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Analysis of the European Supply Chain

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EXECUTIVE SUMMARY

DTOceanPlus will accelerate the commercialisation of the Ocean Energy sector by developing and demonstrating an open source suite of design tools for the selection, development, deployment and assessment of ocean energy systems (including sub-systems, energy capture devices and arrays). The suite of tools will include a Structured Innovation tool, for technology concept selection, a Stage Gate tool, for the technology development process, as well as a set of Deployment Design and Assessment tools for the design of the system and its evaluation. This suite of design tools will reduce the technical and financial risks of the technology to achieve the deployment of cost-competitive wave and tidal arrays. DTOceanPlus will underpin a rapid reduction in the Levelised Cost of Energy offered by facilitating improvement in the reliability, performance and survivability of ocean energy systems and analysing the impact of design on energy yield, operations & maintenance and the environment, thus making the sector more attractive for private investment.

These objectives and impacts will be achieved through the implementation of 9 work packages covering user engagement, tool development, demonstration of tools against real projects (thus outputting a suite of tools at TRL 6), analysis of supply chains and potential markets, exploitation, dissemination and education.

WP8 will conduct research related to the ocean energy marketplace and combine this with results generated and lessons learnt during the project in order to produce a freely available, state of the art knowledge base.

Task T8.2 will gather the information gained as part of DTOceanPlus to develop a complete understanding of the supply chain across Europe. This will include inputs from the consortium and potential users of the tools including developers, funders, investors and other groups represented in the project, as well as the experiences from real case studies, which helped to inform the analysis.

The public deliverable D8.2 "Analysis of European Supply Chain" analyses the value chain of ocean energy, regarding its stakeholders, structure, current engagement and breakdown of project costs. It explores the mapping of the opportunities for European companies and encompasses the typical project lifecycle activities, such as project management, supply of ocean energy devices and balance of plant, as well as the installation, commissioning, operations&maintenance, and decommissioning activities.

The similarities between Offshore Wind and Ocean Energy are presented in this report and can be exploited to transfer knowledge and experience. These similarities can be found not only on the technological aspects but also on the installation, operations&maintenance, commissioning and decommissioning. Taking advantage of these potential synergies can help address the challenge related to the cost competitiveness of Ocean Energy technologies as well as encourage third parties to engage with the Ocean Energy sector and enter the value chain.

Cost competitiveness is identified as a major challenge facing the Ocean Energy sector, since the majority of the existing technologies are not yet in a commercial stage and cannot compete with

other more mature renewable energy technologies. The detailed assessment of costs is still a difficult task within the sector given the scale and number of deployments to date.

Ocean Energy is bringing unique challenges to marine governance frameworks. Legal and regulatory aspects are frequently regarded as major non-technical challenges to the deployment of ocean energy, as a stable and complete policy framework for the ocean energy sector is currently missing, being currently tailored for more established uses of the sea, such as the oil and gas industry, fishing, and shipping.

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ABBREVIATIONS AND ACRONYMS

DG-MARE	Directorate General for Maritime Affairs and Fisheries
DMEC	Dutch Marine Energy Centre
Dx.x	Deliverable x.x from a task or work package
CAPEX	Capital Expenditure
CfD	Contract for Difference
EMEC	European Marine Energy Centre
EPCI	Engineering Procurement Construction and Installation
EU	European Union
EWEA	European Wind Energy Association
EWTEC	European Wave and Tidal Energy Conference
FiP	Feed in Premium
FiT	Feed in Tariff
ICOE	International Conference on Ocean Energy
IEA-OES	International Energy Agency- Ocean Energy Systems technology collaboration programme
JRC	Joint Research Centre
LCoE	Levelised Cost of Energy
MEPB	Marine Energy Programme Board
MESCG	Marine Energy Supply Chain Gateway
MRE	Marine Renewable Energy
MSP	Marine Spatial Planning
O&M	Operations and Maintenance
OEM	Original Equipment Manufacturer
OE	Ocean Energy
OEC	Ocean Energy Converter
OPEX	Operational Expenditure
OW	Offshore Wind
PCP	Pre-Commercial Procurement
PESTLE	Political, Economic, Sociological, Technological, Legal and Environmental
PPA	Power Purchase Agreement
PSO	Public Service Obligation
PTO	Power Take-Off
RD&D	Research, Development and Demonstration
R&D	Research and Development
RE	Renewable Energy
SPV	Special Purpose Vehicle
TEC	Tidal Energy Converter
TRL	Technology Readiness Level
Tx.x	Task x.x within a work package
WEC	Wave Energy Converter
WES	Wave Energy Scotland
WP	Work Package

1 INTRODUCTION

1.1 DTOCEANPLUS PROJECT

DTOceanPlus will accelerate the commercialisation of the Ocean Energy sector by developing and demonstrating an open source suite of design tools for the selection, development, deployment and assessment of ocean energy systems (including sub-systems, energy capture devices and arrays).

At a high level, the suite of tools developed in DTOceanPlus will include:

- **Structured Innovation tool**, for concept creation, selection, and design.
- **Stage Gate tool**, using metrics to measure, assess and guide technology development.
- **Deployment tools**, supporting optimal device and array deployment.
  - Site Characterisation (e.g. metocean, geotechnical, and environmental conditions);
  - Machine Characterisation (to characterise the prime mover);
  - Energy Capture (at an array level);
  - Energy Transformation (PTO and control);
  - Energy Delivery (electrical and grid issues);
  - Station Keeping (moorings and foundations);
  - Logistics and Marine Operations (installation, operation, maintenance, and decommissioning).
- **Assessment tools**, to quantify key parameters:
  - System Performance and Energy Yield;
  - System Lifetime Costs;
  - System Reliability, Availability, Maintainability, Survivability (RAMS);
  - Environmental and Social Acceptance.

This suite of design tools will reduce the technical and financial risks of the technology to achieve the deployment of cost-competitive wave and tidal arrays. DTOceanPlus will underpin a rapid reduction in the Levelised Cost of Energy (LCoE) offered by facilitating improvement in the reliability, performance and survivability of ocean energy systems and analysing the impact of design on energy yield, operations & maintenance (O&M) and the environment, thus making the sector more attractive for private investment.

These objectives and impacts will be achieved through the implementation of nine work packages covering user engagement, tool development, demonstration of tools against real projects (thus outputting a suite of tools at TRL 6), analysis of supply chains and potential markets, exploitation, dissemination and education.

Through its work on a market analysis and implementation feasibility of ocean energy technologies, DTOceanPlus will conduct research to underpin innovation across the entire sector, not just for users of the DTOceanPlus tools. Analysis and recommendations for development in the fields of supply chain (this report), as well as potential markets, business models, exploitation plans and legal/ institutional/political barriers will be produced.

1.2 SCOPE OF THE REPORT

The deliverable D8.2 "Analysis of the European Supply Chain" is mainly focused on maximising impact of the project. It is a public deliverable of the DTOceanPlus project, produced in the context of WP8, Task 8.2.

Work package WP8 will conduct research related to the ocean energy marketplace and combine this with all results generated and lessons learnt during the project in order to produce a freely available, state of the art knowledge base. This work will combine the knowledge gained throughout the project and demonstrate how the results can be integrated into improved methods of creating, delivering, and capturing value, both for individual organisations and for the sector as a whole. The specific objectives of this WP are:

- Produce a detailed assessment of potential markets for ocean energy technology.
- Analyse critically the European supply chain, including a cost-benefit analysis to deliver sustainable impact for the ocean energy sector (which is the aim of this report).
- Propose improved business models and pricing methods for ocean energy.
- Establish the integration of these methods in the design tools.
- Forecast progress towards achieving long term target impacts.
- At a higher level, report how legal, institutional and political frameworks could act as a barrier or enabling element for future deployment of ocean energy.

More specifically, task T8.2 will gather information gained as part of DTOceanPlus to develop a complete understanding of the supply chain across Europe. This will include input from the consortium and potential users of the tools including developers, funders, investors and other groups represented in the project, as well as the experiences from real case studies.

Previous studies, such as those detailed in ANNEX II: REVIEW OF PREVIOUS SUPPLY CHAIN STUDIES, have provided overviews of the supply chain and ocean energy market as well as listed strengths and weaknesses in regional and national supply chains. Therefore, there is room for a systematic assessment of the opportunities and limitations encountered to date for the development of the ocean energy supply chain. This report will pursue this objective focusing on the case of Europe. Coupled with the benefits of DTOceanPlus tools, this deliverable seeks to aid the ocean energy sector on its path to commercialisation.

1.3 STRUCTURE OF THE REPORT

The public deliverable D8.2 develops a complete understanding of the supply chain across Europe and is structured as follows:

- **Section 1: Introduction**. Explains the context and the objectives of the DTOceanPlus project and briefly describes the scope of this document.
- **Section 2: Ocean Energy Sector Overview**. Presents an overview of the ocean energy sector attending to its opportunities, needs, state-of-the-art, markets, volume and nature of supply and support policies.

- **Section 3: Ocean Energy Supply Chain**. Describes the value chain of ocean energy regarding its stakeholders, structure, current engagement with the ocean energy sector and breakdown of project costs.
- **Section 4: Mapping of European Opportunities.** This section addresses the development phases of deployment of marine projects (that includes development, project management, construction, installation, commissioning, operation, maintenance and decommissioning) for Europe.
- **Section 5: Limitation and Challenges for the supply chain.** This section presents the technical barriers, standardisation and certification, financial risks, lack of track record, contracting and legal framework.
- **Section 6: Conclusions.**

2 OCEAN ENERGY SECTOR OVERVIEW

Interest in the ocean energy sector is driven by the large potential resource of renewable energy, with many developers exploring how to exploit this. The technically exploitable resource worldwide could meet a significant portion of current electricity demand. The wave energy resource has been estimated to be around 2,000 to 5,500TWh/yr, with the tidal energy resource (including tidal range) around 1TW (~3,000TWh/yr), as discussed in section 2.2.3.

Both the European Marine Energy Centre (EMEC) and the European Commission's Joint Research Centre (JRC) show there are many developers active in the sector. EMEC provides a list of 253 wave energy devices, and 97 tidal stream energy devices, as of 2019 [1]. The JRC listed the number of active companies in 2016 at 43 for wave and 34 for tidal energy [2] [3].

The budget available for research, development, and demonstration (RD&D) of ocean energy projects is rising, showing the interest of both private and public investors. This is covered in more detail in the DTOceanPlus study of Potential Markets [4].

A study performed by the University of Edinburgh in 2013 produced an International Marine Energy Attractiveness Index [5] investigating 21 countries across fundamental themes of the ocean energy supply chain: resources, policy, finance, industries and infrastructures. The results of the surveys show a significant interest in ocean energy from the United States, the United Kingdom, France, Canada, Spain and Chile. A major role in this field is played by regulatory support, and of course from the support of developers, researchers and investors interested in ocean energy.

Considering the significant role that electricity is expected to play in the future global energy system, it is important to review how ocean energy is expected to progress and what kind of contribution it could make to the electrification trend [6].

Wave and tidal stream technologies will either need to be cost-competitive with technologies such as offshore wind or provide additional benefits in comparison with similar technologies to make them more attractive alternatives [4].

2.1 STATE OF THE ART

2.1.1 SUPPLY CHAIN MODEL

Designing a supply-chain operating model, which encompasses the supply chain's organisational structure, governance, and processes, becomes an increasingly complex undertaking, as stated in McKinsey's article[1]. All these components of such a model have to be carefully designed especially when referring to fully commercial sectors and more mature technologies.

In pre-commercial sectors, such as ocean energy, building a resilient supply chain structure to service the emerging market is an important component of sector development towards full

[1] https://www.mckinsey.com/industries/consumer-packaged-goods/our-insights/is-your-supply-chain-operating-model-right-for-you

commercialisation [7]. Having a stronger market demand, in a complementary manner, will make the supply chain more resilient. Therefore, the supply chain structure will be further explored at section 3.1.1.

A report produced by OCEANERA-NET consortium provide lists of companies and examples of supply chain models [7]: their structure primarily reflects the stage of development of ocean energy technology, with a tendency to cover most of the aspects of the supply chain as part of their research, technology development and innovation activities. However, with some technologies progressing to demonstration and pre-commercial stages, particularly in tidal energy, the establishment of a resilient supply chain is becoming increasingly topical, because it contributes to shaping individual company strategies as well as the sector as a whole, becoming a significant part of their competitive advantage.

The activities illustrated in Figure 2.1 are integral to the structure of the ocean energy supply chain and are going to be fully described in section 3.1.1.

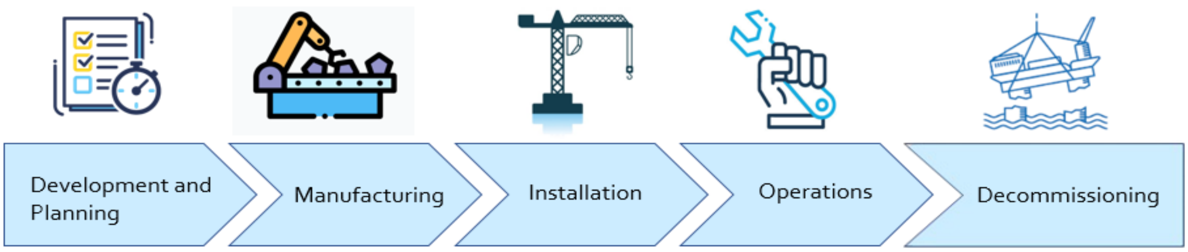

FIGURE 2.1: SUPPLY CHAIN FOR OCEAN ENERGY

2.1.2 PATHS TO COMMERCIALISATION AND SUPPORT POLICIES

The path to commercialisation for emerging technologies is a complex and dynamic process. Technology improvements, market demand, organisational dynamics and support policies can alter a technology's development path. The latter can have a particularly influential role. These can, for example, shape the marketplace for technologies or ensure that the technologies do not have detrimental social or environmental impacts.

Figure 2.2 depicts potential paths to commercialisation. Four stages are identified in which technology innovation occur: i) prototype and demonstration; ii) wide cost and performance gap; iii) narrow cost and performance gap; and iv) competitive without financial support [8]. As a technology progresses through these stages, different stakeholders come into play and different support policies are required. Figure 2.2 conveys the message that this path is not linear and cannot be achieved unilaterally. Innovation and long-term track records serve as the foundation for widespread deployment in paths that occur concurrently and in, sometimes, overlapping stages of the process. Progress relies on RD&D for novel technologies and improvements to existing technologies, learning-by-doing (i.e. incremental improvements as experience with the technology is gathered), scale-up of production (enabling economies of scale and optimised value chains), and exchange of knowledge among stakeholders and sectors/industries.

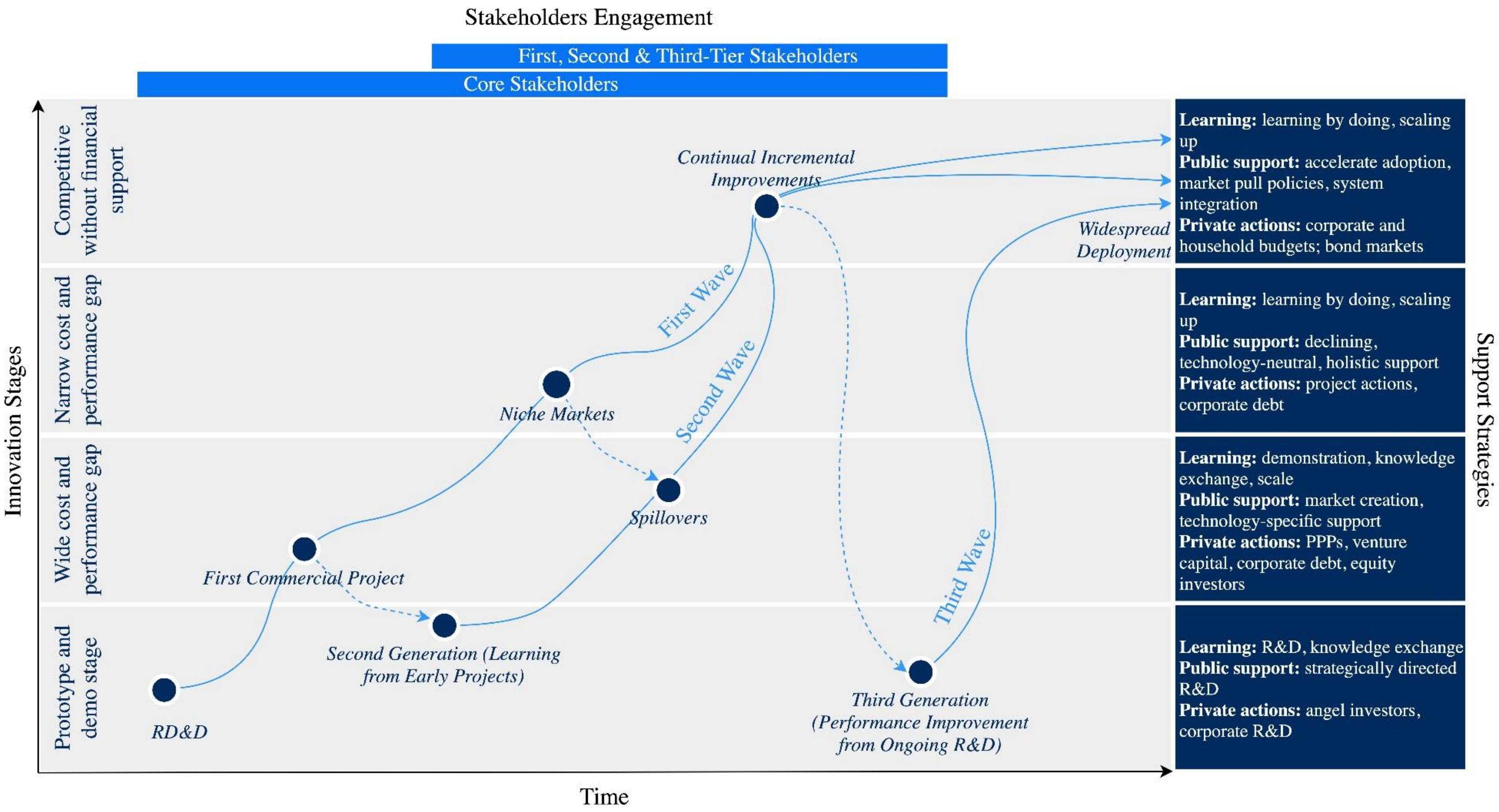

FIGURE 2.2: THE TECHNOLOGY INNOVATION PROCESS, STAKEHOLDERS ENGAGEMENT AND SUPPORT STRATEGIES FOR EMERGING ENERGY TECHNOLOGIES
SOURCE: ADAPTED FROM [8]

At the prototype and demonstration stage, research and development (R&D) are fundamental. R&D is undertaken in corporate research labs, universities, government research institutions and small firms. It is followed by demonstration or testing, where information on costs and performance is made available for manufacturers, potential buyers and policy makers. At this stage, investors face the highest risks and there is strong governmental support. Policy instruments are utilised to enable access to finance. Strategically targeted public RD&D can effectively support projects at the prototype and demonstration stage. Public RD&D investment may come from venture capital and seed funding. Countries such as the UK and the US have programmes to provide seed funding to small innovative businesses [8]. In many other countries, there are numerous push policies that facilitate early-stage investment including public-private partnerships, loan guarantees, incubators and business networks, tax incentives and prizes. Most support strategies at this stage are primarily targeted to technology developers; however, this stage offers the opportunity to begin building up the supply chain [8].

