Current Developments and Future Prospects of Offshore Wind and Ocean Energy

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Abstract

The year 2008 saw the emergence of the first generation of commercial ocean energy devices, with the first units being installed in the UK and Portugal. This means that there are currently four ways of obtaining energy from sea areas, namely from wind, tides, waves and thermal differences between deep and shallow sea water. This paper focuses on current developments in offshore wind and ocean energy, highlighting the efforts currently underway in a variety of countries, principally some of the projects typically less talked about such as those in the Asian-Pacific countries. Finally, the growth potential of these industries will be assessed, using as a basis the historical trends in the offshore wind industry and extrapolating it to compute future growth potentials. Using this as a basis, the percentage of the world's electricity could be produced from ocean based devices is estimated to be around 7% by 2050, and this would employ a significant amount of people by this time, possibly around 1 million , mostly in the maintenance of existing installations. The paper will also evaluate the likely cost of production per kW of ocean energy technologies using a variety of learning factors.

Keywords: ocean energy, offshore wind, growth scenarios, cost, current developments

1. Introduction

Much of the debate on and investment in technological solutions to climate change has so far centred on a range of technologies such as carbon capture and storage (CCS) or geo-sequestration, ocean fertilization, the so called new generation of nuclear technologies, and biofuels. Most of these technologies, however, have been associated with some type of environmental problems. It is still not completely clear if CCS is viable, or whether it can represent a long-term solution. The environmental impacts of large-scale biofuels have also been called into question by a number of authors (see Gasparatos et al. [1] for a critical assessment of the tradeoffs). With regards to nuclear power, independent of its potential and any benefits that it may have, the long-term contamination, suffering and world-wide emotional response the Fukushima Nuclear reactor has caused makes it unlikely that democratic countries will have an easy time building new installations of this type.

However, it is imperative that new ways of producing energy are found to satisfy the world's growing appetite for energy. The year 2008 saw the introduction of the first generation of commercial ocean energy devices, with the first units being installed in the UK and Portugal (SeaGen and the Pelamis respectively). With them there are currently three types of energy mechanisms in sea areas from which energy can be generated in a commercial way (i.e. wind, tides and waves). These sets of technologies are not only clean (in terms that they produce no greenhouse gas emissions) but they also have an almost negligible visual impact, especially compared to other renewable sources such as hydropower or onshore wind (provided of course, that offshore turbines are located at a sufficiently long distance from the coastline, according to Landenburg [2]).

The Ocean Energy sector has the potential to make an important contribution to the supply of energy to countries and communities located close to the sea, though this considerable source of renewable energy that have so far not been utilised on a significant scale [3]. The 1992 United Nations Framework Convention on Climate Change (UNFCCC) recognises the important role the development, application and diffusion of new technologies will play in reducing greenhouse gas emissions. More recently the United Nations Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report has highlighted the important role that technology will play in addressing climate change. In fact, large penetrations of various combinations of renewable power could theoretically power entire countries, such as Portugal [4] or even Japan [5].

The objective of the current work is to assess what could be expected from ocean-based renewable energy technologies in the middle to long term. Generally offshore wind and ocean energy systems are not included in the same analysis, and in the present papers the authors argue that as they share the same environment and a number of common characteristics, energy scenario projections should include both sectors together. To develop these scenarios the authors have carried out a review of the history and potential of ocean energy installations, and have built a database of all cutting-edge research and applications of ocean and offshore wind energy. A general outline of the state of this sector will be presented in parts 2 and 3 of this paper. In part 4, this information was then fed into a model based on the development of the offshore wind industry to attempt to predict the future development of ocean energy for a variety of scenarios. A prediction was then made of around which date ocean energy is likely to become competitive with other forms of electricity production and the approximate size of the sector in terms of jobs. Part 5 will then comparing the results obtained to those of other studies, and this will then be followed by a discussion on the obstacles facing such a large development in ocean-based renewable energy.

2. Description and Potential of Ocean Energy

Ocean Energy defines a wide range of engineering technologies that are able to obtain energy from the ocean using a variety of conversion mechanisms. It is an emerging industry, with the first commercial units coming online in 2008 and 2009. It is important to remember that there are technical limits to its application, since although it has been reported that the theoretical global potential for the various types of ocean energy is between 20,000 and 92,000 TWh/year, compared to the world consumption of electricity of around 16,000 TWh/year, it is unlikely that this technology by itself will be able to solve the energy needs of the planet [6]. For instance, although there is estimated to be around 3000 GW worldwide of tidal energy, less than 3% is located in areas suitable for power generation (World Offshore Renewable Energy Report [7]). Wave Energy on the other hand has an estimated potential of around 1000-10,000 GW, which is in the same order of magnitude as world electrical energy consumption. However, one advantage of tidal currents over waves (or wind) is its predictability, as tides can be accurately predicted weeks or even years in advance.

Some researchers such as Scruggs and Jacob [8] and Cornett [9]recently noted how the potential for ocean energy is promising, and across Europe, the technically achievable resource has been estimated to be at least 280 TWh per year [8]. In 2003, the U.S. Electric Power Research Institute (EPRI) estimated the viable resource in the United States at 255 TWh per year (6% of demand), comparable to the energy currently generated in the United States by conventional hydropower [8]. Ocean energy can be converted into electricity in four main ways, namely the energy present in the waves, currents, thermal or osmotic energy [6].

3. Current Developments in Ocean Energy

3.1.Tidal Barrages

Tidal barrages were built as early as 1966, when the plant at La Rance (France) came into operation, and is still in operation today. China also started to build a number of barrages around this time, as part of policies from 1958 that emphasised energy independence as a key route to poverty alleviation [10]. One of the 4 stations built, at Shashan, stopped operating in 1984 when the local area was connected to the national grid, due to the high cost of operating the plant [11]. Elsewhere, Canada also built a barrage at Annapolis, which began service in 1984.

