage)	Installation			🟨	🟥	🟥		🟨		🟨			🟨
	O&M		🟨				🟨	🟥	🟥	🟨			
	Decommission				🟨	🟨	🟨	🟨		🟨			🟨
OTEC	Installation				🟥	🟥				🟨			🟨
	O&M								🟥				
	Decommission				🟨	🟨				🟨			🟨

Red	Yellow	White
Significant Impact	Potential Impact	Unlikely Impact

Wave energy

Wave energy is promising, holds a huge potential to reduce reliance on fossil fuels, and is considered to be relatively environmentally benign at this time. Pelc and Fujita (2002) note that small-scale wave energy plants are likely to have minimal environmental impacts. However, some of the very large-scale projects that have been proposed have the potential for harming ocean ecosystems. Covering very large areas of the surface of the ocean with wave energy devices would harm marine life and could have more widespread effects, by altering the way the ocean interacts with the atmosphere. Further research into wave energy is recommended. For new wave plants, particularly of large capacity, siting should be carefully considered not only for the potential to generate power, but also for the ecosystem's reliance on and response to powerful waves, and wave plants should be avoided where calming of the waves would result in significant community changes or disrupt natural ecological processes.[125]

Tidal range

Estuaries with a high tidal range are the preferred locations for large tidal projects due to their cost-effectiveness (Burrows et al. 2008, Wolf et al. 2009); and technological feasibility (Wolf et al. 2009). On those type of projects, environmental implications have been long recognised and documented (Hodd 1977), Baker (1991) Matthews and Young (1992). More recently, Wolf et al. (2009) provided a comprehensive overview of environmental impacts related to tidal barrages. As tidal barrages inevitably impound the water for part of the tide, this will lead to changes in the estuary basin and channels.

The most well known impact of tidal barrages might be the potential loss of certain habitats, especially (often protected) intertidal mudflats and salt marshes, vital to specific bird species. Bottom stress due to modified waves and currents may change benthic habitats. Unless fish passes are constructed, migratory fish may be impeded. Fish and marine mammals may suffer damage by collision with the barrage and turbines. Some estuaries may no longer be suitable as nursing grounds for breeding fish or other species. The population of filter feeders may be enhanced due to an increase in primary production.[126] All these effects are site specific and to a large degree dependent upon the design and mode of operation of the barrage. Numerous mitigation methods already have been developed to avoid or reduce negative impacts. New tidal barrages should be constructed taking care not to close off the estuary from the ocean during construction as was the case with La Rance, and these plants should not be built until detailed environmental assessments demonstrate a minimal impact on the marine ecosystem.

Tidal stream technologies

Tidal plants sited at the mouths of estuaries pose many of the same environmental threats as large dams[127]. By altering the flow of saltwater into and out of estuaries, tidal plants could impact the hydrology and salinity of these sensitive environments. Tidal fences and tidal turbines are likely to be more environmentally benign .Tidal fences may have some negative environmental impacts, as they block off channels making it difficult for fish and wildlife to migrate through those channels.

Tidal turbines could be the most environmentally friendly tidal power option. They do not block channels or estuarine mouths, interrupt fish migration or alter hydrology [128].Tidal turbines and tidal fences both may offer considerable generating capacity without a major impact on the ocean, while tidal barrages are probably too damaging to the marine ecosystem. Research in tidal energy should focus on turbines, fences and similar technologies. These projects should be sited and built so that major migration channels are left open. Turbines should turn slowly enough that fish mortality is

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[125] Pelc and Fujita 2002

[126] Wolf et al. 2009

[127] Pelc and Fujita 2002

[128] Pelc and Fujita 2002

minimized and nutrient and sediment transport is largely unaffected. Tidal fences should be built across narrow channels, but not blocking an entire bay or corridor[129].

Ocean thermal energy conversion (OTEC) technologies

Further research into environmental impacts is necessary, but if the technology is shown to be benign, the development of OTEC should be a priority. Appropriate measures should be taken to control environmental impacts including:

- Refraining from siting OTEC plants in sensitive areas including prime fishing grounds, spawning areas, and sensitive reef habitats.
- Making use of discharge for ancillary benefits, which prevents discharges from altering local water temperature significantly.
- Carefully regulating the use of toxins such as ammonia and chlorine, and avoiding coating the plants with toxic hull coatings used on ships in harbors which are known to pollute the waters.
- Relying mainly on relatively small plants. While there may be economic benefits to scaling up, large-scale plants are more likely to damage a local community through discharge or impingement/entrainment. Also, benefits from economies of scale are likely to dwindle at the 50MW scale[130]. Similarly, if several small OTEC plants are used these plants must be suitably spaced to prevent altering local ecology significantly at any one site[131].

Salinity or Osmotic gradient power

In literature, several techniques for energy conversion of the salinity gradient have been proposed: pressure-retarded osmosis (Loeb 1976), reverse electro dialysis (Pattle 1954), and vapor-pressure difference utilization (Olsson et al. 1979). Pressure-retarded osmosis (PRO) and reverse electro-dialysis (RED) are the most frequently studied membrane-based processes for energy conversion of salinity-gradient energy[132].

The implementation of a salinity gradient power plant can have a considerable effect on the surroundings. The power plant may obstruct or affect the natural course of rivers and estuaries and disturb naturally occurring hydrodynamics and salinity gradients. Potentially, negative impacts can be expected with the construction of access roads, channels and connections to the electricity grid, as natural habitats can be damaged, disturbed or lost in the process[133].

Hybrid solutions

There are numerous possible combinations of OE technologies with other offshore activities, and most of these combinations are in early stages of development (OTEC and aquaculture, wave power and aquaculture installations, wave power and desalination, wave and wind energy). Knowledge of environmental impacts of the individual technologies might shed a light on the environmental impacts of hybrid technologies, but for reliable indications of how large scale implementation of hybrid technologies might affect the environment, extensive research and monitoring will be necessary.

Concluding remark on environmental impacts

As noted, firm conclusions about specific environmental impacts of the various OE technologies are limited at present by the lack of data. Based on **Table 4.16**~~Table 4.16~~ general potential impacts can be characterized as follows for the various technologies relative to one another. All OE renewable technologies have lower impact than fossil fuel energy throughout their respective life cycles. Tidal barrage appears to have the greatest overall likely impact of the technologies considered, in

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[129] Pelc and Fujita 2002
[130] Pelc and Fujita 2002
[131] Pelc and Fujita 2002
[132] Post et al.2007
[133] Skilhagen, 2009

particular for benthic and behavioural disturbance during the installation phase, and on geomorphological and hydrological factors during operation and maintenance (O & M) phases. OTEC apparently has somewhat less impact, similar to tidal barrage during installation, and particularly on salinity and temperature during O & M phases.

4.3.3 GHG reductions – contribution of OE

Like other renewable energy, OE technologies will contribute to both GHGs emission and renewable energy targets. It is hard to say how significant this contribution will be based on the current development of the technologies. No commercial devices are in operation sufficiently long to have reliable monitoring data. Therefore, the information collected is based on estimating the future installation of OE technologies and applying energy conversion factors and appraisal GHG guidance such as DECC/DEFRA guidance in the UK.

In this context, several studies and initiatives aimed at quantifying the contribution of those technologies as regards Green House Gases emission. There are different methodologies for calculating the CO_2 avoided by wind energy and they all depend on the assumptions made about which fuels are displaced when electricity from OE is produced.

The energy mix together with the base load is different between Member States. Ideally CO_2 avoided by OE should be calculated based on the energy mix and intermediate load in each Member State.

Several initiatives have estimated the potential CO2 reduction by OE technologies. They used different base year and different mythologies resulting in not easily comparable estimates. For example, in 2010, a UK study “valuation offshore “estimated that the deployment of offshore renewable energy would contribute to 1.1 billion tonnes of CO2 emissions avoided between 2010 and 2050. This is the total carbon reduction from offshore renewable, including offshore wind, assuming avoided CO_2 emissions of 430g/kWh from 2010 to 2030, falling to 20g/kWh by 2050 due to the changing nature of the energy mix. This is based on DECC’s 2010 GHG appraisal guidance, and uses CCGT power generation as the reference generation alternative between 2010 and 2030. If we extract the OE contribution which represented 9% of the total installation, and assuming similar levels of emissions reduction, then OE could contribute to approximately 100 million tonnes of CO2 emissions[134].[135].

Another study from Ireland comes with an estimated CO_2 abatement potential of up to 94 MtCO2 to 2050 from power generation if 29GW of OE are deployed (see Figure 4.8~~Figure 4.8~~).