Examples of successful RD&D policies in Europe can be found in the UK and Denmark. In 2013, the UK established the Offshore Renewable Energy Catapult (ORE Catapult), focused on innovation to accelerate the success of UK companies in the offshore wind, wave and tidal sectors. Since its beginning, the initiative has supported over 250 R&D projects and several hundred SMEs [9]. ORE Catapult seeks to create links between the UK supply chain and emerging offshore renewable energy markets. In Denmark, the Danish Energy Agency established the Energy Technology Development and Demonstration Programme (EUDP) to support the development, demonstration and market introduction of innovative sustainable energy technologies for a fossil-free Danish energy system by 2050. Under this programme, funding is allocated through a tender process that takes place 2-3 times a year. The precondition for receiving grants is that a private investor or applicant's partner is willing to finance more than half of the project and commercialise its results [10]. Furthermore, the Danish transmission grid operator Energinet.dk provides funding for a support research programme for the development and integration of environmentally friendly power generation technologies. There is a call for funding every year and the programme is financed through a Public Service Obligation (PSO) paid by final energy consumers [11].

At later stages of innovation and development, pull mechanisms are required to strengthen the market and develop the supply chain. These support policies include incentives for consumers of new technologies such as tax credits and rebates and investment subsidies; tradeable permits as portfolio standards and emission trading schemes; auctions; capacity markets; quota obligations; green certificates; and production subsidies such as feed-in-tariffs (FiTs), feed-in-premiums (FiPs) and contracts-for-difference (CfDs). Some examples are provided in Table 2.1 below.

TABLE 2.1: SAMPLE OF PULL MECHANISMS ADOPTED BY COUNTRIES AND APPLICABLE TO OCEAN ENERGY [12] [11]

Country	Pull mechanism applicable to ocean energy
United Kingdom	**FiT**. Accredited Renewable Energy (RE) plants with a capacity of up to 5MW sell their electricity to a FiT licensee at fixed rates that are updated annually by the Gas and Electricity Markets Authority (Ofgem). The rates vary per technology and date of eligibility. All technologies used in the generation of electricity from RE sources are eligible. As an example, the tariff for non-solar PV power is £55.0/MWh (~€60.9/MWh) exported [13]. **CfD**. The contract is based on a difference between the market price and an agreed "strike price". Eligible RE generators take part in an allocation round. The last allocation round took place in April 2017. All new RE plants over 5MW built after April 2017 are eligible.[2] **Tax regulation mechanism**. A Carbon Price Floor has been in place since April 2013 applicable to fossil fuels for electricity generation. RE is exempt from this tax [14].
Denmark	**Premium tariff**. The operators of RE plants usually receive a variable bonus paid on top of the market price. There is, nevertheless, a statutory maximum per unit of power and energy source that should not be exceeded by the sum of the market price and the bonus. Technologies such as wind energy, biogas, biomass, solar energy, wave and tidal energy as well as hydro-electric power stations not exceeding 10MW are eligible. For wave power plants commissioned between 2018 and 2020, the installed capacity must be less than 1MW to be eligible. Wave energy plants are deemed of strategic importance and plants with an installed capacity of up to 6kW may receive a maximum subsidy (bonus plus market price) of 130 DKK (approx. €17.4) per MWh, applicable for 10 years after the grid connection. Plants with an installed capacity of more than 6kW may receive a maximum subsidy (bonus plus market price) of 600 DKK/MWh (~€80/MWh), applicable for the first 10 years of operation, and 400 DKK/MWh (~€53.5/MWh), applicable for a further 10 years.[3] **Net-metering**. Plant operators using all or part of the electricity produced for their own needs are exempt from paying the PSO or part of it. All technologies, except for geothermal energy, are eligible. Wave and tidal energy plants up to 11kW are exempt from the whole PSO tariff whilst plants larger than 11kW are exempt from the surcharge for the support of RE.[4]
Netherlands	**Premium tariff**. A premium can be granted to RE producers to compensate for the difference between the wholesale price of electricity from fossil fuels and the price of electricity from renewable sources. The sum is variable and depends on the annual electricity market price development. It is paid for a period of up to 15 years and allocated on a 'first come, first serve' basis. In general, all RE sources are eligible.[5] **Net-metering**. This applies to all technologies connected to the electricity grid through a small-scale connection (≤ 3x80A). The exact level of support depends on the amount of electricity fed-in to the grid and the client's electricity consumption.[6] **Tax regulation mechanism**. RE generators that use the electricity they consume may be exempt from the tax levied on electricity consumption (i.e. Energy tax). Plants generating electricity from waves and tidal flows are eligible for an exemption from the Environmental Protection Tax. This tax has several bands depending on the level of consumption and ranging from €0.06/kWh to €10.46/kWh.[7]

[2] http://www.res-legal.eu/search-by-country/united-kingdom/tools-list/c/united-kingdom/s/res-e/t/promotion/sum/204/lpid/203/
[3] Support system for Renewable Energy sources in Denmark.

Country	Pull mechanism applicable to ocean energy
Norway	**Quota system**. The Electricity Certificates Act obliges electricity suppliers and certain electricity consumers to prove that a certain quota of the electricity supplied by them was generated from RE sources [15]. Tradable certificates allocated to RE producers serve as evidence of compliance. Ocean energy is fully eligible. The quotas range from kro.137/MWh (~€13/kWh) of electricity in 2017 through kro.183/MWh (~€17/kWh) in 2025 to kro.008/MWh (~€0.75/kWh) in 2035. Eligibility ends after 15 years from the initial support date.[8]
France	The country aims at producing 9TWh of electricity from offshore wind and ocean energy by 2023 [16].[9] **FiT**. These shall progressively be replaced with the "compensation mechanism". However, small installations or non-mature energies such as wave, tidal and run-of-river plants can still benefit from FiTs for a period of 20 years.[10] **Premium tariff**. The premium tariff corresponds to the difference between the reference tariff called "Te" defined each year per technology, and the tariff obtained by the producer for the sale of its electricity production on the wholesale market. In addition, the RE producer is also eligible to a so-called "management premium", which aims at compensating the marketing and balancing costs of RE producers on the electricity market. Installations using the hydraulic power of lakes and watercourses as well as water piped via gravity are eligible, provided their installed capacity does not exceed 1 MW.[11] **Tenders**. The ministry responsible for energy may use bidding procedures at irregular intervals to reach the targeted production of electricity from renewable sources. In this regard, the multi-annual programming for energy (Programmation Pluriannuelle de l'Énergie) set out technology-specific targets in terms of total installed capacity to be developed by 2023.[12] **Tax regulation mechanism**. Persons investing in renewable energy plants are eligible for an income tax credit (Crédit d'Impôt). Furthermore, the purchase of such commodities by private individuals is indirectly promoted through a reduced VAT rate.[13]

Finding the adequate balance between push and pull mechanisms is important. These two types of support policies can enable appropriate levels of competition and stimulate innovation. DTOceanPlus D8.3 Feasibility and cost-benefit analysis will elaborate on this matter.[14]

The support policies considered here can support the development of the ocean energy (OE) sector, providing much needed confidence for new investors and regulatory stability. It is important to mention that these support initiatives are highly sector specific. However, the OE supply chain could

[4] http://www.res-legal.eu/search-by-country/denmark/single/s/res-e/t/promotion/aid/net-metering/lastp/96/
[5] http://www.res-legal.eu/search-by-country/netherlands/single/s/res-e/t/promotion/aid/premium-tariff-sde/lastp/171/
[6] http://www.res-legal.eu/search-by-country/netherlands/single/s/res-e/t/promotion/aid/net-metering-1/lastp/171/
[7] http://www.res-legal.eu/search-by-country/netherlands/single/s/res-e/t/promotion/aid/tax-regulation-mechanisms-i-reduction-of-environmental-protection-tax/lastp/171/
[8] http://www.res-legal.eu/search-by-country/norway/single/s/res-e/t/promotion/aid/quota-system-3/lastp/379/
[9] http://www.res-legal.eu/search-by-country/france/tools-list/c/france/s/res-e/t/promotion/sum/132/lpid/131/
[10] http://www.res-legal.eu/search-by-country/france/single/s/res-e/t/promotion/aid/tenders-appels-doffres/lastp/131/
[11] http://www.res-legal.eu/search-by-country/france/single/s/res-e/t/promotion/aid/premium-tariff-complement-de-remuneration-par-guichet-ouvert/lastp/131/
[12] http://www.res-legal.eu/search-by-country/france/single/s/res-e/t/promotion/aid/tenders-appels-doffres/lastp/131/
[13] http://www.res-legal.eu/search-by-country/france/tools-list/c/france/s/res-e/t/promotion/sum/132/lpid/131/
[14] To be published early 2021

also benefit from other support policies that support not only the OE sector but, more broadly, market access for new suppliers such as import and export licensees, border administration (i.e. efficiency of customs), telecom and transport infrastructure (e.g. availability of quality tracking and communication services) and business environment. These policies create conditions for healthy competition, thereby driving prices down and encouraging quality.

2.2 MARKETS

2.2.1 SIZE AND TRENDS

Ocean energy is abundant, geographically diverse, predictable, and environmentally friendly. Currently, Europe is at the forefront of ocean energy development. Between 2010 and 2019, 27.7 MW of tidal stream and 11.8 MW of wave energy was deployed in Europe [17]. Of this, 10.4 MW of tidal stream capacity and 1.5 MW of wave energy capacity are currently operating. The European tidal energy pipeline consists of a total capacity of approximately 4.4 GW, with expected dates for full commissioning between 2019 and 2027 [18]. According to the JRC [18], 43 companies are actively engaged in the development of tidal stream energy devices with a Technology Readiness Level (TRL) higher than 5. Almost 60% of these companies are in Europe. Similarly, about 3.5 GW of wave energy capacity is in the pipeline up to 2027 [18] and nearly 250 companies are engaged in the development of these technologies according to EMEC [1], of which approximately two-thirds are in Europe [18].

Regarding the supply chain, the number of European businesses involved in ocean energy is over one thousand and growing, as interest in exploiting ocean energy increases. This has been demonstrated by the participation of over 3,500 participants in recent editions of the International Conference on Ocean Energy (ICOE) and the participation of more than 700 attendees in the European Wave and Tidal Energy Conference (EWTEC) 2019 in Naples, Italy. An estimated 59% of the companies involved in the development of tidal energy are in Europe, primarily the UK, the Netherlands, France, Germany, Ireland and Italy [18]. Similarly, an estimated 64% of the companies involved in the development of wave energy technology are in Europe, particularly Denmark, Italy, the UK, Sweden, Spain, Ireland and France [18]. Furthermore, most suppliers related to offshore contracting, installation vessels, and system subassemblies are in Europe [19].

Considering all types of public and private stakeholders in the ocean energy value chain, the number of potential users is expected to exceed 4,000 including both utilities and off-grid markets.The global addressable market is estimated at €53bn per annum by 2050. While the value to individual users will vary significantly, the value for Europe can be found in accelerated achievement of strategic energy goals related to clean, affordable and secure energy supply. Total savings of around €2.5 billion in innovation investments can be expected from cumulative accelerated development of the sector [20] [17].

2.2.2 GLOBAL ELECTRICITY MARKET

The primary market for ocean energy is likely to be electricity. This can be either for grid power, use in remote coastal and island communities or industrial applications. In 2017, the global electricity demand was 23,696TWh, with European demand accounting for approximately 3,874TWh [21].

To tackle the challenge of climate change while addressing the strong growth in demand, large investments in renewable energy capacity is needed. These sources of clean energy are expected to account for up to two-thirds of electricity supply by 2040 [22]. Currently, despite the growth in renewable technologies, the global power mix is still dominated by coal and gas as can be seen in Figure 2.3. Nonetheless, considering recent technological developments and the climate emergency, there is scope for further development of all types of renewable electricity generation.

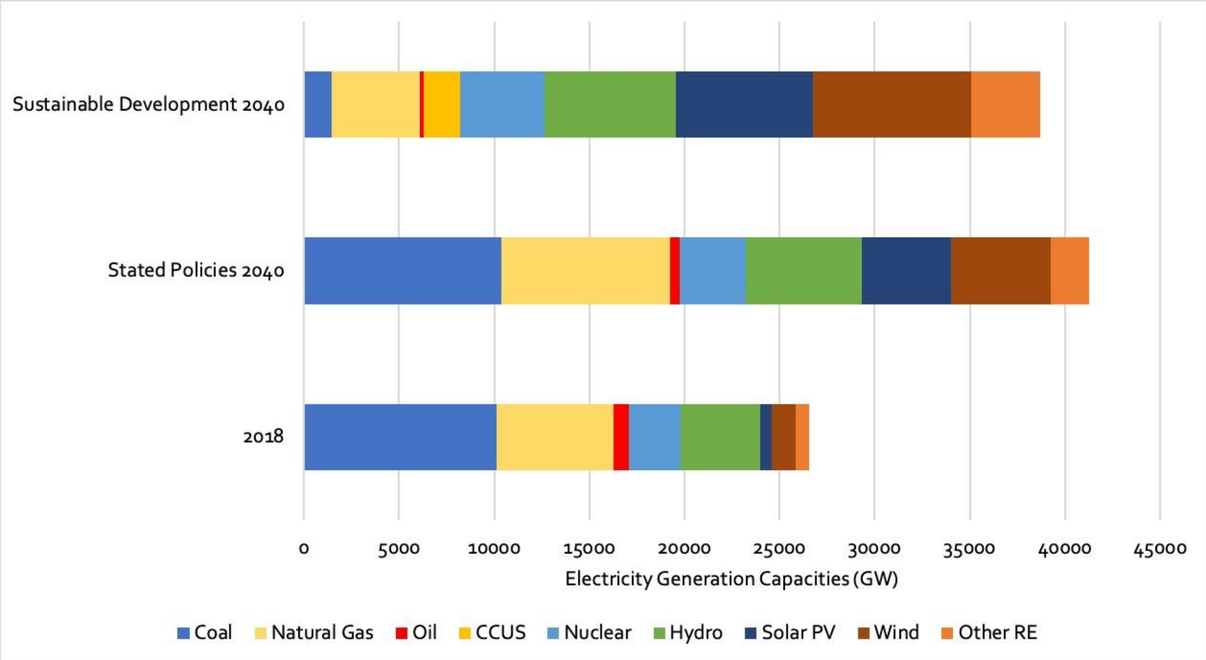

FIGURE 2.3: GLOBAL ELECTRICITY GENERATION MIX IN 2018 AND 2040
SOURCE: ADAPTED FROM WORLD ENERGY OUTLOOK 2019 [22]

2.2.3 OCEAN ENERGY RESOURCE

The global resource for wave and tidal-stream energy is extremely large and could potentially provide a significant proportion of electricity demand. Nevertheless, some caution needs to be taken when reviewing global resource estimates, as it is unlikely to be technologically or economically feasible to capture much of this large theoretical potential.

Figure 2.4 differentiates between three classes of resource assessment and some of the available estimates for both wave and tidal resource. Headline figures often give the theoretical resource, even though it is not technically, let alone economically, possible to extract this energy. The technical resource may be an order of magnitude less than the theoretical resource. The practical resource is also site and technology specific, so there are few, if any, studies covering the resource for a whole country or the world.

Although not feasible to harness, the global theoretical wave energy resource has been estimated at over 29,500TWh/yr[15], with approximately 2,800TWh/yr located in Western and Northern Europe [23]

[15] Excluding areas where wave power is very low ($P \leq 5kW/m$) and locations which may experience ice coverage at certain times of the year.

[24]. Globally, the technically extractable wave energy resource has been estimated to be around 2,000 to 5,500TWh/yr [25] [26], i.e. approximately 8% to 23% of 2017's electricity demand.

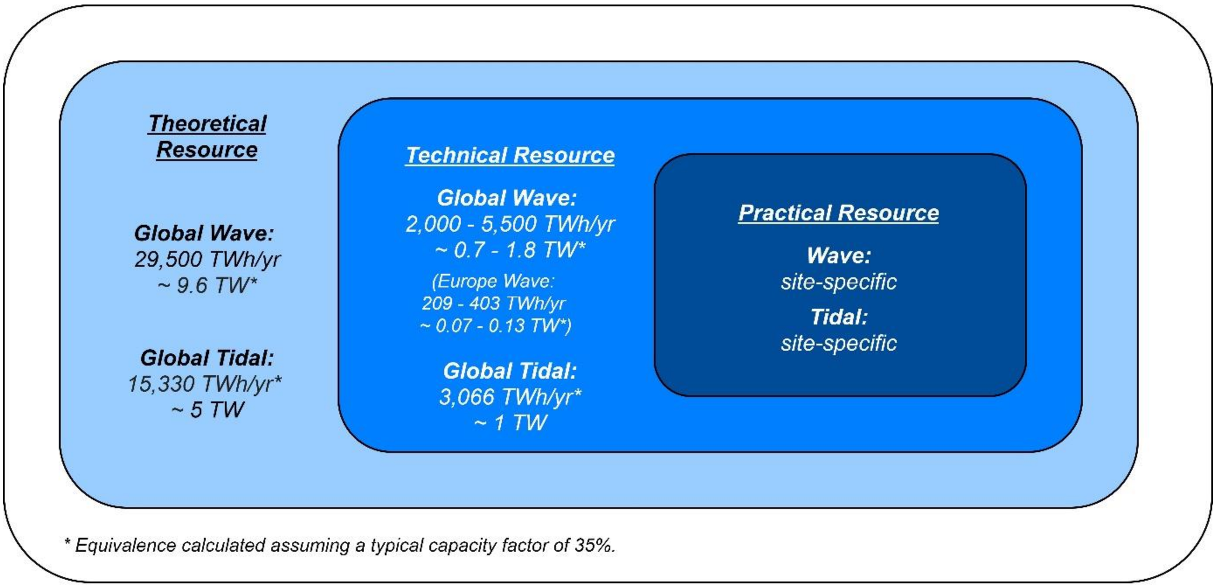

FIGURE 2.4: NESTED CLASSES OF RESOURCE
SOURCE: ADAPTED FROM [27], [23], [25], [28]

Various high-level reconnaissance assessments are available for global tidal resource, although these typically combine both tidal range and tidal stream. For example, Charlier and Justus [29] provide an estimation of 5TW of power from ocean currents. IRENA reports that technically harvestable tidal energy resource is estimated by several sources at around 1TW [30], with tidal stream having a much larger percentage of this than tidal range. The IEA has also estimated the total worldwide theoretical tidal energy resource (including tidal range) as being 1,200TWh/yr [28]. Detailed estimates for Europe suggest the technical resource could be in the region of 30–48TWh/yr [31] [32], or ~1% of the European electricity demand.

