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STATUS REPORT ON TECHNOLOGY DEVELOPMENT, TRENDS, VALUE CHAINS AND MARKETS

Joint Research Centre

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Contents

Abstract

Ocean energy has been acknowledged in the context of the European Energy Union as a fundamental research and development priority to achieve 2050 climate objectives. The European Green Deal included ocean energy in the technologies necessary toward a transition to climate neutrality. The aim of this report is to provide an update of the state of the art of ocean energy technology. It provides an analysis of R&D development trends focussing particularly on the technology progress made in EU-funded research until end of 2021 in view of the SET-Plan targets. Moreover, this work provides an analysis on EU position and global competitiveness within the ocean energy value chain and identifies potential bottlenecks and risks towards the targets formulated in the European Green Deal.

Foreword

This report is an output of the Clean Energy Technology Observatory (CETO). CETO's objective is to provide an evidence-based analysis feeding the policy making process and hence increasing the effectiveness of R&I policies for clean energy technologies and solutions. It monitors EU research and innovation activities on clean energy technologies needed for the delivery of the European Green Deal; and assesses the competitiveness of the EU clean energy sector and its positioning in the global energy market.

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Executive summary

The Clean Energy Technology Observatory (CETO) prepares a set of annual reports on a range of technologies, addressing technology maturity status, development and trends; value chain analysis and global market and EU positioning.

Ocean energy has been acknowledged in the context of the European Energy Union as a fundamental research and development priority to achieve 2050 climate objectives. The European Green Deal included ocean energy in the technologies necessary toward a transition to climate neutrality.

Wave energy and tidal stream energy are the two ocean subtechnologies that dominate deployments, technological advancements and potential in the EU. Installed capacity has been increasing for all types of ocean energy with Sweden having the largest installed capacity amongst EU countries followed by France. A limited amount of devices has reached commercial readiness and there is a limited amount of ocean energy devices deployed in a commercial capacity. The development of the market relies on multiple technological, financial and environmental parameters.

In terms of the technology, devices and procedures must be furtherly refined in order to establish ocean energy as a reliable source of energy. While for tidal there is a convergence in horizontal axis technology devices, for wave energy the sector is more fragmented with multiple devices being currently pursuit. By refining the technologies and increasing the number of deployed devices, cost will be reduced as well. Currently costs are still high with average Levelised Cost of Electricity (LCoE) for wave energy devices 0.27 EUR/kWh and for tidal energy devices 0.2 EUR/kWh. According to SET plan, by 2030, LCoE for tidal energy should reach 0.1 €/kWh, whilst for wave energy the target is of 0.15 €/kWh.

Financially, EU have been supporting companies through public investments, leading the sector globally by contributing 46% of the worldwide public investments in the last decade. In terms of private investments, EU companies are the second largest investors in ocean energy following China. Venture capital investments in the EU are dominated by investment in later stages accounting for 77% and 74% of the total investments in period 2010-2015 and 2016-2021 correspondingly. Financial availability in the EU lead to an increased number of high-value patents compared to global competitors (34% of the high-value inventions originate from the EU). In order to establish ocean energy as a main source of energy, further investments is necessary.

EU is highly competitive in the ocean energy sector with the majority of tidal stream developers (41%) with TRL larger than five being located in the EU. Similarly, the majority of companies developing wave energy devices are located in the EU (52%). EU is also leading in the number of scientific publications in the wave energy sector, while for the tidal sector is positioned second, following closely UK. In Table 1, the major strengths, weaknesses, opportunities and threats (SWOT) of ocean energy technologies are presented.

Table 1. Ocean energy major strengths, weaknesses, opportunities and threats (SWOT)

Strengths	**Weaknesses**
• Constant energy source • Reduced visual impact, leading to increased public acceptance • Large number of projects in the pipeline • Multiple European companies have project experience and knowledge • EU is in a good position in terms of publications, patents, private and public R&I.	• Due to the immaturity of the sector there are still high initial cost (CAPEX) which are expected to decrease with an increasing number of employments • Maintenance can be costly/ difficult, leading in to higher operational costs (OPEX) • Limited data on the length of lifetime leads in conservative assumptions of the lifetime for the calculations of coast. • Geographically limiting factors especially for tidal energy where most of the developed devices require strong tidal currents in order to operate.
Opportunities	**Threats**
• Under the right conditions, ocean energy could contribute around 10% of EU power demand by 2050. • Due to their capabilities both for energy production but also for alternative uses (desalination, aquaculture etc) they have the potential to drive blue economy • EU companies are leading the field so there are substantial export opportunities for both technology and knowledge • Co-development of ocean energy sources with other renewable sources of energy or other activities in common platforms	• The number of commercial projects in the pipeline has increased but more is needed to achieve ambitious targets. • Administrative barriers. Due to not well defined procedures and environmental impacts, licensing procedures are often long and complicated • Ocean energy technologies are more costly compared to other marine renewables

Source: JRC, 2022.

1 Introduction

The ocean contains a vast renewable energy potential, which could support economically sustainable long-term development and can be a crucial component in the world's emerging blue economy. Ocean energy - including wave, tidal salinity gradient and ocean thermal energy conversion technologies - can provide both provide reliable and stable electricity, as well as support other components of the blue economy, such as aquaculture and desalination.

The purpose of this report is to provide an assessment of the state of the art of ocean energy technology, evaluate the value chains and to identify their development needs and barriers and to assess the market. The analysis focuses primarily on tidal and wave energy technology, considering their potential to provide a significant contribution to the European energy mix in the coming years. This report is organised into three main blocks: (i) Technology assessment and state of the art, (ii) Value chain analysis and (iii) EU position and global competitiveness.

For the identification of the technology trends, needs and barriers, the technology roadmaps and reports from various organisations and initiatives such as the International Energy Agency (IEA), Ocean Energy Europe (OEE), IEA Ocean Energy systems (OES), and the European Technology and Innovation Platform for ocean energy (ETIP Ocean) have been used.

The TRL assessment follows the definitions as described in (European Union, 2014) .Finally, to determine the TRL of a sub-technology we assume that there should exist at least one project at the specific TRL assigned.

In section 2 the technological state of the art is presented, together with the current status in investments, patenting and research activity. The review of the current status of the different ocean energy technologies is based on a variety of sources, from SET plan actions, to scientific articles and online information from credible sources, including the International Energy Agency (IEA), Ocean Energy Europe and Ocean energy systems. In the patenting activities section the data are sourced from the Joint Research Centre (JRC) based on data from the European Patent Office (EPO). Patent data are based on PATSTAT database 2021 autumn version. The methodology behind the indicators is provided in Fiorini (2017), Pasimeni et al. (2019), and Pasimeni (2019).

In the *Impact and Trends of EU-supported Research and Innovation* paragraph, the main sources are CORDIS and internal databases for identifying the EU co-funded projects. On the technology readiness assessment, the focus is on projects granted FP7 and H2020 (2014-2020) funding. It should be noted that in most cases the technology readiness level achieved at the end of a project is not clearly indicated within the project outputs. In such cases expert judgement of results is applied.

In section 3 the value chain is assessed. The role of EU companies globally is highlighted and the environmental and socioeconomic sustainability is discussed. Data for this chapter originate from the PRODCOM database

In section 4 the position of the EU in the ocean energy sector is discussed. Trading data from COMEXT are used to assess the import and export balance and the need of raw materials for the development of ocean energy devices and their support mechanisms are discussed.

2 Technology State of the art and future developments and trends (For each technology)

2.1 Technology readiness level (TRL)

The oceans contain the largest untapped source of renewable energy. While ocean power technologies represent the smallest share of the renewable energy market, they are steadily advancing towards commercialisation (IRENA, 2021).

To take advantage of the constant energy present in different forms in the oceans, different technologies have been developed throughout the years. Depending on the source of energy they are using they can be divided into four main categories: Tidal energy, Wave energy, Ocean Thermal Energy Conversion (OTEC) and Salinity Gradient technologies.

The ocean energy sector has significant potential to contribute to the energy mix and therefore to the decarbonisation of the EU, having a theoretical potential of about 2800 TWh for wave and 50 TWh for tidal energy annually (Magagna, 2020). In Europe the highest potential exists along the Atlantic coast. OTEC due to its nature, is only deployable in tropical seas in EU overseas islands.

In order to achieve the EU's Energy and climate goals the Strategic Energy Technology (SET) plan was develop to enable the coordination of national R&I activities and align the individual national programs with its agenda. The SET Plan declaration of intent for ocean energy (European Commission, 2016) has also set ambitious targets for wave and tidal energy technologies. Tidal technologies are expected to reach a levelised cost of energy (LCoE) of 0.15 EUR/kWh by 2025 and of 0.10 EUR/kWh by 2030. Wave energy technologies are expected to reach the same targets with a five-year delay, 0.15 EUR/kWh in 2030, and 0.10 EUR/kWh by 2035.