More recently, there has been some renewed interest in these schemes, and in late 2004 the Chinese Government planned once more to build a tidal power station near the mouth of the Yalu River [10]. Also, Russia is in the process of constructing its first plant. In the UK, tidal barrages, such as the one proposed for the River Severn, are currently being re-appraised. The Severn Barrage is currently around half way through a Feasibility Study Consultation process, although Owen [12] notes how opposition from the Environment Agency and other groups appear to make it unlikely that the project will ever reach construction. The environmental impacts of these structures have generally hindered their wide-scale application, and they have been known to have some impacts on marine biodiversity [13]. At present the only country which is seriously undertaking efforts to construct tidal barrages is South Korea, which is scheduled to complete a 254MW tidal barrage at Sihwa-ho Lake. Another plant almost three times the size is under planning for Ganghwa. The South Korean government claims that the project will make a profit, as it puts the cost of the project at 355bn won (USD 382 million) [11]. In other countries it is not clear that these plants are economically viable, due to the massive infrastructure investments they require and the fact that often the environmental damage outweighs the benefits of the structure. These traditional, or "old" types of ocean energy are thus not without their problems, though modern ocean energy technology is far more environmentally benign [13].

3.2.Modern Ocean Energy Developments

The modern ocean energy industry is currently moving from the prototype stage to installation of the first showcase commercial farms. The first of these have just recently come into operation, with the Pelamis project (in Portugal) and SeaGen (in Northern Ireland) having completed installation at the end of the summer of 2008 [14]. Many devices that use hydrokinetic conversion systems that take advantage of the flow in tidal or river streams are currently under development (over 60 different schemes are reported by Khan et al., [15]), and a number of devices using other technologies have already completed prototype testing, such as the WaveDragon. Also, there are currently a number of other projects and prototypes undergoing full scale testing (for example at the European Marine Energy Centre (EMEC), which has 4 grid connected births for wave and 5 for tidal devices, all of which are either in use or booked [16] or awaiting for support installations to be constructed (such as the WaveHub).

However although a great deal of research and investment has been carried out in Europe, there have also been a number of significant developments in other continents. For example in Australia there are at least three companies involved in the research, development and pre-commercial testing of wave energy devices. These include the Western Australian based company Carnegie Corporation, developers of the CETO [17] wave power converter which has a commercial scale demonstration at Freemantle. Construction of a commercial scale plant is due to commence by 2010 with completion and connection to the grid due by 2013 [17]. Also in Australia, Oceanlinx re-deployed in February 2009 its pilot plant device at Port Kembla on the New South Wales coast south of Sydney [18]. This oscillating power column technology had been under development since it was first deployed in Port Kembla in 2005, and though one of the prototype units sank in 2010 research into the unit continues [18].

Another type of ocean energy technology that is reaching maturity is that referred to as Ocean Thermal Energy Conversion (OTEC), which has significant potential for countries located in tropical regions. These plants must be located in an environment where the warm surface seawater must differ about 20°C from the cold deep water that is no more than about 1,000 meters below the surface, and the shore must be located within 25km of the ocean region where the temperature difference occurs. This is normally found in areas between latitudes 20° North and South of the Equator, as shown in Fig. 1 [19]. India, for example has considerable potential for the development of OTEC energy, and some trial plants have already built in this country, such as a 1MW OTEC and a 100t/d of fresh water desalination plant [19]. The potential resource for another developing country, Indonesia, has been estimated to be able to produce enough electricity for the whole of the country [19].

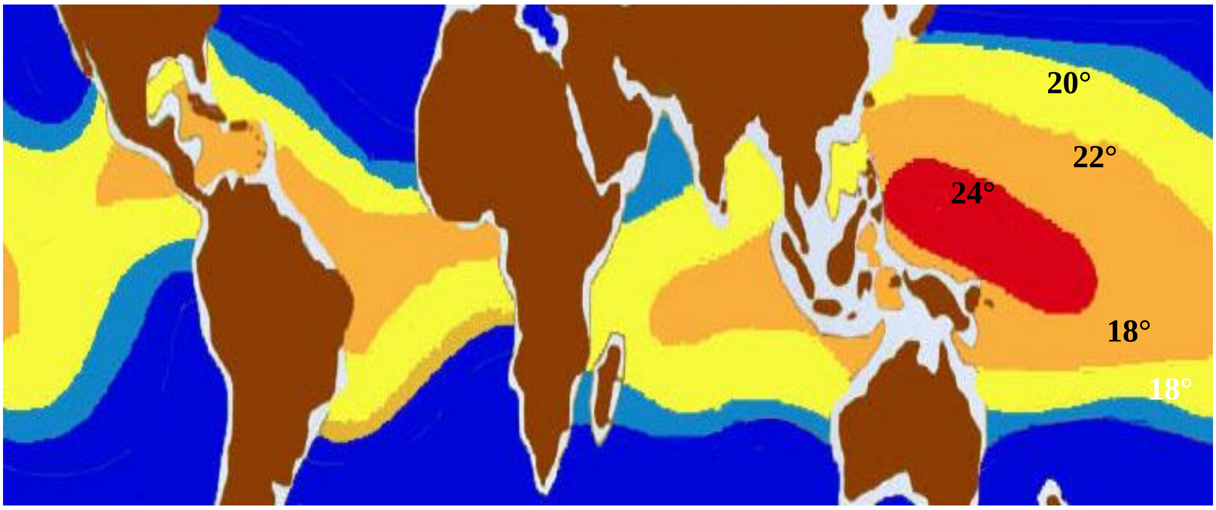

Fig. 1. OTEC Energy Potential (after Ikegami et al, [19])

3.3. Offshore Wind Energy

Although this type of energy is not traditionally considered ocean energy, the authors would like to point out how many of the technologies and constraints present in this sector are the same as those of ocean energy. Thus, this type of energy can be considered to be similar to ocean energy, in that it is located in the same type of environment, and potentially many synergies (such as joint utilization of grid connections) could be found between these two types of energy. European countries have traditionally dominated offshore wind and at the end of 2009 most of the installed capacity was located in European Seas (see Fig. 1). Fig. 2 shows how the U.K. currently has more installed capacity than any other country [20], and the rate of installation is expected to expand considerably in the following years, going from an annual installation rate of 194MW in 2008 to over 400MW in 2009, and in the order of 800 to 1,000 MW per annum for the period 2010 to 2014 [20].