2.2.4 MARKETS FOR OCEAN ENERGY

The role of ocean energy in the energy transition can be reviewed both in the short-to-medium (i.e. to 2030) and medium-to-long term (i.e. to 2050). The Directorate General for Maritime Affairs and Fisheries (DG-MARE) [33] estimates that a maximum of 2,388MW of tidal stream capacity and 494MW of wave energy capacity can be expected by 2030. According to the European Commission's [18], up to 29.9GW of cumulative tidal energy capacity and 30.9GW of cumulative wave energy capacity can be deployed in Europe by 2050. This report states that the UK, France, Ireland, the Netherlands, Spain and Germany represent countries with potential for tidal energy deployment, whilst Spain and Portugal could be the most relevant markets for wave energy across Europe.

Although ocean energy technologies have not reached commercial scale and are not yet competitive in the utility electricity market, there are other applications and niche markets where these technologies may be more cost competitive. The types and sizes of these potential markets for ocean energy technologies are assessed as part of the DTOceanPlus project under task 8.1 and the results are reported in deliverable D8.1 "Potential markets for ocean energy technology" published in Jan 2020 [4]. A thorough description of the markets can be found in that report. Figure 2.5 summarises those markets.

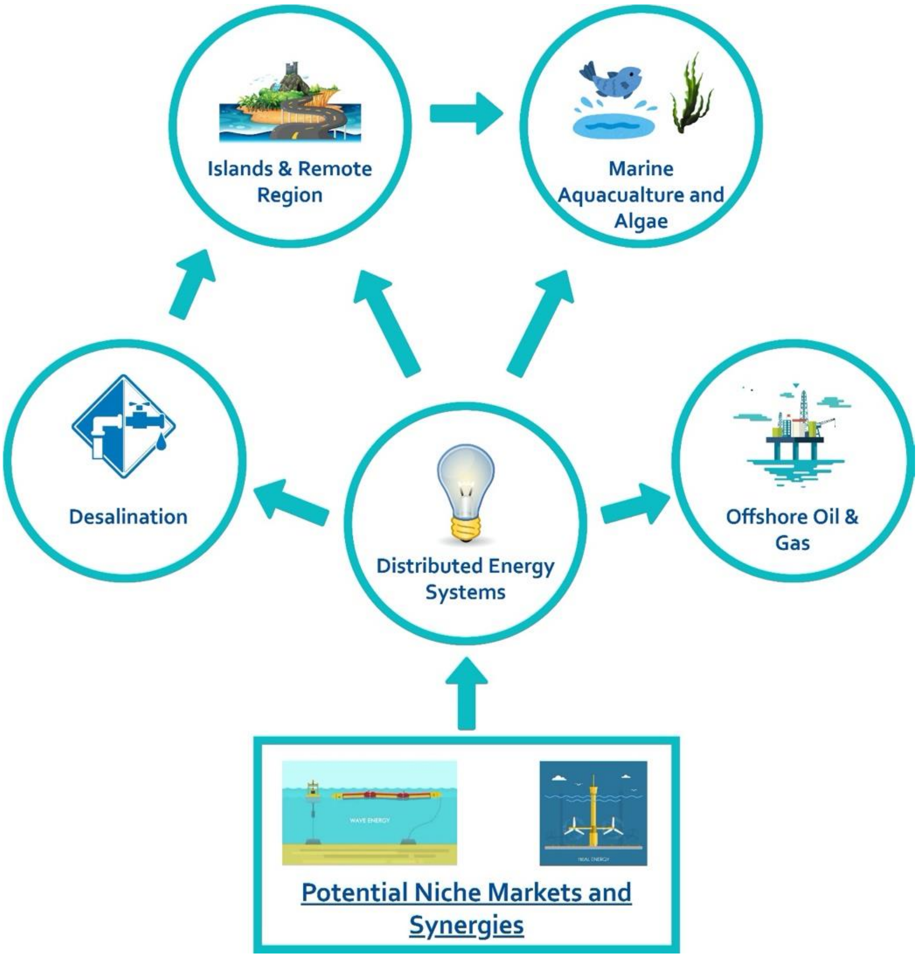

FIGURE 2.5: SUMMARY OF POTENTIAL MARKETS REVIEWED IN DTOCEANPLUS DELIVERABLE 8.1

Some of these applications are complementary, for example coastal recovery might need desalination to supply clean water or marine aquaculture may be located in isolated communities: this actually provides a benefit for the establishment of smart local energy systems. Business models for these markets will be addressed in the future deliverable of the project, D8.4 Specific sector standards for business management models for the ocean energy sector.

2.2.5 VOLUME AND NATURE OF SUPPLY

The DG MARE "Market Study on Ocean Energy" [33] reported that in the next 5 years, 897 MW of tidal stream technology from 25 projects and 111 MW of wave energy technology from 16 projects will be deployed in Europe. In addition, it is expected that at least 67 MW of tidal stream (8 projects) and 10 MW of wave energy (2 projects) will be installed outside Europe over the next few years. Over €6 billion has already been invested worldwide into ocean energy projects and €9.4 billion of investments are foreseen until 2030.

The more mature ocean energy technologies have reached the demonstration phase and a set of array deployment projects are underway. In its first annual report, the H2020-OceanSet project reported that in Europe in 2018, 12 technologies with a TRL>7 were in operation. As the maturity of ocean energy technologies is growing, the nature of supply is changing and the supply chain is becoming more structured.

The nature of supply up to now was mainly in engineering and testing work, with a strong focus on the design of systems in multidisciplinary engineering work, combining electro-technical, fluid dynamics and mechanics. As the first machines are being deployed at sea, new challenges are occurring, which may have strong impacts on delays and competitiveness. Information sharing between projects, industrialisation of the manufacturing and dedicated installation standards will enable project developers, technology providers, authorities, and all stakeholders of the supply chain to adopt strategies to reduce delays and cost.

This report provides an analysis of the organisation of the supply chain, identifying the main challenges, as well as cost breakdown structure expected for ocean energy device projects. Exploring these topics will further support investments in ocean energy devices and projects and help to achieve the €9.4 billion of investments by 2030 as estimated by DG MARE [33].

3 OCEAN ENERGY SUPPLY CHAIN

3.1 SUPPLY CHAIN STRUCTURE AND STAKEHOLDERS

As interest in ocean energy grows and the associated technologies progress, it is pertinent to clearly understand the sector's value chain. The strength of the supply chain can be a determinant for the development of the sector and the advance towards commercialisation.

3.1.1 STRUCTURE

The companies and organisations involved in the wide range of activities required for the development of ocean energy projects can be categorised according to their participation in the different lifecycle stages of the projects. Figure 3.1 summarises these stages. There is a related supply requirement associated with each of these stages. Throughout each project stage, technology developers play an active role in enabling ongoing technological advancements and thus strengthening the sector.

FIGURE 3.1: TAXONOMY OF THE OCEAN ENERGY SUPPLY CHAIN

The **Development and Planning** stage refers to the initial requirements of development, consenting, licensing and project management work usually procured by the developer. These activities may include, but are not limited to, engineering design, environmental and wildlife surveys, administrative and professional services, and environmental monitoring required during construction.

The **Manufacturing** stage refers to construction activities and can be further categorised into device and balance of plant. The former includes the body of the device, its structure and prime mover, the electrical system, etc. as well as the associated commissioning costs related to the device. The latter includes foundations and moorings, electrical infrastructure and transmission systems, substations and export cables, among others.

The **Installation** stage refers to transportation (including dedicated vessels), pre-assembly work, installation of the support structures, mooring systems, etc., as well as commissioning work that does not relate to the device but to the rest of the system.

Operations refers to routine operation and maintenance, unplanned services and repairs, and condition monitoring.

Finally, **Decommissioning** refers to the disassembly, removal and disposal of the device and support structures, environmental work and monitoring legally required at this stage, as well as recycling of materials, where possible.

With the ocean energy sector being in a pre-commercial phase, the supply chain has not yet settled into a structure akin to that in offshore wind, where clear tiers of supply have emerged [34]. The tiers that would be expected in an established sector are:

- Tier 1 suppliers: Prime contractor
  - *Major component suppliers, usually long-term players with appropriate experience in the industry and highly competent.*
- Tier 2 suppliers: Principal supplier
  - *Medium size players partnering with Tier 1 suppliers and taking partial ownership of a site in a familiar market to develop understanding of the contracting and project delivery.*
- Tier 3 suppliers: Specialist supplier
  - *Small suppliers who can adapt quickly to the market and offer solutions for the industry.*

In order for ocean energy to reach this stage of supply chain maturity, it will need the market to develop to a point where there is a demand for standardised goods and services. In the meantime, developers are either relying on "off-the-shelf" solutions which, although cost effective may not be ideal, or bespoke engineered solutions with high development and manufacturing costs.

In ocean energy, it is often the case that the developer of the technology will also adopt the role of project developer. This typically leads to a multi-contracting model where contracts are managed in-house for each of the key activities; the alternative to this is the EPCI model (engineer, procure, construct, install) where larger contracts are issued to a small number of suppliers for key supply elements.

Within the offshore wind (OW) sector, it has mostly been large established developers that have used the multi-contracting model as they have the balance sheet to accept the risk associated with issuing so many contracts. Ocean energy technology developers do not usually have a large balance sheet and are, therefore, exposed to increased risk when issuing multiple contracts. Ocean energy developers are usually small teams with significant resource constraints, projects smaller than OW and contracts are often issued to smaller, local suppliers (Tier 3).

Another consideration in ocean energy is that projects are frequently developed using public funds (such as grants); in some cases, this necessitates the use of public procurement services (such as Public Contracts Scotland[16]) in order to generate competition, encourage local content, and demonstrate good value. This can have the consequence of making the developer feel like they are not in control of the process. As the sector matures it is likely that the supply chain structure will evolve in response.

Current market conditions and the technology status of ocean energy converters have delayed the consolidation of the supply and value chain of the sector, which is highly dependent on the success of technology developers in delivering viable ocean energy technologies. However, the value chain is expected to grow significantly along with the number of devices deployed.

Considering the current European supply chain, the number of businesses involved in ocean energy is over one thousand and growing as interest in exploiting ocean energy increases. Most of these suppliers are in France, Germany, the Netherlands, Ireland, Denmark, Italy and the UK [36]. Moreover, considering all types of public and private stakeholders in the ocean energy value chain, the global addressable market of the DTOceanPlus tools is expected to exceed 4,000 potential users. While the value to individual users will vary significantly, the value for Europe can be found in accelerated achievement of strategic energy goals related to clean, affordable, and secure energy supply.

3.1.2 STAKEHOLDERS

The traditional view of measuring project success has evolved through time to include stakeholder satisfaction. OE stakeholders can be defined as individuals, collectives and organisations who have an interest in wave and tidal energy technologies, who can influence project development or be affected by the project, as well as those who can directly or indirectly impact the decision-making processes.

In addition to the supply chain, the ocean energy value chain also involves different high-level and core stakeholders, including public and private investors, utility companies, and project developers. A recent study on wave energy led by Sandia and NREL in the WaveSPARC project identified twenty-six different stakeholders having an active role in the project lifecycle [37]. Adapting the findings from this study, the stakeholders and supply chain participants in the value chain can be grouped into four categories as depicted in Figure 3.2. Their role over the different lifecycle stages is also depicted and examples of these stakeholders are provided.

[16] https://www.publiccontractsscotland.gov.uk/

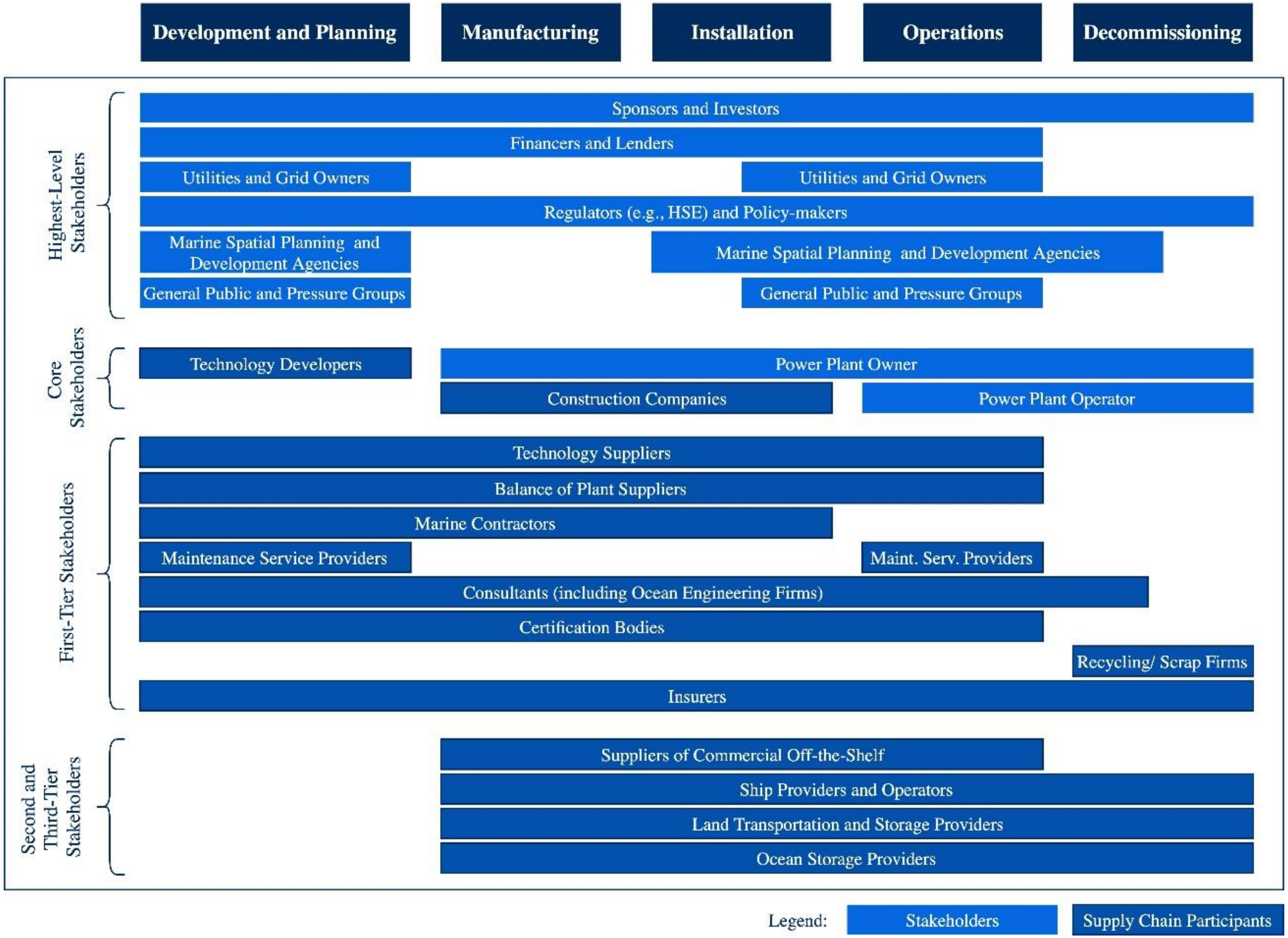

FIGURE 3.2: STAKEHOLDERS INTERACTING OVER THE LIFECYCLE OF AN OCEAN ENERGY PROJECT
SOURCE: ADAPTED FROM [37]

High-level stakeholders

For future, grid connected, utility-scale ocean energy projects, other stakeholder roles will emerge. Typically, this will involve the creation of Special Purpose Vehicle (SPV) companies to develop, build, maintain, and operate the ocean energy project for its lifetime. The SPV will be the project owner and central administrative entity. It acquires financing, hires a developer, organises power purchase agreements with the off-taker (the buyer of the electricity generated), and maintains overall responsibility for the profitability of the project. The shareholders of this company are the **sponsors** of the project, and their percentage of ownership in the company is proportional to the equity that they have invested.

The SPV company will raise the capital needed to develop and build the project as a mixture of debt and equity. During the development phase, it is common that **sponsors and third-party investors** provide equity. When the project is fully developed, the SPV will secure funds to pay the construction mainly with loans. Loans are secured by project assets and paid entirely from project cash flow. If the SPV has difficulties complying with loan terms, **project lenders** can assume control of the project.

During the consultation process, the **general public and pressure groups** may play an important role in setting further conditions for project approval. Project developers will also engage with organisations that have a strategic interest in ocean energy or represent the interests of other groups, even if not required to do so by law. This can include any groups that may significantly influence the development, either with their support or their opposition (e.g. environmentalists, political parties, community bodies, trade associations, unions, media, or even the general public).

The Government can provide investment and generation incentives to develop the project. There are a number of support mechanisms and policies available as described in Section 2.1.2. These include competitive bidding (i.e. tender or auctioning schemes), renewable energy targets, feed-in tariffs or feed-in premiums, capital subsidies, and tax incentives.

The term **investor** can group all organisations or individuals who contribute with capital and/or resources to the development of renewable energy projects, small or large scale, and who anticipate a financial benefit (e.g. private equity and venture capital organisations, banks, wealthy individuals, ordinary consumers and communities, corporations, utilities, and government bodies).

Over the past years, **marine spatial planning** (MSP) has gained considerable importance: a great number of countries[17] have chosen to use a MSP process to bring together the multiple users of the ocean and coastal areas. This ensures a more coordinated and sustainable approach to growing the "Blue Economy" while also considering biodiversity conservation.

Engagement with **policy makers** is crucial in order to ensure that such a new technology is recognised as a viable energy source. By taking part in planning and implementation of OE projects, they might help to resolve non-technical barriers [38].

[17] For a thorough description of the undertaken initiatives consult: http://msp.ioc-unesco.org/world-applications/overview/

- **Core stakeholders**

Project developers are contracted by the owner to plan and develop the ocean energy farm, often from the beginning stages of site assessment through the final stage of commissioning. The project developer will acquire project rights for siting and permitting of the farm.

