# 4

# Ocean Energy – Wave and Tide

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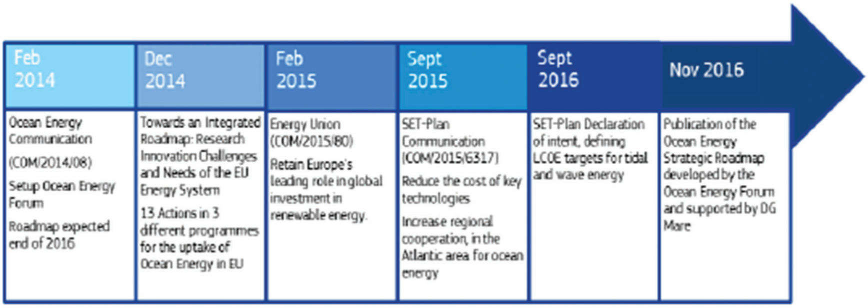
## 4.1 Introduction

### 4.1.1 Policy and EU Strategy Initiatives Overview for the Ocean Energy Sector

Our seas and oceans have the potential to become important sources of clean energy. Marine renewable energy, which includes both offshore wind and ocean energy (wave and tidal energy), presents the EU with an opportunity to generate economic growth and jobs, enhance the security of its energy supply and boost competitiveness through technological innovation. Following the 2008 Communication on offshore wind energy (European Commision 2008), the European Commission (EC) considered the potential of the ocean energy sector to contribute to the objectives of the Europe 2020 Strategy (European Commision 2010) as well EU's long-term greenhouse gas emission reduction goals. It also looked over the horizon at this promising new technology (Blue Growth) and outlines an action plan to help unlock its potential.

In 2008, the European Commission stated that "Harnessing the economic potential of our seas and oceans in a sustainable manner is a key element in the EU's maritime policy" (European Commision 2007). The ocean energy sector was highlighted in the Commission's Blue Growth Strategy (European Commision 2012) as one of five developing areas in the 'Blue Economy' that could help drive job creation in coastal areas. Other Commission initiatives were the Communication on Energy Technologies and Innovation (European Commision 2013) and the Atlantic Action Plan (European Commision 2013). The Atlantic Action Plan recognised the importance of ocean energy and aimed to encourage collaborative research and development and cross-border cooperation to boost its development and published two key reports on Ocean



| Feb 2014 | Dec 2014 | Feb 2015 | Sept 2015 | Sept 2016 | Nov 2016 |
|---|---|---|---|---|---|
| Ocean Energy Communication<br>(COM/2014/08)<br>Setup Ocean Energy Forum<br>Roadmap expected end of 2016 | Towards an Integrated Roadmap: Research Innovation Challenges and Needs of the EU Energy System<br>13 Actions in 3 different programmes for the uptake of Ocean Energy in EU | Energy Union (COM/2015/80)<br>Retain Europe's leading role in global investment in renewable energy. | SET-Plan Communication (COM/2015/6317)<br>Reduce the cost of key technologies<br>Increase regional cooperation, in the Atlantic area for ocean energy | SET-Plan Declaration of intent, defining LCOE targets for tidal and wave energy | Publication of the Ocean Energy Strategic Roadmap developed by the Ocean Energy Forum and supported by DG Mare |

**Figure 4.1** The history of Ocean Energy Policies at EU level. Image from JRC report 2016 (Magagna, Monfardini et al. 2016).

Energy development: "Blue Growth, opportunities for marine and maritime sustainable growth" (Altantic Action Plan 2013), and "Action Plan for a maritime strategy in the Atlantic area" (Atlantic Action Plan 2013). In 2014, the European Commission summarised all the initiatives in its COM/2014/08 final report "Blue Energy Action needed to deliver on the potential of ocean energy in European seas and oceans by 2020 and beyond" (European Commision 2014).

In 2014, the Strategic Initiative for Ocean Energy (SI Ocean)[1], released a report (SI Ocean 2014) detailing four main barriers to widespread wave and tidal energy deployment in Europe, namely:

1. Financial risks: market stresses, public support mechanism fluctuations, reduced investor confidence.
2. Technology risks: lack of commercially ready prototype devices, TRL8 or higher, due to failure of technology developers to overcome technology barriers. Insufficient cost reduction has been demonstrated as technology moves to higher TRL.
3. Regulatory and consenting barriers still exist in most jurisdictions with slow progress on their resolution. On the other hand, environmental impact requirements are increasing, delaying consents and increasing costs.
4. Grid connection, both adequate and sufficient, still remains a huge non-technical barrier, mainly due to the remote nature of most ocean energy resource areas, and lack of existing infrastructure. Lack of grid infrastructure could posing real risk to large scale deployment once technical barriers are overcome.

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[1] https://ec.europa.eu/energy/intelligent/projects/en/projects/si-ocean

The report offered recommendations for addressing those barriers, as part of its market deployment strategy. SI Ocean presented a vision of Europe reaching 100 gigawatts (GW) of installed wave and tidal energy capacity by 2050, the report's subsequent chapters focus on finance, technology development, regulatory regimes and the grid. Each chapter identifies the challenges these risk areas present, offers goals to remove barriers and recommends way to meet those goals. The report suggests that regulators incorporate wave and tidal energy projects into long-term grid development plans.

In 2014, the Ocean Energy Forum[2] was created by the European Commission, under the stewardship of Ocean Energy Europe[3]. The Forum brought together more than 100 ocean energy experts over two years. Ocean Energy Europe created TP Ocean (Ocean Energy Europe 2014) initiative, called the European Technology and Innovation Platform for Ocean Energy. TP Ocean identified six essential priority areas to be addressed to improve ocean energy technology and decrease its risk profile:

1. *Testing* sub-system components and devices in real sea conditions.
2. Increasing the *reliability and performance* of ocean energy devices allowing for future design improvements.
3. Stimulating a dedicated *installation and operation and maintenance* value chain, to reduce costs.
4. Delivering *power to the grid*, with hubs to collect cables from ocean energy farms and bring power to shore.
5. *Devising standards and certification*, to facilitate access to commercial financing.
6. *Reducing costs and increasing performance* through innovation and testing.

In November 2016, the Ocean Energy Forum created the 'Ocean Energy Strategic Roadmap' (Figure 4.1) (Ocean Energy Forum 2016).

The Roadmap puts forward four key Action Plans focused on maximising private and public investments in ocean energy development by de-risking technology as much as possible, ensuring a smoother transition from one development phase to another on the path to industrial roll-out and a fully commercial sector.

The second initiative of the Ocean Energy Forum was Strategic Research Agenda for Ocean Energy developed by Technology and Innovation Platform

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[2] https://www.oceanenergy-europe.eu/en/policies/ocean-energy-forum

[3] https://www.oceanenergy-europe.eu/en/

for Ocean Energy (TP Ocean 2016). The ocean energy sector has identified 12 priority research areas and 54 research and innovation actions. The research areas have been attributed indicative budgets that industry, national authorities and the European Commission need to commit to finance the RD&I programmes. Rolling-out the actions of this Agenda would generate around €1 bn in investment over 4 to 5 years. The outcomes for the ocean energy sector would be the improvement of current technologies and the identification of novel financial instruments to sustain the critical phase of moving to demonstration projects.

### 4.1.2 Tidal Energy Development Demographics

Tidal energy is predictable up to 100 years in advance (Alcorn, Dalton et al. 2014), making tidal energy attractive to grid operators by adding more predictable and consistent sources of renewable energy which has the effect of smoothing out the overall power supply from renewables. In tidal energy, there has been a general convergence of the technologies, with several developers testing full-scale prototypes and plans for commercial deployments.

Worldwide, many companies are currently developing tidal energy devices with most (about 52%) being based in the EU (Magagna, Monfardini et al. 2016). In Europe, the country with the highest level of development is the United Kingdom, followed by the Netherlands, and France. The United States and Canada are the major non-EU players (Figure 4.2).

The development of tidal technology is taking place in countries with the major tidal energy resources: UK, France, and Ireland (OES 2016). Other active countries, with more limited resources include Germany and Sweden.

### 4.1.3 Wave Energy Development Demographics

Wave energy is highly predictable days in advance and compliments wind energy by generally achieving its peak energy after wind energy has reached its maximum (Alcorn, Dalton et al. 2014). Therefore wave energy is a further alternative for grid operators seeking to smoothing out the overall power supply from renewables. By 2016 about 70 different design concepts were under development (OES 2016), Unlike wind energy (or even tidal current), designs for wave energy devices have not converged around a standard technology solution (more likely that wave energy will converge on a number of standard technologies), and relatively few have made it to full scale prototype testing, and there are no current plans for commercial arrays. The majority of

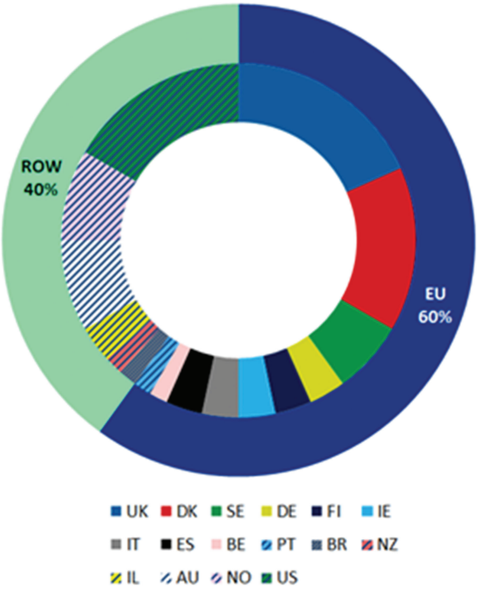

**Figure 4.2** Global spread of tidal development companies. Image JRC Ocean Energy Status Report 2016. (Magagna, Monfardini et al. 2016).

companies developing wave energy devices are based in the EU (Magagna, Monfardini et al. 2016) (Figure 4.3). The United Kingdom has the highest numbers of developers, followed by Denmark. Outside the EU, countries with a larger number of wave energy developers are USA, Australia, and Norway. Globally, about 57 wave energy developers have tested their devices in open waters or will do so in the near future.

See Section 4.5 'Innovation' for details on wave and tidal companies and their lifecycle stage.

## 4.2 Market

There are potentially enormous exploitable energy resources available in the world's oceans. This would suggest significant potential markets for the sale of ocean energy as well as opportunities for supporting industries and services involved in the development, manufacturing, construction, installation and operation (Alcorn, Dalton et al. 2014). However, uncertainty in future costs makes it difficult to estimate the scale of the opportunity and the size of the long term potential market.

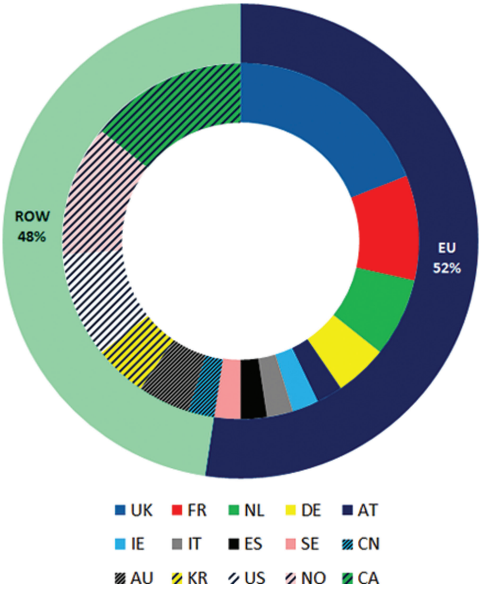

**Figure 4.3** Global spread of wave development companies. Image JRC Ocean Energy Status Report 2016 (Magagna, Monfardini et al. 2016).