Eventually it is believed that the UK's seas could provide enough extra wind energy to power the equivalent of 19 million homes by having an extra 25GW of electricity generation capacity in addition to the 8GW of wind power already built or planned offshore, which would be enough to power every household in the UK [21]. According to some estimates this could provide more than a quarter of the UK's electricity needs and generate up to 70,000 new jobs [21]. Together with ocean energy it could even fill the gap in employment that will be left behind once the North Sea Oil dries up [22].

However, the development of offshore wind in not limited to Europe, and increasingly the Asia-Pacific area is emerging as a significant market [23]. China, motivated mainly by its huge thirst for energy in general, is quickly becoming one of the world leaders in the adoption of offshore wind energy. Offshore energy, in the case of China, has the advantage of being located close to the population centres, in contrast with onshore energy, which is often located far from the main cities. The offshore wind power resource has been estimated at 200GW, almost 10 times the total (onshore) installed wind capacity at present, indicating the huge capacity that this sector would have for generating jobs [24].

The first off-shore wind farm in the Asia-Pacific is currently located in Shanghai, composed of 34 wind-driven generators with a total installed capacity of 102 MW. A further four large scale wind farms are also planned for the Fengxian, Nannhui and Hengsha districts of Shanghai with a planned 1 GW of installed capacity planned for Shanghai by 2020 [25]. Plans for 1000 MW of off-shore wind farms in Zheijiang Province and Jiangsu Province are also underway [26]. Likewise in Hong Kong CLP Power Hong Kong Limited and Wind Prospect are in the early stages of development of a proposed 200 MW wind farm in the south eastern waters off Hong Kong that will provide approximately 1 % of Hong Kong's energy needs [27] and take two years to build. A list of some major offshore wind projects in China can be found in Table 1.

Japan's only off-shore wind farm was built in the Setana Port area on Japan's Northern Island, Hokkaido in 2003. This wind farm consists of two 600 KW wind turbines [28]. Close-by in South Korea there are plans to develop 500 MW of land and off-shore wind farms in Baekun Mountain near Wonju City [29].

In North America while both the USA and Canada have experienced rapid growth in the wind power sector, that growth has largely been confined to developments on land. Most of the attention on off-shore wind energy and ocean energy has been on the east coast of the United States and Canada. The only significant plan for construction of an off-shore wind farm on the Pacific coast of North America is the 110 turbine NaiKun off-shore wind farm, off the northwest coast of British Columbia in Canada [30]. The project received an Environmental Approval in late 2009 and is currently expecting a federal environmental decision, with construction expected to begin in 2010/2011.

Particularly interesting recent developments in offshore wind power include research into floating wind turbines. In this respect the first full scale floating turbine is currently under testing off the coast of Norway [31]. However, research into these units is also popular in other countries with a deep seabed, such as Japan, which tested a $1/10^{th}$ scale prototype that might be followed eventually by a full scale one.

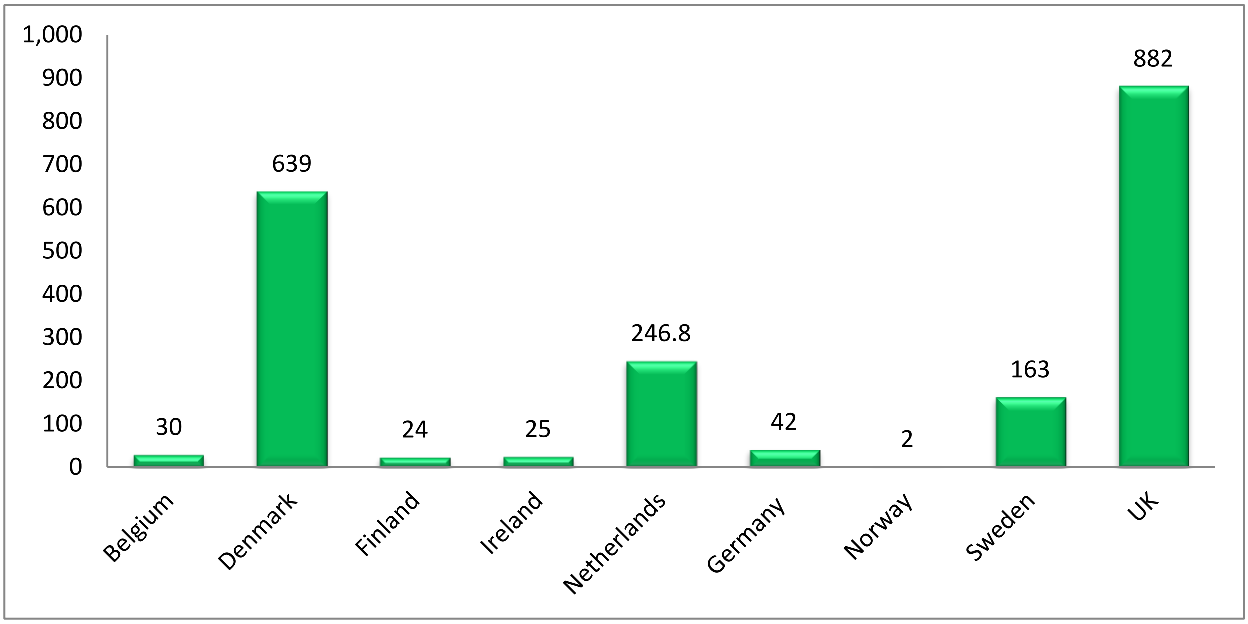

Fig. 2. Installed offshore wind in 2009 in Europe (in MW) [23]

Table 1. List of major projects in People`s Republic of China and Hong Kong (China)

Place	Capacity (MW)	Date	Company	Place	References
Weihai, Shandong	First Period:10, total plan: 1000	In plan	ZhongHaiYou		[32]
Hong Kong	200	In construction	CLP, BMT	in South-eastern Waters of the HKSAR.	[27]
Shanghai, East sea, Bridge(First offshore wind in Asia)	Total: 102 (34 x 3MW)	2009	Datang Power, Guandong Nuclear Power,	East Sea Bridge	Authors site visit
Jiangsu, Rudong Project	3500 (in plan)	Fist set starts from 2009	Guodian Power		[26] [33]
Ningde Fujian	2000(in Plan)	Not clear	Fujian Mindong Power,		[34]

4. Future Potential of Ocean and Offshore Energy

At present, ocean energy is at the initial stage of commercialisation of the First Generation of Technologies (also from time to time referred to as the pre-commercial stage). The first commercial devices are now starting to be connected to the grid [35]. Like other new power generation technologies, it will eventually be followed in 2-3 years by a “Second Generation Technology”, which would further improve the current designs using the benefit of experience. Some evidence that these Second Generation Technologies are already under development has recently started to emerge, such as the beginning of the development of the Pelamis P-2 device.