- **First-tier stakeholders**

The SPV company is responsible for meeting all the obligations stipulated by **regulators** in the site lease. The term regulator is used here to cover all national, regional, or local government bodies that have an administrative or regulatory role defined by legislation. **Independent (certification) bodies** will assess conformity of the project with regards to international standards.

The SPV will enter into different agreements with specialised **firms for construction, operation and maintenance of the project**. Generally, risks are transferred to these contractors. These suppliers include those in the three tiers described in section 3.1.1. Usually, lower tier suppliers provide various goods and services to the main contractors. An **insurance company** is chosen to provide coverage during the construction and operation phases.

- **Second and third-tier stakeholders**

The **commercial suppliers** and **storage providers** interact only indirectly with the core stakeholders, since they are suppliers to the first-tier stakeholders. There are expected to be large numbers of second and third-tier stakeholders, competing in a large market, likely to be broader and not limited to the ocean energy market.

Ship providers for OE can leverage from the more consolidated experience of the offshore wind sector, at both installation and logistics stages.

Finally, the broader consumer body includes individuals and organisations that consume energy and/or pay taxes. The project charges end-users for the energy produced, collects payments, and uses that revenue to cover its costs. Prior to construction, a Power Purchase Agreement (PPA) can be signed with an off-taker, often a utility company, who ultimately sell it to consumers. If lenders can see the company has a purchaser of its production, it makes it easier to obtain financing.

This great variety of ocean energy sector stakeholders will be able exploit the results of the DTOceanPlus project to the benefit of their existing business interests. In this sense, the DTOceanPlus tools can significantly contribute to the development of the ocean energy sector.

3.2 BREAKDOWN OF PROJECT COSTS

The DTOceanPlus suite of new and improved design tools will enable the development of more cost-effective arrays, hence reducing the cost of energy. By leveraging an extensive suite of deployment and assessment tools, DTOceanPlus users will be able to select, develop and deploy technologies that have been optimised for cost effectiveness in a fully integrated deployment scenario. This capability will underpin a reduction in the LCoE offered by ocean energy technologies and allow them to become more cost competitive with other power generation technologies. Such cost competitiveness is crucial since private financiers have to be convinced of the benefits of investment.

The most important parameters for project development are the revenue over the project lifetime and the costs (meaning the overall cost including development, turbines, construction, operations, maintenance, etc.). The costs are often split into capital costs (CAPEX) and operational costs (OPEX) as seen in Figure 3.3. Investigation into the external conditions influencing the economic viability and techno-economic assessment of wave and tidal energy devices and arrays remains cutting edge.

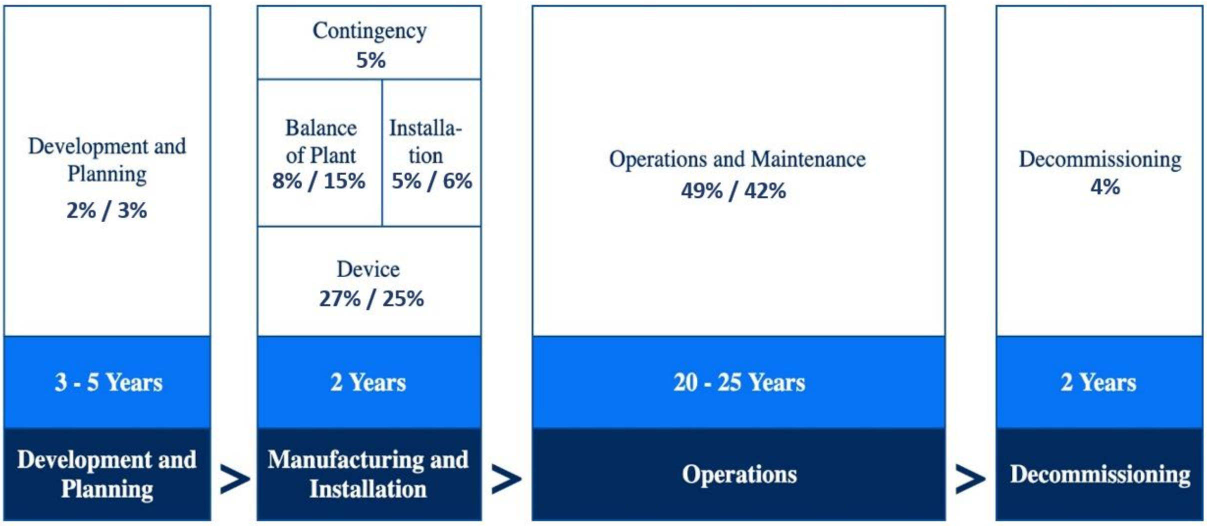

FIGURE 3.3: AVERAGE LIFETIME COSTS FOR WAVE AND TIDAL FARMS
SOURCE: ADAPTED FROM[18], USING DATA FROM THE REPORT [39].

The values (%) in Figure 3.3 refer respectively to:

- Typical cost breakdown for a small-scale (<5MW) wave energy project (point absorber type) commissioned in 2020 with an expected lifetime of 20 years; and
- Typical cost breakdown for a small-scale (<10MW) tidal stream project commissioned in 2020 with an expected lifetime of 25 years.

Table 3.1 and Table 3.2 highlight some of the opportunities for cost reduction in each sector.

[18] https:// www.renewableuk.com/resource/resmgr/publications/supply_chain_review_31.01.20.pdf

TABLE 3.1: SUMMARY OF OPPORTUNITIES (WAVE) FOR REDUCING COSTS, ACCORDING TO [32]

	Capex reduction	Yield improvement	Opex reduction
Structure & prime mover	Material optimisation Upscaling of devices Batch and serial production Reduced over-engineering Regional manufacturing	Geometry optimisation Optimisation of array layout	
Power take-off	Improved power electronics Improved hydraulic system Alternative / Improved PTOs	Improved control systems and algorithms Improved hydraulic system Improvements in metocean forecasting Drive train optimisation Improved power electronics Array yield optimisation	Modular subsystems
Foundations & moorings	Improved moorings Improved foundations Improved piling techniques Cost effective anchors for all sea bed conditions	Deep water installation techniques	
Connection	Off-shore umbilical / Wet-mate connectors Subsea hubs Array electrical system optimisation (transformers etc.) Offshore grid optimisation	Optimised subsea transmission to reduce losses	Improved connection and disconnection techniques
Installation	Specialist vessels Modularisation of subsystems Improvements in metocean forecasting Fast deployment and other economic installation methods Subsea and seabed drilling techniques Improved ROV and autonomous vehicles		
O&M		Improved availability through: Intelligent predictive maintenance Techniques to reduce weather dependency	Increased reliability Modular components Simpler access Specialist vessels Far offshore O&M strategy

TABLE 3.2: SUMMARY OF OPPORTUNITIES (TIDAL) FOR REDUCING COSTS, ACCORDING TO [32]

	Capex reduction	Yield improvement	Opex reduction
Structure & prime mover	Material optimisation Upscaling of devices Batch and serial production Reduced over-engineering Multiple rotor platforms Regional manufacturing	Optimisation of siting to maximise yield Micro-siting techniques Improved yaw and pitch mechanisms Hydrodynamically optimised structures Upscaling length of blades	Multiple rotor platforms
Power take-off	New drive train configurations Alternative and improved PTOs	Direct drive Improved hydraulic actuation systems Improved control systems and algorithms Array yield optimisation	Modular subsystems
Foundations & moorings	Improved subsea/seabed drilling Specialist vessels Improved piling and fixing techniques Improved mooring techniques (floating devices)	Floating or neutrally buoyant devices accessing high energy flows Hydrodynamically optimised foundations/platforms	Specialist vessels
Connection	Off-shore umbilical / Wet-mate connectors Subsea hubs Array electrical system optimisation (transformers etc.)		Improved connection and disconnection techniques
Installation	Specialist vessels Improvements in metocean forecasting Modularisation of components Improved ROV and autonomous vehicles		
O&M		Improved availability through: Intelligent predictive maintenance Techniques to reduce weather dependency	Intelligent predictive maintenance Increased reliability Modular components Simpler access Specialist vessels Improved ROV and autonomous vehicles

The main source of existing information for the ocean energy sector is provided by the offshore wind industry. Although there are significant differences between the two sectors, the greater level of development of wind energy, similar budget conditions and similar environmental challenges (in the case of offshore wind) make the lessons learnt from the wind sector particularly relevant for the development of the ocean energy sector. [40]

Indicators to estimate the economic impact of wind energy consider parameters which take into account several aspects and stages of the energy production process. An EWEA report [41]illustrates the key elements that determine the basic costs of wind energy. Namely:

- Upfront investment costs.
- The costs of wind turbine installation.
- The cost of capital, i.e. the discount rate.
- Operation and maintenance costs.
- Other project development and planning costs.
- Turbine lifetime.
- Electricity production, the resource base and energy losses.

These components of costs are represented in Figure 3.4. When studying the economic impact of wind farms, different metrics or units can be used for each component, in order to focus the attention onto the most sensitive variable. For example, the investment cost of the wind farm can be expressed in terms of capacity installed (addition of upfront/capital costs plus variable costs). If incorporating the energy production, it is of more interest to express the cost of wind energy per kWh produced.

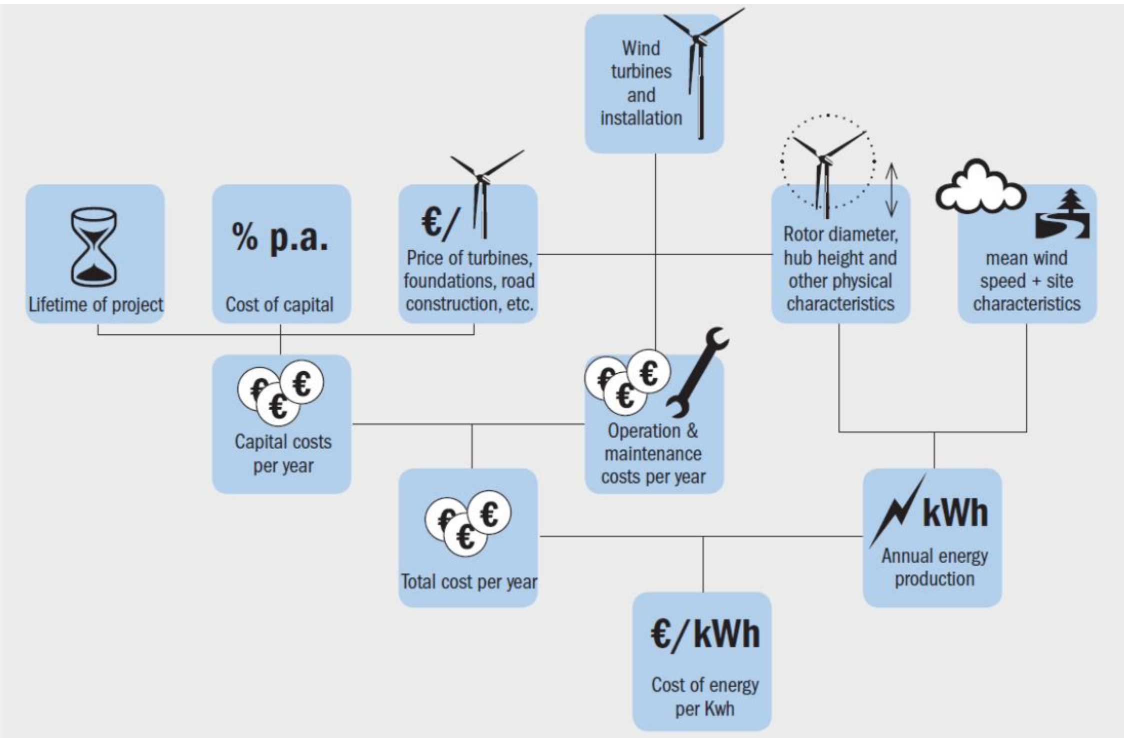

FIGURE 3.4: THE COST OF WIND ENERGY

When evaluating the influence of installation costs, one relevant economic indicator is the cost per installed capacity, however its application to the MRE sector can lead to confusion in a sector where the typical capacity factor of the plant is not established yet.

3.2.1 WAVE ENERGY PROJECTS

The cost of a typical wave energy project is difficult to assess for reasons such as the low levels of installed capacity, the diverse nature of the technologies and the wide variety of sites that can be employed. Carbon Trust points out that analysis of wave energy costs is more difficult than other technologies because of the novel energy extraction concepts employed and the difficulty in modelling performance with certainty [42]. IRENA cites limited commercial experience for the wide range of cost estimates in wave energy [43]. In BVG Associates' value chain study for the Ocean Power Innovation Network they had to resort to using offshore wind trends to estimate the wave energy sub-element costs [39].

Since 2014 Wave Energy Scotland (WES) has been running technology development programmes to enable the advancement of the technical capability and readiness of specific wave energy subsystems and full devices. Each programme runs over three-stages and follows a competitive pre-commercial procurement (PCP) approach, with each of the three stages having specific objectives and outputs that must be achieved. The number of technologies being funded at each stage reduces, as summarised in Table 3.3 which shows the number of participants in each stage of the WES programme, e.g. in the Novel Wave Energy Converter (NWEC) programme, eight technologies were originally funded in Stage 1, reducing to four in Stage 2, and now two are currently being funded in Stage 3.

TABLE 3.3: NUMBER OF PARTICIPANTS IN EACH STAGE OF THE WES PROGRAMMES.

Programme	Number of Participants		
	Stage 1	Stage 2	Stage 3
NWEC	8	4	2
Power Take-Off	10	10 (including 6 projects that entered directly at Stage 2)	5 (including 1 project that entered directly at Stage 3)
Structural Materials and Manufacturing Processes	10	3	2
Control Systems	13	3	2
Quick Connection Systems	7	4	Not completed yet

Although many of the problems related to cost predictions remain, the extensive yet controlled nature of the WES programme provides a good indication of the relative costs of different technology types and sub-elements. As part of the assessment to determine which technologies will progress to the next stage of the WES programme, participants are required to complete an LCoE assessment which provides a high-level indication of the expected values for the main cost parameters for a scenario at a future point in time. The scenario used by WES is for a single device, as part of a 100MW array, at the stage of >1GW global wave energy deployment. Thus, the technology is assumed to be able to take advantage of economies of scale (for the large array), and it can be assumed that the technology and market are fully matured (with over 1GW installed globally). Where project developers are unable to make an assessment of a specific cost, WES uses default values [44]3[19] which are indicative of a generic project.

In total WES has issued more than 90 contracts and undertaken knowledge capture activities to ensure that the learning from legacy projects is not lost. WES therefore has a good dataset for assessing the cost of different aspects of wave energy technology.

A summary is included in Table 3.4, which shows the WES default values compared against anonymised and averaged device family data from 29 individual projects that WES has supported. Variations between the default values and device-family-specific inputs have been observed, particularly in the % costs attributable to the Power Take-off (PTO). OPEX is reported as an annual percentage of CAPEX based on a current understanding of how O&M may be completed. O&M is however very project specific and as noted the total number of deployed projects is limited.

TABLE 3.4: SUMMARY TABLE OF WES DEFAULT VALUES AND BREAKDOWN OF THE DATA FOR DIFFERENT DEVICE TYPES

	Cost centre	WES Default	Attenuator	Point Absorber	OWSC	Other	Average
CAPEX	Structure and prime mover (£k/MW)	38%	43%	21%	47%	34%	35%
	Power Take-off & control (£k/MW)	23%	35%	31%	19%	16%	27%
	Foundations and mooring (£k/MW)	15%	7%	16%	13%	8%	12%
	Connection (£k/MW)	11%	9%	16%	10%	15%	14%
	Installation (£k/MW)	13%	5%	15%	12%	15%	13%
OPEX	*Annual OPEX (% of CAPEX/yr)*	*4.0%*	*3.3%*	*3.9%*	*4.7%*	*6.1%*	*4.5%*

It is worth highlighting that these comparisons are based on values that are input by participants in the WES programme, as such definitions of the different cost centres can be interpreted differently. As an example, one developer may use a gearbox PTO and therefore be able to clearly distinguish their PTO as separate to the main structure, while another may use a flexible membrane where arguably the PTO becomes a significant structural component. Further differences in definitions can also be seen in what is considered "Power Take-off & Control" or "Foundations and Mooring", and what is considered "Connection".

[19] Assumptions:
LCoE tool input values that duplicated the WES default values with limited justification have been omitted.
LCoE tool input values that are wildly dissimilar to those other devices (orders of magnitude difference) have been omitted.
Tools that consider a different scenario to the 100MW array at >1GW global capacity have also been omitted.
The "Average" column is an average of all data inputs, which gives a different value to the average of the data from the four device family bins
The "WES Default" data is not included in any of the four device families.

3.2.2 TIDAL ENERGY PROJECTS

Currently, Europe leads the world in tidal energy installations, with active tidal stream projects generating about 13.5MW to 16MW by the end of 2020, according to statistics released by IRENA [45] (Figure 3.5).

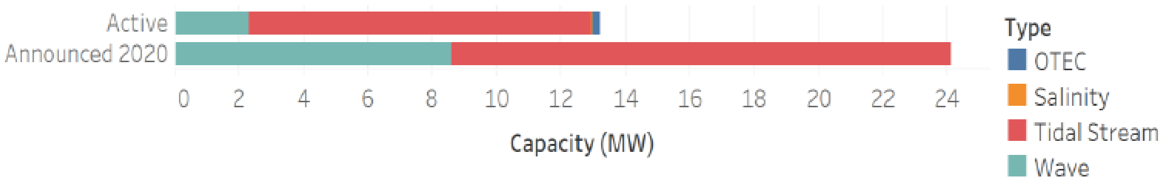

FIGURE 3.5: ANNOUNCED OCEAN ENERGY ADDITIONS BY TECHNOLOGY IN 2020 [45]

These projects have been developed using a variety of collaborative mechanisms, including public funding, partnerships between supply chains, consortium of academia and R&D, etc. Generic cost data of tidal stream energy projects obtained from ORE Catapult [46] [47], provide an LCoE breakdown by component for an average pre-commercial tidal array on a 'per MWh' basis. This is illustrated in Figure 3.6. As with wave energy projects, these cost breakdowns vary significantly by device design and rating.