### 4.2.1 Global Ocean Energy Resources and Potential Economic Return

The total theoretical energy contained in the seas is estimated to be 32,000 TWh/yr for wave (Mork, Barstow et al. 2010) and 7,800 TWh/y for tides (IEA-OES 2011). It is this potential scale that justifies the drive for its development (Alcorn, Dalton et al. 2014, Magagna, Monfardini et al. 2016). Wave energy devices derive energy from the three dimensional movement of ocean waves. Tidal energy devices harnesses the bodily movement of water resulting from the environmental pull between the moon and the earth. The efficiencies of future ocean energy technologies will dictate how much of this resource can be usefully harnessed. The technically exploitable energy of wave energy devices is estimated to be 5,500 TWh/yr (Lewis 2011), which is approximately 30% of world electricity demand. Whilst currently under development, the Ocean Energy Forum goal is to install 100GW of wave and tidal by 2050. This equates to 350 TWh of exploitable electricity and opens up a global market for investment, jobs and growth. This would meet 10% of the power demands of the EU, a significant component in the transition to a low carbon clean economy.

In 2009 the Renewables Directive 2009/28/EC (European Commision 2007) set binding targets for all EU Member States, such that the EU will reach a 20% share of energy from renewable sources by 2020 and a 10% share of renewable energy specifically in the transport sector. The primary production of renewable energy within the EU-28 in 2014 was 196 million tonnes of oil equivalent (toe) – a 25.4% share of total primary energy production from all sources (Eurostat 2016).

For Europe to meet its objective of reducing greenhouse gas emissions to 80–95% below 1990 levels by 2050 (European Commision 2011), Ocean Energy is needed in a diversified low carbon and renewable energy portfolio. Investment wise the global market between now and 2050 is estimated to be worth €653 bn (Ocean Energy Forum 2016) (cumulative, undiscounted) which would bring great benefit to European and world economies. Tidal energy is going strongly in its development and some niche opportunities are expected, whilst wave energy has suffered some setbacks in investment in 2015 in the EU. The World Energy Council estimates the global capital expenditure for wave energy projects to be more than £500 billion, based on a technically exploitable wave resources of 2,000 TWh/year (World Energy Council 2007). So far, over the past 10 years the ocean energy industry has invested an estimated €1 bn in capital to move concepts from the drawing board to deployment in EU waters (OEE 2016 (Ocean Energy Forum 2016)).

### 4.2.2 Installed Capacity and Consented Capacity for Wave and Tidal

This section presents the target deployment predictions of the major policy agencies reviewing ocean energy. There was great optimism in the early 2000's and accordingly ambitious targets. Successive reviews for both near term, 2015, and far term, 2050, were revised downwards, as real deployments failed to materialise. It is likely that the current 2050 projections will be revised down in subsequent reviews.

2020 deployment predictions

JRC and European Commission in 2010 (European Commision 2010) set European targets for wave and tidal of 1.9 GW by 2020. In 2015, OEE downsized the prediction for ocean energy deployment, reaching a cumulative capacity of 850 MW by 2020 (OEE 2015 (Ocean Energy Forum 2016)).

### 2050 deployment predictions

In 2007, the IEA-Ocean Energy Systems Implementing Agreement (IEA-OES), predicted combined wave and tidal deployment of **337 gigawatts (GW)** of capacity worldwide by 2050 (IEA-OES., Khan et al. 2008). (By comparison, the capacity of the much more developed wind energy sector reached the same figure – 336 GW – by the end of June 2014).

Current estimates from 2014 for 2050 deployments, as quoted by SI Ocean (SI Ocean 2014), currently stand at **100 GW** of combined *wave* and *tidal* capacity installed (elaborated by Magagna (Magagna and Uihlein 2015)).

Table 4.1 represents more detailed breakdown provided by OES 2015 Annual Report for Ocean Energy up to 2020 (OES 2015):

- current installed capacity
- consented capacity.

Current capacity (2015) installed for tidal energy exceeds wave energy by a factor of 5, at 2.4 MW for wave energy and 14 MW for tidal.

The current predictions for wave energy deployment was optimistic (consented capacity in Table 4.1), requiring a sizeable increase in deployment

**Table 4.1** Table from Ocean Energy Systems Data taken from OES 2015 report (OES 2015)

| | | Installed Capacity MW 2015 | | Consented Capacity | |
|---|---|---|---|---|---|
| Basin | Country | Wave | Tidal Stream | Wave | Tidal Stream |
| Atlantic | UK | 0.96 | 2.1 | 40 | 96 |
| | Portugal | 0.4 | – | 5 | – |
| | Spain | 0.3 | – | – | – |
| | France | – | 2.5 | – | 21.5 |
| | Ireland | – | – | – | – |
| Baltic | Sweden | 0.2 | 8 | 10.6 | |
| | Belgium | – | – | 20 | – |
| | Netherlands | – | 1.3 | – | 2.2 |
| | Norway | – | – | 0.2 | – |
| | Denmark | – | – | 0.05 | – |
| Caribbean | Inactive | – | – | – | – |
| Mediterranean | Inactive | – | – | – | – |
| Rest of World | Canada | 0.09 | – | – | 20 |
| | China | 0.45 | 0.17 | 2.7 | 4.8 |
| | United States | – | – | 1.5 | 1.3 |
| | Korea | 0.5 | 1 | 0.5 | 1 |
| Total | – | 2.4 | 14.07 | 80.05 | 145.8 |
| | | 16.47 | | 225.85 | |

of 4000% in MW deployed, from current 2 MW up to 80 MW. UK, Sweden and Belgium plan to take the lead, with approx. 20–40 MW deployments in each jurisdiction. Tidal energy also has optimistic deployment gains, although more modest, with a 10 fold increase in MW deployed from 14 MW to 145 MW. Deployments in the remainder of the world are currently modest, with no major plans for increases. The exception is Canada, where tidal energy is predicted to reach 20 MW installed by 2020.

In summary, current capacity deployments to date (2016) of 16.7 MW will make it highly unlikely that the OEE target of 850 MW by 2020 will be reached (OEE 2015 (Ocean Energy Forum 2016)).

However, the global potential market identified by SI Ocean (SI Ocean 2014) of 100GW by 2050 is substantial, with very large capital expenditure. These investments would add significantly to Europe's strategic goals of jobs and growth for the European Area.

### 4.2.3 Capital Expenditure (Capex/MW or €/MW)

Chozas et al., conducted a comprehensive literature review of published data on historical costs, planned projects and reference reports that estimate capital expenditure (Capex costs/MW) for both wave and tidal (Figure 4.4) (Chozas, Wavec et al. 2015). They state that there is a significant variability of CAPEX values for the first pilot projects (up to 1 MW) installed worldwide, ranging from €10–50 M/MW for wave energy, and a much lower €5–20 M/MW for tidal energy. The trends for both technologies were relatively similar as they progressed to commercial stage, converging to €3–6 M/MW for both wave and tidal energy. Other reviews of Capex/Mw for ocean energy are conducted by Dalton et al. (Dalton, Alcorn et al. 2009, Dalton 2010, Dalton,

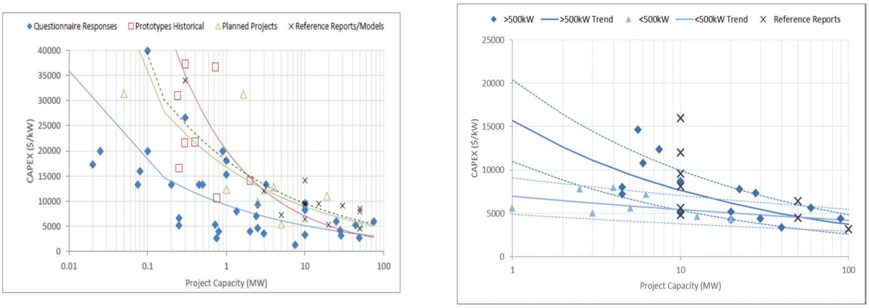

**Figure 4.4** CAPEX cost per kW installed for 1: wave 2: tidal, relative to project deployed capacity. Image taken from Chozas et al., (Chozas, Wavec et al., 2015).

Alcorn et al. 2010, Dalton, Alcorn et al. 2010, Dalton 2011, Dalton and Lewis 2011, Dalton, Alcorn et al. 2012, Dalton, Allan et al. 2016, Dalton, Allan et al. 2016).

### 4.2.4 Prices – Cost of the Product – Levelised Cost of Electricity LCOE

The Levelised Cost of Electricity (LCOE) is one of the most commonly used financial indicators to compare the cost of energy projects. Magagna et al. (Magagna and Uihlein 2015) published a comprehensive report in 2015 on the business cases for wave and tidal. Figure 4.5 compares wave and tidal LCOE to other renewable technologies as well as fossil fuels. LCOE for wave has a range of €500–650/MWH and Tidal a range of €350 to 450/MWh. Their forecast for cost reductions and learning for both however are optimistic, with Wave LCOE dropping to €80/MWH and Tidal €60/MWH, competitive to all other renewables and fossil fuels.

The JCR report, authored again by Magagna (Magagna, Monfardini et al. 2016), approached LCOE reduction from a cumulative installed prospective and in Figure 4.6, also insert timeframe benchmarks. By 2030, they predict

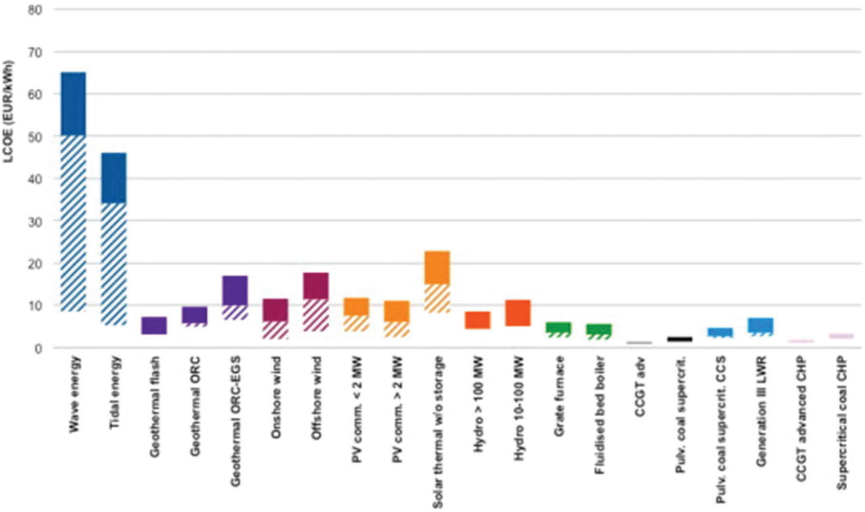

**Figure 4.5** LCOE for alternative and conventional energy technologies. Solid bars indicate current cost ranges, while shaded bars indicate expected future cost reductions. Image taken from Magagna (Magagna and Uihlein 2015).