4.1. Assumptions

Any methodology that attempts to forecast trends in future development essentially builds on a number of assumptions outside which the model is not really valid. These assumptions should be clearly stated from the onset, and for the present paper it is assumed that:

- The state of technological development (and the level of technological challenges) faced by early offshore wind are similar to those faced by wave/tide today. On the one hand it could be considered that drawing such a comparison is difficult, as offshore wind relied on proven onshore wind technology, where there was never any reason to suspect that the fundamental technology would fail. In the case of wave and tide it is not clear which technologies will ultimately be viable. However, many technologies have now reached the full sized prototype stage (pre-commercial) and are connected to the grid, and the sector has recently started to be referred as an "industry" for the first time [16]. Hence it appears to be possible to draw a comparison with the early offshore wind turbines, where although the principle of energy conversion was well understood, the challenges of working in the sea made it difficult to foresee the future of the industry.
- Ocean Energy and Offshore Wind will have similar development constraints. Once a renewable energy technology is developed the major constraint on expansion then becomes the availability of suitable locations. In the case of wind the availability of relatively shallow sea areas close to grid connections, which are easily identified. In the case of wave and tide (particularly tide) the actual extent of sea area with practicably exploitable resource is not well understood, and a clear distinction needs to be made between the theoretical, technical and practical resources. This technical resource in the UK is likely to exceed 50 TWh/annum for wave power and around 20 TWh/annum for tidal power [16]. Clearly a lot more research needs to be done in this area [16] but to date there is little argument that locations do exist were Ocean Energy will be able to be exploited.
- the financial incentives and policy landscapes will be similar. There is little doubt that the key driver for wind in the past and wave tide in the future is the existence of a policy landscape (particularly financial incentives) that encourage development. The present paper argues that given the current high level of interest in renewables the policy landscape for Ocean Energy will be at least as good as for the offshore wind sector during the past 15 years. It is possible that Ocean Energy could benefit from a more positive environment, but this would be more difficult to analyse and would not lead to conservative answers.

4.2.Methodology

The starting point of the current research was to build a database of all ocean energy and offshore wind energy projects. The methodology used to estimate how the ocean energy sector could be expected to develop follows the work of Lemming et al (hereinafter the 'Wind Reference Model' [35]. In that model, offshore wind is assumed to progress under growth rates similar to the current existing plans for the offshore wind sector. As the backlog of current projects and plans for the offshore wind industry only extends a few years into the future, Lemming et al [35] make assumptions regarding the rest of the growth rates up to 2050. The basic assumption that we make in the current paper is that the development of ocean energy can be expected to be similar to the historical developments in the wind sector, as the development patterns should be similar based on similarities in installation and scaling up of the technologies.

4.3. Growth Scenarios

Offshore wind started in the early 1990's, when small offshore installations were built off the Danish, Dutch and Swedish coast. The sector broke the 100MW barrier around 2002, and by 2008 there were almost 1,500MW installed. Fig. 3 shows the historical and the expected growth curve in offshore wind for the next decade, according to the Wind Reference Model ([35]. To build this scenario, it is assumed that offshore wind is expected to grow by approximately 34% annually until 2015 [35]. Growth rates are then expected to decrease to 27% in the period 2016-2020, and then 19.5% in 2021-2030 and 5.5% in 2031-2050. For the case of global electricity consumption, the data available in the Wind Reference Model is also used, which is based on a 2.8% growth in global demand until 2030, followed by an assumed slower growth of 1.5% in the period 2030-2050 [35].

Fig. 3 also shows the projected growth in British offshore wind power [20]. In comparison, scenarios by the European Wind Energy Association [36] put the offshore installed capacity in the UK in 2020 at between 13 and 20GW, though it is clear that significant political will would be required for this to be achieved. In terms of capacity, according to an assessment by the UK government strategic environmental assessment (SEA) an extra 25GW of electricity generation capacity could be accommodated in UK waters [37].

Making an assessment of the outcome of the ocean energy industry from the limited number of projects that are at advanced stages is difficult, as is predicting the growth of the ocean energy industry. So far it can be said that, as of April 2009, there were roughly around 265MW of conventional tidal barrages and 5MW of modern devices (roughly split half and half between wave and tidal devices).