For ocean energy, a SET Plan Temporary Working Group was formed in 2017 with the task of developing an implementation plan in 2018 to achieve the target. This implementation plan was revised in 2021 (European Commission, 2021). According to the implementation plan the high – level targets for the ocean energy sector are:

- to bring ocean energy to commercial deployment,
- to drive down the levelised cost of energy (LCoE),
- to maintain and grow Europe's leading position in ocean energy and
- to strengthen the European industrial technology base, thereby creating economic growth and jobs in Europe and allowing Europe to compete on a global stage

In this section the maturity of ocean technologies will be assessed according to their technological readiness level. The TRL assessment follows the definitions as described by European Union (2014).

2.1.1 Tidal Energy

Tidal energy can be extracted in two main ways, by taking advantage of the water level between the different times of the tidal circle, namely tidal range, and by taking advantage of the tidal currents through tidal stream technologies. While tidal range has the largest installed capacity amongst all ocean energy resources, it is not typically pursuit due to its limited site availability, large initial cost and environmental implications. Currently in EU limited number of projects are operational, with the biggest one being La Rance, France, while only one is in the pipeline (Brouwersdam, Netherlands).

On the other hand, tidal stream has an increasing number of deployments, both for small-scale, lower TRL devices and for full-scale, commercial devices (TRL 9). Tidal stream ocean energy originates from horizontal water currents that are created by the vertical variation of water levels caused by tides. Technologies that take advantage of the tidal stream are the following:

- Horizontal axis turbines (HAT): the tidal stream passes through a turbine, causing the rotors to rotate around the horizontal axis, generating power. HAT devices can be both fixed on the seabed and floating

- Vertical axis turbines (VAT): Similar to the horizontal axis design, but in this case the rotors rotate around a vertical axis.
- Enclosed tips (ET): A funnel-like device that sits on the seabed. The flow of the tidal current drives a turbine directly or the induced pressure differential in the system drives an air-turbine.
- Oscillating hydrofoil (OH): A hydrofoil is attached to an oscillating arm. The tidal current flowing causes the hydrofoil to lift. This motion drives fluid in a hydraulic system and is converted into electricity.
- Tidal kite: A kite carrying a turbine below its wing and is tethered to the sea bed. As the kite 'flies' in the tidal stream the turbine is rotating producing electricity.
- Archimedes screw: Is a helical corkscrew-shaped device that draws power from the tidal stream as the water moves up/through the spiral turning the turbines.

The most prominent sub-technology of tidal stream devices is the horizontal axis. Both floating and bottom fixed designs are considered, while currently there are multiple devices that have a high maturity level, being in a commercial or pre-commercial stage (TRL 8-9). Installed devices have a capacity of 100 kW up to 2 MW per device. Multiple designs proposed for HAT have reached TRL8, with most demonstration projects located in the UK, Portugal, France, the Netherlands and Canada. Tidal kites are also currently being tested at full scale (TRL 8), with currently installed devices having a capacity of 100 kW and a licenced for an array development reaching 80 MW.

In Table 2 the different tidal stream energy technologies, together with their TRL and maximum capacity installed, are presented.

Table 2. Key tidal energy technologies, highest achieved TRL and key developers in Europe

Technology	Highest TRL achieved	Developers
Horizontal axis turbine	9	Atlantis Resources Corp, Magallanes Renovables, Nova Innovation, Tidal stream Limited, Tocardo BV, Orbital Marine
Tidal Kite	8	Minesto, SeaPower scri
Enclosed tips	7	OpenHydro (out of business)
Oscillating hydrofoil	6	ResHydro, EEL energy
Vertical axis turbine	7	HydroQuest
Archimedes screw	-	Flumill (out of business)

Source: JRC, 2022

Notable tidal projects

Some of the tidal energy projects that were deployed recently include Nova Innovation's 100 kW direct drive tidal turbine 'EUNice' deployed in Shetland Islands, UK. Due to its direct drive design, it is able to cut costs by 30% compared to other similar geared models, while at the same time increasing the efficiency and the reliability of the device.

Minesto has deployed for commercial use in Faroe Islands the DG100 tidal kite device. Current plans include the further development of tidal energy deployment in the region, with a potential expansion from 200 kW to 4 MW. Future installations will utilize further Dragon Class D4 (100 kW) and D12 (1.2 MW) devices to mitigates potential project delays from the supply chain, as well as increase the energy production.

Notable installations were also made lately in the European Marine Energy Centre (EMEC) in Orkney, including Orbital Marine Power's O2 floating tidal turbine and Magallanes' ATIR 2MW tidal turbine.

2.1.2 Wave Energy

As opposed to tidal devices, in wave energy there is a greater design variance with is no dominant sub-technology being preferred. The main device types are:

- Point absorbers (PA): Floating structures that take advantage of the motion of the device produced by passing waves.
- Oscillating wave surge converters (OWSC): Submerged devices that take advantage of the pendulum movement of a flat surface, caused by the movement of water in the waves.
- Oscillating water column (OWC): A partially submerged, hollow structure that is open to the sea below the water line, enclosing a column of air on top of a column of water. Waves cause the water column to rise and fall, which in turn compresses and decompresses the air column. This trapped air flows through a turbine to generate electricity.
- Rotating mass (RM): A hollow devices that encloses an eccentric weight of a gyroscope. As the device is moved by the waves, the weight is rotating producing electricity.
- Other: six more are identified having unique characteristics and specific design.

Between the several types of wave energy devices there are significant differences based on how devices are operated and on the power conversion system (PTO) employed ranging from linear direct drive generators to mechanical and pneumatic systems.

Devices currently deployed are showing the capability to survive wave loadings, however reliability is still to be fully proven. Information regarding the electricity generation from wave energy deployment is limited.

The lack of design convergence has been highlighted as one of the drawbacks of wave energy development so far.

In Table 3 the different wave energy technologies, together with their TRL and maximum capacity installed are presented.

Table 3. Key wave energy technologies and their key developers

Technology	Highest TRL achieved	Developers
Attenuator (ATT)	8	EcoWave power, Mocean offshore, WavePiston
Point Absorber	9	Blue power energy, Carnegie Wave energy, CorPower Ocean, Neptune Renewable energy, Oscilla Power, Sinn Power
OWSC	7	AW Energy
OWC	9	Sea Energies
Overtopping	8	AWS Ocean Energy, Wave Dragon
Rotating mass	7	Ecole Centrale de Nantes, Wello OY, Bombora wave power, Calwave

Source: JRC, 2022

Notable wave energy projects

For the testing of wave energy devices, multiple facilities exist in European waters. EMEC has hosted a variety of test devices (eg Wello OY's Penguin and Aquamarine Power's Oyster 800). Two of the most notable in EU waters include the Biscay marine energy platform (BiMEP) and the Mutriku site in Basque county, Spain. Mutriku Wave plant is an OWC multi-turbine facility with an installed capacity of 296 kW that supports the testing and demonstration of various components (air turbines, control strategies, energy storage etc). In BiMEP, various wave energy devices have been deployed, with the most recent example being Wello's Penguin 2 rotating mass device, deployed in 2021 having a capacity of 1 MW.

Wave energy devices have also being deployed in Plataforma oceanica de Canarias (PLOCAN) test site in Canary Islands with one being Wavepiston full scale demonstration system with a capacity of 200 kW.

2.1.3 Ocean thermal energy conversion (OTEC)

OTEC power generation makes use of the temperature difference between the warm surface and the cold deep- sea layers (at 800 to 1000 m depth) and converts it through a thermal cycle into electricity, heat or cold in a heat cycle. For such a conversion cycle to work, the temperature difference must be around 20 °C. This means that since deep-sea water temperature is constant at around 4 °C at 1000 metres depth, the surface temperature must be around 25 °C to utilize OTEC (OES, 2021). Such conditions are only present in tropical regions between latitudes of around 30 degrees north and 30 degrees south. Therefore, for the scope of this report OTEC will not be considered, since it can only be developed in specific EU overseas islands.

2.1.4 Salinity gradient

Salinity gradient energy, also known as osmotic energy, makes use of the pressure potential in the difference in the ocean's salt concentration and transforms it into usable energy with the help of membranes.