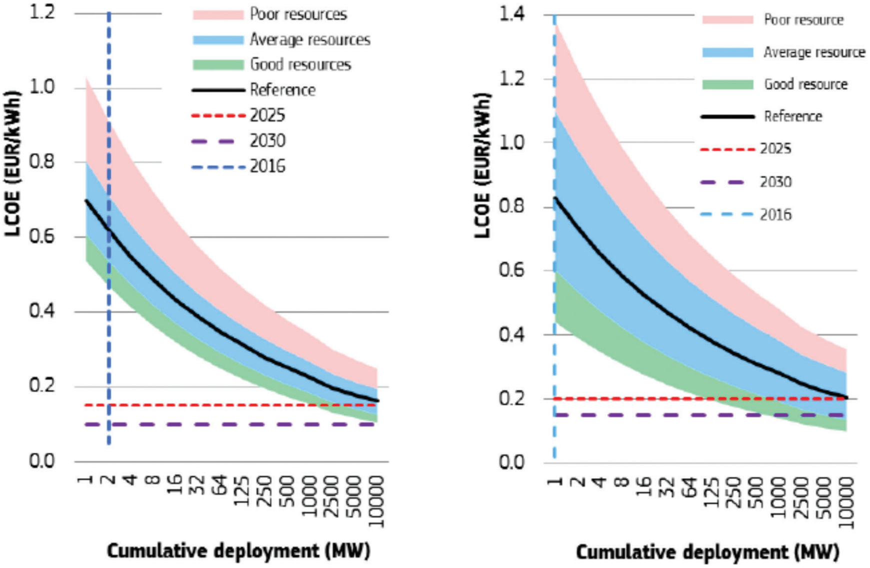

**Figure 4.6** LCOE cost reduction ranges with cumulative deployments; 1. Tidal 2. Wave. Image taken from (Magagna, Monfardini et al. 2016).

cumulative installed capacity for both technologies will reach 10 GW each, and that LCOE for both technologies will drop to €100–120/MWH.

Another JCR report (Global CCS Institute 2013), conducted by Global CCS, has a longer time span projection to 2050, also predicting that wave and tidal LCOE cost will reduce to approximately €80/MWH (Figure 4.7).

A more detailed review and modeling of LCOE of Wave and Tide was published by Chozas (Chozas, Wavec et al. 2015). Table 4.2 is taken from that report, and presents LCOE results for the various stages of commercialization for both technologies, however not specifying size of deployment, cumulative installed capacity or timeframe specified. At full commercial scale, Chozas predicts a tidal LCOE of €130/MWH and most unusually, wave lower than tidal at €120/MWH.

Chozas (Chozas, Wavec et al. 2015) also presents LCOE modeling based on learning curves, as does Dalton (Dalton, Alcorn et al. 2012). Other reviews of LCOE for ocean energy include Dalton et al. (Dalton, Alcorn et al. 2009, Dalton 2010, Dalton, Alcorn et al. 2010, Dalton, Alcorn et al. 2010, Dalton 2011, Dalton and Lewis 2011, Dalton, Alcorn et al. 2012, Dalton, Allan et al. 2016, Dalton, Allan et al. 2016).

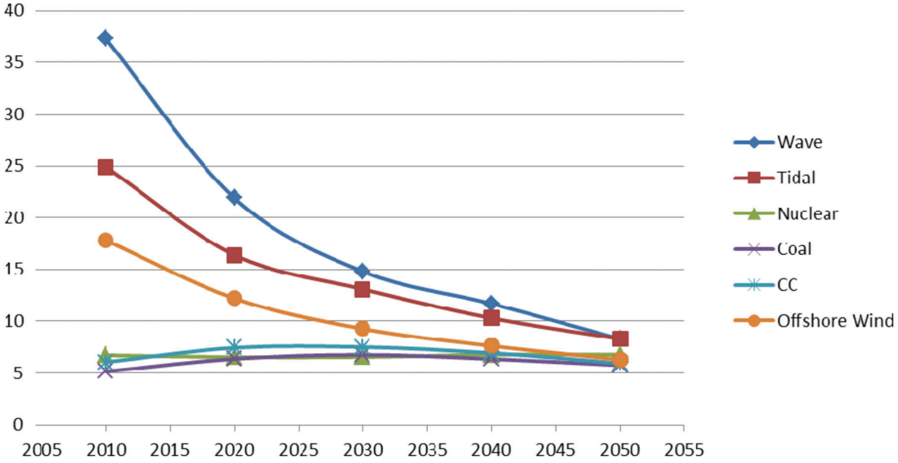

**Figure 4.7** LCoE (€/kWh) projections for the main power generation technologies. Image taken from JCR Report (Global CCS Institute 2013).

**Table 4.2** LCOE of wave and Tidal, for 3 stages of development: First array, second array and Commercial. Table taken from Chozas et al. (Chozas, Wavec et al. 2015)

| | | Wave | | Tidal | |
|---|---|---|---|---|---|
| Deployment Stage | Variable | Min | Max[1] | Min | Max |
| First array/First Project[2] | Project Capacity (MW) | 1 | 3[3] | 0.3 | 10 |
| | CAPEX ($/kW) | 4000 | 18100 | 5100 | 14600 |
| | OPEX ($/kW per year) | 140 | 1500 | 160 | 1160 |
| Second array/ Second Project | Project Capacity (MW) | 1 | 10 | 0.5 | 28 |
| | CAPEX ($/kW) | 3600 | 15300 | 4300 | 8700 |
| | OPEX ($/kW per year) | 100 | 500 | 150 | 530 |
| | Availability (%) | 85% | 98% | 85% | 98% |
| | Capacity Factor (%) | 30% | 35% | 35% | 42% |
| | LCOE ($/MWh) | 210 | 670 | 210 | 470 |
| First Commercial-Scale Project | Project Capacity (MW) | 2 | 75 | 3 | 90 |
| | CAPEX ($/kW | 2700 | 9100 | 3300 | 5600 |
| | OPEX ($/kW per year) | 70 | 380 | 90 | 400 |
| | Availability (%) | 95% | 98% | 92% | 98% |
| | Capacity Factor (%) | 35% | 40% | 35% | 40% |
| | LCOE $/MWh) | 120 | 470 | 130 | 280 |

### 4.2.5 Funding Support Schemes

#### 4.2.5.1 History of EU funding programme support schemes for ocean energy

In 2007 EU approved of the Strategic Energy Technology Plan (SET-Plan) (Europeaan Commision 2015), with aims to develop technologies in areas including renewable energy, energy conservation, low-energy buildings, fourth generation nuclear reactor, coal pollution mitigation, and carbon capture and sequestration (CCS).

In order to implement the research required for the SET-Plan, the European Energy Research Alliance (EERA)[4] was founded by more than 175 research centres and universities in the European Union (EU). The aim of EERA is to expand and optimise EU energy research capabilities through the sharing of world-class national facilities and the joint realisation of national and European programmes, and builds on national research initiatives.

The following are the list of EU funded programs for ocean energy:

1. Within the EERA, a joint programme for investment in ocean energy has been set up. NER 300 is an example of one of the EERA initiatives (see NER 300 described below under push mechanisms). Three ocean energy projects were awarded around €60 million in total under the first round of the NER 300 programme, which will enable the demonstration of arrays from 2016 (European Commision 2014).
2. The development of ocean energy has been highlighted in the recent Commission Communication entitled "Action Plan for the Atlantic Ocean area" (Atlantic Action Plan 2013, European Commision 2013) which encouraged national and regional governments to consider how they could use EU structural and investment funds as well as research funds or European Investment Bank funding to support the development of the sector.
3. Research Framework Programmes (FP4,5,6,7) and the Intelligent Energy Europe Programme provided an amount of up to €90 million for ocean energy development since the 1980s (European Commision 2014). (Ocean Energy Europe[5] reports €124 m to ocean energy projects between 2005 and 2014, almost €14 m per year).
4. Horizon 2020[6], the EU's research and innovation programme, will aim to address important societal challenges including clean energy and

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[4] https://www.eera-set.eu/

[5] http://www.oceanenergy-europe.eu/en/14-policy-issues

[6] https://ec.europa.eu/programmes/horizon2020/

marine research. As such, it is a powerful tool that can drive the ocean energy sector towards industrialisation, creating new jobs and economic growth. Between 2014–15, H2020 programme has funding over EUR 60 million (Magagna, Monfardini et al. 2016) of R&D projects in wave and tidal energy. €30 M[7] in demonstration funding was awarded (LCE3 and 12). For 2016–17, total of €22.6 M will be awarded for ocean energy specific calls, 9.8% of LCE budget. A further €35 M was allocated to Blue Growth and Co-Funded calls, which include ocean energy.

5. Other funding instruments available in Europe are InnovFin[8] (a series of integrated and complementary financing tools and advisory services offered by the European Investment Bank Group together with the European Commission) and the European Regional Development Fund (ERDF)[9]. These funding mechanisms are supporting the deployment of demonstration projects. Collaboration initiatives at regional level are catalysing the formation of marine energy clusters to consolidate the European supply chain.

There are two types of support type mechanisms.

1. Push: = grants and equity
2. Pull: = tariff and other revenue mechanisms

#### 4.2.5.2 Pull support schemes – Feed-in Tariff

Market pull mechanisms for wave and tidal sectors include financial supports mechanisms such as feed-in tariff and renewable obligations.

Feed-in tariffs (FIT) are the most common support mechanism, and are also currently the most popular and sought after mechanism by investors.

A feed-in tariff (FIT, FiT, standard offer contract, advanced renewable tariff, or renewable energy payments) is a policy mechanism designed to accelerate investment in renewable energy technologies (CfD described below separately). It achieves this by offering long-term contracts to renewable energy producers, typically based on the cost of generation of each technology. Ocean energy technologies such as wave and tidal power are offered a higher FIT price, reflecting costs that are higher at the moment. Table 4.3 presents a range of market pull mechanisms.

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[7] http://maritimebrokerageevent2015.eu/media/sites/11/dlm_uploads/2015/11/Ocean-Energy-presentation.pdf

[8] http://www.eib.org/products/blending/innovfin/

[9] http://ec.europa.eu/regional_policy/en/funding/erdf/

**Table 4.3** European Market support 'pull' mechanisms. Information adapted from JRC Ocean Energy Status Report 2016 Edition (Magagna, Monfardini et al. 2016)

| Country | Tariff Support Scheme |
|---|---|
| Denmark | Maximum tariff of 0.08 EUR/kWh for all renewables including ocean energy |
| France | Feed-in Tariff for renewable electricity. Currently 15 cEUR/kWh for ocean energy. |
| Germany | Feed-in Tariff for ocean energy between EUR 0.035 and 0.125 depending on installed capacity |
| Ireland | Market support tariff for ocean energy set at €260/MWh and strictly limited to 30 MW |
| Italy | For projects until 5 MW 0.3 EUR/kWh<br>For projects >5 MW 0.194 EUR/kWh |
| Netherland | The SDE+ (feed-in premium) supports ocean energy with a base support of 0.15 EUR/kWh minus the average market price of electricity in the Netherlands (support is given for a 15 year period). Total budget for SDE+ capped (EUR 8 billion in 2016) |
| UK | Renewable Obligation (RO) Scheme. Renewable Obligation Certificates (ROCs) price set to 44.33 GBP in 2015/16. Replaced by a Contract for Difference (CfD) scheme in 2017. Wave and tidal energy technologies will be allowed to bid for CfDs, however they are currently expected to compete with other technologies (e.g. Offshore Wind) to access CfD. |

In addition, feed-in tariffs may include "tariff degression", a mechanism whereby the price (or tariff) ratchets down over time. This is done in order to encourage technological cost reductions. The goal of feed-in tariffs is to offer cost-based compensation to renewable energy producers, providing price certainty and long-term contracts that help finance renewable energy investments.