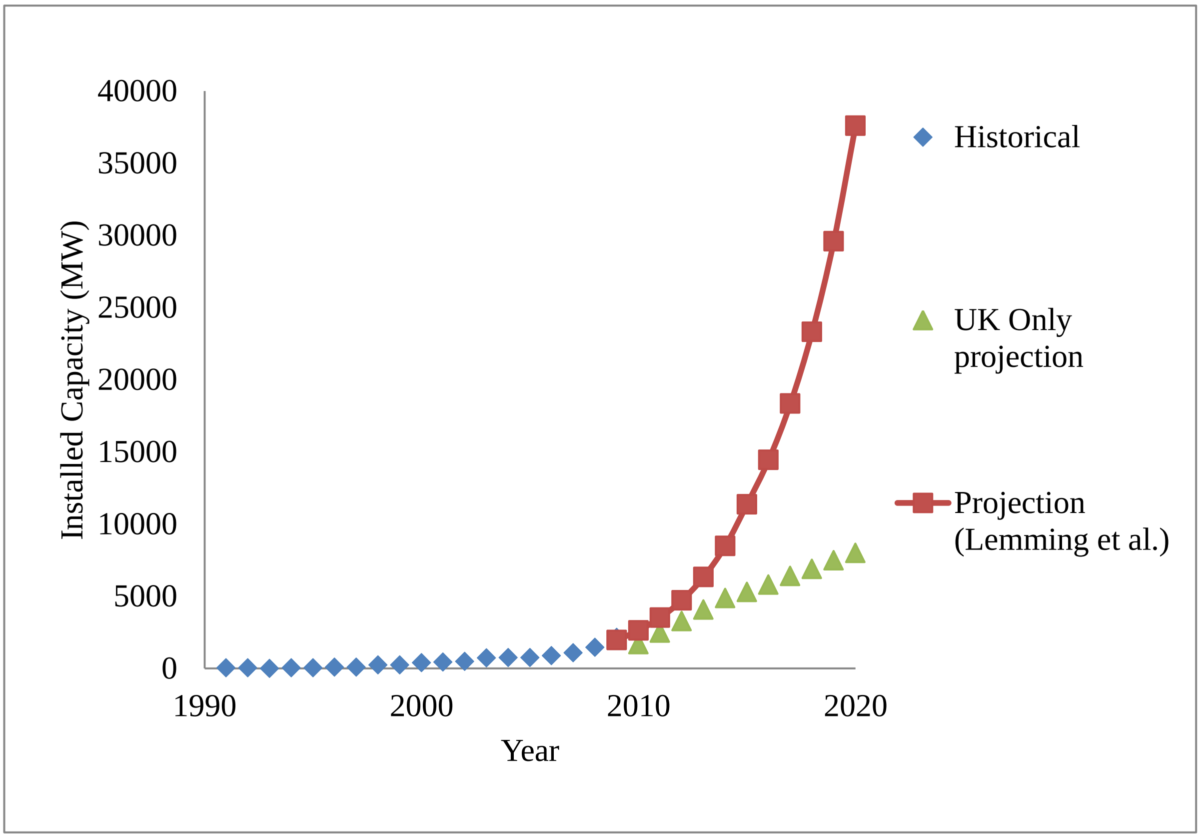

Fig. 3 Historical and projected growth of offshore wind

The fact that about 5MW of these devices have been installed at present could make the year 2008 for ocean energy equivalent to the year 1991 for offshore wind, when Denmark completed the installation of a 5MW of offshore wind farm at Vindeby. So, development of ocean energy from 2008 is assumed to develop at the same speed as offshore wind energy after 1991. From the year 1994 to 2008, offshore wind installation progressed at an annualized pace of around 55%, though growth was slower in the first 6 years and increased in pace between 2000 and 2008.

To estimate the growth of the ocean energy sector two different scenarios were chosen,

- A Conservative Ocean Energy Scenario, where the growth of ocean energy between 2009 and 2025 is exactly the same as the growth of offshore wind energy in the period 1991-2008 (55.5%), and then from 2025 to 2050 the assumptions of the Wind Reference Model [35] are used
- An Aggressive Ocean Energy Scenario, which has an initial rapid development in ocean energy followed by growth rates similar to those shown in Wind Reference Model [35] for offshore wind.

The various growth rates used in each of these scenarios are summarised in Table 2. To estimate future electricity production an assumption also needs to be made about the level of the average capacity factor of each renewable. The capacity factor is defined as the ratio of the actual output over the maximum theoretical output during a certain period of time. The Wind Reference Model [35] assumes a capacity factor for offshore wind of 37.5% for the whole period until 2050, as they expect the higher production of new turbines to moderate the lower availability of good wind sites. However, for the case of tidal barrages the load factor is much lower, typically around 23% [38]. It is claimed, however, that modern ocean energy 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 [39]. These figures however should be treated with caution, as there is yet no definitive evidence for them. Hence the authors have used a capacity factor of 27% for ocean energy in the scenarios proposed.

4.4.Scenario Projections of Ocean Energy Growth

Using the parameters shown in the previous section, Fig. 4 can be produced. This Fig. shows the results of the Wind Reference Model [35] for offshore wind electricity, which indicate how by 2050 around 5.5% of the world's electricity could come from offshore wind. For the two ocean energy scenarios produce completely different outcomes, which would mean that ocean energy could eventually produce 1.7% (the "Conservative Ocean Energy Scenario") and 9.84% (the "Aggressive Ocean Energy Scenario) of the world's total electricity production. By comparing these two scenarios to the Wind Reference Model it seems that the Aggressive Ocean Energy Scenario could be too optimistic. However, it should be noted that the UK alone is planning a large expansion in Ocean Energy, and large areas around Pentland Firth and the Orkneys have recently been leased to companies in the sector (these areas could have a capacity to generate 1.2GW of energy, to be installed by 2020 [40]). It is possible that in the next 10 years other projects will be proposed and executed and that even more renewables could be installed, though it is difficult to foresee that at present. Nevertheless, applying the factors in Table 2 for the case of the UK after 2020 (and assuming that indeed 1.2GW of energy will be installed by then) provides us with a "High British uptake only" Scenario, that shows how the "Aggressive Energy Scenario" is not as unbelievable as it would first seem.