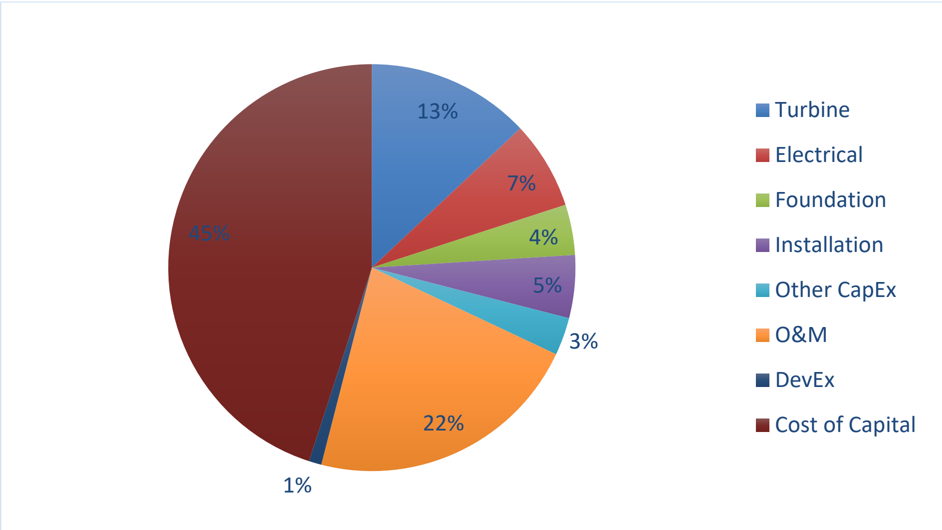

FIGURE 3.6: AVERAGE PRE-COMMERCIAL TIDAL PROJECT COST BREAKDOWN

As seen in Figure 3.6, over 70% of the levelised cost of tidal stream energy project relate to the capital costs of the project, arguably one of the main barriers to market penetration. The required scale of capital, together with the uncertainty of risks associated with reliability and performance of technologies, and unpredictability of the costs and future revenue streams, weigh on potential investments, which are crucial to the development of this sector [47]. The tidal energy industry can take steps to manage these risks and make tidal stream technology an attractive investment [47]. Steps such as prospective market opportunities have been identified and reviewed in DTOceanPlus D8.1 [4], highlighting potential future market for grid power, in addition to a range of alternative markets for wider applications of tidal energy projects.

Table 3.5 provides a breakdown of different tidal energy project cost centres based on data from a number of different sources.

TABLE 3.5: SUMMARY TABLE AND BREAKDOWN OF THE DATA FOR DEPLOYED GENERIC TIDAL DEVICE VALUES

	Cost Centre	ORE Catapult [46]	ETI [48]	BVGA [49]	IEA [50]	Average
CAPEX	Tidal generator/ platform	41%	53%	58%	48%	49%
	Foundation and mooring	12%		17%	14%	13%
	Connection	22%	13%		20%	18%
	Installation	16%	19%	12%	12%	15%
	Other CAPEX	9%	15%	10%	-	11%
OPEX	Total OPEX for the lifetime of the device	22%	-	40%	39%	34%

It is worth highlighting that these comparisons, in Table 3.5, are based on a variety of different assumptions, technology scales, infrastructures, costs and levels of deployment.

The operation, maintenance and service costs remain highly variable due to the wide range of direct negative impacts of unscheduled maintenance routines. As such, there is limited data available from the existing projects in service.

The ETI target LCoE roadmap [51] suggested a significant reduction in OPEX costs as more arrays are deployed from early pilot arrays as seen in Table 3.6. Factors such as availability levels, learning rates, insurance costs and transmission charges will have a significant impact on the overall operational costs.

TABLE 3.6: EXAMPLE OF ARRAY SIZE IMPACT ON OPEX [48]

Number of 1MWe turbines	Boat costs	O&M base running costs	Total fixed OPEX costs
4	9.6p/kWh	4.8p/kWh	14.4p/kWh
10	3.8p/kWh	1.9p/kwh	5.7p/kWh
30	1.3p/kWh	0.65p/kWh	1.95p/kWh

3.3 REQUIREMENTS OF THE OCEAN ENERGY SECTOR

We can consider that Ocean Energy is a term that includes several technologies, in different development stages, having in common the fact that they primarily seek to exploit power/movement of the ocean to produce energy. Wave energy and tidal energy share a common environment, but the concepts behind their functioning are inherently different. Wave energy epitomises this granularity, with several competing technologies under the same sector, none of which has yet emerged as dominant. Wave and tidal energy are also at different stages of development, with tidal energy closer to commercialisation.

A thorough overview of financial challenges in the ocean energy sector should consider the stage of development of the different technologies involved. Wave technologies are mainly in the initial demonstration phase of single units, largely involving short-term tests, with only a few prototypes starting the first steps into the marketing phase. Tidal technologies, have already several arrays deployed and companies are ramping up the marketing phase. As such, at a broad scale, the ocean energy sector in its entirety shares many commonalities with other sectors at an early development stage, where companies often find it difficult – or too costly – to access credit.

Currently, ocean energy is still in the early development phase, with wave energy in the prototype testing stage and tidal energy in the demonstration phase [52]. Tidal is ahead of wave in terms of TRL, where the sector has achieved some technological convergence and more full-scale operational data and pre-commercial projects plans are available. Planning an ocean energy array is still a very challenging and diverse process, where lots of different issues need to be taken into account; therefore, there is an intrinsic need for the development of analysis and decision tools in order to facilitate the decision-making process at this stage.

Tools that are currently available tend to be dedicated to hydrodynamic numerical modelling of both tidal and wave energy converters. From these tools, the standard output would be the annual energy production as the focus on performance. This is only one parameter to consider when making decisions on ocean energy arrays. Costs, reliability, environmental issues, site assessment are other key factors when planning an array deployment. In addition, tools should be computationally efficient when planning arrays of hundreds of devices, however most available tools are designed for the analysis of individual devices.

3.4 CURRENT ENGAGEMENT WITH OCEAN ENERGY SECTOR

A rapid shift toward renewable energy development is ongoing, and economic projections indicate that this trend will continue to accelerate. Wind and solar power developments have been leading the way with annual capacity increases of over 30% for the last decade. The ocean energy sector is poised to continue with this momentum. In addition to the significant ocean energy resource highlighted before, other drivers are oil prices instability and global climate change and emissions reduction.

Europe is the global leader in the development of ocean energy technologies [18]. To accompany the technological progress and the innovations driving the development of the OE sector in Europe, a strong and stable supply chain is required. Europe has previously shown high in-house manufacturing capabilities in the wind energy sector with overcapacities in all key wind turbine components[20]. This

[20] When considering European deployment rates between 12.1 and 22.7 GW per year [19].

expertise and the synergies between the offshore wind and ocean energy sectors position European industries at an advantage once the OE market is established regionally and globally. This report presents an assessment of opportunities and challenges for the OE supply chain in Sections 4 and 5.

Generally, the manufacturing and assembly occur locally, i.e. in the vicinity of the deployments and has largely involved bespoke designs. However, the increasing interest of large manufacturers such as AndritzHydro Hammerfest, SKF, Lockheed Martin, Siemens, among others, in the OE sector could indicate that the supply chain is beginning to consolidate. The landscape is evolving swiftly.

The DTOceanPlus consortium has used the PESTLE (Political, Economic, Sociological, Technological, Legal and Environmental) methodology to identify and analyse the external issues that may act to impede achievement of the impacts, which was further described in the previous deliverable D8.1 [4].

3.5 THE ROLE OF DATABASES IN THE ANALYSIS OF THE SUPPLY CHAIN

The role of databases is fundamental to gather information from the activities carried out in each sector of the supply chain. The analysis of supply chain databases in ocean energy is primarily aimed at sharing the knowledge and the skills acquired in this field to the benefit of the entire industry, thus accelerating the sector's pace to industrial roll-out. Grouping databases for the ocean energy sector at a national level is also a way to get an idea of the state of advancement of each country in the context of ocean energy. Some European countries have examples of existing and mature supply chain models, listing several companies in their databases, while others are in a less advanced state.

In this context, OCEANERA-NET [7] provides a list of available databases and organisations which manage them:

- The UK's main renewable energy supply chain database is available to view at MESCG (Marine Energy Supply Chain Gateway) and it has been operating since July 2015. The database is organised into three main areas of activity: technology development based on TRL (research and innovation, test and demo facilities), project developers (consultancy services, naval architects) and technology manufacturing and integration (engineering services, manufacturing and component supply, ports and operations, marine operations, installation and subsea support, training and skills, financial, legal and support services). For each main activity and sub-activity, the number of organisations involved is indicated.
- Marine Energy Programme Board (MEPB), set up in 2013, includes information related to the project management (design, ownership and asset management), devices and subsystem components, subsea array and cables, vessels and on-board equipment.
- Marine Energy Pembrokeshire, established in 2010, focuses on providing support and guidance for the marine energy sector, promoting wider public understanding of the benefits of marine energy.
- Dutch Marine Energy Centre (DMEC), launched in June 2016, seeks to create a knowledge platform for SMEs active in the technologies for energy from waves, tides and salinity gradients.
- Regen SW publishes a Marine Energy and Offshore Wind, South West Company Directory containing over 350 companies. The directory has general chapters covering offshore energy

resources, technology developers, research capabilities, PRIMaRE, demonstration sites, ports, port operations and land-based support.

Companies who have experience within the offshore oil & gas industry, working in a similar environment to wave or tidal energy, may also be suitable for involvement in the marine energy supply chain. These companies have the potential to engage and be included in databases especially for activities centred on installation, maintenance, environmental monitoring and decommissioning.

3.6 BACKGROUND ON OCEAN ENERGY INDUSTRY IN EUROPE

There is an active industry evolving around ocean energy, both in terms of technical evolution and in commercial planning: a number of technologies have progressed significantly, albeit at relatively high expense (it requires between €20 million and €40 million to reach the development of the first 1MW demonstration project) [53]. The most crucial phase for technology developers is bringing their device to the market: to progress from smaller scale proven prototypes to commercial projects, the technology needs to be demonstrated at commercial scale for a prolonged duration of time. Most developers are now in this so-called "Valley of Death" phase.

Within the tidal energy market, some key players are moving to the next level. The core of the technology is developed, with tidal energy devices having a rated power capacity of between 0.5 and 1 MW per device, at a current speed of 2.5 m/s. Plans for the future would be having an offshore array of such devices capable of a large scale production of 50-200 MW per region, but initially smaller commercial demonstration arrays between 10-20 MW are expected [53]. The next step for tidal technology will be reducing costs and increasing the performance reliability. For wave energy technologies, there are hundreds of concepts under development and only a few dozen have reached the stage of prototype-proven designs.

The market for wave and tidal energy conversion is undergoing a transition from technology invention, development, and testing, towards pre-commercial demonstration projects, small arrays and servicing. Both in tidal and wave energy conversion, several pioneering players have built up a prominent position over the past 10-15 years, while new entrants are arriving today, indicating a growing interest in entering the market. Of great importance at this stage is the involvement of major original equipment manufacturers (OEMs), as well as the increasing interest and investment of major energy utilities. This happened, in part, thanks to the support from key industry players in the hydro power generation market, such as Alstom Power, Siemens, ABB, Andritz Hydro, Voith Hydro, Bosch Rexroth and Rolls Royce. Through this industrial support these new technology developers are catching up quickly and making significant progress. Various European developers and utilities are present in the UK and are preparing or executing commercial scale or demonstration tests. The European Marine Energy Centre (EMEC) in the UK is the most prominent test facility in the world, with readily available test berths for both tidal and wave testing.

Financing is currently the biggest barrier to the deployment of ocean energy projects: the cost of the projects remains high and uncertain. Ocean energy can benefit from a different set of programmes from the EU, where one of the main economic supports has been provided by the research framework programme. In the past 20 years, 42 projects have been assisted, with an allocated support of about

€60 million [53]. RD&D activities performed directly by the private sector or sponsored by public funding create intellectual capital and support the development of future industries. The importance of the support is relevant particularly for less mature technologies.

On the other hand, there will be a growing interest for existing industries to provide services and goods to the ocean energy sector: in case of the oil & gas sector, for example, contractors and suppliers will eventually be attracted by this new market, as their activities may show a gradual decline in the coming decades. Various companies are starting to develop tailor-made services for the ocean energy sector: one example is Bluewater Energy Services BV from the Netherlands, a global leading offshore mooring systems contractor. Synergies also exist between the offshore wind and ocean energy sectors. Working in the same environment, the wave and tidal energy sector and the offshore wind sectors face common challenges and, in some areas, have similar supply chain needs [54]. Experience gained and challenges overcome in the supply of either sector will be transferable between sectors and to other markets.

Well-developed infrastructure is also necessary in order to facilitate the expansion of the ocean energy sector. Most wave and tidal installations are located away from the coastline, where infrastructure can be complex and difficult to develop.

Ocean energy is an emerging sector, but to become commercial and competitive it has to have a consolidated supply chain. This depends on the success of technology developers in delivering successful ocean energy converters [19]. The success of ocean energy also depends on policy makers creating a viable energy market.

One of the critical issues for the ocean energy sector over the past few years has been the lack of engagement of OEMs, but the situation is rapidly changing thanks to the technology validation projects currently ongoing in many European test centres [19]. Since 2016 a number of demonstration projects have been deployed, with the main goal of proving the reliability of electricity generation based on ocean energy technologies and to prove the bankability of the technology in the long term. The data from the demonstration projects show capacity factors of 40% for tidal energy demos, and a considerable amount of electricity delivered to the grid. The reliability of the data from the demonstration projects can attract OEMs to the ocean energy sector. There are many areas on the western fringes of Europe that could host wave and tidal energy developers and benefit from the growth of the ocean energy market.

Given the localised nature of wave and tidal energy resources, it is expected that ancillary activities, such as project development and operations and maintenance, will be carried out by local companies. The manufacturing of ocean energy converters, as in the case of wind, will play a fundamental role in shaping the technology market and in defining the position of European companies in the global market. Technology developers are already investigating markets in locations that offer growth both in terms of manufacturing capabilities and deployment of their technologies.

4 MAPPING OF EUROPEAN OPPORTUNITIES

4.1 METHODOLOGY

Ocean energy technologies require high level political support to create a market that will drive the investment needed to bring costs down to levels competitive with other renewable energy technologies. The outputs of DTOceanPlus aim to be relevant and of great value to a wider group of key stakeholders including policy makers, regulators, standards bodies, insurance providers and the supply chain. This will contribute to the strengthening of the European industrial technology base, thereby increasing job growth and European competitiveness.

Experience from other sectors that have had to go on similar journeys not only provides a key learning to reduce costs, but also significant opportunities to reinforce the European supply chain. Potential sectors for cross-collaboration are aerospace, automotive, aquaculture, energy storage, oil & gas, shipbuilding, and offshore wind. In particular, the ocean energy (OE) sector presents a considerable diversification opportunity for offshore wind (OW) companies, considering that the offshore wind supply chain is already well established in several European countries. Since the first installation over 20 years ago, offshore wind has become a significant proportion of Europe's renewable energy mix and has attracted significant investment. Synergies, technology transfer, and supply of products and services can all be opportunities for offshore wind companies to enter the ocean energy sector.

The supply opportunities for ocean energy projects can be evaluated as a function of the structure of key activities and combined according to their relative weight over the whole project life. The categories from the supply structure described in section 3**¡Error! No se encuentra el origen de la referencia.**, which covers the main phases of a project's life, have been selected for the analysis of opportunities. These are:

- Development and project management
- Construction
- Installation, commissioning and decommissioning
- Operations and maintenance

In the case of the construction phase, the supply of components and services has been further divided into several sub-elements, allowing a suitable level of granularity for this report:

- Ocean energy devices: structural elements, PTO, and other device subsystems
- Balance of plant: mooring and foundations, and energy delivery (i.e. electrical infrastructure)

A breakdown of the percentage contribution from each area to the lifetime project cost was presented in section 3.

In order to identify the opportunities, an assessment has been made based on five main criteria for each of the categories and sub-categories which are detailed in the following sections:

- Synergies with offshore wind
- Appetite or awareness from ocean energy

- Potential for LCoE benefit
- Size and timing of investments
- Size of the opportunity

Table 4.1 presents the above criteria to assess the opportunities of the European supply chain from the perspective of offshore wind companies as well as the scale for scoring them. This does not preclude that other opportunities for cross-collaboration might emerge with companies from the aerospace, automotive, aquaculture, energy storage, oil & gas and shipbuilding sectors. However, the incipient nature of the OE sector makes it difficult to make an appropriate analysis of these opportunities.

TABLE 4.1: CRITERIA TO EVALUATE OPPORTUNITIES BETWEEN OFFSHORE WIND AND OCEAN ENERGY SECTORS

CRITERION	Score (higher is better)			
	1	2	3	4
OW-OE synergies	**Limited synergies** between OW and OE	**Some synergies** between OW and OE but significant learning needed by new entrants	**Many synergies** between OW and OE and some learning would be needed by new entrants	**Strong synergies** between OW and OE and goods and services can be supplied to OW without much learning
Appetite from OE	**Strong competition** between five or more mature players using optimal technical solutions	**Healthy competition** between three to four players using technical solutions close to optimal	**Competition** between three to four players but technical solutions for some tasks are suboptimal. There is demand for new solutions from parallel sectors	**Less** than three established suppliers and/or the technical solutions for critical tasks are suboptimal. There is demand for new solutions from parallel sectors
Potential for LCoE benefit from new involvement by OW companies	Standard technology in OE is **close to optimal** with few opportunities for OW companies.	Standard technology in OE is **well established** with OW companies only likely to contribute about 0.1-0.5% of LCoE reduction to OE Farms	Standard technology in OE is **adequate** but OW companies could contribute between 0.6% and 2% of LCoE reduction to OE Farms	Standard technology in OE is **immature or inadequate** and OW companies could contribute up to 8-10% of LCoE reduction to OW farms

CRITERION	Score (higher is better)			
	1	2	3	4
Size and timing of investments by OW companies	**Significant investments** are needed to be competitive for projects that need to be amortised over several orders. Investment must be made **before a confirmed order**	**Significant investments** are needed to be competitive for projects that need to be amortised over several orders. Investment can be made **before the first confirmed order**	**Significant investments** are needed to be competitive for projects, but they can be set against a single project. Investment can be made **in response to a confirmed order**	**Minor investments** can be made incrementally to be competitive. Investment **in response to a confirmed order**
Size of the opportunity	The serviceable market opportunity is **very low** along the lifetime expenditure	The serviceable market opportunity is **low** along the lifetime expenditure	The serviceable market opportunity is **high** along the lifetime expenditure	The serviceable market opportunity is **very high** along the lifetime expenditure

The next subsections provide an analysis of the various project phases and criteria. The scores and comments have been collected directly from a survey to industrial partners in the project (Bureau Veritas, Enel Green Power, EDP CNET, Nova Innovation, Orbital Marine Power, Sabella, CorPower and IDOM) and enriched with existing supply chain studies [55] [56] [39].

4.2 DEVELOPMENT AND PROJECT MANAGEMENT

Development and project management makes up to 2-3% of lifetime expenditure. While this spend is relatively small, opportunities exist for experienced offshore project developers, particularly when projects are developed abroad. Table 4.2 shows the analysis of opportunities for development and project management.