The disadvantage of Feed-in tariff support schemes is that they are only beneficial in stimulating investment when the technologies are near commercial (at TRL9[10]). They have benefited the tidal developments to some extent, but have not provided a benefit to wave energy prototypes. The advertised tariffs for wave energy could be viewed as purely theoretical, as the funds allocated have never been drawn-down. Moreover, many studies for wave energy financial viability have stated that current tariff support offered by most countries are inadequate, and need to be at least over €0.30c/kWh, to be financially viable (Dalton, Alcorn et al. 2012, Teillant, Costello et al. 2012).

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[10] Technology Readiness Level: www.westwave.ie/wp-content/uploads/downloads/2012/10/Wave-Power-Systems-Technology-Readiness-Definition-ESBIoe-WAV-12-091-Rev2.pdf

Ireland, in 2016, completed a second review of the marine energy sector, called “Our Ocean Wealth task force report” (Development Task Force 2015). The report recommended the introduction of an market support scheme, funded from the public service obligation levy, equivalent to €260/MWh and strictly limited to 30 MW for ocean (wave and tidal). This will be allocated by public competition and focused on pre-commercial trials and experiments. A subsequent review will determine the most appropriate form and level of support for projects beyond 30 MW.

Portugal had perhaps the most developed tariff scheme (Figure 4.8), which incorporates the tariff degression method (this scheme has now lapsed). The tariff scheme supported prototype deployments under 4 MW at €0.26/kWh (Brito Melo 2010). Five pre-commercial projects were to be supported of 20 MW each, with FIT of €0.22/kWh. FIT rates for commercial projects would then drop to a range from €0.16/kWh for under 100 MW farms, €0.11/kWh for 100–250 MW and €0.075/kWh for farms over 250 MW.

The UK had the Renewable Obligation, active until the end of 2017, mandating electricity suppliers to deliver a certain proportion of their electricity from renewable sources, evidenced each year through the submission of the appropriate amount of Renewable Obligations Certificates (ROCs). ROCs are distributed to each renewable energy generator for each MWh of electricity sold. This effectively establishes a market for ROCs that is separate to the market for electricity. The price of a ROC in 2008 was approximately £0.047 (Scottish Government 2008). From April 2009, two ROCs was issued for each

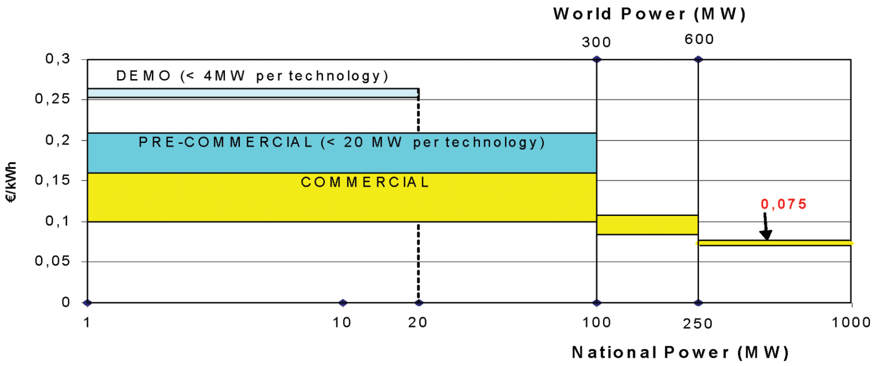

**Figure 4.8** The proposed range of FIT offered in Portugal for the various stages of R&D and capacity deployed. (Brito Melo 2010).

MWh of wave generated electricity in England and Wales (equating to a value currently of £0.09/kWh), that is supplementary to the price received for the electricity). In Scotland five ROCs was allocated for each MWh of wave and tidal generated electricity (equating to £0.225/kWh based on current prices), also in addition to the electricity market price.

Post 2017 projects rely on Contract for Difference (CfD) for support in the UK market (Department of Energy and Climate Change 2014). CfD offers a fixed price above the market price for electricity, guaranteed for a period of time. Changing from the ROCs systems to the CfD is a major change for the UK renewable electricity sector. UK Government states that CfD will give Wave and Tidal much benefits and greater certainty[11]. It is argued that CfD will lead to lower finance costs, which will reduce the overall project costs. A potential wave or tidal development would need to bid into the new system and need win a successful bid to get access to the long term contracts. Once this is secured, CfD offers more revenue certainty, relative to the previous ROC regime. Wave and tidal developers will have access to a general pot of £260m which includes other renewable sectors such as advanced conversion, anaerobic digestion, dedicated biomass with CHP, geothermal. This does mean that wave and tidal will be competing with these other technologies to secure funding in a mechanism where the support will go to the cheapest technology. The highest strike price for both wave and tidal with be of 305 £/MWh, this is the Initial administrative (maximum) strike prices (£/MWh in 2012 prices). This change may have an initial settling period, where investors will be uncertain of the new market.

#### 4.2.5.3 Push support scheme

Technology push support mechanisms for wave and tidal include public grants and private equity. Table 4.4 presents push mechanisms implemented by four EU member states to favour the development of ocean energy (Magagna, Monfardini et al. 2016). Push mechanisms tend to provide upfront capital for the deployment of pilot projects.

Examples include €26 million in Ireland to more than about €285 million in the United Kingdom.

The largest push support fund to come from the EU is called NER 300[12]. It is composed of European Commission, European Investment Bank

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[11] https://www.gov.uk/government/publications/contracts-for-difference/contract-for-difference

[12] http://www.ner300.com/

**Table 4.4** Summary of Push schemes for wave and tidal energy. Information from JRC report (Magagna, Monfardini et al. 2016)

| Country | Fund | Total Million |
|---|---|---|
| France | Two projects | €103 |
| Ireland | SEAI Prototype Development Fund, | €4 |
| | Ocean Energy Development Budget | €26 |
| Portugal | Fundo de Apoio à Inovação (FAI) | €76 |
| UK | Marine Energy Array Demonstrator (MEAD), | £20 |
| | Energy Technologies Institute (ETI), | £32 |
| Scotland | Renewable Energy Investment Fund (REIF) Scotland, | £103 |
| | Marine Renewables Commercialisation Fund (MRCF) | £18 |
| | Saltire Prize, Scotland, | £10 |
| | Wave Energy Scotland funding, | £14.3 |

and Member States. The NER 300 is a common pot of €300 M EU ETS allowances set aside for supporting 8 CCS and 34 renewable energy projects. The allowances will be sold on the carbon market and the money raised could be as much as €4.5B if each allowance is sold for €15. Up to 50% of "*relevant costs*" are funded under the scheme. Each member state will allocated at least one and a maximum of three projects[13]. The maximum return would be achieved by securing funding for the three largest demonstration projects that are in the public interest. The remaining costs will need to be co-funded by Member State governments and/or the private sector. A total of three ocean energy projects will be funded including wave, tidal and ocean thermal. Wave energy devices of up to 5 MW nominal power are eligible to apply[14].

NER 400[15] will supersede NER 300. Called ETS Innovation Fund, and proposes €2.1 bn EUR awarded for the period 2021–2030 (with some amount possibly made available before 2021). NER 400 will fund 38 innovative renewable energy and one CCS project and will additionally include measures to decarbonise industrial production.

Figure 4.9 provides a visual summary of market push and pull mechanisms for ocean energy, based on developers stage of technology or commercial development stage (Magagna, Monfardini et al. 2016, Vantoch-Wood 2016).

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[13] http://ec.europa.eu/clima/funding/ner300/docs/faq_en.pdf

[14] http://ec.europa.eu/clima/funding/ner300/00031/index_en.htm

[15] http://ner400.com/

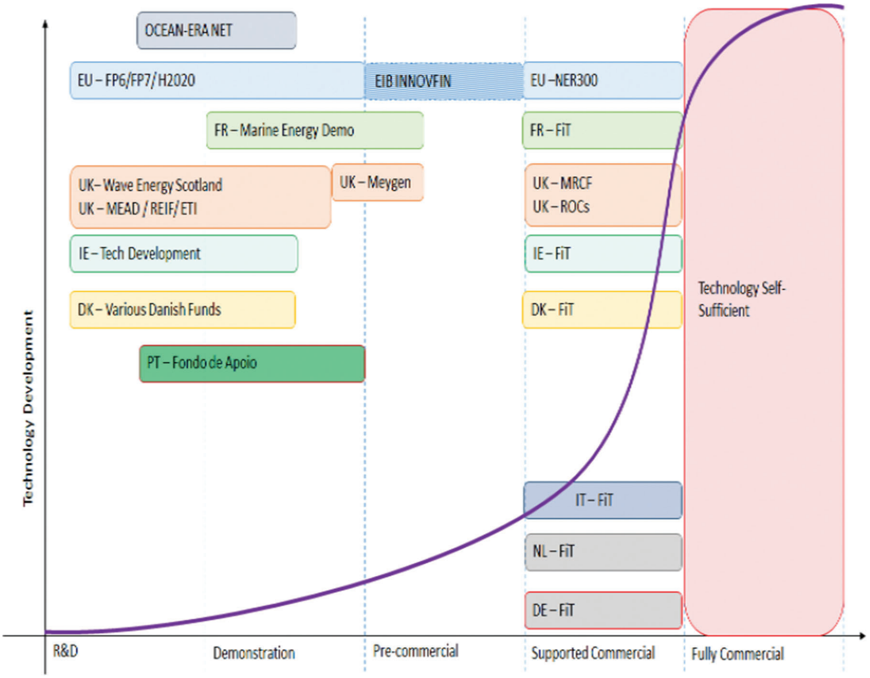

**Figure 4.9** Summary of market push and pull mechanisms for ocean energy in the EU based on Carbon Trust deployment scenarios. Image taken form JRC report and Vantoch-Woods (Magagna, Monfardini et al. 2016, Vantoch-Wood 2016).

The OES Annual report (OES 2016) presents an excellent summary, country by country of:

- National strategy
- Market Incentives
- Financing

## 4.3 Sector Industry Structure and Lifecycle

### 4.3.1 Wave and Tidal Sectors – Present and Future Centres of Developer Activity

ReNews (ReNews 2014) in 2014 compiled an exhaustive list of stakeholder companies in the Wave and Tidal sectors, viewable in the following reference link: http://renews.biz/wp-content/assets/WTP-Research-Review-Winter-2014.pdf

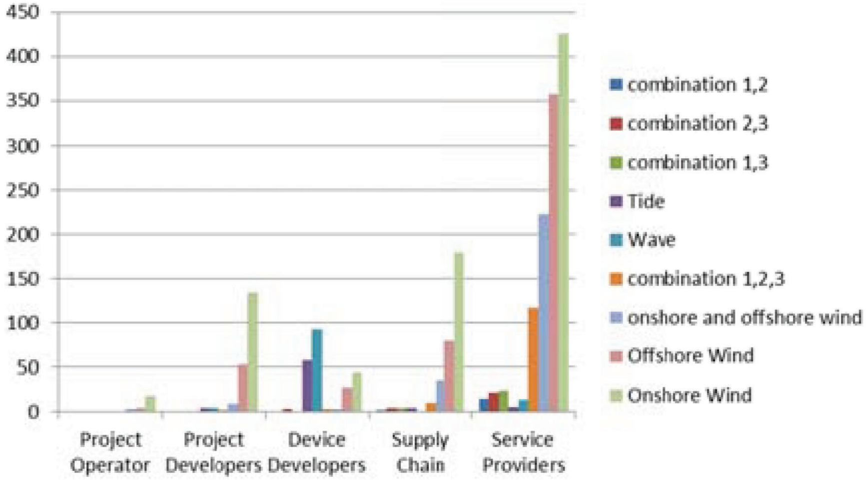

**Figure 4.10** Number of Ocean energy companies defined by technology including onshore wind. Figure provided by Exceedence Ireland[16](1=tide, 2=wave, 3=offshore wind, combination 1,2 = tide and wave).