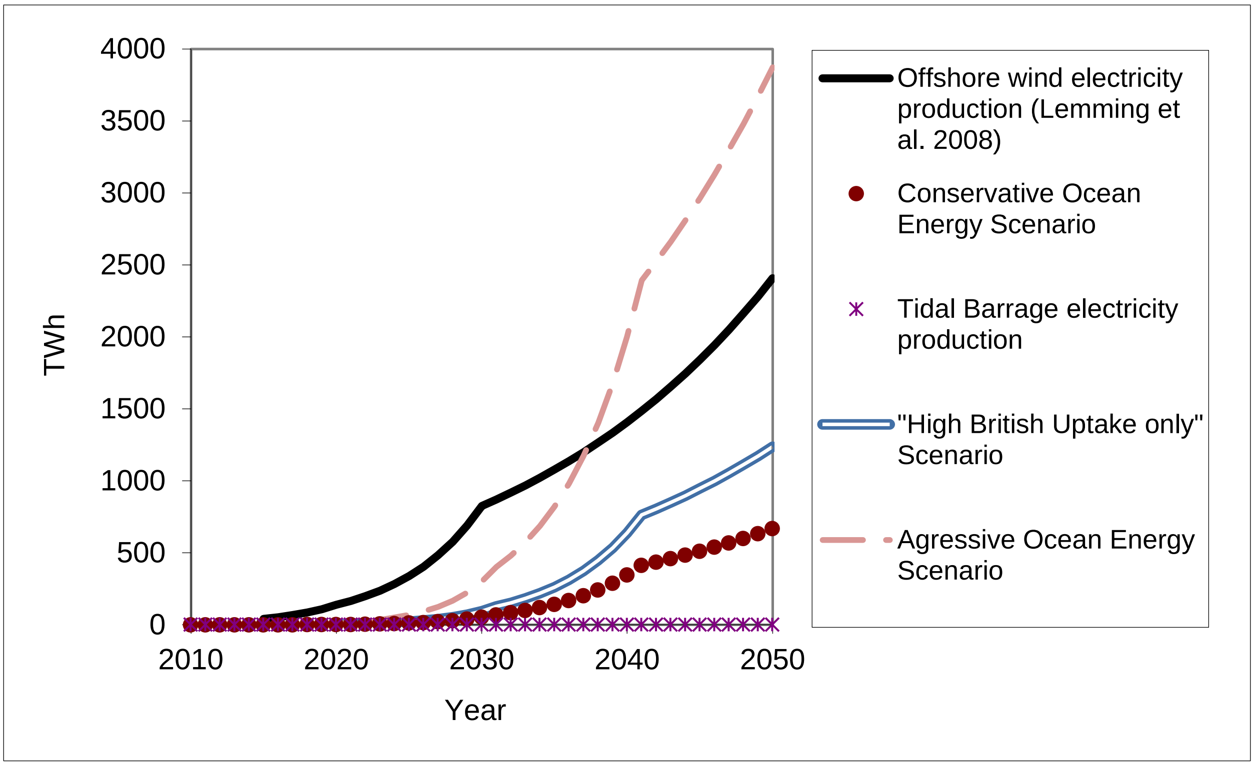

Fig. 4. Estimation of future ocean energy (OE) and offshore wind electricity production

Table 2. Modern Ocean Energy Growth Scenarios

Year	Expected World electricity consumption TWh	Yearly growth in Modern ocean energy %		
		Period	Scenario A	Scenario B
2015	21,300	2009-2024	55.5%	410MW by 2015, then 55.5%
2020	23,800	2025-2031	34.0%	34.0%
2030	29,750	2032-2041	19.5%	19.5%
2050	40,100	2042-2050	5.5%	5.5%

4.5. Projected Cost of Ocean Energy

The cost of energy from initial tidal stream farms has been estimated in the range of US$0.15-0.55 per kWh for tidal and wave energy farms and US$0.11-0.22 per kWh for tidal streams [41]. These are expected to decrease to US$0.10-0.25 per kWh by 2020. Estimated learning factors are believed to be 10-15% for offshore wave and 5-10% for tidal stream [41]. One of the most concrete examples of the perceived cost of first generation of modern ocean energy units can be found in Portugal, where the government has put in place a feed-in tariff, (a legislative price incentive which encourages the adoption of renewable energy) currently equivalent to approximately €0.23/kWh [42].

To identify long-term cost developments, learning curves have been derived for different technologies, which identity the correlation between cumulative production volumes of a given technology and a reduction in costs. For many technologies, the learning factor (or progress ratio) falls in the range of between 0.75 for less mature systems to 0.95 for well-established technologies [43]. A learning factor (L.F.) of 0.9 would signify that costs are expected to fall by 10% each time that the cumulative output for that technology doubles.

It is possible to compute the price decrease using as a basis the €0.23/kWh and applying a variety of L.F. Ocean energy can thus be expected to be competitive with oil sometime between 2017 (L.F.=0.75) and 2033 (L.F.=0.9). Alternatively, a third scenario where the L.F. decreases linearly between 0.75 for €0.23/kWh and 0.95 for €0.05/kWh, which would result in ocean energy becoming competitive by 2021 (See Fig. 5)