The salinity of the ocean is not homogenous across the globe. Its concentration is lower in the proximity of the poles, which is predominantly due to the melting ice. Other factors such as river runoff or melting glaciers as well as heavy or lack of precipitation also impact the salinity in certain regions. Although the salinity levels vary, the presence of river beds, where fresh water discharges into the sea, is most important to harness salinity for energy generation purposes. This is because the amount of energy that can be generated is proportional to the difference in salt concentration, making a freshwater-saltwater system extremely efficient. Estuaries can be found globally, and salinity plants can in theory run continuously to provide baseload power. In comparison to other ocean energy technologies, however, the geographical requirements pose strong limitations to the overall potential, making it comparably small at 1650 TWh per year (Thorsen and Holt, 2009).

The technology remains in conceptual stage and is significantly less mature than tidal, wave or OTEC, but research is being conducted intensively, data are being collected, and laboratory testing is ongoing.

Two main processes to make use of this potential energy are being tested and applied: pressure retarded osmosis (PRO) and reversed electro dialyses (RED). PRO technology is being pursued mainly by SaltPower which aimed at having its first commercial unit in 2021, while RED is used for a demonstration plant on a test rig in the Netherlands by REDstack (TRL 7).

Since there is only very limited deployment, this technology does not fall in the scope of this report.

2.1.5 Alternative applications

The predictability of tidal energy coupled with the possibility of ensuring almost 20 hours of generation per day, has led to exploratory projects where electricity that cannot be used by the grid is directed towards the production of hydrogen.

Characteristic example of ocean energy storage is Nova Innovation's Tidal Energy Storage System, which uses a 300 kW tidal array coupled with a Tesla Battery to provide baseload electricity in Shetland Islands (Nova Innovation, 2019).

Similarly for wave energy the sector is investigating the use of the technology for sectors other than the utility-scale electricity market. Currently methods that combine wave energy, for example Resolute Marine Energy OWSC device, to desalination are tested. OPT Power Buoys in conjunction with ENI and Premier Oil highlight the possibilities that wave energy technology offers to provide clean power to stand-alone application, such as environmental data gathering and transmission (OPT, 2018). MoorPower scaled demonstrator project uses wave energy to directly power aquaculture activities and Wave2O which uses wave energy to power a desalination system

Hybrid approaches that incorporate more than one renewable energy sources are also started to be deployed at a small scale. Incorporating ocean energy devices to offshore wind, floating offshore wind and floating PV technologies will help lower the cost of ocean energy technologies through sharing facilities and procedures (e.g. maintenance procedures), while maximizing and stabilizing the energy outcome. W2Power Wind and Wave system concept by Pelagic Power, combines a semisubmersible offshore wind turbine platform with multiple oscillating body wave energy and Poseidon Wave and Wind system by Floating Power Plant combines 3 wind turbines and multiple wave energy devices in the same platform

OES has identified six projects to demonstrate the capabilities of ocean energy in alternative markets, ranging from desalination and aquaculture applications to multi-use platforms (OES, 2021)

2.1.6 Challenges for the ocean energy sector

ETIP Ocean (2020) has identified the challenge areas for the ocean energy sector that focus should be put in the next period. While there are technology specific challenges some of the most pressing challenges are common for all ocean energy technologies:

- Design and validation of ocean energy devices
- Foundations, connections and mooring
- Logistics and marine operations
- Integration in the energy system
- Data collection, analysis and modelling tools

These challenges are furtherly elaborated as shown in Table 4.

2.2 Installed energy capacity, Generation/Production

In the last decade, installed capacity has been increasing for all types of ocean energy with tidal technologies dominating the deployed capacity. More than 98% of the total combined capacity that is currently operational (521.5 MW) is tidal range technology. Three main projects account for the majority of the installed capacity – a 254 MW plant in the Republic of Korea (since 2011), a 240 MW plant in France (1966) and a 20 MW station in Canada (1984). Despite the dominance of this technology, no tidal barrage power plants of relevant scale have been developed in almost 10 years, and there is relatively low resource potential to be explored at a high environmental and financial cost. Smaller installations (e.g. Tocardo's 1.2MW tidal power station in Eastern Scheldt Storm Surge Barrier) are still under development, but their application is limited geographically.

In terms of tidal stream and wave energy capacity, deployments pace peaked in 2017. In 2020 and early 2021, due to COVID19 restrictions, most projects have been postponed and only a limited amount of projects were deployed. However, currently the pace both for tidal and wave energy deployments is increasing.

Table 4. Challenges for the ocean energy sector

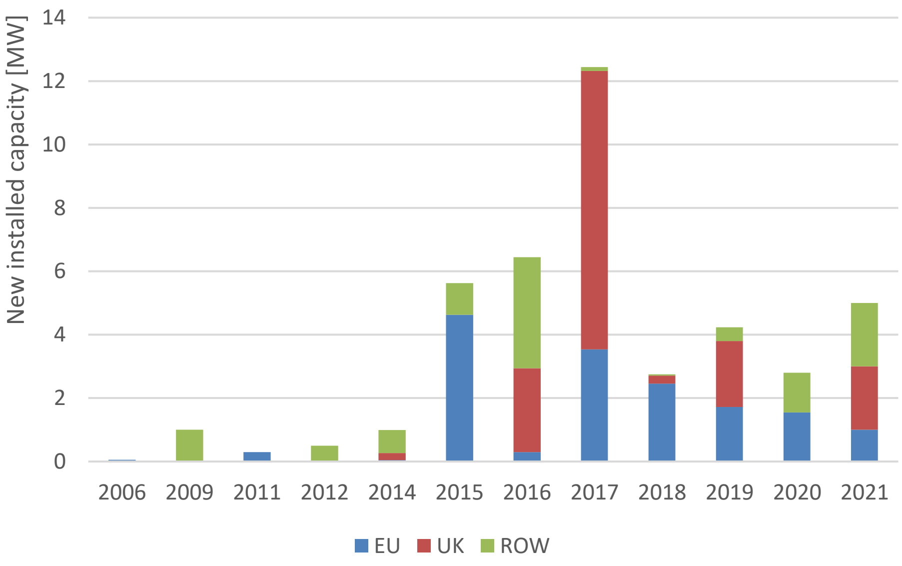
Challenge	Sub category	Technology
Design and Validation of Ocean Energy Devices	Demonstration of ocean energy devices to increase experience in real sea condition	Tidal and Wave
	Demonstration of ocean energy pilot farms	Tidal and Wave
	Improvement and Demonstration of PTO and control systems	Wave
	Application of innovative materials from other sectors	Tidal and Wave
	Development of novel wave energy devices	Wave
	Improvement of tidal blades and rotor	Tidal and Wave
	Development of other ocean energy technologies	Other
Foundations, connection and mooring	Advanced mooring and connection systems for floating ocean energy devices	Tidal and Wave
	Improvement and demonstration of foundations and connection systems for bottom-fixed ocean energy devices	Tidal and Wave
Logistics and Marine Operations	Optimisation of maritime logistics and operations	Tidal and Wave
	Instrumentation for condition monitoring and predictive maintenance	Tidal and Wave
Integration in the Energy System	Developing and demonstrating near-commercial application of ocean energy in niche markets	All
	Quantifying and demonstrating grid-scale benefits of ocean energy	Tidal and Wave
Data Collection & Analysis and Modelling Tools	Marine observation, modelling and forecasting to optimise design and operation of ocean energy devices	Tidal and Wave
	Open-data repository for ocean energy	Tidal and Wave
Cross-cutting Challenges	Improved knowledge of the environmental and socioeconomic impacts of ocean energy	Tidal and Wave
	Standardisation and certification	Tidal and Wave

Source: ETIP Ocean, 2020

Overall, since 2010 the cumulative installed capacity in European waters is 30 MW for tidal and 13 MW for wave energy devices. Worldwide for the same period the cumulative capacity is 40 MW for tidal stream and 25 MW for wave energy. However, since most of the devices were demonstrator and testing devices, only a fraction of this capacity is still in the water. By the end of 2021 in European waters, tidal stream capacity was 11.5 MW, while for wave energy capacity was 1.4 MW.

In the past the largest installed capacity deployed was part of multiple small capacity demonstration projects, decommissioned after a couple of months/ years once their respective project ended. Currently, especially for tidal energy which reached technology maturity, fewer full-scale and capacity devices are currently being installed. In Figure 1 is presented the annual installed capacity for the European Union (EU), United Kingdom (UK) and the rest of the world (ROW) for tidal stream and wave energy projects.