JRC Ocean report (Magagna, Monfardini et al. 2016) contains a non-exhaustive list of companies currently active in the field of ocean energy, ranging from technology developers to component suppliers. The majority of technology developers are based in countries with significant ocean energy resources, many intermediate components suppliers are based across the EU (Germany, Sweden, Finland, Italy, Austria).

Figure 4.10 presents an analysis of the spread of sectors for the global wave and tidal industry, conducted by Exceedence[16]. The figures shows that service providers are by far the largest category, followed by supply chain. As anticipated, the majority are focused on onshore and offshore wind. These service providers are mostly based in the UK currently (Figure 4.11). It is anticipated that there will be transferable skills and business prospects.

The majority of wave and tidal developer companies are based in the UK and USA, Figure 4.12, with very sizeable annual turnover in USA as presented in Figure 4.13.

A visual representation of the European spread of wave and tidal industry is presented in Figure 4.14, created by SETIS[13], Eurostat for JRC. The map concurs with Exceedence findings, namely that the UK contains the most of the wave and tidal companies in Europe. The image also concurs that that

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[16] www.exceedence.com

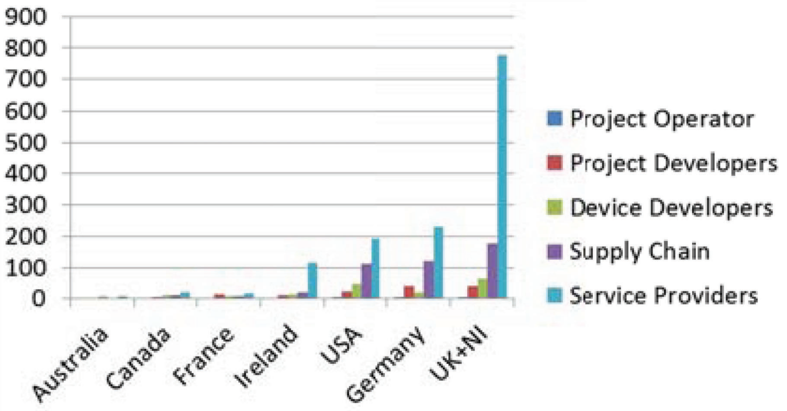

**Figure 4.11** Number of companies in sample countries defined by stakeholder type. Figure provided by Exceedence Ireland[11].

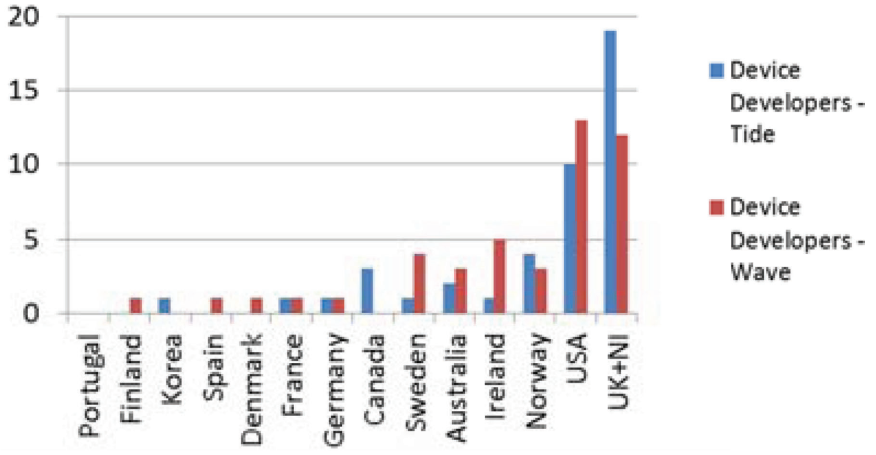

**Figure 4.12** Number of wave and tidal developer companies in sample countries. Figure provided by Exceedence Ireland[11].

wave and tidal developers only comprise a small proportion of the overall stakeholder industry representation.

An important recent milestone has been a number of large engineering firms taking controlling stakes in device development companies, primarily in tidal technology companies, indicating that the tidal industry is closer to maturity than wave (Alcorn, Dalton et al. 2014). Companies include Siemens,

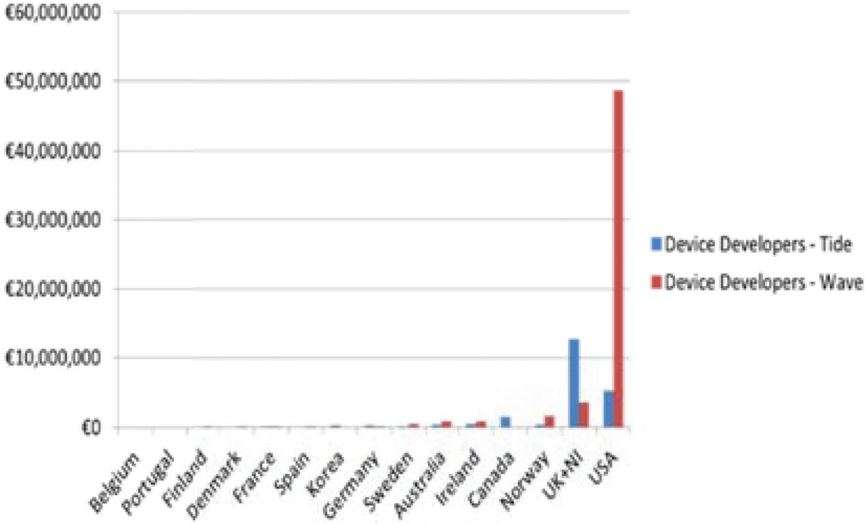

**Figure 4.13** Total Annual turnover of all companies in Wave and Tidal in sample countries. Figure provided by Exceedence Ireland[11].

DCNS, Andriz Hydro, Alstom and others. In the last 7 years up to 2014, total private sector investment has been over €600 m in the last 7 years in Europe (EU-OEA 2013).

## 4.3.2 Supply Chain

Current market conditions and technology status of ocean energy converters have affected the consolidation of the supply and value chain of the sector (Magagna, Monfardini et al. 2016).

Supply chain consolidation is project-driven for technologies that are commercially viable. As witnessed in the wind energy sector, a strong project pipeline ensures that there is sufficient demand for Original Equipment Manufacturers (OEMs), and as a result guarantees demand for the manufacturing of components and subcomponents and for the supply of raw materials. On the other hand, for technologies that are not yet market-ready, such as ocean energy technology, the consolidation of the supply chain is dependent on the ability of reliability of the technology and its progress to higher TRL. Uncertainties in the project-pipeline are amplified throughout the supply chain, with potentially serious implications for the providers of components and raw materials. This can result in both price variation of good and materials, and in limited supply of products.

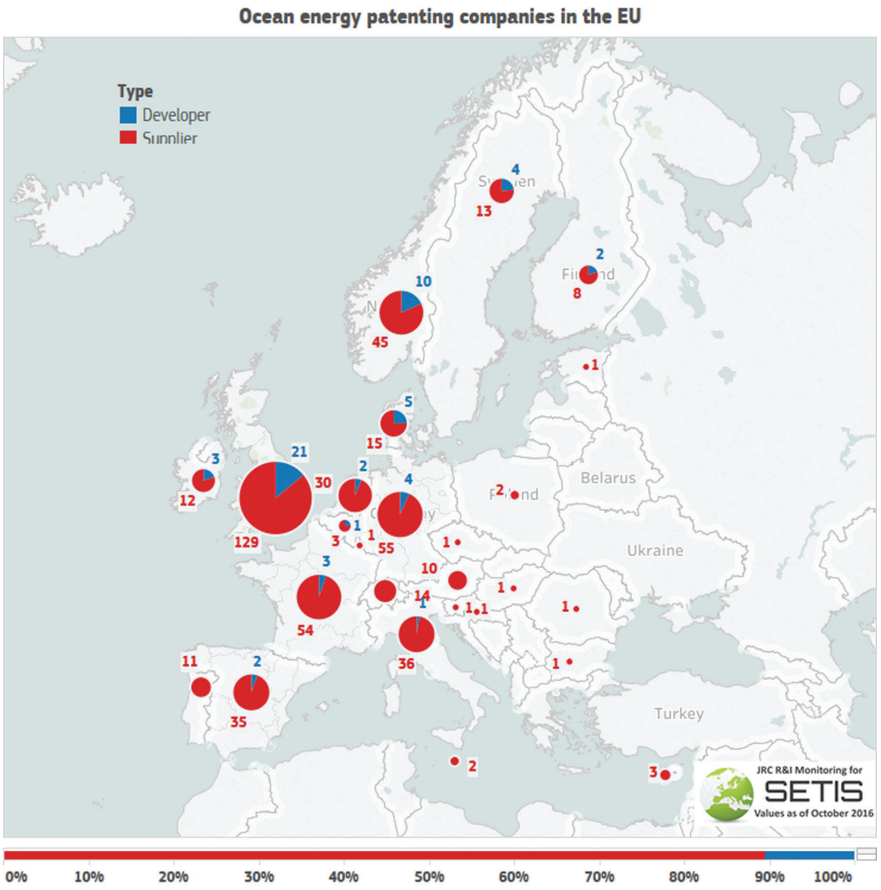

**Figure 4.14** Ocean Energy patenting companies in the EU in 2008–2013 Companies identified as wave and tidal energy developers are represented in blue, supply chain and components manufacturers are classified as suppliers and represented in red. Image from SETIC JRC.[17]

One of the critical issues for the ocean energy sector over the past few years has been the lack of engagement of OEMs. Currently, however, as the separation between tidal and wave energy is more marked, it can be seen that, OEMs are either acquiring or investing tidal energy developers with DCNS, Andritz Hydro-Hammerfest, Lock-heed Martin, General Electric all making investments despite the exit of Siemens from the sector. For wave energy, however, since 2012 an exodus of OEMs has been witnessed.

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[17] https://setis.ec.europa.eu/sites/default/files/report_graphs/patenting_companiese_eu_0.png

The necessity of reducing the cost of ocean energy technology, also through economy of scales, implies that the presence of OEMs with access to large manufacturing facilities could be seen as an indicator of the consolidation of the supply chain.

The Exceedence[11] company compiled a list of main supply chain companies supporting Wave and Tidal, categorised by marine basin, and is presented in Table 4.5.