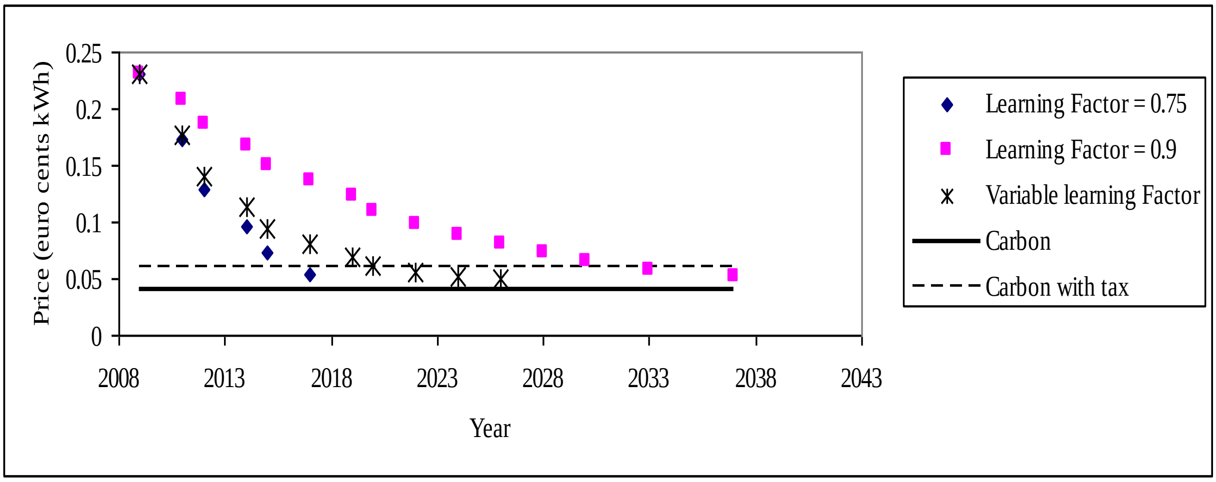

Fig. 5. Different cost scenarios for various learning factors Scenario A

4.6. Employment Generated by Ocean Based Energy Devices

Using the employment factors given in Rutovitz and Atherton [44], an estimate could be made of the number of people involved world-wide in the construction, maintenance and operation of ocean energy devices by the year 2050. These factors are summarised in Table 3. It should be noted that Rutovitz and Atherton [44] do not give decline rates for the years 2030, and hence in the present paper the authors have used lower decline rates of 1% per year after this date. When interpreting these graphs the fact that they are based on the scenarios detailed before should be clearly kept in mind. These scenarios provide sharp declines in the rate of installation of certain renewables at given years, and hence produce the massive “lay-offs” seen in Fig. 6. This might appear somewhat unrealistic, but the overall message is that while these technologies are able to provide a great number of jobs for a number of years, once they reach a critical point (in terms of all the best sites being fully exploited, technology development reaching a certain point where less workers are needed, etc) the number of people involved in their installation will sharply decrease. Historically this could be compared to the development of the nuclear industry in developed countries, where large numbers of people were employed in the construction of nuclear power stations, though a comparatively small number is involved nowadays due to no new stations being built (hence only employing maintenance and operation personnel). In a similar way, offshore renewable would one day reach "mature" or "saturated" state and the installation of new units would decrease substantially. However, this point will likely not be achieved for the next decades, and it this point it should just be considered as a distant possibility.

Table 3. Employment factors for ocean based energy devices

Energy type	Installation and Manufacturing (Person years/MW)	Operation and Maintenance (Jobs/MW)	Decline Rates in job factors 2010-2020	Decline Rates in job factors 2020-2030	Decline Rates in job factors 2020-2050
Offshore Wind	28.8	0.48	3.90%	1.50%	1.00%
Ocean	10	0.32	7.80%	7.80%	1.00%

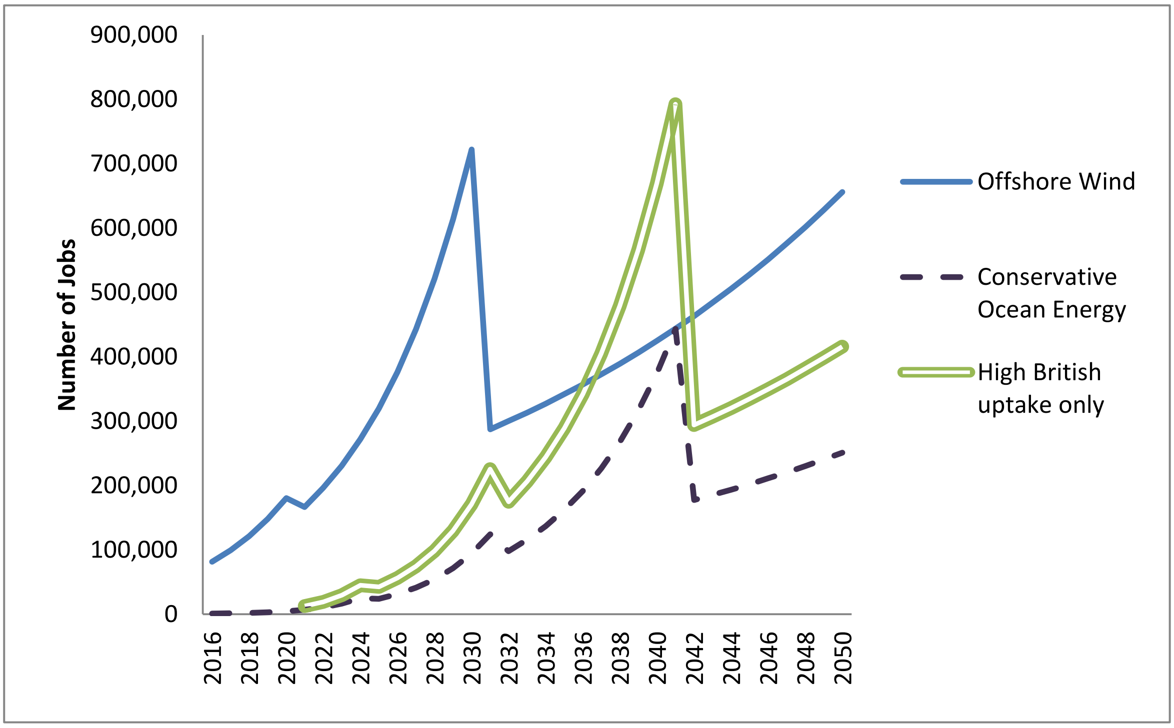

Fig. 6. Future scenario employment patterns of Offshore and Ocean Energy

5. Discussion

The results derived in the previous sections are based on the assumption that general electricity consumption will not decouple from GDP, and that electricity needs will continue to grow in the future. In the past “each 1% increase in global GDP has been accompanied by a 0.6% increase in primary energy production” [43]. Thus, in the simulation carried out by the Energy [r]evolution report [43] world GDP is assumed to grow on average by 3.6% over the period 2005-2030, but energy intensity is reduced by 1.25% on average per year, leading to a reduction in final energy demand per unit of GDP of about 56%. In their model three scenarios are assumed:

- The Reference scenario, as published by the International Energy Agency [41], which assumes an annual growth of world GDP of 3.6%. This scenario would have the primary energy demand of the world at 867,700 PJ/a by 2050.
- The proposed (Revolution) scenario, which would increase efficiency throughout the economy and only increase primary energy demand from 474,900 PJ/a (2005) to 480,860 PJ/a (2050). The electricity generating sector is targeted to be the pioneer in renewable utilization, and by 2050 they would like 77% of it to be produced from renewables. A global installed capacity of 9,100 GW would thus produce 28,600 TWh per year by 2050 [43].
- An advanced scenario would have a much bigger drive for renewables, with all coal fired stations phased out by 2050, and 86% of electricity coming from renewables. The writers of the report believe that this scenario is too optimistic as it calls for coal power stations to be decommissioned 20 years before the end of their commercial life (mainly the ones currently being built in China and India) [43].

In their proposed scenario, the percentage of electricity demand that will be met by ocean energy is similar to that of the Conservative Ocean Energy Scenario in the current paper (around 2%). However, the Energy [r]evolution report [43] proposes that very little growth in global electricity demand should occur, which means that this is achieved by a comparatively smaller installed capacity, 194GW compared to 280GW in the current paper. They do state, however, that “[t]he use of ocean energy might be significantly higher, but with the current state of development, the technical and economical potential remains unclear” [43]. The surge in interest in ocean energy in the last year and the array of new projects under proposal adds to the impression that the figures given by that study could prove to be an underestimate.