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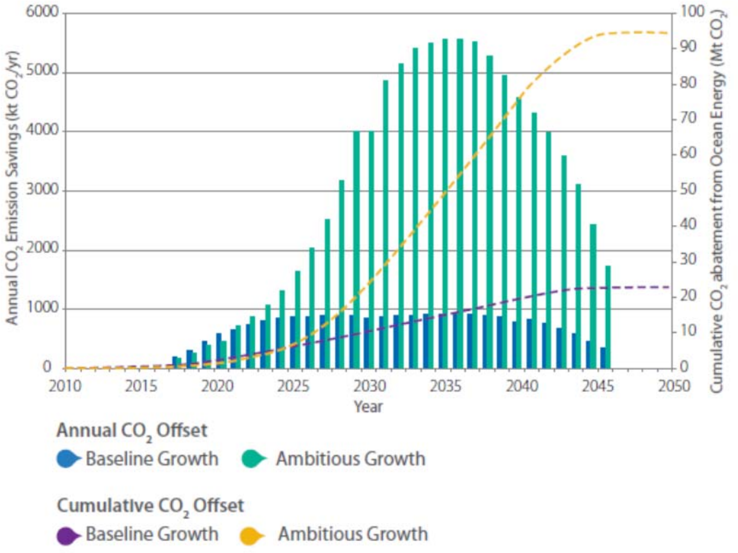
[134] The Offshore Valuation Group (2010): The Offshore Valuation – A valuation of the UK’s offshore renewable energy resource p.81

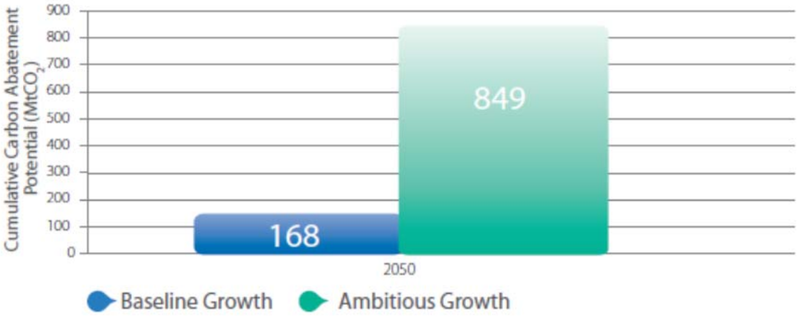
[135] The Offshore Valuation Group (2010): The Offshore Valuation – A valuation of the UK’s offshore renewable energy resource p.81

Figure 4.8 Estimated annual & cumulative CO2 emissions offset from power generation to 2050



Source: Sustainable Energy Authority of Ireland: OE Roadmap

Figure 4.9 Cumulative CO_2 abated from OE generation potential to 2050 when compared to natural gas electricity generation



Source: Sustainable Energy Authority of Ireland: OE Roadmap

According to DECC[136], "*by 2050, for a high deployment scenario of 27GW installed capacity, wave and tidal stream technologies could save 61Mt of CO2*" (for comparison, total emissions from the power sector in 2010 were 156 MtCO2 in the UK).

The Ocean Energy Association estimates that for each MWh generated by wave and tidal energies, 300 kg of CO_2 can be avoided. In total the EU-OEA estimated an avoidance of 2.61 Mt/year in 2020 and 136.3 Mt/year by 2050 using a 300kg/MWh ratio over the all period. In addition, these figures do not account for the base load fossil fuel-produced power necessary to firm up OE intermittency. The typical savings of OE in comparison to fossil fuels are illustrated in **Table 4.17**~~Table 4.17~~.

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[136] source: House of Commons, 2012

Table 4.17 Typical greenhouse gas avoidance from OE generation

1 MWh avoidance of	CO2	SO2	NOx
Coal	780 kg	0.13 kg	1.17 kg
Oil	878 kg	2.63 kg	3.48 kg
Gas	415 kg	0.00kg	0.92 kg

Source: European Energy Association 2009

Table 4.18~~Table 4.18~~ presents avoided CO_2 emission by OE according to various sources in literature.

Table 4.18 Comparison of avoided GHG emissions expected by various literature sources

Source	Total emissions from OE	Kg CO2 per MW/h	Assumptions
Valuation offshore	100 million tonnes from 2010 to 2050	430 (2010-2030) 20 (2030-2050)	Technologies considered: Tidal and wave DECC 2010 GHG appraisal guidance
Carbon trust	1 to 3.3 million tonnes a year for 1 to 2.5 GW		
JRC EU OEA	2.61 million tonnes per year in 2020 136.3 million tonnes per year in 2050	300 Kg	Technologies considered: Tidal and wave An estimation of NOx and SOx is proposed

As the energy mix is expected to change over time, in our calculations we have used declining carbon intensity values developed within the European Commission Roadmap 2050 (the development of carbon intensity in the “current policies initiatives” scenarios has been used in the calculations). Under these assumptions carbon intensity levels start at 330 kg per MW/h and then continuously decrease over time until they reach 150 kg/MWh in 2035. This results in the potential contribution as regards CO_2 emissions reduction for the different scenarios.

To estimate the effect on CO_2 reduction under our three scenarios, we need to make an additional assumption on the capacity factor. As mentioned earlier, the range of expected capacity factors varies from a bit more than 20% to even 45%. This is due to the fact that we are mainly talking about power plants which will be built in the future. For our estimations we have chosen a more conservative capacity factor of 25%. We have also calculated CO_2 reductions with a more optimistic 35% capacity factor in line with recent studies in the UK[137]. The following figure shows the annual CO_2 reduction under the three scenarios and the two capacity factors.

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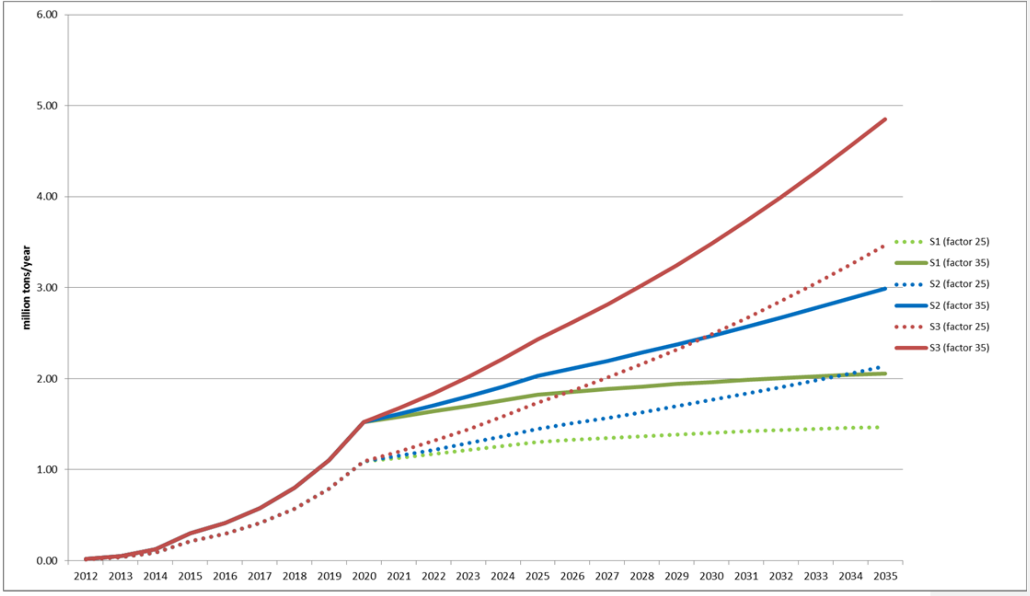
[137] Cost of and financial support for wave, tidal stream and tidal range generation in the UK, Black and Veatch Ernst and Young, October 2010

Figure 4.10 CO2 reduction in million tons/year under capacity factor 25% and 35%



Source: Ecorys

As visible in the figure above, the annual range in CO_2 reduction varies from 0.01 - 0.02 Mt/year in 2012 (under all three scenarios) to 1.09–1.52mt /year (under all three scenarios) in 2020 to 1.5-2.05 mt/year under scenario 1, 2.13 – 2.99mt /year under scenario 2 and 3.47– 4.85 mt/year in 2035.

If we sum the annual reductions we can estimate the expected cumulative overall benefits. The following table gives an overview on the expected CO_2 reduction from 2012 until 2020, 2025, 2030 and 2035 under each scenario in million tons of CO_2 per year.