TABLE 4.2: OPPORTUNITIES FOR DEVELOPMENT AND PROJECT MANAGEMENT

CRITERION	SCORE	COMMENTS
OW-OE synergies	3	There are several synergies in supply chain regarding project development and management in OW and OE. These sectors share the same challenges of working in a harsh environment and implications for HSE, together with similar EIA, consenting processes and can apply project management strategies. Experience developing projects in the offshore environment should easily transfer to OE.
Appetite from OE	3	OE developers are aware that companies from OW have world class project management capabilities. However, project size makes the current state of OE project different to OW. This means technology developers are in many cases forced to develop projects, which put a lot of strain on the limited resources. There is still room to improve the development framework to stimulate project deployment.
Potential for LCoE benefit from new involvement by OW companies	2.5	Best practices from OW project development could streamline OE project development process, reducing costs and timeframes. Also, there could be opportunities to mutualise some of the development costs for a portfolio of projects, such as legal costs, or better leverage leading to decreased upfront financing fees given the size of the OW companies, as OE developers are mostly SMEs. A small LCoE reduction potential from more competition for such services can be expected.
Size and timing of investments by OW companies	3	Due to early bird stage of OE development, small investments could have a significant impact in the OE sector. Skills are very transferable.
Size of the opportunity	2	Development and management costs represent only a small fraction of the overall costs in an OE project. Project size is smaller compared to OW projects. Although there is currently a limited market for OE, the sector has significant potential and is expected to grow fast. To unlock this potential will be the establishment of support mechanisms suitable for the sector.

A summary of this assessment is presented in Figure 4.1.

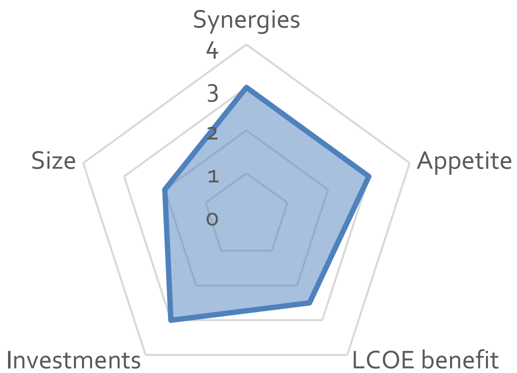

FIGURE 4.1: SUMMARY OF THE ASSESSMENT FOR DEVELOPMENT AND PROJECT MANAGEMENT

4.3 CONSTRUCTION

4.3.1 Ocean Energy Devices

Device cost category can be subdivided into "structure cost", "PTO cost" and "other Device subsystem cost", this one including secondary steelworks. Ocean Energy Converter supply makes up about 25-27% of the lifetime spend of an OE farm. It is the single biggest contract placed by the developer.

4.3.1.1 Structure – Wave Energy Converter (WEC)

Table 4.3 shows the analysis of opportunities for the construction of the WEC structural elements.

TABLE 4.3: OPPORTUNITIES FOR WEC STRUCTURE

CRITERION	SCORE	COMMENTS
OW-OE synergies	2	The critical difference, both in geometry and dynamics, between OW and OE structures create a need to redefine the design and fabrication of OE structures to enable efficient serial manufacturing. This is true for WEC devices, where a great variety of different structures exists. However, synergies exist between OW and OE for main primary and secondary steel work.
Appetite from OE	2.5	High appetite from technology developers for a greater field of potential suppliers for these WEC parts as they transition from bespoke to standard products. A similar supplier development seen in OW will be seen in wave energy.
Potential for LCoE benefit from new involvement by OW companies	3.5	There is clearly a huge opportunity for OW to help the wave sector reduce LCoE. OW is 20 years ahead in the technology roadmap and learnings. Product standardisation and scaling up manufacturing to the volume levels required would be the major cost benefit for WEC farms.
Size and timing of investments by OW companies	2	The timing of investments is different between wave energy and OW. However, the investments by OW companies could speed up the process. The great diversity of wave energy technologies creates uncertainties and is a factor deterring manufacturer investment.
Size of the opportunity	2.5	The production of the WEC structural elements represent a significant fraction of the overall costs in a wave energy project. There is a good potential for the OW companies.

A summary of this assessment is presented in Figure 4.2.

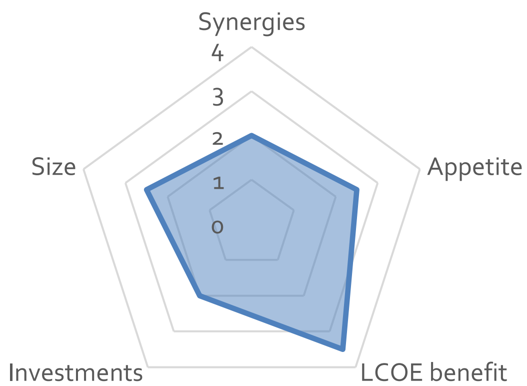

FIGURE 4.2: SUMMARY OF THE ASSESSMENT FOR WEC STRUCTURE

4.3.1.2 Structure – Tidal Energy Converter (TEC)

Table 4.4 shows the analysis of opportunities for the construction of the TEC structural elements.

TABLE 4.4: OPPORTUNITIES FOR TEC STRUCTURE

CRITERION	SCORE	COMMENTS
OW-OE synergies	2.5	Some synergies exist between OW and tidal energy in structure design, building materials and construction. Opportunities in steel fabrication to offshore standards, coating, biofouling solutions and support structure concept. However environmental conditions are different, design standards differ and not quite established for tidal energy.
Appetite from OE	2.5	OW companies could provide significant experience regarding mass manufacturing and scale-up. Besides, there is a reduced number of tidal energy concepts that could facilitate standardisation in the various stages of the projects.
Potential for LCoE benefit from new involvement by OW companies	3	More efficient and mass production of tidal energy structures could have a significant impact on the LCoE. Cost reduction could be expected by increased supply chain engagement, learning transfer and optimisation.
Size and timing of investments by OW companies	2.5	Smaller size of the projects compared to OW means several orders are required to justify entering the market in terms of opportunity cost. This will change in the future, as tidal energy projects will get bigger. OW engagement to explore cost reduction potential would not require significant investments.
Size of the opportunity	3	Tidal energy projects are relatively small compared to OW. This is expected to change soon as more TEC technologies begin to commercialise. The size of opportunity might suit smaller suppliers that cannot compete for large OW contracts.

A summary of this assessment is presented in Figure 4.3.

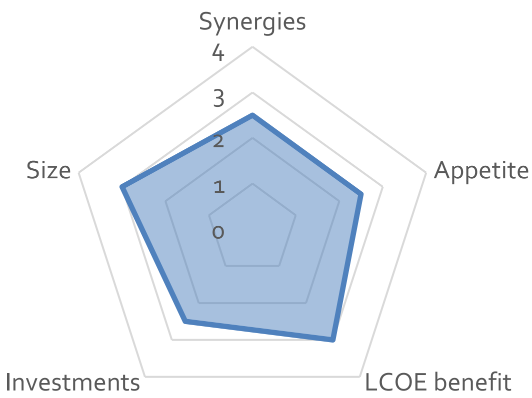

FIGURE 4.3: SUMMARY OF THE ASSESSMENT FOR TEC STRUCTURE

4.3.1.3 PTO – Wave Energy Converter (WEC)

Table 4.5 shows the analysis of opportunities for the construction of the PTO elements for WECs.

TABLE 4.5: OPPORTUNITIES FOR WEC PTO

CRITERION	SCORE	COMMENTS
OW-OE synergies	2	Some synergies between OW and wave energy. However, significant learning is needed by new entrants as the PTO is bespoke to the WECs (which is very different from that of a wind turbine). There are some limited synergies for more standard parts such as the generators, but most would require heavy investment and learning to capitalise on the PTO opportunities.
Appetite from OE	3	High appetite from technology developers for a greater field of potential suppliers for these WEC parts as they transition from bespoke to standard products. Healthy competition between different players can help optimise the PTO system.
Potential for LCoE benefit from new involvement by OW companies	3	The wave energy PTO is bespoke and has a direct influence on the efficiency, reliability and cost. Therefore, a significant opportunity exists to drive down LCoE significantly. Currently only conservative cost reduction factors have been made for PTO costs reductions in future WEC product generations.
Size and timing of investments by OW companies	2	The task of designing and manufacturing a cost-efficient PTO system is definitively not an easy one. It would be ideal for OW to start investing now, but this activity will start once the projects are approved on a project by project basis. The learning curve may be long.
Size of the opportunity	3	The PTO system can have a significant share in the capital cost of a device. There is very good potential for the OW companies.

A summary of this assessment is presented in Figure 4.4.

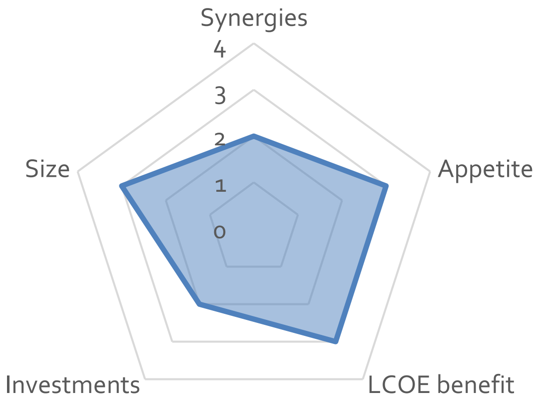

FIGURE 4.4: SUMMARY OF THE ASSESSMENT FOR WEC PTO

4.3.1.4 PTO – Tidal Energy Converter (TEC)

Table 4.6 shows the analysis of opportunities for the construction of the PTO elements for TECs.

TABLE 4.6: OPPORTUNITIES FOR TEC PTO

CRITERION	SCORE	COMMENTS
OW-OE synergies	3.5	Tidal energy PTO designs are becoming more established and tidal energy technology developers are increasingly converging on direct drive horizontal axis devices, similar to wind turbines. Synergies exist between the PTO design in OW and tidal energy. Strong similarities between rotors and generators used in the OW and OE industries, even if the service profile differs. Also, in the pitch system and nacelle. The OE would have a lot to learn from OW experience, but the OW companies must be aware of the difficulties inherent to the OE sector, in particular the very limited access once the turbines are operational.
Appetite from OE	3.5	The similarity in design means there is a demand for proven PTO solutions from OW. There is a strong interest in more PTO supplier engagement.
Potential for LCoE benefit from new involvement by OW companies	3	The PTO is a key subsystem and it still requires improvement and return on experience from OW companies. Involvement from OW companies would not only decrease the costs but also improve system reliability, availability and yield. Opportunity for cost reduction through more competition and supply chain learning in PTO supply chain.
Size and timing of investments by OW companies	2.5	Similarities in PTO design mean a relatively small investment is required. However, this will depend on the tidal energy technology and developer. Due to the size of current projects, a single order would remain small.
Size of the opportunity	2.5	Tidal energy projects are relatively small compared to OW, but the PTO takes up a big part of the device costs. The tidal energy market is expected to grow quickly soon, with technologies getting more established. It might suit smaller suppliers that cannot compete for large OW contracts.

A summary of this assessment is presented in Figure 4.5.

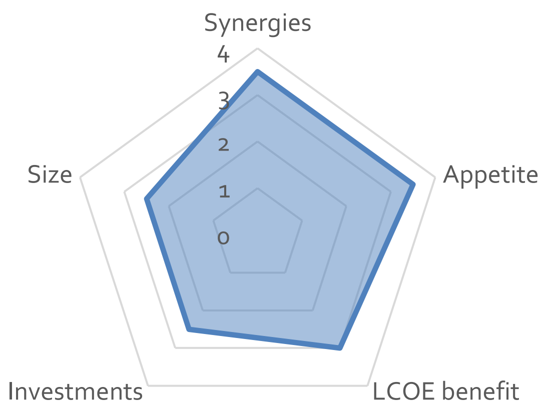

FIGURE 4.5: SUMMARY OF THE ASSESSMENT FOR TEC PTO

4.3.1.5 Other Device subsystems CAPEX

Table 4.7 shows the analysis of opportunities for other device subsystems.

TABLE 4.7: OPPORTUNITIES FOR OTHER DEVICE SUBSYSTEMS CAPEX

CRITERION	SCORE	COMMENTS
OW-OE synergies	3	There are some synergies in OW that can be translated to OE such as materials, manufacturing technology, biofouling, corrosion protection, or monitoring equipment. They can boost overall OE performance.
Appetite from OE	3	Appetite for new entrants is high. The solutions taken individually exist and they are well proven. The relatively small scale of production compared with OW means there are many fabricators who are capable and may be willing to enter OE market.
Potential for LCoE benefit from new involvement by OW companies	2.5	Improvements can lead to increased reliability, device availability, and thus higher power production. The collaboration will reduce the LCoE, but it is essential to find the common interest in other device subsystems.
Size and timing of investments by OW companies	2.5	The size and timing of investment between the sectors are different. OW companies are unlikely to invest significantly in infrastructure. However, this will depend on the subsystem of interest.
Size of the opportunity	2.5	Tidal energy projects are relatively small compared to OW, but the tidal energy market is expected to grow quickly soon, with technologies getting more established. Impact on CAPEX is relatively small.

A summary of this assessment is presented in Figure 4.6.

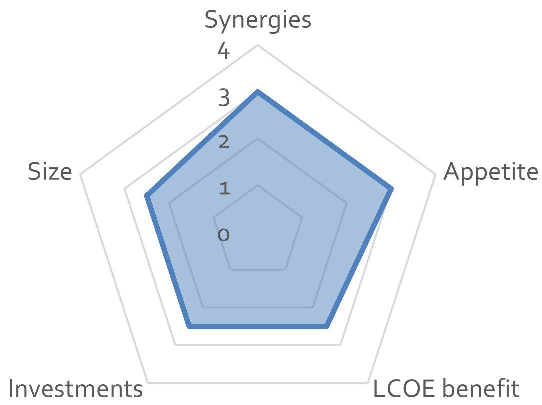

FIGURE 4.6: SUMMARY OF THE ASSESSMENT FOR OTHER DEVICE SUBSYSTEMS CAPEX

4.3.2 BALANCE OF PLANT

Balance of plant includes mooring or foundations systems and the electrical infrastructure for energy delivery such as cables and substations. These contracts make up 8-15% of the lifetime spend of an OE project.

4.3.2.1 Mooring and foundation

Table 4.8 shows the analysis of opportunities for the supply of mooring and foundation systems.

TABLE 4.8: OPPORTUNITIES FOR MOORING AND FOUNDATION

CRITERION	SCORE	COMMENTS
OW-OE synergies	3	Many synergies exist between OE foundations and OW foundations. Both floating and bottom fixed solutions exist in OW and OE. Anchoring and mooring solutions will now start to converge to a similar requirement. Weight and cost are more critical to smaller size of OE devices.
Appetite from OE	2.5	Learnings from OW could improve foundations and moorings for OE technologies. Existing solutions are well established and require few optimisations. The only remaining aspect is standardisation and optimisation of the manufacturing process as the number of devices per project increases.
Potential for LCoE benefit from new involvement by OW companies	2.5	Experience gained in the OW sector helps to reduce cost in OE, although the impact on LCoE is not expected to be very high due to differences in structure (size and weight).
Size and timing of investments by OW companies	2.5	Small size of the projects compared to OW means several orders might be required, though synergies in design will mean a smaller investment is required. For bottom-fixed solutions, the manufacturing process is already in the hands of specialised companies. For floating solutions, floating offshore wind is not mature yet and investments would be significant.
Size of the opportunity	3	Mooring and foundations are a significant project expenditure. OE projects are relatively small compared to OW, but this is expected to change soon as more technologies begin to commercialise.

A summary of this assessment is presented in Figure 4.7.

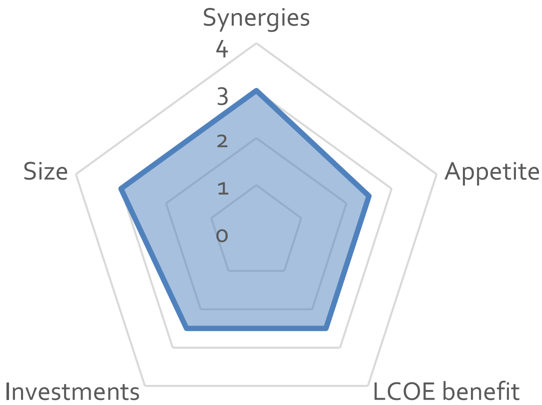

FIGURE 4.7: SUMMARY OF THE ASSESSMENT FOR MOORING AND FOUNDATION

4.3.2.2 Energy Delivery

Table 4.9 shows the analysis of opportunities for the supply of the electrical infrastructure for energy delivery.

TABLE 4.9: OPPORTUNITIES FOR ENERGY DELIVERY

CRITERION	SCORE	COMMENTS
OW-OE synergies	3.5	Energy Delivery present strong synergies between OW and OE such as cables, cable components, substations and modules. However, they do not operate at the same power level and different connection solutions might be required (e.g. wet-mate connectors). Some example of standardised design for substations already exist in OW sector, although there are no industry-wide standards.
Appetite from OE	2.5	The appetite for new market entrants is reasonably strong in the longer term. The array cable market is already well served by several large cable manufacturers that are used to operate in OW sector. Substation components are not exclusive to OE, a good supply chain exists, including some OW suppliers. However, there is room for improvement regarding the supply of wet-mate connectors, subsea hubs and umbilical cables.
Potential for LCoE benefit from new involvement by OE companies	2.5	Innovations in cable design and layout could reduce the cost of the cables and increase energy yield. Potential impact on LCoE could be significant. Substation design and requirements will vary from project to project, improvements in design could reduce costs and increase yield.
Size and timing of investments by OW companies	2.5	Existing synergies mean investment should be limited to take advantage of existing opportunities. Tidal projects are increasingly being deployed in arrays, increasing the opportunity for cable suppliers. Technologies that could make a difference for OE would be mainly subsea hubs, and they cannot be directly transferred from the solutions used in OW.
Size of the opportunity	2.5	The electrical infrastructure for energy delivery represents a significant project expenditure. OE projects are relatively small compared to OW, but this is expected to change soon as more technologies begin to commercialise

A summary of this assessment is presented in Figure 4.8.

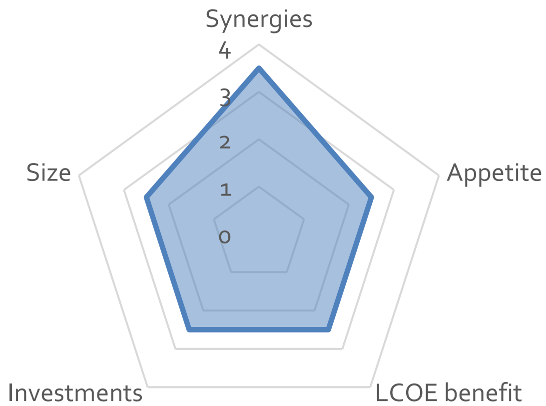

FIGURE 4.8: SUMMARY OF THE ASSESSMENT FOR ENERGY DELIVERY

4.4 INSTALLATION, COMMISSIONING AND DECOMMISSIONING

Installation and commissioning activities make up about 11% of the lifetime spend of an OEC farm. Cost of decommissioning activities is highly uncertain as there is no experience of commercial deployments so far. Table 4.10 shows the analysis of opportunities for the installation and commissioning activities.