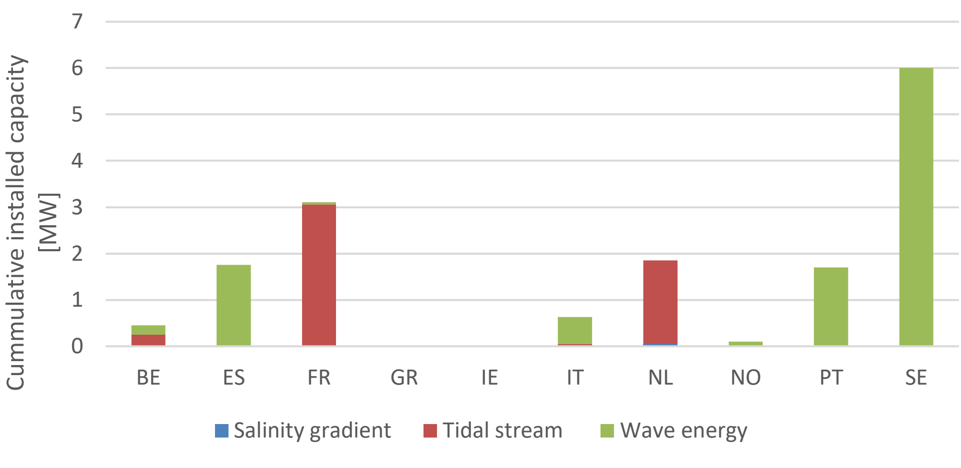
Figure 1. Annual capacity installation of tidal stream and wave energy plants in the EU, UK and rest of the world



Source: JRC database, 2022

In terms of individual EU countries, France and the Netherlands have the majority of installed capacity in terms of tidal stream energy, while Sweden, Spain and Portugal are leading the deployment of wave energy devices (Figure 2).

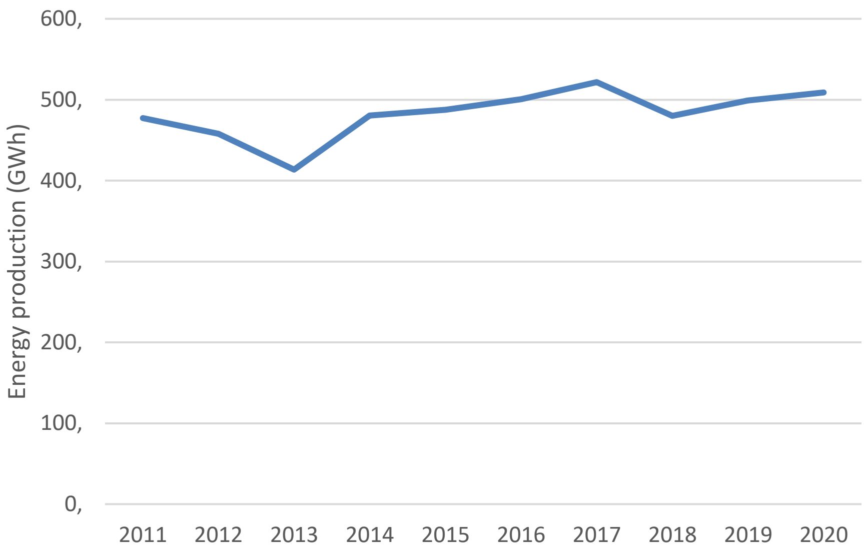
Figure 2. Ocean energy cumulative installed capacity in the EU in 2021



Source: JRC database, 2022

In Figure 3 the annual production for all types of ocean energy (including tidal range) in the EU, according to Eurostat, is presented. The majority of the energy presented in this graph comes from the La Rance Tidal power station (France), with an installed capacity of 240 MW and an annual production of approximately 400 – 500 GWh. The rest of the power production is attributed to smaller ocean energy projects in Spain and Portugal that are connected to the grid. Currently, a lot of deployments are in a demonstrator level (TRL = 5-6), and do not contribute to the network, hence their production is not taken into account in Figure 3.

Figure 3. Annual ocean energy production in EU countries. The figure includes data for all types of ocean energy present in EU waters (Tidal range, tidal stream, wave energy, salinity gradient).



Source: Eurostat, 2022

Globally, electricity generation from tidal stream and wave energy has increased by 33% between 2019 and 2020, reaching 400 GWh annually. Since 2010 tidal stream devices have produced 68GWh in Europe. This amount is significantly above the levels of the previous 3 years (IEA-OES, 2021). However, the deployments have to increase significantly in order to reach both EU targets and Net Zero Emissions scenarios. EC through the Offshore Renewable Energy Strategy set a target of at least 1 GW of installed capacity by 2030 and at least 40 GW by 2050. IEA's Net Zero Emissions by 2050 scenario models 27 TWh of electricity generation by ocean energy in 2030.

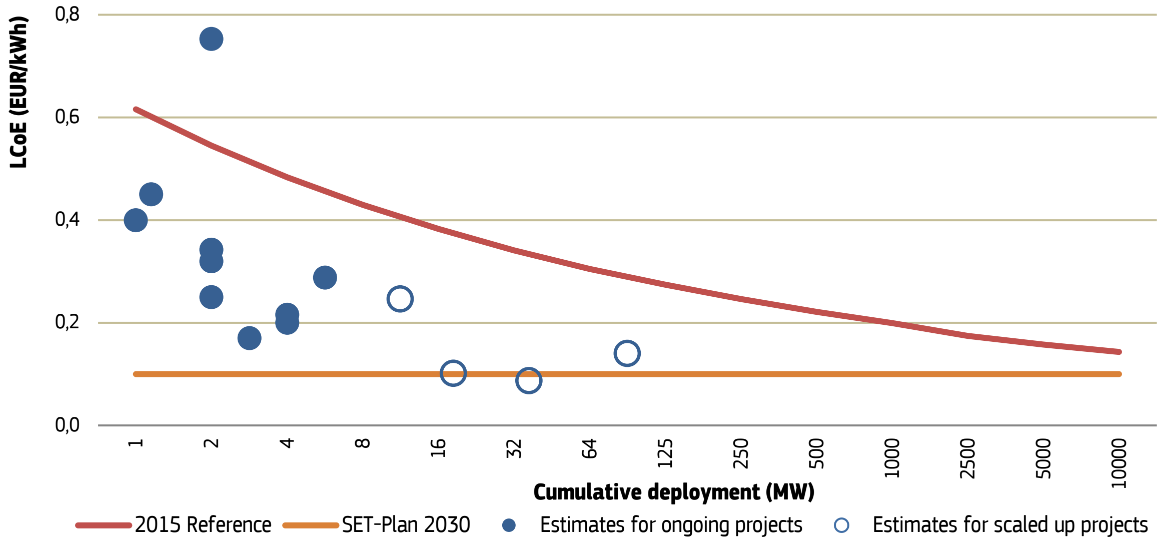
For 2022 onwards a steady, global growth for both tidal and wave energy devices is projected. In terms of wave energy 2.8 MW of capacity is slated for installation in Europe and 1.1MW for the rest of the world. This capacity will predominantly come from full-scale devices, installed in the UK, Spain, Portugal for the European installations and USA and China in the rest of the world. For tidal stream, in the coming year capacity of 1.4 MW in Europe and 1 MW in the rest of the world will be installed. Major installations will happen in the Netherlands, UK and Canada. The next major capacity increase in tidal energy was postponed and is now expected around 2025 (Ocean Energy Europe, 2022).

2.3 Technology Cost – Present and Potential Future Trends

The cost of ocean energy technologies varies from project to project and from one technology to the other. Since most technologies are not mature enough and current deployments consists mostly of single devices, expenses and procedures are not optimized leading to high initial and operating costs. In order for these technologies to be sustainable and contribute to the energy market in the future, significant cost reductions must be achieved.