**Table 4.5** Table of major supply chain companies in the Wave and Tidal industry, spanning all the stakeholder categories categorised by marine basin (compiled by Exceedence)[11]

| Wave | | | | | | |
|---|---|---|---|---|---|---|
| Atlantic | | | | | | |
| PTO & Generator | Electrical & Automation | Bearings | Marine Operations | Hydraulic Components | Coating | Diagnostic |
| Bosch Rexroth | ABB | Hutchinsons | Mallaig Marine | Mallaig Marine | Hempel | BAE Systems |
| Siemens | KTR Couplings | Schaeffler | Fugro Seascore | Hunger Hydraulics | Protective & Marine Coatings | Brüel & Kjær Vibro GmbH |
| Winco/ Dayton | Bailey | SKF | SeaRoc | Hydac | Akzo Nobel Coatings | SKF |
| Alstom/TGL | Eaton | Bailey | aquamarine power | Bailey | ICI paints | James Fisher Marine Services |
| Andritz Hydro/ Hammerfest | SKF | NSK | James Fisher Marine Services | Seaproof Solutions | Jotun | |
| Baltic | | | | | | |
| PTO & generator | Electrical & automation | Bearings | Marine O&M | Hydraulic components | Coating | Diagnostic |
| Bosch Rexroth | ABB | Schaeffler | A2SEA A/S | Hunger Hydraulics | Hempel | Voith |
| SKF | Eaton | SKF | EDF | Andritz Hydro/ Hammerfest | Protective & Marine Coatings | SKF |
| Siemens | Metso | NSK | DNV GL | Hydac | Sherwin-Williams | Brüel & Kjær Vibro GmbH |
| The Switch | KTR Couplings | NKE | | Parker | ICI paints | |
| Schottel | VEO | Wolfgang Preinfalk | | | BASF Coating AG | |

| Wave | | | | | | |
|---|---|---|---|---|---|---|
| Mediterranean | | | | | | |
| PTO & Generator | Electrical & Automation | Bearings | Marine Operations | Hydraulic Components | Coating | Diagnostic |
| Siemens | ABB | Hutchinsons | Oceantec | D&D Ricambi | Protective & Marine Coatings | Metrohm |
| Bosch Rexroth | Eaton | SKF | Robert Bird | Hydac | Akzo Nobel Coatings | SKF |
| Alstom/TGL | SKF | NSK | | Parker | Hempel | |
| SKF | Emerson Industrial Automation | NKE | | | Jotun | |
| | Leroy-Somer | Bosch Rexroth | | | | |
| Caribbean | | | | | | |
| PTO & Generator | Electrical & Automation | Bearings | Marine Operations | Hydraulic components | Coating | Diagnostic |
| Northern Lights | Bailey | Waukesha Bearings | | Hydac | Protective & Marine Coatings | C&C Technologies |
| Winco | Eaton | SKF | | Parker | Hempel | SKF |
| SKF | ABB | Hutchinsons | | Prince | Akzo Nobel Coatings | Hoffer Flow Controls Inc. |
| Marathon generators | SKF | NSK | | Bailey | Jotun | |
| Bosch Rexroth | General Electrics | Bailey | | | | |

### 4.3.3 Lifecycle Stage

Figure 4.15 presents the life cycles stages for ocean renewables (Ecorys 2013). It will be noted that the stages are similar to those of offshore wind.

Table 4.6 presents the Life Cycle Stages for Wave and Tidal technology types.

It can be seen that the tidal industry has two technology types in the Growth phase.

The Wave energy industry has no technology types in the growth phase, all still in the embryonic phase. In addition to this negative picture, is the recent news of four companies liquidating, each company a flagship representative of a wave energy technology type of subsector. Oscillating water

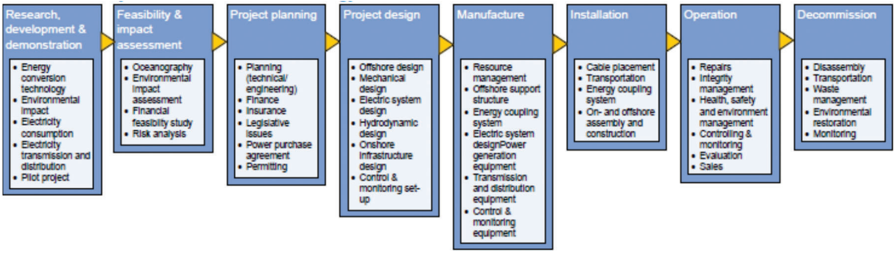

**Figure 4.15** Life Cycle stages for Ocean energy. Image taken for Ecorys report (Ecorys 2013).

**Table 4.6** Life cycle stages for Wave and Tidal industry, subdivided in technology types

| Sector | Sub Sector | Life Cycle Stage |
|---|---|---|
| Tidal Energy | Fixed 3 blades | Growth Stage: multiple companies at array testing |
| | Fixed open centre | Growth Stage: Open Hydro at array testing phase |
| | Floating Tidal | Embryonic Stage; At prototype development phase |
| Wave Energy | OWC | Embryonic Stage; At prototype development phase<br>Ocean Energy Buoy and GRS at prototype testing in Hawaii |
| | Over Topping | Embryonic Stage; At prototype development phase: WaveDragon in Wales and Fred Olsen Bolt |
| | Small scale devices kW | Embryonic Stage; At prototype development phase: Albatern and Seabased |
| | Point Absorber | Liquidated: WaveBob<br>Carnegie Australia, OPT USA, SeaTricity UK |
| | Multiple point absorber | Liquidated: Wavestar |
| | Attenuator | Liquidated: Pelamis |
| | Hinge Flap | Liquidated: Aquamarine<br>Wave Roller: Embroyonic |

columns and Overtopping are the only technologies types remaining, thus indirectly demonstrating technology convergent through attrition.

See Section 4.5 ‘Innovation’ for more details on wave and tidal companies and their lifecycle stage.

## 4.4 Working Environment

### 4.4.1 Job Creation and GVA

The European Commission 2012 report on Blue Economy (European Commision 2012) stated that the EU’s blue economy represents 5.4 million jobs and a gross added value of just under €500 billion per year. In all, 75% of Europe's external trade and 37% of trade within the EU is seaborne. Much of this activity is concentrated around Europe's coasts, but not all. Some land-locked countries host very successful manufacturers of marine equipment.

Figure 4.16 shows that Ocean Energy comprises a small proportion of the Blue growth Jobs and GVA total percentages (European Commision 2012). However, Ocean energy is well positioned to contribute to regional development in Europe, especially in remote and coastal areas. Parallels can be drawn with the growth of the wind industry.

Based on the projections for installed capacity for ocean energy, the following reports quote a wide range of job creation potential for ocean energy and summarised in Figure 4.17:

- Ecorys (2010) (Ecorys 2013) In 2010 about 1000 people were estimated to be employed in the ocean renewable energy sector and about

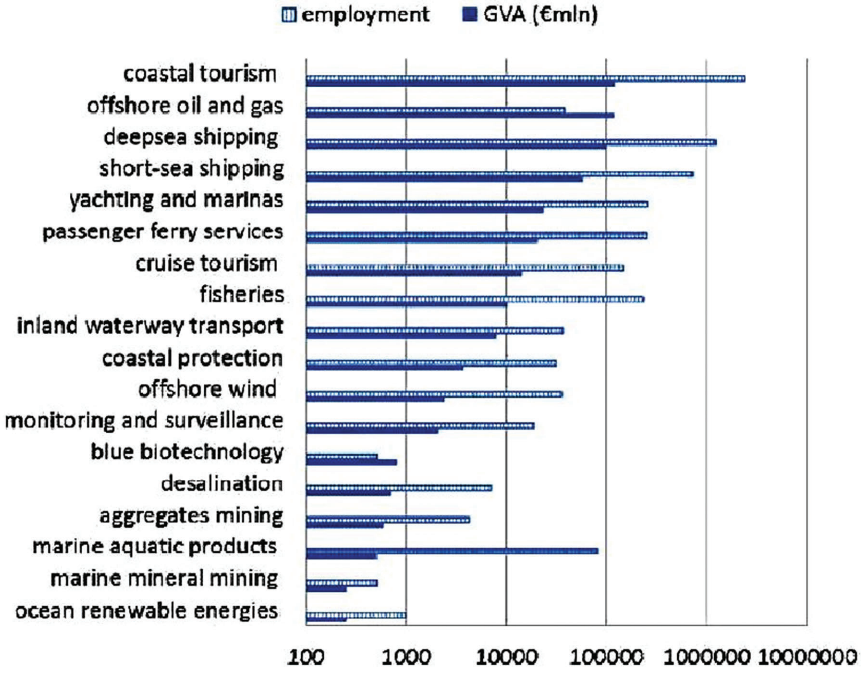

**Figure 4.16** Job employment and GVA for Blue Growth, including ocean energy wave and tidal. Image taken form European Commission Blue Growth Opportunities COM(2012) 494 final (European Commision 2012).

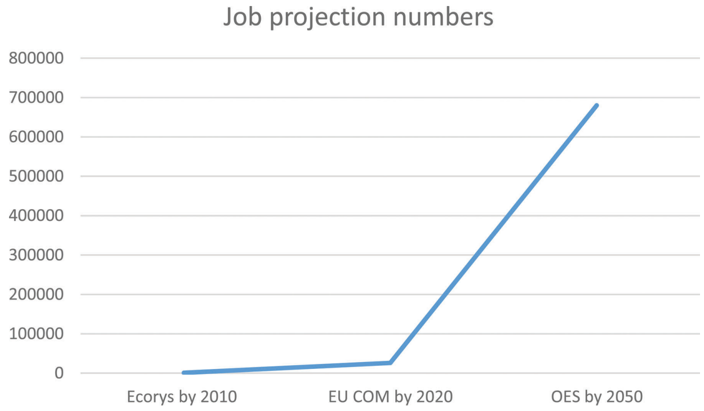

**Figure 4.17** Job projection numbers for ocean energy – visual summary of data from reports.

€250 million of GVA was created in the EU. The great majority was depending on the developments in the Atlantic Arc.

- EU-OES (2010): by 2020 the ocean energy sector will generate over 26,000 direct and 13,000 indirect jobs, for a total of close to 40,000 (EU-OEA 2010). By 2050 these numbers would increase to 314,213, 157,107 and 471,320 respectively. The EU-OEA report further states that if 3,6 GW was installed in Europe by 2020 it would result in an investment of around €8,544 M, generating 40 thousand jobs. By 2050, achieving 188 GW could lead to an investment of €451B and the creation of around 471 thousand jobs.
- European Commission (2014) (European Commision 2014) indicates that indicative job estimates from the impact assessment show that 10,500–26,500 permanent jobs and up to 14,000 temporary jobs could be created by 2035. Other, more optimistic sources estimate 20,000 jobs by 2035 in UK alone (RenewableUK 2013) and 18,000 in France by 2020[18]. A substantial proportion of these employment opportunities will arise in the Atlantic coastal areas, which currently suffer from high unemployment.
- By 2050, the OES (OES 2016) has updated its international vision for ocean energy stating that by 2050 ocean energy has the potential to have deployed over 300 GW economic growth and job creation, estimated by the OES in 680,000 direct jobs.

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[18] French Senate (2012), Report on Maritime Affairs at: http://www.senat.fr/rap/r11-674/r11-6741.pdf

- Other job predictions:
    - UK based (RenewableUK 2011, Energy and Climate Change Committee of the House of Commons 2012): 70 GW creating 68,000 jobs
    - US Based (Ocean Renewable Energy Coalition (OREC) 2011): 15 GW creating 36,000 jobs

#### 4.4.1.1 Jobs/MW for wave and tidal in comparison to wind

Dalton et al. published a detailed paper analysing the metric of Job/MW relating to wind, wave and tide (Dalton and Lewis 2011). The paper stated that the onshore wind industry in Europe reported a total of 13 jobs/MW (direct jobs) were created on average for wind capacity installed in one year only (2007 in the study), or 1.9 jobs/MW (direct jobs) if using cumulative MW was used in the estimation. Installation job rates for many renewable energy technologies can be as labour intensive as fabrication. The European Photovoltaic Industry Association (EPIA) (EPIA 2004) states that more jobs could be created in the installation and servicing of PV systems than in their manufacture (30 jobs/MW). However, this figure contrasts dramatically to the wind energy installation job/MW figure quoted by the EWEA; 9 jobs/MW in their 2004 report (EWEA 2004), and 1.2 jobs/MW in their 2008 report (EWEA, Blanco et al. 2008) (perhaps because they used cumulative MW in estimations).

Wave and tidal studies on jobs/MW are very few as there is no real data to model.