Table 4.19 CO2 reduction in million tons 2012-2035

	2012	2020	2025	2030	2035
Scenario 1	0.01 – 0,02	3.5 – 4.9	9.5 – 13.5	16.5 – 23	23.5 – 33
Scenario 2	0.01 – 0,02	3.5 – 4.9	10 — 14	18 – 25.5	28 – 39
Scenario 3	0.01 – 0,02	3.5 – 4.9	10.5 – 15	21.5 – 30	37 – – 51.5

Source: Ecorys

In comparison, offshore wind power is estimated to avoid the emission of 104 Mt CO_2 in 2021, a figure that will rise to 315 Mt CO_2 in the year 2030. Cumulatively this corresponds to over 2,3 Gt CO_2 avoided by 2030[138] .

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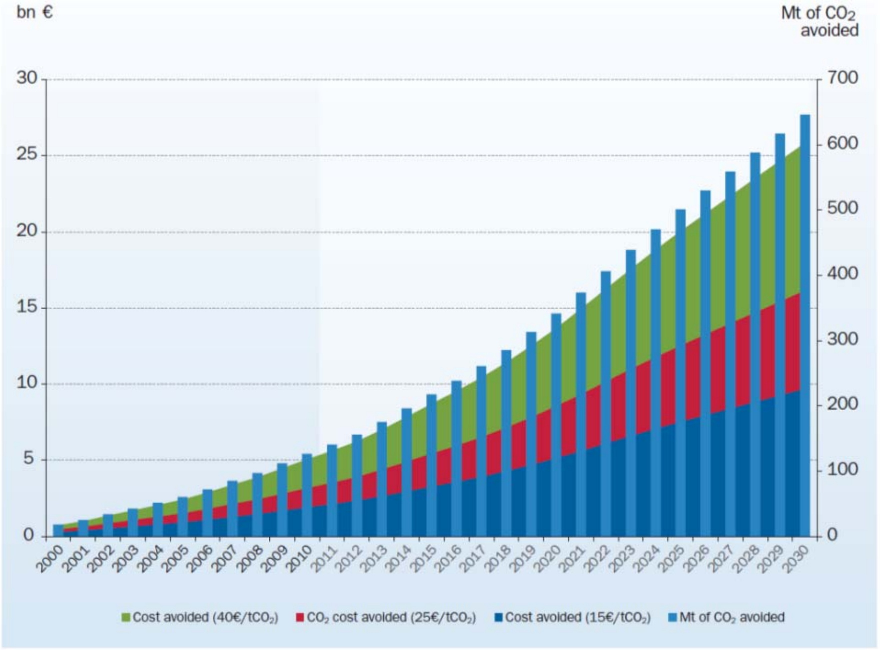
[138] EWAE (2011)

Cost of avoided CO_2 emissions

The avoided CO2 reduction can also be expressed in costs using various cost assumptions regarding the value of CO2. Figure 4.11~~Figure 4.11~~ below present the situation for wind energy using CO2 values of 40€/t CO2, 25€/t CO2 and 15€/t CO2.

Figure 4.11 Wind energy: Mt of CO_2 avoided (blue bars) and associated costs under various cost scenarios

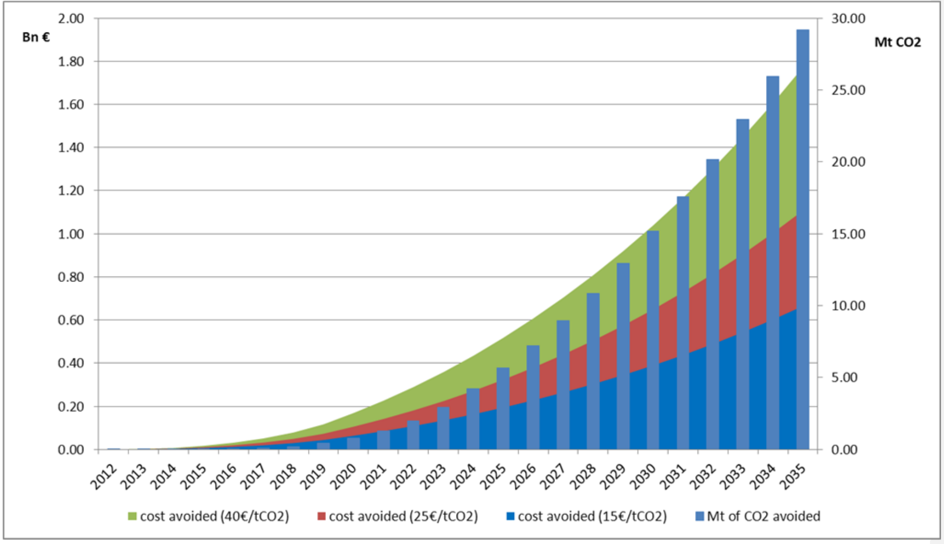


Source: EWEA (2011): Pure Power – Wind energy targets for 2020 and 2030, p.70

At CO_2 price of €25/t, wind power avoided 3.1 bn € in carbon costs (>100 mt CO2 avoided) in 2010 and 8.5 bn € (350 mt of CO2 avoided) in 2020 and 25.8 bn € (650 mt CO2 avoided) in 2030 assuming the price reaches 40 €/t.

Following the principle used for wind for the time period from 2000 to 2030 we have estimated three figures (one per scenario). To keep to the results readable we decided to use an average capacity factor of 30 % instead of plotting ranges on the graphs.

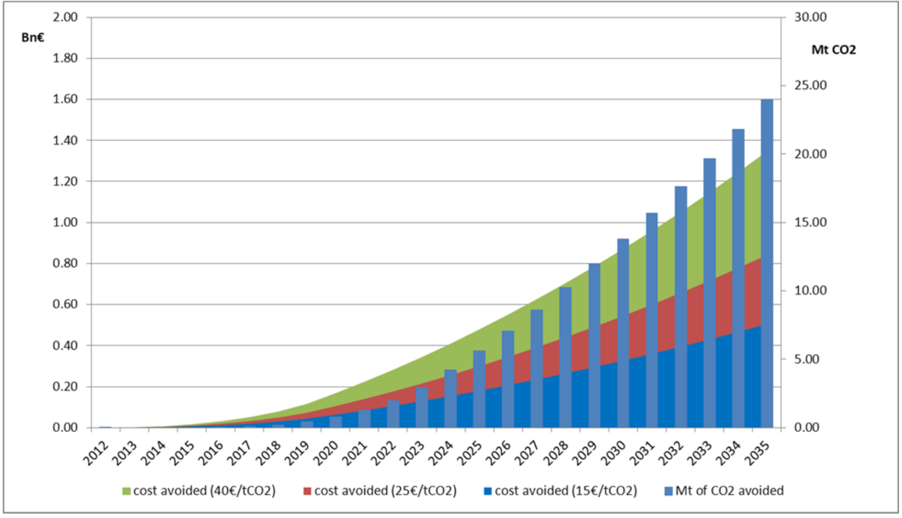
Figure 4.12 OE – Scenario 3: Mt of CO2 avoided (blue bars) and associated costs under various cost scenarios



Source: Ecorys

As we can see in **Figure 4.3**~~Figure 4.3~~ above, the cost reductions expected from 2012 until 2035 for OE under scenario 3 are expected to be about 5% of the cost reductions for wind energy from 2000 to 2030. This means that in 2035, when almost 30 Mt of CO2 will be avoided a range of 0.6 to 1.7 bn€ are saved under the three cost assumptions.

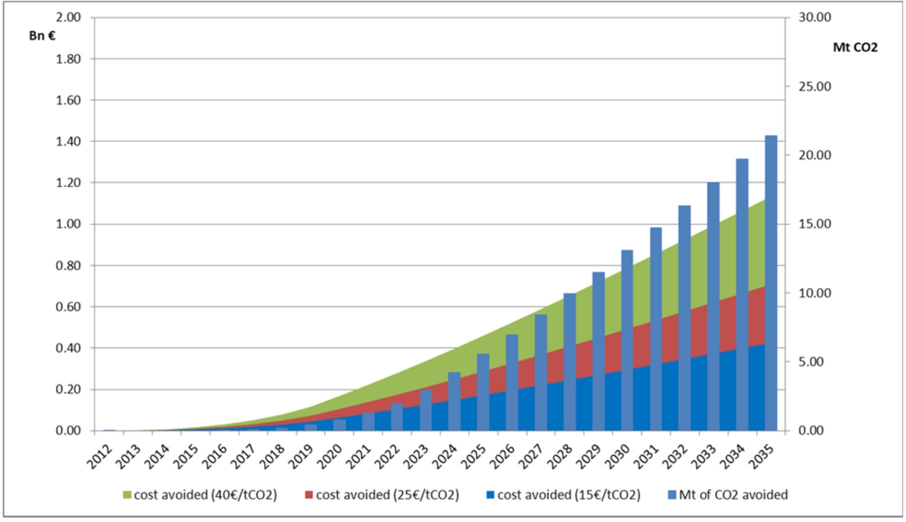
Figure 4.13 OE – Scenario 2: Mt of CO2 avoided (blue bars) and associated costs under various cost scenarios



Source: Ecorys

As we can see in the figure above, about 24Mt of CO2 emissions avoided under scenario 2 until 2035 leads to a cost reduction of 0.4 to more than 1.3 bn€ depending on the cost scenario.