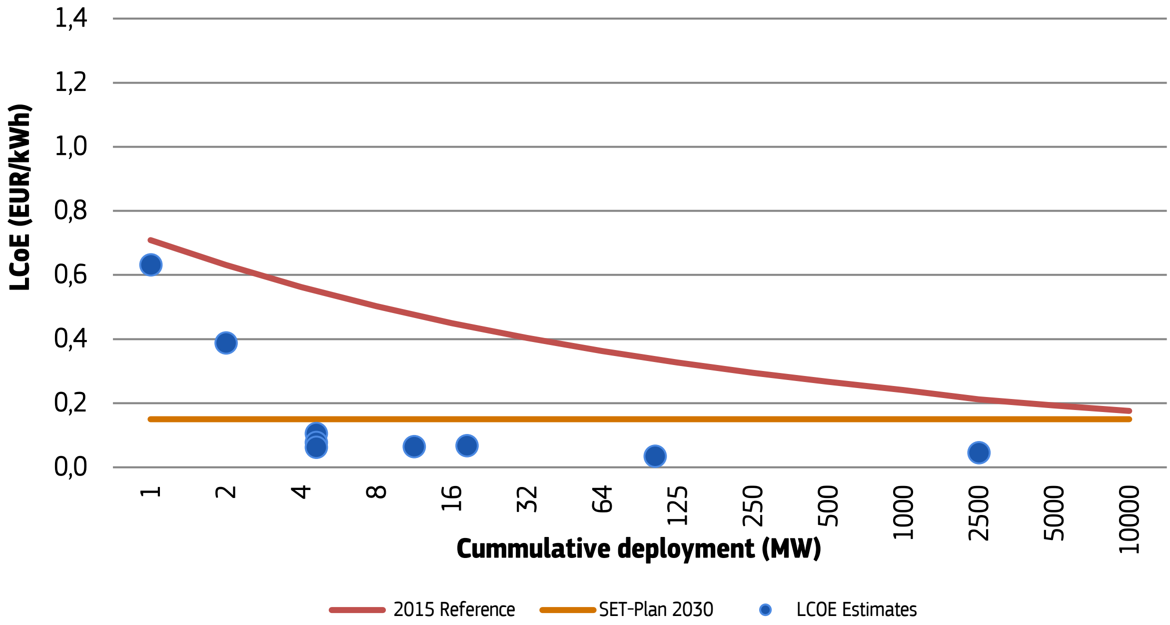
The critical key performance indicator (KPI) for the assessment of the cost-reductions needs for ocean energy technology is the LCoE. Current ocean energy projects have an LCoE 0.11–0.48 €/kWh for tidal stream and 0.16–0.75 €/kWh for wave energy (IRENA, 2021). By 2030, LCoE for tidal energy should reach 0.1 €/kWh, whilst for wave energy the target is of 0.15 €/kWh (European Commission, 2021). For tidal energy, LCoE estimates of current and scaled up projects are presented in Figure 4, while for wave energy project in Figure 5.

Figure 4. Levelised Cost of Electricity (LCoE) of estimated current and scaled up tidal energy devices



Source: Based on JRC database,2022 and IRENA, 2021

Figure 5. Levelised Cost of Electricity (LCoE) of estimated current and scaled up wave energy devices



Source: JRC database, 2022

The LCoE estimates, based on IRENA (2021) and JRC database, presented in Figure 5 indicate that several developers foresee cost of wave energy technology dropping below the 2025 SET Plan targets at a faster rate than expected. This forecast is based on unlocking manufacturing potential as well as improving the performance of individual devices. These improvements could help make a stronger case for wave energy technologies; however, wave energy converters still need to demonstrate their capabilities to attract investor and manufacturers and unlock economies of scale cost-reduction.

The percentage attribution to the capital expenditure (CAPEX) and the level of maturity of each component, for a typical point absorber wave device and a typical horizontal axis bottom fixed tidal device are presented in Table 5 and Table 6 correspondingly (Pennock et al., 2022). The largest cost is attributed to the structural components and the PTO of the device followed by the moorings necessary to keep the device in its place. In wave energy devices around 40% of the components are at a high maturity level, while for tidal device this percentage is 48%.

Table 5. Cost centre breakdown and corresponding component maturity levels assumed for wave (point absorber)

Category	Cost centre	% of CAPEX	Maturity Level
Development	Permitting and environmental compliance	1.8	High
	Site assessment	0.1	High
	Project/Array design, engineering and management	0.9	Medium
Infrastructure	Subsea cables	2.2	High
	Terminations and connectors	0.2	Medium
	Dedicated O&M vessels	2	Medium
Mooring/Foundation	Mooring lines/chain	4.2	Medium
	Anchors	4.2	Medium
	Buoyancy	1.4	High
	Connecting hardware	2.4	High
Device structural components	Surface floaters	13.6	Medium
	Vertical column	14.6	Medium
	Reaction plate	16.6	Medium
	Device access	0.9	High
PTO	Generator	0.5	Medium
	Hydraulic components	2.5	High
	Hydraulic energy storage	0.6	High
	Frequency converter	0.5	Medium
	Step-up transformer	1.1	High
	Riser cable/umbilical	2.3	Medium
	Control system	0.1	Low
	Bearings and linear guides	1.7	High
	Assembly, testing and QA	1.1	Medium
	PTO mounting	0.1	High
	Other	0.1	Medium
Installation	Subsystem integration	5.6	Medium
	Transport to staging site	0.8	High
	Cable shore landing	0.4	High
	Mooring /Foundation system	2.8	Medium
	Cable installation	1.9	Medium
	Device installation	1.9	Low
	Device commissioning	1.9	Low
Contigency (direct % of total CAPEX)		9.1	N/A
OPEX		4 (annual)	Low

Source: Pennock et al., 2022

Table 6. Cost centre breakdown and corresponding component maturity levels assumed for tidal stream (Fixed bottom HAT device)

Category	Cost centre	% of CAPEX	Maturity Level
Development	Permitting and environmental compliance	1.8	High
	Site assessment	0.1	High
	Project/Array design, engineering and management	1.4	Medium
Infrastructure	Subsea cables	0.4	High
	Dedicated O&M vessel	4.3	Medium
Mooring/ Foundation and device structural components	Pile	11.3	High
	Cross-arm	3.3	High
	Nacelles	5.4	Medium
	Device access	2	High
PTO	Generator	5.6	Medium
	Gearbox and driveshaft	8.2	Medium
	Hydraulic system	0.9	High
	Frequency converter	6	High
	Step-up transformer	0.8	High
	Riser cable/umbilical	0.4	Medium
	Control system	5.6	Medium
	Bearings and linear guides	7.8	High
	Rotors	0.5	Medium
	PTO mounting	2.3	High
	Other	4.1	Medium
Subsystem integration		6.8	Medium
Installation	Cable shore landing	0.7	High
	Mooring/Foundation system	3.8	Medium
	Subsea cables	3.3	Medium
	Device Installation	4.1	Low
Contigency (direct % of total CAPEX)		9.1	N/A
OPEX		4 (annual)	Low

Source: Pennock et al., 2022

Three key parameters affect the LCoE, the capital expenditure (CAPEX) of a project/device, the operational expenditure (OPEX) per year, and the annual energy production (AEP) which is dependent on the capacity factor. Since procedures, materials and manufacturing of ocean energy devices is not streamlined, both CAPEX and OPEX are currently high, but are due to become lower with the commercialization of more projects and with the increase of the installed capacity. European Commission (Directorate General for Maritime Affairs and Fisheries., COGEA., and WavEC., 2018) the OPEX and CAPEX of wave and tidal energy devices was estimated using a variety of sources both bibliographic and operational projects at a different TRL, as see in Table 7. As expected, the largest the installed capacity, the more economic their deployment is, in terms of both CAPEX and OPEX.

Table 7. Capital expenditure (CAPEX) and operational expenditure (OPEX) of wave and tidal stream energy in terms of installed capacity.

	Wave energy		Tidal energy	
Capacity	CAPEX	OPEX	CAPEX	OPEX
	MEur/MW	MEur/MW/year	MEur/MW	MEur/MW/year
0-0.001	360	68	223	48
0.001-0.009	173	50	177	26
0.009-0.02	124	22	56	12
0.02-0.1	70	12	37	2.5
0.1-0.3	44	9	27	2
0.3-0.9	30	6	20	1.6
0.9-3	19	4	15	1.4
3-7	14	3	10	1.2
7-20	9	2	7	1
20-250	4	1	5	0.8

Source: DG MARE COGEA., and WavEC., 2018

Recent data collected by OceanSET (2022) through a developers survey conducted in 2020 for whole-system TRL 7-9 devices concluded in the key indicators in Table 8, that reflect the current status of ocean technologies.