Sorensen and Naef [42] also suggest an estimate of what could be expected from ocean energy by the year 2050, though these authors give three different scenarios:

- A “very optimistic” scenario, which would have 309GW installed by 2050, giving 1,281 TWh (or 4.2% of total electricity demand, estimated by EREC at 27,524 TWh)

- An “optimistic-realistic” scenario, with 194GW producing 773 TWh (2.5% of demand)
- A “pessimistic” scenario, with 40GW producing 152 TWh (0.5% of demand)

Their scenarios, however, are based on the estimated development of only one type of technology, the WaveDragon, and rely on the load factor increasing from 34% in 2007 to 47% in 2050 (for the very optimistic scenario). The final figure they come up with for their “optimistic-realistic” scenario is close to the 2% found by the present study, but it should be noted that these authors use a figure of 27,524 TWh for the total global electricity demand, which is lower than that given by the Wind Reference Model [35]. Also to note is how both these values are higher than the more conservative values of 27% used in the current study.

It is worth pointing out that these scenarios were all built on fairly linear assumptions that generally neglect the effect of the current economic crisis. The final effect that it could have on renewable energy development is significant, as some countries might opt to postpone investment and others might use their stimulus packages to heavily invest in renewable technology. In its 2009 budget report, for example, the UK government injected GBP £525m into renewable energies, such as offshore wind, and announced that up to £4 billion of new capital from the European Investment Bank through direct lending to energy projects and intermediated lending to banks. These types of “green industrial recovery” schemes could greatly enhance the chances that the optimistic scenarios outlines above could become a reality.

6. Problems With Large Scale Implementation of Ocean Energy Projects

There are a number of problems which are perceived to hinder the large scale penetration of ocean based renewable energy sources. Some of these problems are legal or regulatory in nature [45] [46], while others relate to the financial [13] considerations of the projects, as generally these type of energy are more expensive than traditional forms of energy, as explained previously.

However, the main criticism often voiced about intermittent renewable sources regards their reliability. It is generally believed that renewable power poses a problem to traditional grid systems due to fluctuations in the electricity produced by these systems, which generally depends on the time of day and season. In particular, the production of energy from sea areas would depend on the wind and waves at a given location, as during times of low wind or waves little electricity would be produced, a problem often referred to as intermittency. Traditional grids were not originally designed to cope with significant peaks and falls in the electricity supply and therefore load leveling and the absorption of fluctuations are believed to represent a problem for the widespread use of renewable power. However, Esteban et al. [22] showed that this problem of intermittency is party attenuated in large countries such as Japan, as unfavourable weather conditions in one part of the country for one renewable source might be compensated by better conditions for a different renewable in the same area or elsewhere. This effect is often referred to as "smoothening", and thus it is very important that the study of a comprehensive smart-grid renewable electricity system should include geo-physical variables and thus be analysed on an hourly basis. It is also worth noting that tidal energy is far more predictable in this sense, and follows daily fluctuations that can be predicted years in advance, and would thus contribute to smoothening the system [13].

The use of electricity storage techniques, together with other sources of renewable energy (such as hydropower and biomass) can also be used so that a country such as Portugal could rely 100% on renewable power, according to Krajacic et al. [4]. The problem, however, is not only how to effectively store excess energy during periods of high production for it to then be used at other times, but the fluctuations in the level of demand. These can broadly be classified into two types: short-term fluctuations between day and night, and long-term variations associated with the different seasons of the year [5]. For a 100% renewable electricity system, the short-term fluctuations could be absorbed using batteries in electric vehicles (EV) or specially built storage units. Batteries in electric vehicles would, thus, serve the dual purpose of eliminating CO_2 emissions from transportation and providing storage during fluctuations in renewable power production. Some future scenarios propose that a large number of electric vehicles (EV) will progressively substitute conventional oil-powered ones [47]. If such a high penetration of electric vehicles does come to be they would store the wind and wave power produced during the night, and this would be more economically feasible than using batteries dedicated exclusively to electricity storage. The storage potential of electric cars could also be complemented by batteries dedicated exclusively to electricity storage, and there is already a battery unit in the north of Japan that stores part of the electric load of a 50-MW wind farm. A total of 17 batteries (2 MW-NAS) are employed, using a total area of just over 4,000 m^2 of floor space. For the case of long-term storage, hydrogen, in particular, could be a good storage medium [48] [49], where electrolytically produced hydrogen could be stored in conventional tanks under pressure and then re-electrified in peak power demand seasons through various custom-made fuel cells.

7. Conclusions

The current research shows that it does not appear unrealistic that around 7% of the total global electricity production by 2050 could come from ocean areas. Employment in the sector is likely to increase rapidly throughout the world, and could reach almost 1 million people by 2030. The scenarios used in the present work show sharp fluctuations after that time, which would represent each of the two sectors (offshore and wind) maturing around different times, with maturity representing a sharp slowdown in the number of people involved in the installation of new devices. Although it is not clear that such an effect will indeed happen, what is clear is the potential for the sectors to provide substantial amount of jobs in the next 20 years.

Although it appears unlikely that ocean based energy devices will be able to satisfy the electricity needs of the entire planet, it can form one of a suite of measures necessary to find a sustainable solution to future energy needs. According to the cost scenarios developed in this paper, ocean energy could become competitive with other forms of electricity production such as coal by the late 2010's or early 2020's. The cost of wind energy depends on the area where it is located, though in some places around the world it has started already started to reach grid parity.

However, for future developments to happen in the fields of offshore renewable, governments will have to create favourable policies for the development of the industry in the coming years (such as the feed-in-tariffs given by the Portuguese government to ocean energy) so that the required innovations and economies of scale can be produced.

Acknowledgments
Funding for David Leary's research has been provided by the Faculty of Law at the University of New South Wales and from funding generously provided to the Faculties Climate Change Law and Policy Initiative by UNSW Law Alumni Madelein Tan.

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