Batten et al., (Batten and Bahaj 2006) in 2006 produced a comprehensive prediction of job creation for wave and tidal, based on each stage of the development of an ocean energy project, as well as direct and indirect jobs (Figure 4.18). This data was used in the report European Ocean Energy Association 2010 report, “Waves of Opportunity” (European Ocean Energy Association 2010). The analysis predicts the job/MW rate for both wave and tidal, direct and indirect, to be very similar, with wave having on average 1 job/MW more than tidal for each category. The greatest job intensities in device construction supply and foundation constructing (4-5jobs/MW for wave, 3jobs/Mw for tidal), followed by installation 1 job/MW. Batten’s report predicts that by 2015, 19 direct and indirect jobs/MW at the start, falling to 7 jobs/MW by 2020. Direct jobs in device and foundation supply are quoted at around 10 jobs/MW falling to 3.5 jobs/MW.

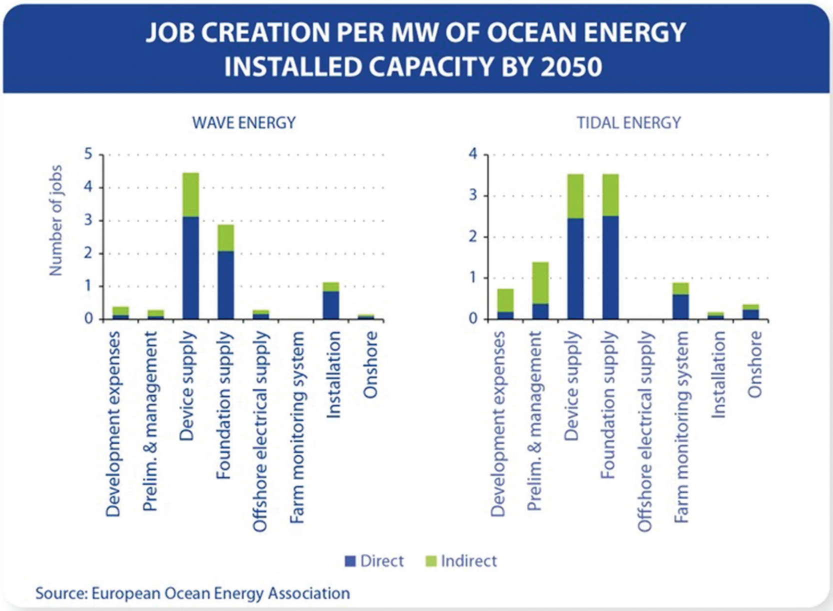

**Figure 4.18** Job creation per MW of Ocean Energy. Image taken from SETIS Ocean Energy Association 2010 (European Ocean Energy Association 2010).

Further reports predicting jobs/MW figures for 2050 based on at least 10,000+MW installed are:

- Ireland (SEAI 2012): 2.4 Jobs/MW (based on 70,000 jobs created installing 29 GW)
- UK (RenewableUK 2011, Energy and Climate Change Committee of the House of Commons 2012): 1.08 Jobs/MW (based on 68,000 jobs created installing 70 GW)
- USA (Ocean Renewable Energy Coalition (OREC) 2011): 2.4 Jobs/MW (based on 15 GW installed and 36,000 jobs)

### 4.4.2 Skills Required, Workforce Mobility and Availability/Competition for Skills

It is expected that workforce characteristics for ocean renewable energy will be similar to offshore wind and other offshore activities (Ecorys 2013). Ocean renewable energy requires a combination of skills from hydropower and offshore skills also needed for offshore wind, but also offshore oil & gas.

For different parts of the value chain, different skills are needed. Furthermore, as the sector is still under development, there are many research and consulting skills required.

### 4.4.2.1 Population centres versus ocean energy 'Hotspot' centres

Ideally, power production is located as close as possible to population centres to reduce energy loss via cable transmission. In the majority of northern European cases, the premium 'hotspot' sites are in remote locations, far from population centre. Analysis will be necessary to ascertain the economic optimum location taking both these factors into account.

Table 4.7 presents general information on skilled labour trends in 4 maritime basins. The following observations can be observed that are of relevance to wave and tidal development in the Atlantic and Baltic nations:

- Economies of Atlantic and Baltics nations are strong, with positive political stability favouring investment in the high-risk areas of Ocean Energy development.

**Table 4.7** Population stats for 4 maritime basins, labour costs and migration trends (information taken for Maribe WP4- Wave and Tide Context report)[19]

| | Atlantic | Baltic | Mediterranean | Caribbean |
|---|---|---|---|---|
| Population Stats | 311,871,390 | 145,911,069 | 482,217,455 | 344,520,725 |
| Pop growth or decline [%] | 0.27 | –0.05 | 0.81 | 1.03 |
| Economic climate (growing, static, decline) (GDP) [%] | 1.68 | 1.96 | 0.18 | 2.29 |
| Political stability (stable, neutral, unstable) [from –2.8 to 1.5] | 0.78 | 0.94 | –0.44 | 0.19 |
| Skilled labour (workforce with tertiary education) [%] | 33.8 | 33.1 | 23.3 | 21.3 |
| Skilled Migration trends | low labour mobility | relatively low labour mobility | relatively high labour mobility | high labour mobility |
| Annual average wage cost [$] | 49,193 | 35,345 | 16,851 | 14,658 |

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[19] http://maribe.eu/blue-growth-deliverables/blue-growth-work-packages/

- Third level skilled labour numbers are is high in Atlantic and Baltics nations favouring R&D in the high tech areas required for development of Ocean Energy.
- Negatives for the Atlantic and Baltics nations in developing ocean energy sector:
    - Labour mobility is low, posing a barrier to development of ocean energy in remote locations. Labour might be filled by highly mobile skilled workforce form Mediterranean and Caribbean.
    - Wages are high, posing a financial barrier to device development. Cheaper labour sourced from Mediterranean and Caribbean might be the solution.

### 4.4.2.2 Construction and fabrication skilled workforce

Manufacturing of turbines and other parts of ocean energy spare parts is mainly done by companies which have experience in related technologies. These bigger companies can easier shift workforce from one sector to the other. For example, Voith[20] used its knowledge from automotive industry, aerospace industry and apply it towards ocean renewable energy. Andritz[21] used its experience and knowledge on hydropower plants and transfers this towards the ocean tidal devices.

#### 4.4.2.2.1 *Shipyards*

WEC devices will more than likely need to be built in shipyards (Previsic 2004), where existing maritime construction expertise and facilities exist. So far, most of the WEC prototypes have been constructed in local shipyards e.g. OE buoy in Cork Dockyards[22], Wavebob in Harland and Wolf, Belfast[23] and the 'Mighty Whale' in the Ishikawajima Harima shipyards in Japan[24]. The steel sections and power conversion modules of Pelamis were constructed in Scotland, but were assembled at the site of deployment: e.g. Peniche shipyards in Portugal[25] and Hunters Bay shipyards in San Francisco (Previsic 2004). The last two decades have witnessed a major contraction in

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[20] http://voith.com/en/index.html

[21] http://www.andritz.com/

[22] http://www.irishexaminer.com/business/eco-energy-company-rides-on-a-wave-of-success-80844.html

[23] http://www.irishtimes.com/business/wave-generator-damaged-by-storm-1.1018087

[24] http://www.nsf.gov/pubs/1998/int9815/ssr9809.doc

[25] http://www.ain.pt/index.php/178703956051dad39d28963.pdf?mod=articles&action=downloadDocument&article_id=+++++++++++++++++237&document_id=256

**Table 4.8** Shipyards for the four marine basins

| Shipyards | | | |
|---|---|---|---|
| Atlantic | Baltic | Mediterranean | Caribbean |
| Harland & Wolff, Belfast, UK | Riga Shipyard, Riga, Latvia | Hellenic Shipyards, Piraeus, Greece | Grand Bahama Shipyard, Bahamas |
| Luerssen-Werft, Bremen, Germany | Western Shipyard, Klaipėda, Lithuania | Gibdock, Gibraltar | Ciramar Shipyards, Dom.Rep. |
| Peniche PT, Peniche, Portugal | Admiralty Shipyards, St. Petersburg, Russia | Tuzla Shipyard, Istanbul, Turkey | CL Marine Limited Caribbean Dockyard, Trinidad & Tobago |
| Damen Shipyard, Gorinchem, Netherlands | Meyer-Werft, Turku, Finland | Palumbo Shipyard, Messina, Italy | Cotecmar Shipyard, Colombia |
| Les Nefs Shipyard, Nantes, France | | | |

Europe's shipbuilding capacity (Stopford 1997). Consequently future large-scale production of WEC devices in European shipyards may not be viable. Even if the choice were available, overseas competing shipyards in Poland, Korea and China, could feasibly outbid local contractors even factoring in shipping costs, due to lower overseas wages and cost of materials (Salonen, Gabrielsson et al. 2006).

Table 4.8 presents a list of shipyards, categorised into four marine basins, that may potentially serve the wave and tidal industry in construction and maintenance.

### 4.4.2.3 Installation and operations & maintenance (O&M) skilled workforce

Installation and operations & maintenance (O&M) of the ocean energy devices, cables and moorings also requires a skilled workforce and facilities. Specialised tugs companies are required to toe the devices to site, experienced underwater divers are required for deployment and maintenance of WEC and moorings, and specialised cable laying services for the electricity connector cable. A local skilled workforce may not available in the location for construction and deployment, or may be in limited supply due to competing technologies such as offshore wind. An example of this situation was when Seagen's tidal turbine was supposed to have been installed by

**Table 4.9** Employment in operations and maintenance on ocean energy b7 2035. Table taken form Ecorys (Ecorys 2013)

| 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 |

a local specialised tug early 2008. A higher offer made by the Thames off-shore wind project for the tug services left Seagen without a boat for installation (ReNews 2008). It took another 3 months for another contractor to be sourced, at a far higher cost, for the single installation.

Ecorys (Ecorys 2013) predicts that in 2035 total employment in operations and maintenance on ocean energy ranges from 4,500–26,500, depending on the scenario chosen.

### 4.4.3 Availability/Competition for Skills

As in other related sectors, shortages in engineering skills might occur and ocean energy may have to compete with the main competing sector; offshore wind. In offshore wind in the UK from 2013 onwards bottlenecks are expected as energy sectors are expected to grow at the same time (Scott Dickinson, Jonathan Cook et al. 2011). This affects ocean renewable energy. In the short-run employment will need to come from other sectors (e.g. offshore wind, offshore oil & gas) (Scott Dickinson, Jonathan Cook et al. 2011).

Ecorys (Ecorys 2013) predict that SMEs may struggle to attract skilled people from related sectors to fill skill requirements. Big companies will not be exposed to this risk due to the fact that they should be able to shift employment within their organisation, as per example of Voith and Adritz detailed above.

### 4.4.4 Infrastructure and Support Service Requirements

The necessary infrastructures such as reinforcing electrical grid networks and deepening of ports required for the roll-out of large-scale ocean renewables are still many years from materialising (Intelligent Energy Europe (IEA) 2010). Investors see that most sites of high ocean renewable potential are very remote from population centres, with inadequate current plans for upgrading facilities to the scale of development planned. Investor confidence will be significantly boosted if it sees major government funding to upgrade infrastructures at this current time, providing the ingredients for a successful future technology development roll-out.