Figure 4.14 OE – Scenario 1: Mt of CO2 avoided (blue bars) and associated costs under various cost scenarios



Source: Ecorys

As we can see in the figure above, about 22 mt of CO2 emmissions avoided under scenario 1 until 2035 lead to a cost reduction of 0.4 to 1.2 bn€ depending on the cost scenario.

Table 4.20~~Table 4.20~~ gives an overview on the impact on costs safed under the scenarios explained above.

Table 4.20 Overview on costs avoided in bn€ by cost assumption and scenario

	Costs avoided (40€/tCO2)	Costs avoided (25€/tCO2)	Costs avoided (15€/tCO2)
Scenario 1	1.13	0.71	0.43
Scenario 2	1.35	0.84	0.51
Scenario 3	1.77	1.11	0.66

Source: Ecorys

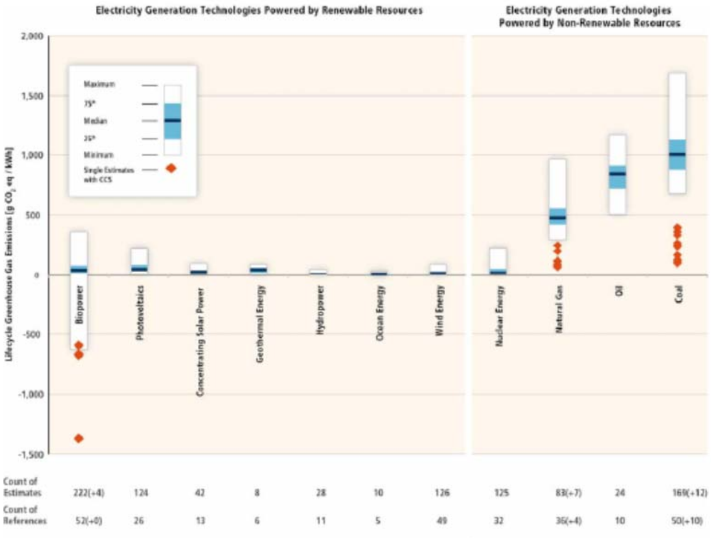
Life Cycle assessment

The previous section refers mainly to the carbon dioxide emissions avoided by OE devices assuming a certain energy mix. Figures for abated carbon dioxide emissions were calculated on the assumption that for every kWh of power generated from OE 300 grams of CO2 emissions would be avoided.

The carbon footprint of those technologies would be incomplete if we do not consider the complete life cycle (emissions of OE. This is because while zero emissions will be produced during operation, finite emissions will occur due to manufacturing, fabrication, transportation, installation, maintenance and decommissioning.

Lifecycle assessments for electricity generation indicate that GHG emissions from renewable energy technologies are, in general, significantly lower than those associated with fossil fuel options, and in a range of conditions, less than fossil fuels employing CCS. The median values for all renewable energy sources are ranging from 4 to 46 g CO2 eq/kWh while those for fossil fuels range from 469 to 1001g CO2-eq/kWh (excluding land use change emissions).

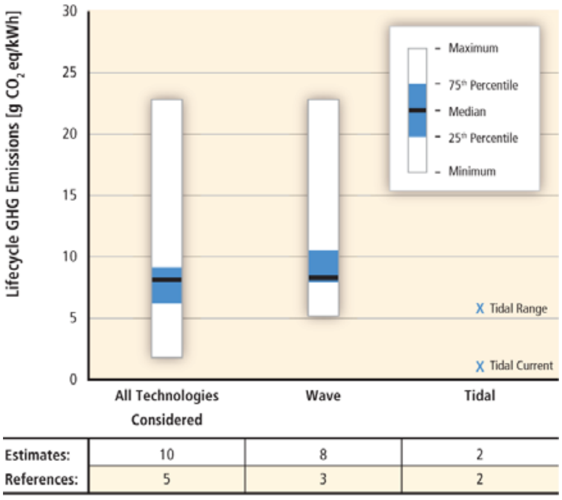
Figure 4.15 Estimates of lifecycle GHG emissions (g CO2-eq/kWh) for broad categories of electricity generation technologies, plus some technologies integrated with CCS.



Source: IPCC, Edenhofer et al. 2011

Only a limited number of studies are available that address the energy demand of OE during the different life cycle stages. According to a study by the University of Edinburgh[139], the largest contribution in the energy balance of wave converters is the energy needed for the materials used; this is usually steel. The energy needed for transport is usually negligible, while the energy needed for winning raw materials usually is one order lower than the energy needed for the primary production, as is the energy needed for assembling and decommissioning.

Figure 4.16. Lifecycle GHG emissions of OE technologies, from: Lewis et al., 2011



Source: IPCC, Edenhofer et al. 2011

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[139] Douglas, 2007

Studies of tidal and ocean current, ocean thermal energy conversion and salinity gradient devices that pass the quality screens are lacking in this overview. Regardless, in comparison to fossil energy generation technologies, the lifecycle GHG emissions from OE devices appear low.

Carbon footprints could be further reduced in all electricity generation technologies if the manufacturing phase and other phases of their life cycles were fuelled by low carbon energy sources. For example, if steel for turbines was made using electricity generated by wind, solar or nuclear plants. Using fewer raw materials would also lower life cycle CO2 emissions, especially in emerging technologies. Burning ‘carbon neutral’ biomass and capturing the emissions using carbon capture and storage (CCS) technologies would result in a net removal of CO2 from the atmosphere.

A related concept to life cycle emissions is the energy payback period, which is the time it takes for a device to generate the energy that was used in these activities. A UK study[140] published in 2006 calculated the energy payback period for one particular wave energy converter that employs 665 tonnes of steel[141] and has an annual average Energy Production of 2.3 GWh/year has estimated life cycle emissions of between 25 and 50 g/kWh and an energy payback period of about 20 months[142] made during the MEC indicate that life cycle emissions and energy payback periods vary between wave and tidal stream device concepts, but are generally low.

4.3.4 Conclusions

OE technologies are still fairly new. Further research is needed on the environmental effects as well as economic feasibility of renewable OE projects. However, research has shown that these technologies hold promise, and further research and development could help address serious threats to the environment and society associated with global climate change. Impacts of various renewable energy technologies are likely to be highly site specific and scale dependent. Like many other renewable energy technologies, the environmental benefits (e.g. Green House Gas reduction) seem to outweigh their potential (but still unknown) negative impacts. Careful planning and continued environmental research will be needed to secure an environmental friendly development of those technologies such as recommended by the Marine Board of the European Science Foundation in 2010.

Future Research efforts – Marine Board - Marine Renewable Energy: Research Challenges and Opportunities for a new Energy Era in Europe, Vision document 2010

Future research efforts must target inter alia:

- Defining national and international environmental protocols and guidelines (e.g. Strategic Environmental Assessments, Environmental Impact Assessments) in collaboration with public authorities and stakeholders in order to assist both developers and regulators in the design and approval of licensing and environmental monitoring and analysis frameworks.
- Developing a better understanding of environmental impacts and responses to commercial scale installations and predicting the cumulative environmental interactions of scaling-up to large offshore device arrays.
- Developing new cost-effective environmental monitoring devices (e.g. bird detection radar) to be embedded in the automatic monitoring of devices, especially for remote offshore installations.

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[140] Future Marine Energy Results of the Marine Energy Challenge: Cost competitiveness and growth of wave and tidal stream energy (Carbon Trust, 2006)

[141] It has previously been found that carbon dioxide emissions are broadly proportional to energy use, and given this, the most important life cycle stages are manufacturing of structural materials. Consequently, a preliminary estimate of life cycle emissions of a marine renewables device can be made by comparing the emissions due to structural materials with total energy production over the device’s service life. See ETSU (1999), A Brief Review of Wave Energy.