Table 8. Key indicator for whole-system TRL 7-9 devices, for the wave and tidal ocean technologies

Key indicator	Wave	Tidal
Average CAPEX (Million EUR/MW)	6.4	3.4
Average OPEX (Million EUR/MW/year)	0.5	0.5
Minimum technical lifetime (years)	20	20
Maximum technical lifetime (years)	30	25
Average LCOE (EUR/kWh)	0.27	0.2

Source: OceanSET, 2022

2.4 Public R&I funding

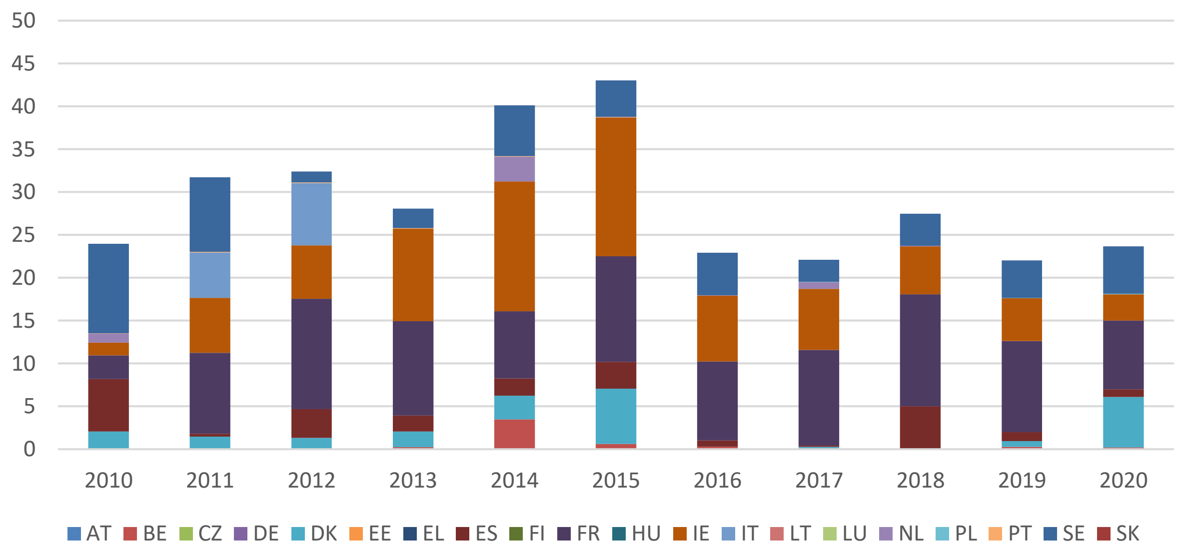
Public investment can have a significant positive effect on the development and deployment of a technology, creates a positive environment for private initiatives, and affects among others the number of relevant publications and patent applications. As such, it is an important indicator of the level of development and competitiveness in a given technological area. The following information is based on JRC analysis with data from the IEA (IEA, 2022).

The ETS Innovation Fund supports the commercial demonstration and deployment of innovative low-carbon technologies, encompassing ocean energy technologies under its renewable energy generation focus.

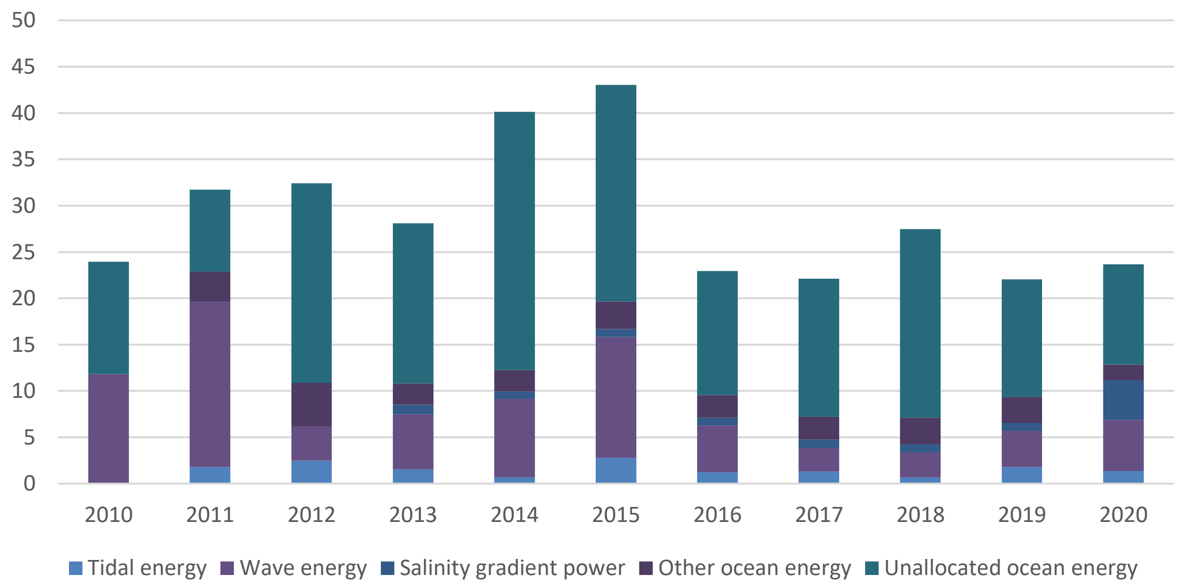
Public R&D Investment in Europe reached its 10-year maximum in 2015 (Figure 6), followed closely by 2014. In the decade 2010-2020 largest investments have been awarded in France (108 million EUR), Ireland (85 million EUR) and Sweden (54million EUR). Ocean energy technologies supported by public investments are categorised in wave energy, tidal energy, salinity gradient, other ocean energy (that includes OTEC and ocean current power, as well as sitting studies for all types of ocean energy) and unallocated ocean energy (including techniques, processes, equipment and systems related to ocean energy that cannot be allocated to one specific area and where it is not possible to estimate the split between two or more categories. The majority (58%) of the public investments in the last decade fall in the unallocated ocean energy category.

Figure 6. a) Public R&D investments (in million EUR) in ocean energy in the EU by year and by MS; b) Public R&D investments (in million EUR) in ocean energy in the EU by year and by technology

a)



b)

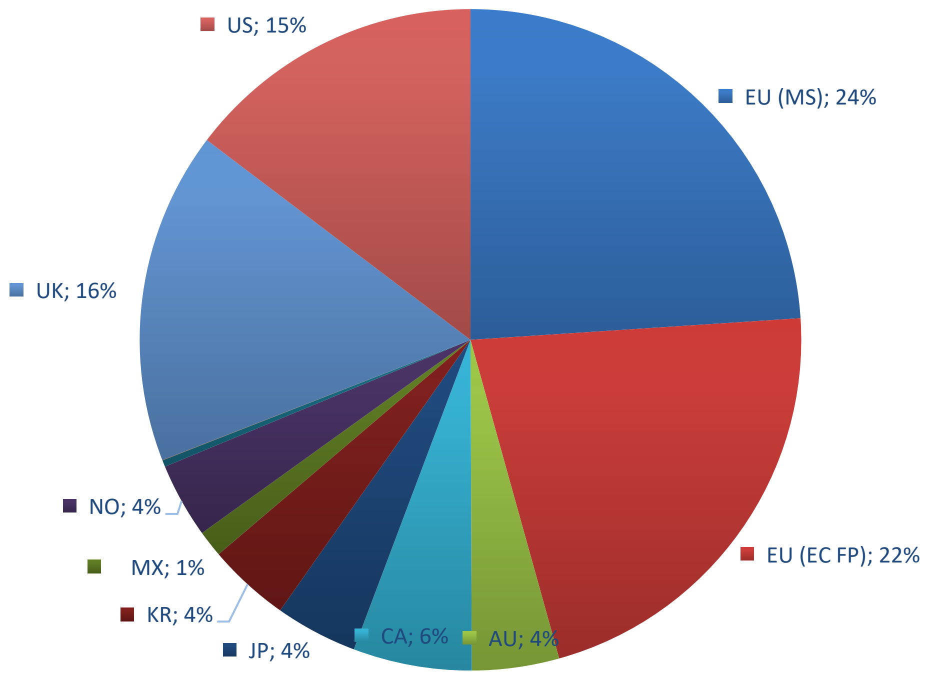


Source: JRC based on IEA, 2022

OceanSET (2022) estimated that about 200 million EUR public budget will support the technological development of marine renewable technologies in the period 2021-2023 in Europe.

Globally EU is leading in R&D Investments, accounting for 46% of the worldwide public investments in the last decade. This is attributed both to direct investments by the member states (24% of the total investments) but also to funding from EU framework programmes (22%). The UK (16%) and the US (15%) are following in ocean energy investments.

Figure 7. Global public R&D investments (in million EUR) in ocean energy for the period 2010-2019. EU (EC FP) refers to the EU framework programmes while EU (MS) to the direct investments by the member states. Countries with a share of less than 1% are not illustrated



Source: JRC based on IEA, 2022

2.5 Private R&I funding

The analysis presented in the following is based on the JRC methodology (Pasimeni, et al., 2019; Fiorini et al., 2017), with data referring to the period 2010-2018. In this methodology patent data are used as a proxy for extracting information about private R&I funding. This methodology includes two steps: the patent analysis and the R&D estimation procedure. In the first step results in a list of all companies active in the ocean energy sector and quantifies the number of inventions per company. Then patent share is used in order to split the R&D effort proportionally for companies that have disclosed their R&D expenditure. In the case of companies for which R&D data is not publicly available, but there is evidence of patenting activity in this technological area, an average unitary expenditure per patent/invention is assigned each year. The sum of this indicative cost, multiplied by the number of patents provides an estimate of the corporate R&D effort for that year.