## 4.5 Wave Technology Innovation

### 4.5.1 Wave Technology Innovation

| Technology Categories | Company Examples | Technology Innovation and Future Development | Future Prospects |
|---|---|---|---|
| Attenuator | Pelamis | The Scottish based company Pelamis Wave Power went into administration in November 2014. The company was after being unable to secure the level of additional funding required for the further development of their technology[26]. Development agency Highlands and Islands Enterprise (HIE) has acquired th intellectual property and a range of physical assets previously owned by Pelamis. HIE has obtained the assets on behalf of Wave Energy Scotland (WES) | Liquidation (Assets are owned by WES) |
|  | Dexa-Wave | Danish company, Blue Ocean Energy (BOE) project aims to adapt and test the feasibility of the DEXA WAVE. The company participated in €6 million EU funded research, H2Ocean, on wind-wave power open-sea platform equipped for hydrogen generation with support for multiple users of energy. No news since 2012 | No news |
|  | AlbaTERN | Scotland's Albatern WaveNET device is a scalable array of floating "Squid" generator units that harvest wave energy as their buoyant arms rise and fall with the motion of the waves. Each Squid can link up to as many as three others, effectively | Progressing |

*(Continued)*

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[26] http://tidalenergytoday.com/2015/01/19/wave-energy-scotland-bags-pelamis-assets/

**Table:** Continued

| Technology Categories | Company Examples | Technology Innovation and Future Development | Future Prospects |
|---|---|---|---|
| | | creating a large, floating grid that is flexible in every direction. The bigger this grid gets, the more efficient it becomes at harvesting energy, and the more different wave movements it can extract energy from. Albatern's 10-year target is to have 1.25 kilometre-long floating energy farms pumping out as much as 100 megawatts by 2024 | |
| Flap | Aquamarine Power | Aquamarine the company which developed the Oyster 800 device is now in liquidation. Emerging from the group was the WavePOD consortium which aimed at developing a sealed sub-sea generating unit that can be used by many different WECs. The WavePOD is a standardised self contained generator,<br>at tenth scale testing for the moment. In November 2015, there were no offers made for Aquamarine Power as a going concern, and Aquamarine ceased trading. | Liquidation |
| | AW Energy | 2016–19, 5.6 MW nominal capacity, Installation in Peniche. 11–12 GWh targeted annual output, Project funding: EUR 9 million EU NER300 grant, EUR 13.5 million private investments, EUR 1.5 million Carbon Fund grant<br>AW Energy has commissioned a PTO testing centre to test real scale PTO units. WaveRoller has got the second endorsement from Lloyd's Register Energy (LRE). | Progressing (Not Static) |
| | Bio Power Systems Australia | The Bio Power Systems device, the BioWAVE, will soon be at ocean-testing phase. The data collected through this final test phase will enable the development of a larger 1 MW device commercial scale BioWAVE unit. | Progressing |

| Technology Categories | Company Examples | Technology Innovation and Future Development | Future Prospects |
|---|---|---|---|
| Single point absorber | Carnegie Australia | Carnegie is developing the new CETO 6 device. Size, efficiency and power generation capacity are increased (compared to CETO 5). The aim is to be able to harvest wave energy further offshore, in higher sea states, and at lower cost. The innovation lies in the fact that the buoy will integrate the power generation. Thus power will be generated offshore and then transferred onshore with cables. 2016, $7.5 million microgrid project, a 2 megawatt solar photovoltaic array, a 2MW/0.5 megawatt hour battery energy storage system and a “sophisticated” control system integrated with Carnegie’s CETO 6 wave technology and existing desalination plant | Progressing |
| | Ocean Power Technologies (OPT) USA | OPT is currently working on its PTO technology. This new technology will be integrated in the new device APB 350 (A1), followed by the APB 350 (A2) which geometry will be improved for a better operational stability and so that it can fit into a standard 40-foot container (to reduce transportation and deployment costs).<br>In 2016, OPT announced the deployment of its commercial design of the PB3 PowerBuoy approximately four miles off of the coast of New Jersey | Progressing |
| | Seatricity UK | Future improvements are two-fold: research optimisation options for predicted device outputs used to compare the results with the full scale Oceanus 2 testing, and examine the tether loadings in storm conditions to improve the mooring system. | Progressing |

*(Continued)*

**Table:** Continued

| Technology Categories | Company Examples | Technology Innovation and Future Development | Future Prospects |
|---|---|---|---|
| Multipoint absorber | Wavestar | Wavestar was one of the longest surviving wave energy companies. Private investment of approx. €80 M over 18 years led to 1/4 scale testing of its device at Hanstholm. Wavestar succeeded in H2020 LCE3 funding, total €30 M. Unfortunately key partner financing withdrawal, and uncertainty if deployment location, led to the H2020 fund cancelation, ultimately leading the liquidation of Wavestar. | Liquidation |
| | Global Renewable Solutions (GRS) Australia | GRS is currently in the process of project planning for a 1/4 scale deployment. GRS is working closely with The SEA Ireland to develop the Atlantic Marine Energy Test Site which will enable GRS to test the performance of their pre commercial Power Platform. | Progressing |
| Oscillating Water Column | Oceanlinx | Oceanlinx wave energy device 'greenWAVE' sank during the transportation from Port Adelaide to Port MacDonnell. The company then went into liquidation. | Liquidation |
| | OE Bouy Ireland and USA | The longest surviving OWC technology company. Received funding from US DOE in 2016 for deploying 4/5 scale device at *US* Navy's Wave Energy Test Site, Kaneohe, *Hawaii* in Hawaii at 4/5 scale. https://energy.gov/sites/prod/files/2016/04/f30/100590.pdf | Progressing |
| | Voith Hydro WaveGen | In March 2013 Voith Hydro decided to close down Wavegen choosing to concentrate on tidal power projects. | Liquidation |
| Overtopping | Wave Dragon Denmark and UK | Applying for Wales/Ireland funding, deploy 4 MW full scale device in Wales for 2019. | Static |
| | Fred Olsen Bolt Norway | Sound & Sea Technology (SST) has completed the assembly of Fred. Olsen's Lifesaver wave energy converter ahead of its planned deployment at Navy's Kaneohe Bay Wave Energy Test Site (WETS) in Hawaii. | Progressing |

### 4.5.2 Tidal Technology Innovation

| Technology Categories | Company Examples | Technology Innovation and Future Development | Future Prospects |
|---|---|---|---|
| Horizontal Axis 3 blade Fixed | Atlantis Resources Corp UK | Atlantis Resources Limited has almost completed construction of the first phase of the MeyGen project – the world's largest planned tidal stream array; in Scotland's Pentland Firth. 2017 is due to be spent expanding the array to a capacity of 6 MW, thus completing phase 1A of the project. Full capacity across all phases is to be up to 398 MW. | Progressing |
| | Andritz Hydro Hammerfest Norway | ANDRITZ HYDRO delivered three turbines to MeyGen project; The Project "Development and Optimization of a Drive Train for Tidal Current Turbines" was successfully completed in 2015 after running for more than two and a half years. | Progressing |
| | Sustainable Marine Energy UK | successfully installed four subsea drilled rock anchors at its Fall of Warness for their first PLAT-O system, which hosts two SCHOTTEL Instream Turbines (SIT). | Progressing |
| | Nova Innovation Scotland | Nova Innovation are currently exporting power from two turbines installed off the coast of Shetland in Scotland, with a third turbine due to go live in early 2017. | Progressing |
| Horizontal Axis 3 blade Floating | Nautricity Ltd UK | Nautricity) are due to run test and demonstration projects at EMEC in the course of 2017 | Progressing |
| | Scotre newables UK | Construction of first phase (10 MW) expected to start in 2017 550-tonne 2 MW tidal turbine arrived at EMEC in 2016, | Progressing |
| | TidalStream Limited UK | The TRITON, developed by SCHOTTEL HYDRO subsidiary TidalStream Ltd., carries. 40 SCHOTTEL Instream Turbines, reaching a total nominal | Progressing |

*(Continued)*

**Table:** Continued

| Technology Categories | Company Examples | Technology Innovation and Future Development | Future Prospects |
|---|---|---|---|
| | | power output of 2.5 MW. Deployment at FORCE, Bay of Fundy, Canada, is scheduled for 2017. | |
| Venturi | Open Hydro/ DCNS Ireland/ France | Openhydro installing a turbine in the Bay of Fundy (a scaled-up version of the 6m turbines. They have been testing at EMEC since 2007) | Progressing |
| Kite | SeaCurrent NL | SeaQurrent has conducted the first tests on its 'multi wing' tidal kite technology at the MARIN research institute in the Netherlands. | |
| | Minesto Sweden | In 2017, Minesto plans to build and commission the first demonstrator of the Deep Green technology at commercial scale. The device will be installed at Minesto's site in Holyhead Deep, some 8 km outside the coast of northern Wales. In Holyhead Deep, for which Minesto holds an Agreement for Lease from the Crown Estate, the company will gradually expand installed capacity to a 10 MW commercial array (20 Deep Green units). Minesto has received funding from KIC Innoenergy and European Regional Development Fund through the Welsh Government. | Progressing |

## 4.6 Concluding Remarks

Ocean energy research and development started in earnest in the early 1970's, in the wake of the oil crisis (Cruz 2008). In 2006, the Carbon Trust stated that the value of worldwide electricity revenues from wave and tidal stream projects could potentially be substantial, with predictions of electricity revenues between €75 billion/year and €237 billion/year, requiring Investments of over £500 bn (€600 bn) contributing 2000 TWh/year worldwide (Carbon Trust and Callaghan 2006).

With such commercial potential, a question that must be asked in 2017 is "*Why has the wave and tidal industry in 2017 not established itself as a competing renewable technology*" (Dalton 2010, Dalton 2014)? The contributing ingredients to the delay in consolidation of the sector are multidimensional. However significant progress has been made particularly in the tidal sector.

The primary issue for the majority of investors is lack of confidence. Stated simply, there are no fully commercial arrays of wave or tidal devices in the water (Meygen may be considered a commercial array depending on definition), demonstrating that neither technology currently have the technical capacity to generate reliably.

On the positive side, tidal technology development is moving to the final stages of pre-commercial demonstration (eg Meygen), raising the confidence levels in that sector substantially. In many respects tidal technologies are an extension of well-proven wind technologies. Tidal technologies are now being tested at pre-commercial phase via private and public (FP7/NER300) project funding, with relatively few technical setbacks. Tidal energy seems certain to be technically viable, and in time should become economically and commercially viable. However, the market is niche, due to the limited global tidal energy resource.

Wave energy development, on the other hand, has been hampered by a lack of confidence in current existing technology concepts. It has been questioned how so many wave energy companies move all the way through the TRL levels, reaching pre-commercial scale, and fail. The current lack of confidence in wave energy technology development is reflected by the recent closures of some longstanding wave development companies e.g. Pelamis, Aquamarine, and, Wavestar. Moreover, two major NER300 projects for wave demonstration have also been withdrawn or postponed: Waveroller, as well as the Westwave project.

Wave projects have failed to achieve, what may be overambitious TRL, design and testing targets, set by funders. Consequently a lack of investor confidence has dried up funding added to this, additional pressures from government support mechanisms which rewards energy production rather than robust designs (Alcorn, Dalton et al. 2014).

More stringent concept evaluation, driven centrally, by government funding bodies, at early stage development would eliminate the weakest design concepts. Stringent adherence to stage testing along the TRL scale should help ensure positive technical results. Investors increasingly require evidence that this standardised technology development approach is implemented. Finally, strong and consistent national government driven policy (Dalton and Gallachóir 2010), combining best practice pull and push market mechanisms based on successful innovation development is crucial to bring pre-commercial ocean energy companies to commercial ready stage.

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