[142] Source: Black & Veatch.

- Developing mitigation measures both specific to identified environmental impacts, and to each device type in line with technological and design evolution.
- Turning the environmental factor into a competitive advantage through the development of new marketable technologies and processes for impact monitoring and mitigation.
- Contributing to the development of standards and testing protocols, and strengthening the role of testing centres in Europe as centres for practical R&D related to both technology development, and environmental monitoring and measurement .

Overview of environmental impacts under the three scenarios

An overview of likely environmental impacts of each of the three scenarios is given in the table below.

Table 4.21 Overview of environmental impacts under each scenario

	Scenario 1	Scenario 2	Scenario 3
Environmental impacts	Impacts of single pilot installations local, at few hotspots. Local level impacts	Potential cumulative impacts of large-scale implementation of various technologies at several hotspots most likely concentrated. Regional level Potential conflict with others users of marine areas and resources. Regional level impacts.	Cumulative impacts of large-scale implementation of many different technologies, large areas. Likely long-term. Increasing mitigation costs and probable conflicts with other users. European level impacts
GHG reductions (cumulative reduction in 2035; million tns)	37-52	45-63	60-85
Avoided costs of GHG emissions (at 25 Euro/tn)	1.11 bn€	1.35 bn€	1.81 bn€

Source: Ecorys

4.4 Social impacts

4.4.1 Employment effects

Employment impacts of ocean energies concern the quantitative amount of jobs created under the different OE uptake scenarios, the effect on geographical areas and the implications with regard to skills required. The increased development of OE will affect the demand for workers in a direct and indirect way, resulting both in employment related to the manufacturing and installation of new sites and employment related to the operation and maintenance of facilities.

Furthermore it implies employment will be created in coastal centres near the offshore energy sites as well as elsewhere in Europe where supplier companies and providers of ancillary services are based. To understand where employment is created the phases of development of OE can be used:

1. **Project development:** In the first stage there are direct jobs created e.g. in the areas of permitting, regulatory studies, licensing, design and scaled model testing and indirect jobs in the area of financing and insurance.

2. **Component manufacturing:** In the second stage direct jobs are created mainly in the field of turbine production, while there are many indirect jobs created e.g. in other spare parts and governor and control systems production.
3. **Project deployment:** The third stage is the actual construction stage at the location of the power plant. There workers are needed in the area of construction and commissioning, but also in indirect fields as finance and insurance.
4. **Operation stage:** While all work created in the first three stages is temporary work ending with the completion of the power plant, the fourth stage generates steady long-term employment in operating the power plant, but also in minor overhauling of equipment.[143]

Quantitative employment effects of the scenarios

As the technologies of OE are not yet implemented in a broad scale, it is rather difficult to assess in a quantitative manner its actual employment effects. The range of forecasts on jobs created per megawatt of installed capacity found in the literature is very broad. Table 4.22~~Table 4.22~~ compares estimates from various sources.

Table 4.22 Overview on various employment forecasts due to OE investments

Geographic area	Total jobs created	Capacity created (in MW)	Time horizon	Jobs/MW
Europe[144]	40.000 (26.000 direct)	3.600	2020	11.1 (7.2 direct)
	471.320 (314.213 direct)	188.000	2050	2.5 (1.67 direct)
Ireland[145]	70.000	29.000	2050	2.4
United Kingdom[146][147]	2.500	2.300	2030	1.08
	68.000	70.000	2050	0.97
U.S.[148]	36.000	15.000	2030	2.4
U.S. Department of Energy[149]	1.400.000[150]	n/a	2025	14

Source: Ecorys based on various sources

We assume that there are three main reasons for the huge differences in Table 4.22~~Table 4.22~~:

1. **Direct or indirect:** Some sources only refer to directly related jobs, while others include indirectly related jobs or simply do not distinguish between them.
2. **Operation versus manufacturing:** It is not always clear if estimates include jobs in the planning and construction stage or only forecast the number of operating jobs created.
3. **Experience and efficiency:** As there are not yet many OE power plants installed, it is highly work intensive to plan, design and build new power plants. We assume that lower jobs per MW ratios seen in the table for long time horizons are related to the fact that growing experience and skills in the field reduce the efforts needed to operate additional power plants at a later stage and therefore reduce the overall ratio.

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[143] Navigant Consulting (2009): Job Creation Opportunities in Hydropower

[144] Ocean Energy Association (2011): Position Paper Towards European industrial leadership in Ocean Energy in 2020

[145] Sustainable Energy Authority of Ireland: Ocean Energy Roadmap

[146] Energy and Climate Change Committee of the House of Commons (2012): The Future of Marine Renewables in the UK. Eleventh Report of Session 2010-12 Volume II

[147] Includes offshore wind

[148] Ocean Renewable Energy Coalition (2011): U.S. Marine and Hydrokinetic Renewable Energy Roadmap

[149] U.S. Department of Energy (2012): Water Power for a Clean Energy Future

[150] Cumulative number

Esteban and Leary (2011) discuss these problems and provide assumptions to distinguish between employment associated with the manufacturing and installation of facilities and the employment connected to the operation and maintenance of the OE devices. This implies that in their view during the period of capacity build-up, employment levels grow rapidly, with a drop at the point when the majority of installations is realised and a gradual growth afterwards along with more mature market developments. Also it is noted that there will be an optimal capacity at the point where all 'attractive sites' are occupied, with much slower growth afterwards.[151]

Rutovitz and Atherton (2009) have defined employment factors for various renewable energy sources including OE, which clearly show that employment levels related to manufacturing and installation are much higher on a per MW basis than employment related to operation and maintenance, with factors of 10 person-years/MW and 0.32 jobs/MW respectively (combined figure for wave and tidal power). It is noted that both figures are (much) lower for OE than for other renewable energy sources. Figures for these indicators for offshore wind for instance are 28.8 and 0.48 respectively. All figures relate to direct employment only. As with the cost developments, also concerning employment ratios a learning curve is expected which for OE is steeper than for offshore wind as the latter has already matured. The employment factors related to operation and maintenance given are much lower than the ranges found elsewhere as presented above (range 1-2.5 jobs/MW).[152]

Given the uncertainty at the current stage and the broad range of sources we have used as multipliers for direct and indirect employment related to the operation and maintenance of OE the figures of the OEA (1.67 for direct employees and 0.84 for indirect employment), which are similar to the figures used by Ireland and the USA (2.4 jobs/MW), but includes a distinction between direct and indirect employment. Furthermore we compare these figures with results using an average of the UK scenarios including the same ratio of direct/indirect for permanent employment (1.025 permanent jobs/MW; 2/3 direct, 1/3 indirect).

Table 4.23~~Table 4.23~~ shows the forecasted permanent employment (this employment due to operation and maintenance but not construction of power plants) in 2035 under the various scenarios.

Table 4.23 Jobs in operation and maintenance of OE in 2035 under the three different scenarios

	Direct	Indirect	Total
Scenario 1 -Baseline	3.000 – 7.500	1.500 – 4.000	**4.500 – 11.500**
Scenario 2 – Intensified Coordination	4.500 - 11.000	2.000 - 5.500	**6.500 – 16.500**
Scenario 3 – Strong Stimulus	7.000 – 17.500	3.500 – 9.000	**10.500 – 26.500**

Source: Ecorys

The lower ends of the ranges shown in the table above are the result of using the UK multiplier, while the higher ends are estimates using the OEA multiplier. The resulting number of jobs in operation and maintenance in 2035 can be compared with the levels expected by Rutovitz and Atherton (2012) who estimate direct jobs at about 10.000-20.000 in high uptake scenario.[153]

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[151] Esteban, M and D. Leary (2011): Current developments and future prospects of offshore wind and ocean energy. Applied energy 90 (2012) 128-136

[152] Rutovitz, J. and A. Atherton (2009, Energy sector jobs to 2030: a global analysis. Final report. Institute for Sustainable Futures. Study conducted on behalf of Greenpeace.

[153] Rutovitz, J. and A. Atherton (2009, Energy sector jobs to 2030: a global analysis. Final report. Institute for Sustainable Futures. Study conducted on behalf of Greenpeace.