Globally over time, EU companies are the 2nd largest investor in ocean energy technologies, investing 892.7 million EUR (Figure 8). China is leading the sector having triple the amount of investments. However, as it will been seen from section 2.6, China has a large amount of patent applications and only a small percentage of them are high value or international. Since patents are acting as a proxy for private investments in this methodology, there is an inherited risk of overestimating investments in countries with large amount but less significant patents.

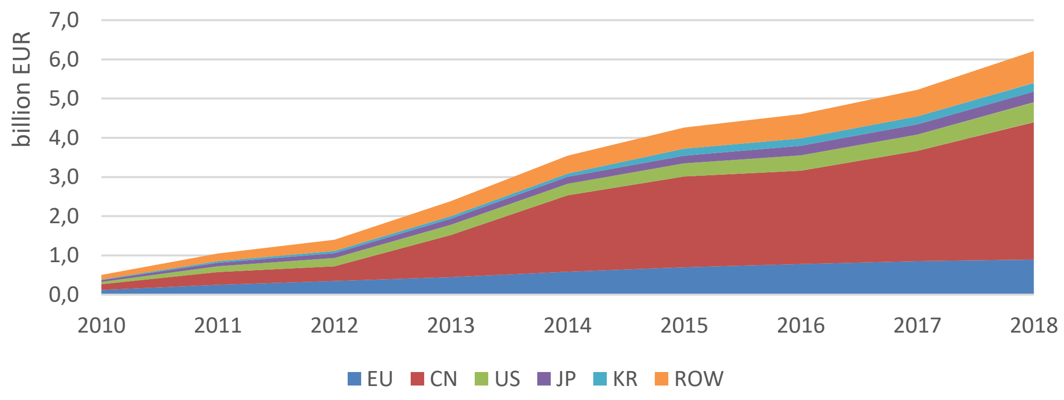
In the EU, largest private investments for the period 2010-2018 were reported for Germany, followed by France and Sweden (Figure 9).

Private investments in the EU peaked in 2014, accounting for 134.5 million EUR. In total, in the period 2010-2018, 930 million EUR have been privately invested. Top investors in the EU include Robert Bosch GMBH, AW Energy OY and Ocean Harvesting Technologies AB. In the global leader board, the majority of the top investors originate predominately from China, followed by Korea.

The development of ocean energy technologies appears to be mostly driven by venture capital companies (representing 66 % of identified innovators). Within the leading group of four countries that host 64 % of active innovators over the 2016-21 period, Japan (4th) figures as an exception.

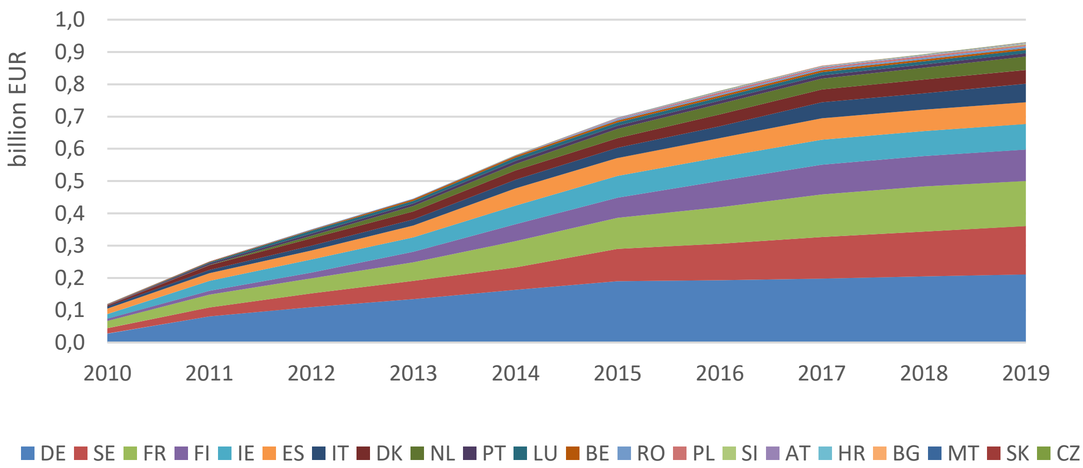
The US (1st), the UK (2nd) and France (3rd) all rely on a very strong base of venture capital companies. Supported by innovators in several member states, the EU accounts for 43 % of identified innovators and is well positioned to develop a leadership.

Figure 8. Cumulative global R&I investments in ocean energy for the time period 2010-2018



Source: JRC SETIS according to Fiorini et al., 2017; Pasimeni, et al., 2019

Figure 9. Cumulative private R&I investments per EU member state for the time period 2010-2018 (incomplete data for 2019)

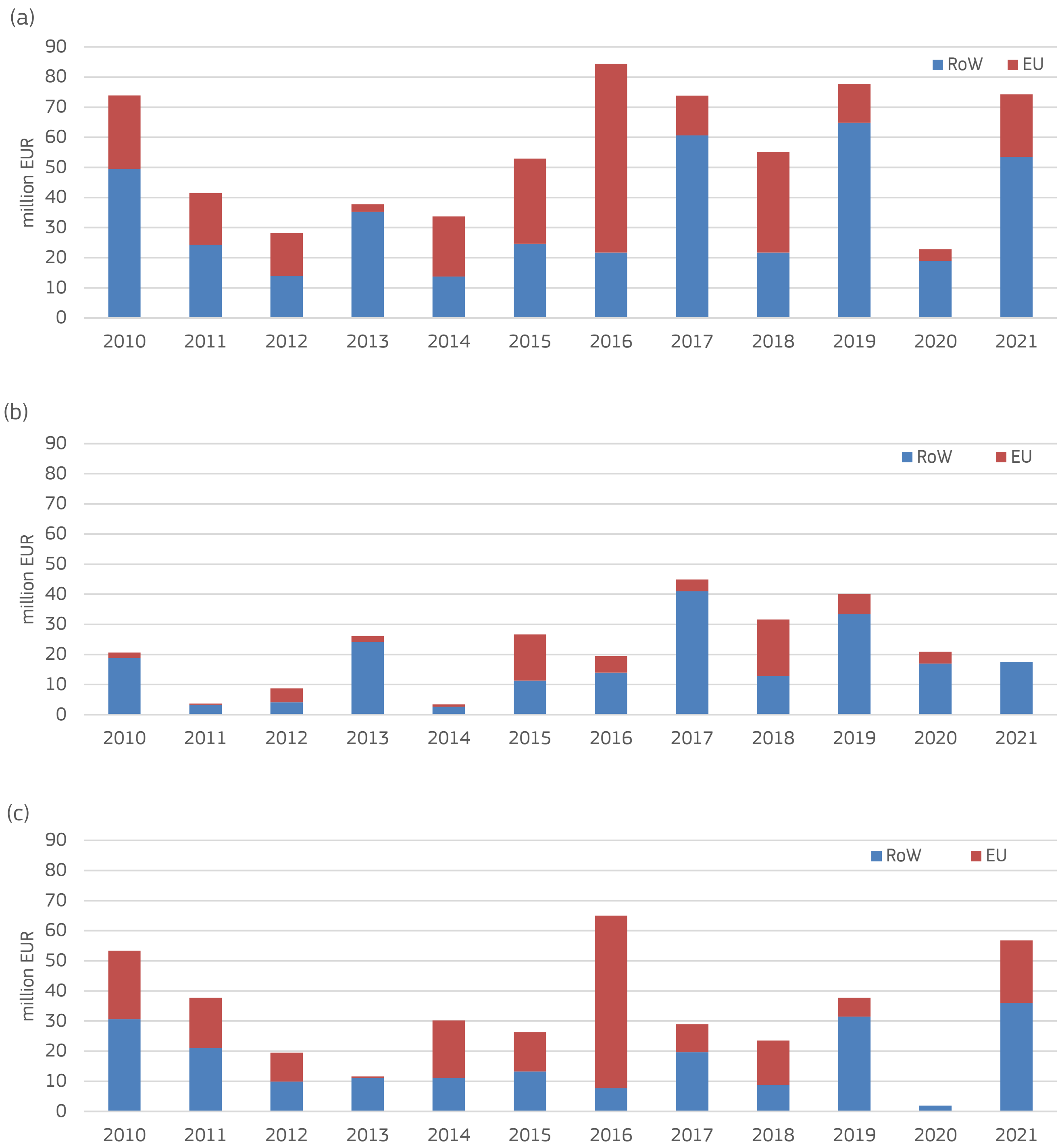


Source: JRC SETIS according to Pasimeni et al., 2019; Fiorini et al., 2017

Venture Capital (VC) early and later stage investments considered are focusing on two time frames, 2010-2015 and 2016-2021. Early stage investments include grants, Angel & Seed as well as early stage VC, while later stage investments include small M&A, growth private equity and late stage VC, but exclude buyout private equity and public investments. In Figure 10 the size of VC investments per region and divided by early and late investments is presented. In the last decade there is an increase of global VC investments. However, despite the considerably higher levels (+45 % in period 2016-2021 as compared to 2010-2015), investments seem to stagnate and amount to € 388 million. Early stages still account for a large share (56 %) of global VC investments outside of the EU, while later stages investments are largely predominant in the EU.