TABLE 4.10: OPPORTUNITIES FOR INSTALLATION, COMMISSIONING AND DECOMMISSIONING

CRITERION	SCORE	COMMENTS
OW-OE synergies	3	There are strong synergies between the two markets, although there are some differences in the size and weight of the devices and structures. There are similarities regarding the type of vessels used and the associated logistics. OW skills can be readily applied to OE, which is already looking to the OW sector for best practices.
Appetite from OE	3	Availability of supply chain varies heavily from country to country. Certain countries already have a more established supply chain, while in others there will be more of an appetite from OE. There is a large appetite to utilise the time and cost savings seen in OW.
Potential for LCoE benefit from new involvement by OE companies	3	LCoE costs for installation and commissioning are mostly linked to the use of expensive vessels. Reducing installation time and vessel size could have a big impact on LCoE. There is an opportunity to benefit from OW innovation and return on experience to reduce risks, decrease the duration of installation / removal operations, and thus decrease the OPEX.
Size and timing of investments by OW companies	3	Likely to have easily transferable skills without significantly new investment. Existing equipment should be transferable to OE, particularly if capacity grows to serve OW. Investment will mostly be in manpower when demand soars.
Size of the opportunity	2.5	Marine operations contribute a significant part of the project costs. This will depend on the country, but the opportunity could be big as the OE market continues to grow.

A summary of this assessment is presented in Figure 4.9.

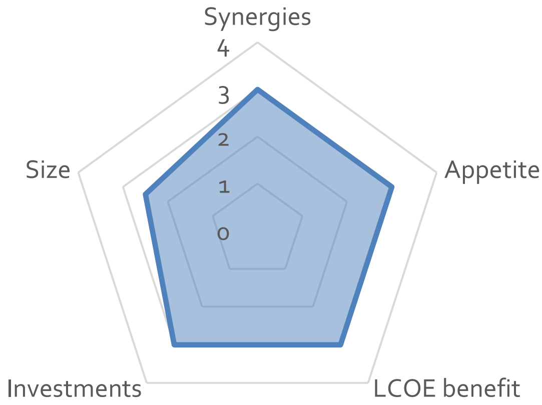

FIGURE 4.9: SUMMARY OF THE ASSESSMENT FOR INSTALLATION, COMMISSIONING AND DECOMMISSIONING

4.5 OPERATION AND MAINTENANCE

O&M activities are expected to make up about 42-49% of the lifetime spend of an OE project. Table 4.11 shows the analysis of opportunities for the operation and maintenance activities.

TABLE 4.11: OPPORTUNITIES FOR OPERATION AND MAINTENANCE

CRITERION	SCORE	COMMENTS
OW-OE synergies	3	Many synergies are to be expected between OW and OE. OW suppliers have a vast amount of experience in O&M for offshore assets. There are synergies in terms of defect detection, planned maintenance and asset repair. Standards and maintenance practices are transferrable to OE. A strong OW service supply chain has been developed over several years, and several specialist disciplines are highly transferrable.
Appetite from OE	2.5	Appetite from OE for a greater field of potential marine operators for O&M activities at competitive/affordable rates. O&M services are likely to be carried out by the original manufacturers while assets are under warranty. In the future 3rd parties will be expected to enter the sector, as they have for wind energy.
Potential for LCoE benefit from new involvement by OW companies	2.5	OE technology availability is of primary importance, therefore efficient servicing and innovative repair techniques can contribute significantly to LCoE reduction. Innovative approaches from the OW sector will be welcomed by OE asset owners. Any learning and optimisation from experienced marine contractors, particularly for early stage projects, would have a significant impact on LCoE.
Size and timing of investments by OW companies	3	While the size of the market is relatively small right now, this is expected to expand in the future as more projects come online. The synergies in O&M mean that a small investment is required to establish a market presence. However, strong cooperation is required with the OE developers
Size of the opportunity	3	O&M spend is high and consistent over the lifetime of the project. The market is expected to grow significantly in the near future. Long term contracts will lead to high returns if successful.

A summary of this assessment is presented in Figure 4.10.

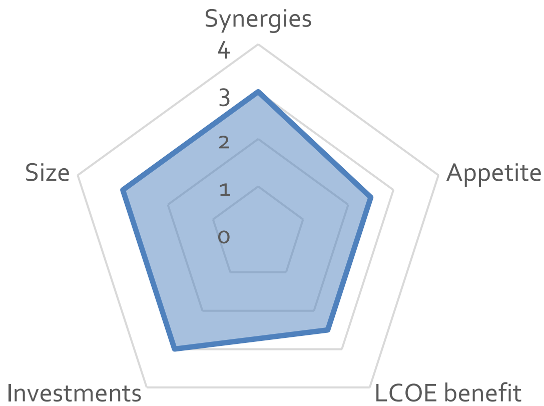

FIGURE 4.10: SUMMARY OF THE ASSESSMENT FOR OPERATION AND MAINTENANCE

4.6 OVERALL RESULTS

The following table shows a comparison of the absolute values assigned to each cost category in function of the several opportunities.

TABLE 4.12: OEC OPPORTUNITIES (ABSOLUTE SCORES)

Absolute value of the criteria for cost category	DEVELOPMENT & PROJECT MANAGEMENT	OCEAN ENERGY DEVICES					BALANCE OF PLANT		INSTALLATION, COMMISSIONING AND DECOMMISSIONING	O&M SERVICES
		STRUCTURE		PTO		OTHER DEVICE CAPEX	MOORING & FOUNDATION	ENERGY DELIVERY		
DEVICES	**OEC**	**WEC**	**TEC**	**WEC**	**TEC**	**OEC**	**OEC**	**OEC**	**OEC**	**OEC**
Synergies	3	2	2.5	2	3.5	3	3	3.5	3	3
Appetite from OE	3	2.5	2.5	3	3.5	3	2.5	2.5	3	2.5
Potential for LCoE benefit	2.5	3.5	3	3	3	2.5	2.5	2.5	3	2.5
Size and timing of investments	3	2	2.5	2	2.5	2.5	2.5	2.5	3	3
Size of the opportunity	2	2.5	3	3	2.5	2.5	3	2.5	2.5	3

As it can be seen, the main opportunities for the supply chain boil down to:

- Many synergies and little competition expected for the supply of the balance of plant and PTO components.
- Many synergies and minor upfront investments to provide project development, installation and O&M services.
- High benefit for LCoE reduction of device manufacturing costs and installation services.
- High market opportunity for the supply of ocean energy devices, balance of plant and O&M services.

5 LIMITATIONS AND CHALLENGES FOR THE SUPPLY CHAIN

Section 4 showed that the OE supply chain could benefit from the expertise of other energy supply chains, such as those of the OW and oil & gas. Additionally, there are valuable lessons to be drawn from the automotive, ship building, and even aerospace industries. Collaboration and synergies among these industries and the different stakeholders involved in the OE value chain can be established for the development and strengthening of the supply chain.

The OE sector is poised to continue with the momentum created by the rapid shift toward low-carbon energy systems. Nonetheless, its supply chain faces challenges due to the emerging nature of the sector. A major challenge facing the sector is cost competitiveness. The large number of technologies at different stages of development are yet to reach commercial scale and be cost competitive with other more mature renewable energy technologies. Whilst tidal energy technologies are currently more cost competitive than wave, both are still significantly expensive when compared to other more mature technologies. The detailed assessment of costs is still a difficult task within the sector given the scale and number of deployments to date. This situation hampers the development and strengthening of the OE supply chain.

The limitations and challenges experienced by the supply chain can be broadly classified into technical and non-technical and they spread throughout the project lifecycle stages. This section elaborates on such challenges and sheds light on the prospects available to overcome them, this way those challenges can be turned into opportunities instead of limitations.

5.1 TECHNICAL CHALLENGES

The technical challenges threatening the development of the OE supply chain extend throughout the lifecycle of OE projects and include the size of the projects, bespoke designs and products, and the lack of standardisation and optimisation of the manufacturing and installation processes.

It is difficult to assess a market that has not been established yet. Suppliers and manufacturers can offer discounts or lower their prices once the size of the projects – and, thus, of the orders – scales up. Moreover, it is necessary to prove the technologies before scaling-up. Therefore, governments should facilitate market growth through targeted support and an enabling regulatory framework. Furthermore, investment in grid infrastructure may be required to accommodate new power generation developments where the resource exists and enable the integration of OE into the power utility market. DTOceanPlus can help to streamline the integration of ocean energy technologies into the grid with a significant focus on designs that provide high quality, flexible and grid compliant power.

With larger projects, a transition to standard products would be beneficial, enabling mass production, increasing competition and lowering production costs. Developers should address the need for technology performance optimisation to ease installation and deployment. This is expected to reduce the need for specialist vessels and equipment, reduce the threats to health and safety during operation and maintenance, increase reliability and, ultimately, have an important impact on the levelised cost of energy. DTOceanPlus can facilitate cost reductions in the design, development and deployment of ocean energy. The opportunities for cost reductions would benefit the development of the value chain and the OE sector.

As indicated in Section 4, there are similarities between OW and OE that can be exploited to transfer knowledge and experience. These similarities include rotor and generator designs, pitch systems and nacelles, foundations and moorings, cables and substations. The similarities also cover operations such as installation, commissioning and decommissioning as well as maintenance and asset repair. Taking advantage of these synergies can help address the challenge related to the cost competitiveness of OE technologies as well as encourage third parties to engage with the OE sector and enter the value chain.

5.2 NON-TECHNICAL CHALLENGES

5.2.1 STANDARDISATION AND CERTIFICATION

As seen in more mature energy sectors, investor confidence and the engagement of insurance and guarantee providers is greatly influenced by the application of commonly accepted standards. The adoption (or development) of standards for the wave and tidal stream sectors can aid validating the performance and quality of the devices developed. In this regard, the wave and tidal stream sectors can benefit from cross-sector knowledge exchange, particularly from the offshore wind and oil and gas industries. Standards currently under development will guide the certification and accreditation of future technologies and deployments, becoming increasingly important in driving sales, increasing confidence, and attracting investment. The International Electrotechnical Commission (IEC) has been developing Technical Specifications, i.e. guidelines that will evolve into standards for the OE sector. These provide a uniform terminology plus information regarding design requirements and best practices. Several parts of IEC-TS-62600 have been published already with others due in the coming months/years.

In the meantime, independent certification and inspections can help the OE industry move forward safely, speedily and with confidence. Since existing codes and standards do not completely address the specifics of OE technology yet, certification bodies try to develop robust certification schemes and other third-party services that allow cutting-edge technologies to gain acceptance and achieve scale-up. Some guidance for developers and suppliers is currently available from certification bodies to address some of the standardisation and certification needs within the OE sector. For example, Bureau Veritas' Guidance Note NI 631 presents a certification scheme applicable to Marine Renewable Energy technologies. Stakeholders can identify the certification requirements necessary to conduct their projects, which include Approval in Principle, Prototype Certification, Component and Types Certificates and Project Certification. Guidelines applicable to tidal turbines and foundation design are also available (see NI603 R01 and NI605). Similarly, DNV GL has released standards for the certification of tidal turbines (DNVGL-ST-0164) as well as tidal and wave energy converters (DNV-OS-312). Lloyd's Register offers similar certificate processes too. Nonetheless, there are no benchmarks across the OE sector and standardisation of the testing and certification procedures remains necessary.

Standards and certification can resolve new and complex issues, de-risk projects and optimise costs. Designers and operators of OE technologies must prove performance to secure funding for their technologies. OE developers also need to de-risk their innovative technologies and ensure safety and quality. There is a pressing need for international standards to demonstrate to public authorities, finance providers, insurers, site owners and, ultimately, end users that new asset designs and operations are safe and cost-effective. Valuable lessons can be drawn from other marine energy sectors to ease the development of such standards and/or certification schemes to contribute to the strengthening of the OE sector.

5.2.2 FINANCIAL RISKS

Driven by both new technologies and new business models, there have been dramatic changes in the way companies and firms interact these days, leading to an establishment of increasingly complex and dynamic network of supply chain partners. While the interdependencies between these networks have lengthened, it has also made the supply chain riskier and more vulnerable. An analysis of the supply chain-related risks is particularly important for pre-commercial sectors like ocean energy, where building resilient supply chains to service the emerging market is vital for the sector's transition towards full commercialisation.

This section gives a brief introduction to supply chain related financial risks and other closely associated risks that have direct or indirect impacts on firms within the network.

- **Financial risk** is one of the most severe forms of risk that can expose a firm to potential losses. While the common reasons behind its occurrence are uncertainties in the financial markets and specific debtor insolvency, they may also stem from uncertainties around cash transactions between organisations, organisational expenses, improper investments, settlement process disruption and lack of transparency in the overall supply chain [57] [58] [59].
- **Credit risk** arises when parties to whom a company has extended credit then fail to fulfil their obligations. Customer defaults or delays in making anticipated payments can easily impact cash transactions within the supply chain network causing ratings downgrade or even bankruptcy of organisations [60].
- **Capital risk** results from disruptions in capital flow that might be impacted due to increase in capital demand through increase in the price of resources, unmarketable products, non-payment and low stock price [61].
- **Market risk** arises due to uncertainties caused by fluctuations in the market prices of financial or non-financial assets. Also sub categorised into fiscal risks, currency risks or economic risks, it occurs due to changes in tax rates, interest rates, commodity prices, share prices and exchange rate policies. Market risks are primarily relevant for multinational firms where volatility in market economics can have a significant impact on both its income statement and its balance sheet, including the value of its loan portfolio, and the market value of its debt. This in turn can easily lead to disruptions in cash movements and settlement processes involving accounts payable, leading to financial risk within the network [60].

Besides the above-mentioned risks, there are also **business risks** and **political risks** which are associated with business drivers and political/government stability respectively. While these risks do not directly cause financial risks within the supply chain; fluctuations in customer demand, supply disruptions, technology change, legal liabilities, regulatory changes and government instability can still lead to uncertainties in the financial markets. It is seen that even though different types of risks exist within the supply chain, most of these risks are overlapping and do not exist in isolation. This is particularly relevant for the ocean energy sector which is still in its pre commercial stage of development and uncertainties in the project-pipeline can be easily amplified throughout the supply chain giving rise to various types of risks. Also, because of its existing synergy with other sectors, the supply chain risks arising within this network can not only have a direct impact on the sectors profit and revenue, but can also travel down the supply networks due to its interconnected nature and create ripple effects across the entire supply ecosystem.

For example, price variations in components, inputs and raw materials, including limited supply of products, can have serious consequences for the suppliers and buyers within the ocean energy network [3]. This can easily disrupt the supply chain leading to capital risks, credit risks, market risks, business risks and financial risks. At the same time, floating exchange rates or rising prices from suppliers can easily increase acquisition costs leading to market risks and procurement risks. Also, while the UK supply chain is well placed to support the full scope of supply for wave and tidal energy, lack of experience and understanding of the technology, supply chain and market from the investor side, poses a serious problem to this industry. Lack of proper financing instruments including export credits not only stalls the development of the ocean energy supply chain, but can also easily lead to financial and market risks. As mentioned by BVG Associates in their report on 'Wave and Tidal Supply Chain Development Plan', proper de-risking and cost reducing instruments are required to establish a strong supply chain and encourage exports [62].

Another challenge for the sector is **insurance**. There are a limited number of insurers willing to underwrite wave and tidal businesses given that this insurance market is still at an embryonic stage. Furthermore, typically, insurers are reluctant to offer a full insurance coverage, i.e. ensure full replacement values and third-party liabilities associated with a specific technology. An option has been to have insurers work collectively to insure ocean energy devices. Another option has been to work with some dedicated marine insurers and not only dedicated renewable energy or offshore energy insurers given their better understanding of the nature of these technologies and the environment that they operate in. However, some challenges remain. For example, Defect Exclusion and technology Series Losses Clauses are narrower for ocean energy than for offshore wind farms. Ultimately, this sector expects to see the same shift of insurance buying control, i.e. as ocean energy technologies develop and more capacity is deployed, developers might start to control the insurance making Delay in Start-Up and Business Interruption coverage more accessible.

Finally, another concern for the stability of the supply chain is that today's suppliers and developers of prototype and demonstration projects remain part of the industrialised supply chain beyond 2020. Investors in fact could withdraw from the industry due to the slow progress in the validation of the technologies and decide to move to investments with more immediate returns.

5.2.3 LACK OF TRACK RECORD

Currently, there is no long-term track record of the survival and maintenance costs of competing designs given that most technologies are in their infancy. Where proven extensive operational records exist, it is based on technology used in the wind energy sector. Tidal range, the most mature of the ocean energy technologies, has a proven track record that stretches back to the 1980s; however, there is limited deployment to date [63]. The available track record corresponds mostly to small projects in the prototype or demonstration stage with limited opportunities to develop an integrated supply chain. Realistic estimates of the survival and maintenance costs of competing designs are still missing. This lack of track record, coupled with the wide diversity of bespoke designs for converters and their components as well as the high costs and unproven status of the technologies, has hindered the confidence of the investors and limited the opportunities for developing a strong value chain [7].

Valuable lessons can be drawn from previous experiences. A well-known wave energy example is that of the Scottish company Pelamis Wave Power [64]. Pelamis developed the first WEC to reach commercial readiness. An array of three 750kW WECs was deployed and connected to the grid in Portugal. The Aguçadoura Wave Farm was conceived by the Portuguese renewable energy company Enersis which was later bought by the Australian infrastructure company Babcock & Brown. The farm was officially opened on September 2008 but was shut down two months later due to technical glitches and financial difficulties of the Australian firm. Pelamis went on to develop its next generation of devices and sought to develop the technology into a fully commercial venture by engaging with large utilities such as E.ON and Scottish Power Renewables. The Pelamis P2 was installed for E.ON in October 2010 off the west coast of Orkney and in May 2012 for Scottish Power Renewables on an adjacent berth to E.ON's device. Unfortunately, Pelamis Wave Power went into administration in 2014 after being unable to secure the additional funding required for further development of its technology. WES now owns Pelamis Wave Power's Intellectual Property; the device ordered by E.ON has been dismantled. Scottish Power Renewables' device remains in-situ and is now owned by Orkney Islands Council.