For employment in construction, planning and manufacturing, which is sometimes expressed in person-years of work, the range of figures is even broader as, in the long run, employment factors are expected to decline due to both scaling up of technology (see cost reduction section 6.2.1) as well as greater efficiency in production processes.[154] Esteban and Leary (2011) and Rutovitz and Atherton (2009) assume a decrease in employment intensity after a certain stage due to a learning effect. However, the methods used are very different and underlie strong assumptions. While Esteban and Leary (2011) assume a sudden sharp decrease due to technological development and decreasing availability of the best places for new power plants, Rutovitz and Atherton (2009) assume e.g. an annual learning effect of 7.8% until 2030, which may be compared with the investment cost learning curve estimated at 5-10% (section 6.2.1).[155]

From our point of view, the assumptions needed to include a learning effect when estimating employment figures can be discussed and applying them could cause a stronger bias in the results than they would add value to the forecasts. Moreover, we expect the highest learning effect on the side of technology costs rather than employee efficiency and therefore do not include it in our job estimations. We decided to show the range between a low multiplier (jobs/MW) found in the literature (Esteban and Leary: 10) and a high one (U.S. Department for Energy: 14).

Table 4.24~~Table 4.24~~ shows the results of our estimation for person-years[156] of employment related to construction in each of the scenarios:

Table 4.24 Person-years of work in construction in the years 2012, 2020 and 2035

	2012	2020	2035
Scenario 1 – Baseline	140 – 190	7.000 – 10.000	2.000 – 3.000
Scenario 2 – Intensified Coordination	140 – 190	7.000 – 10.000	4.500 – 6.500
Scenario 3 – Strong Stimulus	140 - 190	7.000 – 10.000	10.000 – 14.500

Source: Ecorys

As we can see in **Table 4.24**~~Table 4.24~~, the impact on construction work until 2020 is similar in all scenarios and starts to deviate afterwards. The uptake under scenario 3 would give substantially higher number of jobs after 2020 compared to the other scenarios.

Geographical impacts

While employment created due to operating power plants is geographically linked to the location of the power plants and therefore in the EU to the coastlines of Member States along the North Sea and the Atlantic Ocean, the production of parts of power plants (e.g. turbines) can also take place anywhere else in Europe.

Figure 4.17~~Figure 4.17~~ shows the wave and tidal impoundment resource distribution in Europe:

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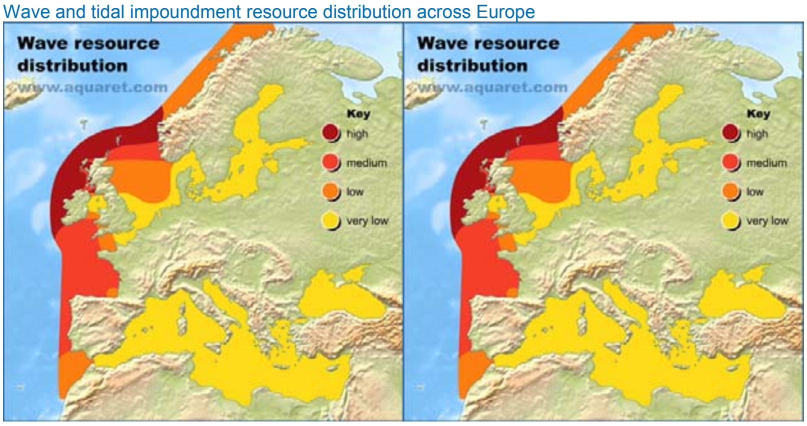
[154] Rutovitz, J. and A. Atherton (2009, Energy sector jobs to 2030: a global analysis. Final report. Institute for Sustainable Futures. Study conducted on behalf of Greenpeace.

[155] Rutovitz, J. and A. Atherton (2009, Energy sector jobs to 2030: a global analysis. Final report. Institute for Sustainable Futures. Study conducted on behalf of Greenpeace.

[156] This method of measurement is used not to create confusion by double counting the same persons working on the construction of power plants over a defined time horizon.

Figure 4.17 Wave and tidal impoundment resource distribution across Europe



Source: Aquaret

Regions with a coast along red or orange coloured sea in Figure 4.17~~Figure 4.17~~ are preferred regions for OE projects and can therefore expect permanent employment creation for operation of OE plants. These regions are located in the UK, Ireland, France, the Netherlands, Spain and Portugal.

Table 4.25 Unemployment rates in EU MS with high OE potential (in %)

Country	2007	2008	2009	2010	2011
Spain	8.3	11.3	18.0	20.1	21.6
Ireland	4.6	6.0	11.7	13.5	14.4
Portugal	8.0	7.6	9.5	10.8	12.7
France	8.4	7.8	9.5	9.7	9.7
United Kingdom	5.3	5.6	7.6	7.8	8.0
Netherlands	3.2	2.8	3.4	4.5	4.4
EU	**7.2**	**7.0**	**8.9**	**9.6**	**9.6**

Source: Eurostat

In Table 4.25~~Table 4.25~~, at a first glance especially for Spain, Ireland and Portugal investments in OE appear to be a good way to partially increase employment in countries facing high unemployment rates in the EU. But this picture might be questioned when looking into regional statistics. Table 4.26~~Table 4.26~~ compares therefore average unemployment data from coastal regions with OE potential, the average unemployment rate of countries with OE potential and the EU unemployment rates from 2007 to 2011:

Table 4.26 Unemployment rates by regions and countries with OE potential (in %)

Geographic area	2007	2008	2009	2010	2011
Average (OE countries)	6.3	6.9	10.0	11.1	11.8
Average (OE regions)	5.9	5.8	7.6	8.8	8.5
EU 27	**7.2**	**7**	**8.9**	**9.6**	**9.6**

Source: Eurostat

In Table 4.26~~Table 4.26~~ we can see that the average unemployment rate of relevant countries strongly increased over the last five years and is now higher than the unemployment rate of the EU as a whole. In contrast, the average unemployment rate of the selected coastal regions is lower than the average unemployment rate of the selected countries.

However, there are huge differences between regions with OE potential. The unemployment rate of these regions ranges from about two percent in “Overig Zeeland” (NL)[157] to more than 22 percent in “Huelva” (ES)[158]. Therefore a general conclusion on the positive effect for poor regions by investing in OE cannot be made. It will furthermore depend on the specificities of individual regions and the skill base present whether OE can be a way out of high unemployment or rather if it creates the challenge of attracting skilled people from somewhere else.

Furthermore, in the pre-operational stage of power plants the employment effects of OE do not have to be in the same location as the power plants themselves and are even expected to be to a certain amount in more industrial areas were specialised companies are located to manufacture components such as turbines and spare parts. There higher investments in OE can boost economic development and job creation.

High uptake scenarios 2 and especially 3 are expected to lead to additional employment compared to the more conservative scenario 1 and as such can, for coastal regions with high unemployment, provide the necessary demand for jobs, whereas for regions with low unemployment rates probably a higher labour mobility will be required under these scenarios.

Another aspect of the potential of OE is that to a large extent the most promising areas are concentrated at the more remote ends of Europe where low population densities are located far away from larger cities, which causes relatively high costs of providing consumables such as fossil energy. The expansion of locally generated (sustainable) power thus contributes to a reduction of the dependency of these regions, avoiding the need of relatively high cost imported energy. The importance of this will vary by region and will also depend on the energy mix present.

4.4.2 Impacts on education

When measuring the impact of OE on the educational system and the required skillsets potential employees need to possess, we have to distinguish between skills which are transferable and those which are specific to OE.

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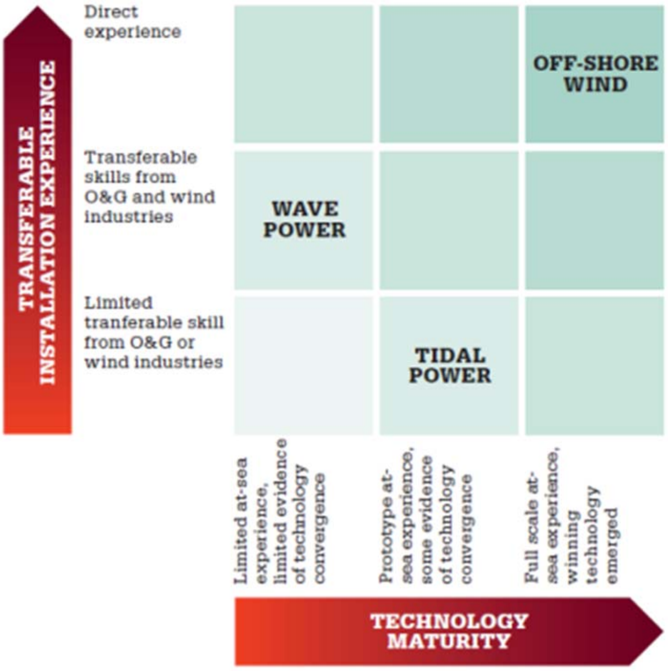
[157] Eurostat figure from 2008

[158] Eurostat figure from 2009

Figure 4.18 Transferable design and installation experience



Source: Institute of Mechanical Engineers

1. **Transferable skills:** The impact in this segment will be limited to the extent that no new educational programmes have to be launched for jobs with transferable skills. Important linkages and inter-dependencies already exist between ocean energies and offshore wind with regards to skills.[159]Nevertheless, an increase in the demand for skilled engineers will tighten the competition between various energy sectors. OE providers can profit from efforts already made by the offshore wind sector to increase the number of skilled engineers. Therefore, integrated planning is required in order to address potential tensions between ocean energies and offshore wind. Further efforts to increase the number of skilled engineers in the segment of water power and offshore engineering will be needed to address this potential bottleneck for growth of the sector as shortage of skills is an issue in many maritime sectors in Europe[160]. This refers both to white-collar professions (e.g. naval architects), but also to skilled blue-collar jobs. It is strongly linked to the perceived attractiveness of maritime jobs: there is a problem of image, a problem of working conditions (especially in those professions where employers are faced with cost pressures), but also problems related to health and safety especially when working at sea itself. Challenges exist not only in recruitment but also in retention. This eventually feeds back in the number of people who choose a technical education, which prepares them for such professions. A better image of the sector as a whole and an increased awareness of possible career paths are needed.[161] For the non-coastal part of the value chain adaptation to ocean energies might therefore be easier, as water turbine providers for hydro-electric power plants should be able to increase their business by also providing turbines for tidal or wave power plants.

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[159] Ecorys (2011): Blue Growth – Scenarios and Drivers for Sustainable Growth from the Oceans, Seas and Coasts, Intermediate Hearing 9-10th November 2011

[160] See Ecorys (2012), Blue Growth final report

[161] Ecorys (2011): Blue Growth – Scenarios and Drivers for Sustainable Growth from the Oceans, Seas and Coasts, Intermediate Hearing 9-10th November 2011

2. **Non-transferable skills:** Skills that are very specific to OE can be a bottleneck for growth in the segment and the lack of engineers obtaining these skills can cause high competition for workers under high demand growth caused by high uptake scenarios. As explained above, areas with high OE potential are very often regions with a low population density. If it is not possible to correctly train engineers in these areas or attract others to move there, growth of the sector is threatened. 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- chain for OE. 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 OE systems. Work in progress on OE systems includes: relevant terminology, design requirements, resource characterisation and its assessment, and the evaluation of performance of OE converters in the open sea.[162].

Comparing our scenarios, we can see that under scenarios 2 and 3 more skilled workers will be needed in coastal areas, which might lead to a tightening competition with e.g. the offshore wind industry. Nevertheless, it provides a chance for more peripheral regions to gain attractiveness. Producers of for instance water turbines can profit more under scenarios 2 and 3 as they should be able to apply their competences also on OE power plant spare parts and therefore increase their business activities.

4.4.3 Public acceptance

Public acceptance is identified in literature[163] as an important non-technical factor for the success of OE plans, for three main reasons:

- if acceptance is low, it may result in the development of genuine resistance, resulting in delays or even abortion of plans and slowing down OE development in general;
- if acceptance is high, it may offer opportunities for attracting public funding.

Increasing acceptance may be obtained by addressing three elements, as identified in Waveplam (2009): awareness (knowing what OE is and what it can do), worries on the electricity bill (will the new source be more expensive than the old one), and generic mistrust against new technologies (will it work, will it not interfere with existing activities). Awareness of OE is relatively low and public awareness campaigns may provide similar benefits as was enjoyed by the wind industry in its early days[164].

In order to resolve the issues related to public acceptance, it is essential that stakeholders are consulted and licensing procedures are transparent. If multiple parties are involved in the decision making, the social and environmental impacts can be properly addressed and the conflicts reduced. People who tend to accept the process also tend to accept its outcome[165.]

In particular potential adverse impacts have the potential to generate significant opposition from marine industries, conservation bodies and the general public, leading to the refusal and

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[162] Ecorys et al. (2012): Blue Growth Scenarios and Drivers for Sustainable Growth from the Oceans, Seas and Coasts – Maritime Sub0Function Profile Report 3.3 “Ocean Renewable Energy Sources”, p.28

[163] See for example European Ocean Energy Association (2009), IEA-RETD, 2011. Accelerating the deployment of offshore renewable energy technologies; Renewable UK, 2010; Soerensen H.C., Lars Kjeld Hansen & Rune Hansen (EMU) & Karin Hammarlund (Hammarlund Consulting), 2003; . Waveplam, 2009. Del. 2.2: Non-technological Barriers to Wave Energy Implementation. Final version, March 2009.

[164] Soerensen, H.C. and A. Weinstein: Ocean Energy: Position paper for IPCC

[165] G. Walker (1995): Renewable energy and the public; Land Use Policy 1995:12 (1), pp 49-59

cancellation of projects[166].This includes potential visual impacts of installations. Regarding this issue, wave and tidal devices, with their smaller profiles, will be less visible and therefore less likely to provoke an adverse reaction than wind energy turbines. However, shoreline wave energy devices may face similar reactions[167].

On the positive side 'The public perception of wave energy as a potential large-scale contributor to the electricity generation scheme can play an important role for political support of this sector'.[168] As a result of the 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.

Public participation

Public participation can be directly influenced by an appropriate public participation. Public participation can be characterised by the participation ladder, counting three levels: inform, consult, co-decide. All three levels may offer the most appropriate approach in the right circumstances.

Three participation strategies are discerned (Soerensen et al.) information strategy, planning participation and financial participation.

Information strategy is the most common approach; it is to quite passively inform people and carry out the minimum requirements regarding consultation. People are in such cases almost never offered a direct influence on the decision making. Often this strategy is based on the assumption that the local public opposition can be overcome by rational decisions made by experts, and that people will eventually get used to change. However, infrastructural development is no longer automatically looked upon as a common good as we move deeper in to the post-industrial society.

Planning participation involves the local public directly, early in the planning phase, and incorporates the recommendations into the project at an early state. The purpose of this strategy is to give the local population a motivation to accept change by, for example, giving them a say in the planning of the project which will generate an interest and also eliminate misconceived threats The "risk" of this strategy is that the public debate generates so much awareness that it delays the whole planning procedure. A delay, which on the other hand is unavoidable when permits are appealed against and projects face the threat of never being realised. If a sense of control is created through an open and dynamic dialogue, the confidence of the public can be achieved. This is a very efficient way to navigate towards not only a successful outcome of a project but also future confidence in renewable energy developments.

Financial participation has developed in some offshore wind projects where the public has been involved as owners of (part of) the farms e.g. when buying shares, and thereby sharing potential economic risks and profits from the project. This is the case for instance at the Middelgrunden and the planned German Butendiek offshore projects. One obvious advantage from public financial involvement is the fact that the specific project and the specific energy source in each shareholder will have a (mostly well-informed) advocator who can spread information to relatives, friends and colleagues, thereby increasing public interest and acceptability.
It is believed that the strong public participation, including the public financial participation in the Middelgrunden offshore wind project, was an important pre-condition for the success of the project, where the public resistance has been surprisingly small compared to the visual impact from 20 2 MW turbines near many recreational areas in Copenhagen.