Because of the large amount of literature on the Pelamis device, it remains a benchmark in the OE sector. The device's cost and technical information have been used to probe the economic [65], technical [66] and even environmental feasibility [67] of wave energy underlining the importance of track records for the development of this emerging energy industry. The experience and knowledge gained through Pelamis serves as groundwork and will most likely be integrated into other technologies.

In the case of tidal energy, the experience of OpenHydro offers valuable lessons [68]. This company developed a 250kW open centred turbine and test rig. The device has been tested in three sites: EMEC in the Orkney Islands, Alderney in the Channel Islands and the Bay of Fundy in Nova Scotia. OpenHydro's device was the first tidal turbine to be grid connected in Scotland. In April 2017, OpenHydro obtained a Marine License for a two-turbine demonstration array scheduled to commence in 2018. Unfortunately, Naval Energies (OpenHydro's parent company) decided to liquidate the company a year later due to insolvency. As in the case of Pelamis, OpenHydro struggled with limited commercial prospects for tidal stream project development. The test rig remains in its berth at the Fall of Warness potentially available for future opportunities.

Despite achieving significant milestones for a new industrial sector, the road to commercialisation is yet to be paved. Long-term track records are a repository of lessons learned. Knowledge exchange and networking is fundamental at this stage to develop the OE supply chain. Cross-sectoral and cross-regional collaboration would enable knowledge transfer and provide opportunities for networking. Projects such as the Ocean Power Innovation Network (OPIN) [21], Wave Energy Scotland Knowledge Library [22], the ELEMENT [23], IMAGINE [24], or UMACK [25] projects, among others encourage these collaborations and enable opportunities for potential synergies such as those described in Section 4. These synergies can serve as platforms to strengthen the OE supply chain.

5.2.4 CONTRACTING

In the energy industry, contracting between parties and particularly between project developers and the supply chain will mostly follow two approaches. The first approach relies on a **multi contracting approach**, meaning the project developer will negotiate individual contracts for engineering studies, hardware, construction and installation. The alternative relies on an Engineering, Procurement, Construction and Installation (**EPCI) approach**, which involves the project developer hiring an EPCI contractor which has the responsibility for the engineering, procurement, construction and installation of the project and will negotiate with different subcontractors and suppliers.

The pros and cons of both models are discussed in the table below.

TABLE 5.1: PROS AND CONS OF MULTI-CONTRACTING MODEL AND EPCI MODEL

Pros	Cons
Multi-Contracting Model	
▫ Provides the project developer with greater control and freedom over subcontractor/supplier contracts. ▫ Allows the project developer to award contracts for specific aspects of the project development to specialised subcontractors ▫ If well managed, can lead to an overall lower project cost, and higher return on investment. ▫ Increases flexibility for the developer to respond to unexpected changes during the development (a common risk in a new sector with relatively few earlier projects to learn from). ▫ Gives the developer direct experience of the EPCI process – a valuable skill in an emerging sector.	▫ Increased complexity due to dealing with multiple subcontractors/suppliers. ▫ Increases risk, especially interface risks, and could lead to costs overrun and project delays if not properly managed. ▫ Requires specific project management/supply chain management/engineering skills that not every developer will possess and are hard to cultivate. ▫ Greater resource / time commitment for the project developer ▫ Could be less efficient, if experienced and reliable EPCI contractors are available who can bring the

[21] https://www.nweurope.eu/projects/project-search/opin-ocean-power-innovation-network/
[22] https://library.waveenergyscotland.co.uk/
[23] https://element-project.eu/about-the-project/
[24] https://h2020-imagine.eu/
[25] https://www.corpowerocean.com/commercial-projects/umack/

▫ Could be the only option on the table if suitable EPCI contractors are not available at an affordable price.	benefit of experience gained on multiple previous projects.
EPCI Model	
▫ Simplifies contracting and project management for project developer. Single point of responsibility. ▫ Reduces project developer's risks, especially time cost and interface risks (assuming a well-designed contract). ▫ Can provide greater clarity ahead of time on project costs and timelines (if successful). ▫ Is often used when using project financing to develop renewable energy projects. ▫ Potential for greater efficiency between engineering design and project build, especially if EPCI has experience from previous similar projects. ▫ Reduces the need for project developers to build a full skillset in engineering, procurement, construction, and installation.	▫ Transfer of risk from developer to EPCI could lead to higher risk premium up front. ▫ Difficult for both developers and contractors to gauge risks and appropriate prices in an emerging sector. ▫ Project developer puts all their eggs in one basket, concentrating counterparty risk. ▫ Less control and flexibility for project developers. ▫ Smaller number of qualified EPCI companies in the offshore sector, many focused on much larger projects, such as oil and gas or GW scale offshore wind. ▫ Especially in new sectors, few EPCI contractors will have the required specialised knowledge and experience in-house.

While both models are present in Offshore Wind development, project developers in tidal and wave energy, will often take the multi-contracting approach. This is because tidal and wave energy technologies are still in the demonstration project phase; these projects are often too small or too R&D focused to attract independent project developers or EPCI contractors, forcing technology developers to act both as the project developer and EPCI contractor and take a multi contracting approach. This is quite different to the mature wind energy sector, where turbine OEM companies like Vestas, Enercon and Siemens Wind do not act as project developers.

While this adds a layer of complexity to the development of wave and tidal energy demonstration projects, it also provides wave and tidal technology developers with significant project development and EPCI experience. This experience can allow technology developers to access a new market, providing services to future wave and tidal project developers. It further provides technology developers with valuable feedback from the supply chain and first-hand experience with the design and installation of their devices. These learnings can be incorporated into improved technology designs and methodologies, significantly improving the usability, and reducing the cost of ocean energy devices. It also allows technology developers to offer full water-to-wire experience to their clients.

5.2.5 LEGAL FRAMEWORK

Ocean energy is bringing unique challenges to marine governance frameworks. Legal and regulatory aspects are frequently regarded as major non-technical challenges to the deployment of ocean energy. There's a need to understand and address these legal challenges and develop appropriate governance structures for OE to reach a sustainable commercial scale. Some key factors relate to the following core themes:

- **National and international law**

  Ocean energy potentially falls within the mandate of many international, regional, and technical organisations, though at present the link between ocean energy and many existing instruments is merely incidental. Most ocean energy projects are currently located within 12 nautical miles (territorial waters), proving the urgency in dealing with domestic legal issues. The challenge lies in finding how institutional fragmentation can be addressed.

- **Consenting processes**

  Considerable regulatory uncertainty remains in several jurisdictions and relevant data is often difficult to obtain. The main challenges relate to the number of authorities involved (lack of 'one-stop shop' authority) and communication between them, stakeholder consultation wrongly perceived as ineffective, lack of dedicated consenting process to ocean energy projects, integration of onshore structures, length of time to secure consents and timelines involved. There are several questions related to the integration of the various regulatory bodies as well as to feasible modifications of the process so that they reflect scale of development, level of risk and environment sensitivity.

- **Environmental impacts**

  Several studies already show a broad range of environmental interactions and the potential impacts of OE in the marine environment. However considerable knowledge gaps related mainly to baseline data and uncertainty remains. This is due to insufficient practice with device deployment and complexity in studying the marine environment. Challenges are thus posed both to developers carrying out Environmental Impact Assessments (EIA) and to regulators when approving projects. Consequently, regulators tend to adopt a precautionary approach leading to additional time and cost. Uncertainties regarding the ocean energy devices' interactions with the environment must be better accommodated in regulatory processes and based on adaptive and risk management strategies. This should take into account evidence of earlier deployments – currently there is uncertainty about the transferability of this information.

- **Management of the marine space**

  Permission for marine space occupation is the foundational basis for project deployment. By requiring exclusive occupation of marine space, ocean energy is effectively privatising a common good and creating potential for conflict with other rights-holders and existing marine users. It is still unclear the extent to which rights can be granted to private users and how these rights will be integrated with, and managed by, marine spatial planning procedures. Marine Spatial Planning (MSP) has rapidly developed as a tool for managing ocean spaces, though it is not yet clear how ocean energy, and other new marine industries, can be integrated into these processes. Prioritisation of uses is a major issue and how the legal framework will adapt to co-existence of certain activities e.g. multi use sites.

A stable and complete policy framework for the ocean energy sector is currently missing [53]. Key elements in such a framework include: a stable funding policy, guaranteed grid access with sufficient transmission capacity, clean spatial planning and permitting procedures in which health, safety and environmental requirements are precisely stated. This is complicated by the regulatory and energy policy differences across the EU and even within certain countries: a big challenge here is the transferability of environmental evidence.

Current policy frameworks and permitting procedures are tailored for more established uses of the sea, such as the oil and gas industry, fishing, and shipping.

6 CONCLUSIONS

The objective of D8.2 "Analysis of the European supply chain" is to gather together the information gained as part of DTOceanPlus to develop a complete understanding of the supply chain across Europe, including input from the consortium and users of the tools including developers, funders, investors and other groups represented in the project, as well as the experiences from real case studies (Annex I).

This deliverable analyses the value chain of ocean energy, regarding its stakeholders, structure, current engagement and breakdown of project costs. It explores the mapping of the opportunities for European companies and encompasses the typical project lifecycle activities, such as project management, supply of ocean energy devices and balance of plant, as well as the installation, commissioning, O&M, and decommissioning activities.

As highlighted throughout this document, experience from other sectors that have had similar trajectories, not only provide key learnings to reduce costs, but also significant opportunities to reinforce the European supply chain. Potential sectors for cross-collaboration are aerospace, automotive, aquaculture, energy storage, oil & gas, shipbuilding, and offshore wind, as identified in section 4. However, the incipient nature of the OE sector makes it difficult to make an appropriate analysis of these opportunities.

The supply structure described in section 3**¡Error! No se encuentra el origen de la referencia.**, covers the main phases of a project's life and were selected as significant categories for the analysis of opportunities for the OE sector:

- Development and project management
- Construction
- Installation, commissioning and decommissioning
- Operations and maintenance

In order to identify the opportunities, each of the main phases of a project's life had an assessment based on the five main criteria:

- Synergies with offshore wind
- Appetite or awareness from ocean energy
- Potential for LCoE benefit
- Size and timing of investments
- Size of the opportunity

A significant opportunity for the OE sector, is identified in section 4, describing the many synergies with offshore wind (OW) and transfer possibilities between OW and OE sectors. Also, in Annex I, there are several case studies that highlight some of these opportunities and present some cross-sectoral collaboration opportunities that will be further explored in the future deliverable D8.4, along with alternative/niche markets and business model description.

Section 4 also highlights the similarities between OW and OE that can be exploited to transfer knowledge and experience. These similarities include rotor and generator designs, pitch system and nacelles, foundations and moorings, cables and substations. The similarities also cover operations such as installation, commissioning and decommissioning as well as maintenance and asset repair. Taking advantage of these potential synergies can help address the challenge related to the cost competitiveness of OE technologies as well as encourage third parties to engage with the OE sector and enter the value chain.

In section 5, cost competitiveness is identified as a major challenge facing the OE sector, as the large number of technologies at different stages of development are yet to reach commercial scale and be cost competitive with other more mature renewable energy technologies. Whilst tidal energy technologies are currently more cost competitive than wave ones, both are still expensive when compared to other more proven technologies. The detailed assessment of costs is still a difficult task within the sector given the scale and number of deployments to date.

The limitations and challenges experienced by the supply chain are broadly classified into technical and non-technical, as elaborated in section 5, and they are spread throughout the project lifecycle stages.

Ocean energy is bringing unique challenges to marine governance frameworks, as stated in Section 5. Legal and regulatory aspects are frequently regarded as major non-technical challenges to the deployment of ocean energy, as a stable and complete policy framework for the ocean energy sector is currently missing, being currently tailored for more established uses of the sea, such as the oil and gas industry, fishing, and shipping.

It is expected that DTOceanPlus will underpin a rapid reduction in the Levelised Cost of Energy offered by facilitating improvement in the reliability, performance and survivability of ocean energy systems and analysing the impact of design on energy yield, O&M and the environment, thus making the sector more attractive for private investment.

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ANNEX I: CASE STUDIES

The following case studies related to Aquaculture, Desalination and Disaster Recovery represent possible European opportunities (these will be further explored in the future deliverable D8.4 about Business Models).

Technology	Implemented	Not implemented	Description	Business Case	Source
DESALINATION (Reverse Osmosis)		✓	A single desalination unit placed on the platform of a marina, located in the Caribbean basin. The power to the RO unit would be supplied by a wave energy converter technology of adequate power.	This concept could be extended to all the areas which need water resources to maximise net revenue from tourism. The product offered in this case is a **WAVE POWERED DESALINATION SYSTEM**, more specifically a 15 kW WEC with RO unit mounted on a breakwater of a tourist marina. Potential customers are: existing and new marinas, eco hotels and islands' governments and utilities.	'C2 Wave Energy desalination and Tourism Strategic Plan' [Rory McKevitt, Tadej Grabnar, Gordon Dalton UCC]
DESALINATION (Reverse Osmosis)		✓	Supplying the entire water needs of a small Caribbean island with a larger WEC.	The outcome of this solution would be to face the increasing number of tourists in the area. The product in this case is **DRINKING WATER VIA REVERSE OSMOSIS**, through 1 MW WEC using RO (capable of meeting the 74% of the annual water requirements). Potential customers are, again: existing and new marinas, eco hotels and islands' governments and utilities.	'C2 Wave Energy desalination and Tourism Strategic Plan' [Rory McKevitt, Tadej Grabnar, Gordon Dalton UCC]
DESALINATION (based on RE)	✓		Photovoltaic desalination, geothermal desalination, solar thermal desalination, wind power desalination.	Renewable desalination is likely to reduce its cost in the near future and become an important source of water supply for regions affected by water scarcity. The right combination of a renewable energy source with a desalination technology can be the key to match both **POWER** and **WATER DEMAND** economically, efficiently and environmentally friendly.	'Water desalination using renewable energy' [IRENA]

Technology	Implemented	Not implemented	Description	Business Case	Source
AQUACULTURE		✓	Supplying partly or completely (according to the size) the energy consumptions of an aquaculture farm using MRE.	Given the high energy consumptions of aquaculture farms for their pumping, lighting, purification and aeration systems, offshore installations such as aquaculture facilities could benefit from MRE. This would **LIMIT THE DIFFICULTY (AND THE COSTS) ASSOCIATED TO ENERGY TRANSPORTATION FROM THE SHORE**.	'Marine renewable energy: opportunities, challenges and potential for integration in aquaculture farms' [Rosa-Santos P, Clemente D and Taveira-Pinto F]
AQUACULTURE		✓	Wave farm protecting an aquaculture installation in Aguçadoura, north of Portugal, by inducing a significant shadow effect that would protect the fish farm.	**INSTALLING A FISH FARM DOWNWAVE OF THE ENERGY FARM**, with the purpose of sheltering the fish farm, would increase the viability of aquaculture offshore and decrease the possibility of the structure of being damaged.	'The effect of a wave energy farm protecting an aquaculture installation' [Dina Silva, Eugen Rusu, C. Guedes Soares]
DISASTER RECOVERY		✓	Following an emergency, power will be required to run medical equipment, communication network and devices, lighting, heating/air conditioning, refrigeration and many other necessary services. This power could be supplied by marine energy devices off the coast. For communities along sizable rivers, riverine devices could supply power in the same manner.	Typically, FEMA (Federal Emergency Management Agency) and/or state or community emergency services provide diesel generators for emergency power systems. Marine energy could be used to **AUGMENT OR REPLACE** power from **DIESEL GENERATORS,** as well as provide black-start capability to isolated portions of the grid. This could benefit isolated community which are largely dependent on imported fossil fuels. Marine energy must prove that is equal to or greater than other technologies (diesel generators, solar energy and battery energy storage systems) in order to be competitive.	'Coastal resiliency and disaster recovery' [U.S Department of Energy, Office of Energy Efficiency & Renewable Energy]

ANNEX II: REVIEW OF PREVIOUS SUPPLY CHAIN STUDIES

Nº	Title	Author(s)	Year	Objective
1	JA.3. SME Engagement & Support: Ocean Energy Supply Chain Analysis Summary Report	OCEANERA-NET [7]	2018	Analysis of existing supply chains in OCEANERA-NET consortium and other countries
2	Supply chain of renewable energy technologies in Europe: An analysis for wind, geothermal and ocean energy	Magagna et al. [19]	2017	Overview of the supply chain of several renewable energy technologies (wind, geothermal, and ocean energy). The report focuses on the current market for these technologies and the position of EU companies as well as the EU's strengths and weaknesses.
3	JRC Ocean energy status report: 2016 Edition	Magagna et al. [3]	2016	Section dedicated to the description of the market status and its future projections, and an assessment of the European supply chain. Aye
4	Wave and Tidal Supply Chain Development Plan: Supply chain capability and enabling action recommendations	Hundleby et al. [BVG Associates] [62]	2015	Identification of strengths and weaknesses in the UK supply chain and suggest interventions to grow value-creating, sustainable and confident sectors.
5	The Supply Chain for the Ocean Energy Industry in Ireland – Discussion Paper	Marine Renewables Industry Association (MRIA) [54]	2013	Identification of supply chain needs, capabilities and opportunities in the Irish context
6	Ocean energy supply chain study: Assessment of Irish companies' capability to supply products and services to the marine energy sector	Sustainable Energy Authority of Ireland [36]	2012	Brief description of the marine energy supply chain structure in Ireland and identifies services and components within the supply chain where Ireland has strong and limited capabilities.
7	Marine Renewable Energy Supply Chain Development: Engagement and Strategy Report	SLR Consulting [69]	2013	Discussion of technical challenges being faced by the tidal energy sector in Nova Scotia, Canada as well as their relative significance in terms of effect on cost and overall viability.
8	The Marine Renewable Energy Sector Early-Stage Supply Chain	CanmetENERGY [70]	2011	Report on Canada's marine renewable energy supply chain offering short- and medium-term visions.
9	Ocean energy development in Europe: Current status and future perspectives	Magagna and Uihlein [71]	2015	Critical review of ocean energy technologies, focusing on wave and tidal energy development in the EU.
10	Stakeholder requirements for commercially successful wave energy converter farms	Babarit et al. [37]	2017	Lists stakeholder requirements for wave energy farms.

N°	Title	Author(s)	Year	Objective
11	Ocean Power Innovation Network value chain study: Summary report	BVG Associates [49]	2019	Quantification of the value chain for three marine energy technologies: tidal stream, wave, and floating wind energy. This report provides cost estimates for marine energy projects assumed to be commissioned in 2020 and outlines technological challenges.
12	Maximising the Value of Marine Energy to the United Kingdom	RenewableUK [72]	2014	Examination of the economic potential of the marine energy sector, how value from developing wave and tidal resources can be generated and retained within the UK.

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