Success factors of public participation processes are:

- Appropriateness of the form of participation:

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[166] IEA-RETD (2011)
[167] IEA-RETD (2011)
[168] Waveplam (2009)

- Meet the generic principles of good participation (speed, openness)
- Transparency and good communication
- Leadership of the public sector and vision are critical.
- Illustrating the benefits to local stakeholders

5 Overview of impacts under the 3 scenarios

An overview of the different scenarios and their economic, environmental and social effects is given in Table 5.1~~Table 5.1~~:

Table 5.1 Comparison of scenarios and their impacts

	Scenario 1 **Baseline**	**Scenario 2** **Intensified coordination**	**Scenario 3** **Strong stimulus**
Key characteristics			
Installed OE capacity (2035)	4.3 GW	6.4 GW The precise path of this scenario is highly uncertain and the impact therefore hard to measure. Figures should be treated with caution.	10.5 GW
Number of households supplied with OE generated electricity (2035)	3.0 million	4.4 million	7.2 million
Economic impacts			
Reduction investment costs (2035 compared with 2020)	5-10%	7-14%	10-20%
Gross Value Added OE	1.3-2.8 bn€	2.3-3.6 bn€	4.2-8.2 bn€
Competitive position EU27	Weakened competitive advantage. Potential risk of loosing first mover advantage	More conscious R&D programming with stronger industry involvement. EU27 able to move ahead with other OE countries	Enhanced link between R&D and commercialisation. Strengthened position of EU27 OE technology providers. Increased export potential.
Benefits to energy system of RES diversification	+	++	+++
	Reduced variability and increased reliability of aggregate electricity output levels. Reduced back-up and reserve capacity needs and electricity “spills”. Reduced dependence on imported fossil fuels and related price volatility.		
Environmental impacts			
Greenhouse gas reductions (million tns; cumulative in relation to baseline)	0 tons	8-11 Mln tons	23-33 Mln tons
Avoided costs of CO2 emissions	1.1 bn€	1.35 bn€	1.81 bn€
Environmental impacts	Impacts of single pilot installations local, at few hotspots. Local level impacts	Potential cumulative impacts of large-scale implementation of various technologies at several hotspots most likely concentrated. Regional	Cumulative impacts of large-scale implementation. of many different technologies, large areas. Likely long-term. Increasing

	Scenario 1 **Baseline**	**Scenario 2** **Intensified coordination**	**Scenario 3** **Strong stimulus**
		level Potential conflict with others users of marine areas and resources. Regional level impacts.	mitigation costs and probable conflicts with other users. European level impacts
Biological and physical impacts during installation and operation	-	--	---
	Environmental impacts still much unknown due to limited experience with OE. Main impacts are expected to be related to habitat and behaviour disturbance at specific sites. Careful siting and design should be able to mitigate impacts. Wave energy relatively environmental benign. Tidal streams potential impact on hydrology & salinity estuaria but impact can be decreased through design. Tidal barrages and osmotic/salinity gradient technologies potentially have a larger impact.		
Social impacts			
Employment (total number of jobs, 2035)	6,500- 14.500	11.000 – 23.000	20,500 – 41.000
• Manufacturing	• 2.000 – 3.000	• 4.500 – 6.500	• 10,000 – 14.500
• Operation OE	• 3,000-7.500	• 4,500 – 11.000	• 7,000-17,500
• Indirect (during operation)	• 1,500 – 4.000	• 2.000 – 5.500	• 3.500 – 9.000

What becomes clear from **Table 5.1**~~Table 5.1~~ is that scenario 3 is accelerating the market uptake of OE the strongest. In this scenario, the risk that OE would remain a niche market or might even not take off at all due to not reaching the required critical mass to really reduce costs and drive the market forward, is the lowest.

Scenario 3 is also expected to provide the largest competitive advantage for EU players in this energy and moving towards a low-carbon society. Furthermore it would contribute strongest to further diversifying the renewable energy mix, overcoming some of the unreliability of supply characteristics of other energy sources such as (offshore) wind. Scenarios 1 and 2 also move in the same direction, but the outcomes are more uncertain as slower uptake bears the risk of slower responses by stakeholders compared to non-EU players.

In general, the impacts of OE can be seen as positive. The highest uncertainty exists regarding the environmental impacts where still many unknowns exist due to the low level of OE deployment at this stage. The available information seems to indicate that with careful design and siting most of the negative impacts can be mitigated. Nevertheless active monitoring and research of environmental impacts is deemed to be necessary to limit potentially negative impacts.

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Annex A - Levelised costs of energy (LCoE)

The Levelised Cost of Energy (LCOE) is calculated using the following formula[169]:

$$\frac{I * \left(\alpha + O\&M_f\right)}{8760 * \eta} + \ O\&M_v$$

$$\frac{I * \left(\alpha + O\&M_f\right)}{8760 * \ \eta} + \ O\&M_v$$

With α being calculated as:

$$1 - (1 + r)^{-\ n}$$

$$1 - (1 + r)^{-\ n}$$

With:

I	specific investment costs(€/kW)
r	interest rate
η	load factor
n	economic lifetime
O&M$_f$	fixed operation and maintenance costs (as a percentage of the investment costs)
O%M$_v$	variable operation and maintance costs (€/kWh)

Table 0.1 Input variables for the LCOE calculation of wave energy

Wave	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
n	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
r	0,080	0,078	0,076	0,074	0,072	0,070	0,068	0,066	0,064	0,062	0,060	0,059	0,058	0,057	0,056	0,055
η	0.25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25
O&M$_f$ (%)	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
O&M$_v$ (€/kWh)	0,0005	0,0005	0,0005	0,0005	0,0005	0,0005	0,0005	0,0005	0,0005	0,0005	0,0005	0,0005	0,0005	0,0005	0,0005	0,0005

Source: Joint Research Centre draft (2012) 'Short overview of marine energy technologies andt heir European potential'

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Annex B - Potential barriers for OE supply chain development

The table below lists the potential barriers and solutions for the deployment of a supply chain for OE (see Equimar study)

Type of action	Issue	Restriction	TImeliness	Precedents	Solution
	Manufacturing	Timeliness of supply, knowledge base for fabrication of unique components, conflicts with other industries	Restrictions more likely for early arrays, approaching mass production.	Long lead times and gearing up for new supply typical for many fledgling industries	Device developers to place orders at earliest opportunity. Use of existing processes and components where practical. A successful industry at all stages will gain supplier confidence.
	Transport (to shoreline)	Transit path from manufacturing point to shoreline egress. Transport of heavy or large parts of devices. Quantity of material required to transport.	More applicable for large arrays where volumes are high.	Wind industry where longest blades cannot be easily transported by road network. Manufacturing relocated to waterside and boat transport.	As technology progresses relocation of key manufacturing closer to deployment site to minimise onshore transport.
	Infrastructure at ports and harbours	Space, conflict with other activities. Heavy lifting and transport equipment, dockside assembly, dry dock facilities.	More applicable for large arrays where volumes are high	European harbours (e.g. Hull, UK) expanding to accommodate large offshore wind manufacturing and deployment.	specific ports close to areas of high marine energy modified or created to prioritize marine energy device deployment. Modification could include expansion or reallocation of space for marine energy industry.
	Onshore electrical grid	Capacity and distance from array location. Grid connection infrastructure,	Applicable to all stages of arrays. Early arrays are small and	Grid 'queues' have existed in most European at some time.	Strategic planning to be conducted involving electrical grid and marine energy stakeholders

		permission and cost for connection and time taken. Many aspects specific to individual countries.	might not be given priority. Later arrays might suffer from onshore grid strength.		to identify bottlenecks and restrictions for deployment. Governments can often fast track or streamline certain regulatory issues to expedite array deployment.
Marine based actions	Device Installation vessels	Quantity, availability and functionality of existing vessels for deployment of marine energy converters. Existing industries (especially oil and gas) can afford to pay premium rates for vessel contracts. Vessels are often designed with these industries requirements not marine energy.	Already an issue for devices at sea trial stage. Has the potential to delay deployment by several months which could be extended due to avoidance of winter deployment actions.	Tidal energy converter installation delayed and forced to use installation vessel with excess performance capacity	Device developers to evolve devices to require less-specialist vessels or to develop their own vessels/components to expedite deployment. Aim to use the smallest, most numerous vessels in the largest sea states. Vessel construction takes time so supply side must be confident that marine energy industry will provide good investment in they expand their range of services. A high-level review strategy of existing deployments and predicted with possible conflicts/restrictions should be conducted with key stakeholders.
	Array site metocean quantification	Time to gain consent for measurements, conflicts with other maritime stakeholders	More applicable for large arrays where spatial and temporal resolution of measurement data is high	No specific precedents. Consenting for offshore measurements in UK can take several weeks and is uncertain as many separate permissions are required.	Dependent upon country but not perceived to be a key bottleneck. Streamlining of application processes could be viewed as a positive step.
	Offshore	Cable laying in	Technical	Connection and	Strategic planning of

	electrical installation	high currents (tidal), heavy sea states. Interconnection of devices within an array	issues likely to increase with scale of array deployment	cable delays with two recent wave energy projects	projects, scheduling of cable laying actions to avoid conflict with other array actions and between related offshore industries.
	Operation and maintenance actions	Vessel availability, suitability, metocean weather windows	Maintenance frequency per device likely to be higher for demonstrator arrays. Potentially higher total maintenance load per array for large installations	No specific but prototype open-sea tidal device could not be accessed over winter months	Improved vessel designs to increase accessibility. Development of specialist vessels to best service arrays. Device design to minimise O&M actions and to more easily facilitate any potential O&M.

Source: Ecorys, based on EQUIMAR, deliverable 5.7

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