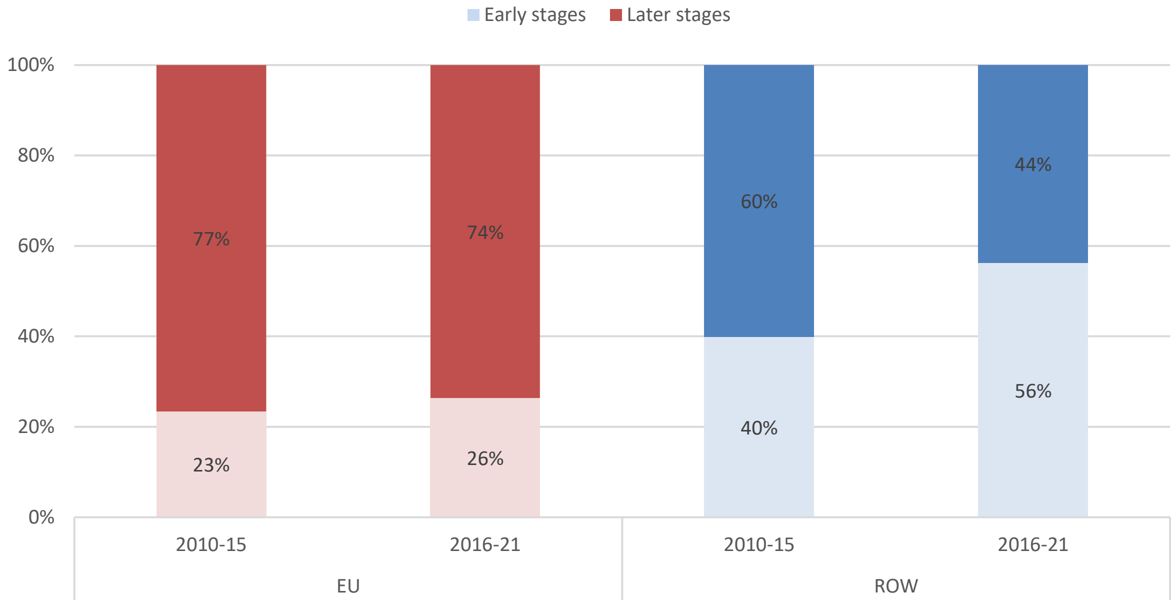
Overall, as seen in Figure 11, VC investments in the EU are dominated by investment in later stages accounting for 77% and 74% of the total investments in period 2010-2015 and 2016-2021 correspondingly. In the rest of the world for the period 2010-2015 later stage investments dominated the investments (60%), while for the period 2016-2021 there was a change in the trend, with 56% of the total VC investment happening at an earlier stage. This willingness to invest more in earlier stages of development shows an increase in the confidence in the technologies currently being developed.

Figure 10. Venture Capital investments in Ocean energy (a) Total investments (b) Early stages investments (c) Later stage investments for the EU and the rest of the world



Source: JRC based on Pitchbook, 2022

Figure 11. Investments by stage and region (Share of capital invested)



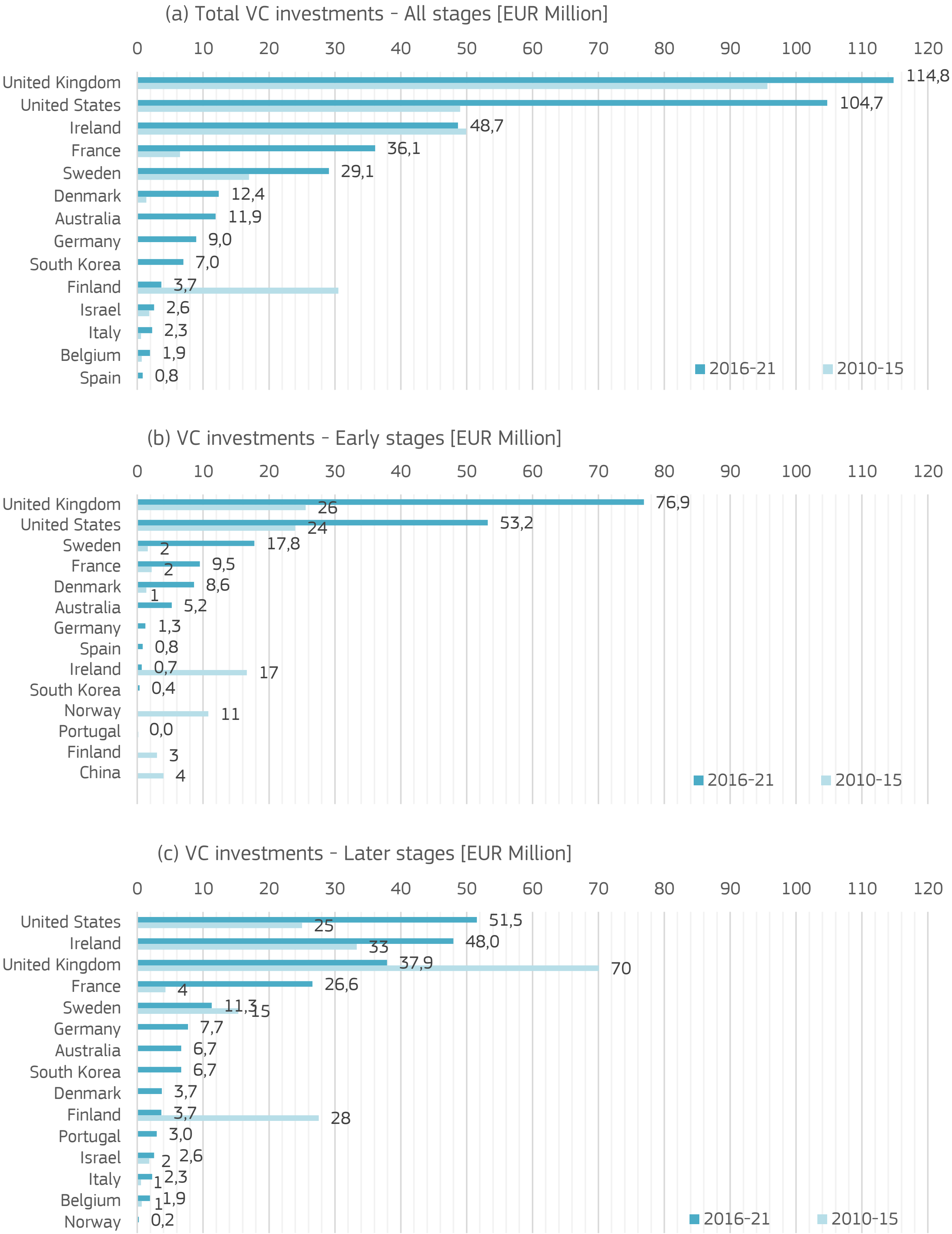
Source: JRC based on Pitchbook, 2022

Early ocean energy ventures remain largely dependent on public funding (grants account for 83 % of early stage investments over the current period). While twice higher than over previous period (€ 174 million since 2016), early stages investments have been steadily declining over the past years, and in the EU in particular. Conversely, the US and UK attracted significantly higher levels of investments and account for most over the current period (resp. 44 % and 31 %), downgrading the EU (22 %) from a former co-leading position.

In terms of individual countries, overall United Kingdom has the largest total and early stage VC investments globally for the period 2010-2021, while for later stage investments, UK had the largest investments in the period 2010-2015. For the period 2016-2021 US had the largest later stage investments, followed by Ireland (Figure 12).

Later stages investments are increasing over the 2016-21 period, amounting to € 213 million (+20 % as compared to previous period), despite a sharp drop in 2020. EU accounts for 51 % of those investments with the majority of them especially in the latest years being scattered in smaller sized deals across several companies. The whole of growth and expansion investments is indeed realised in larger deals in the US and the UK.

Figure 12. Venture Capital investment by country for (a) total investments (b) Early stages investments (c) Later stage investments



Source: JRC based on Pitchbook, 2022

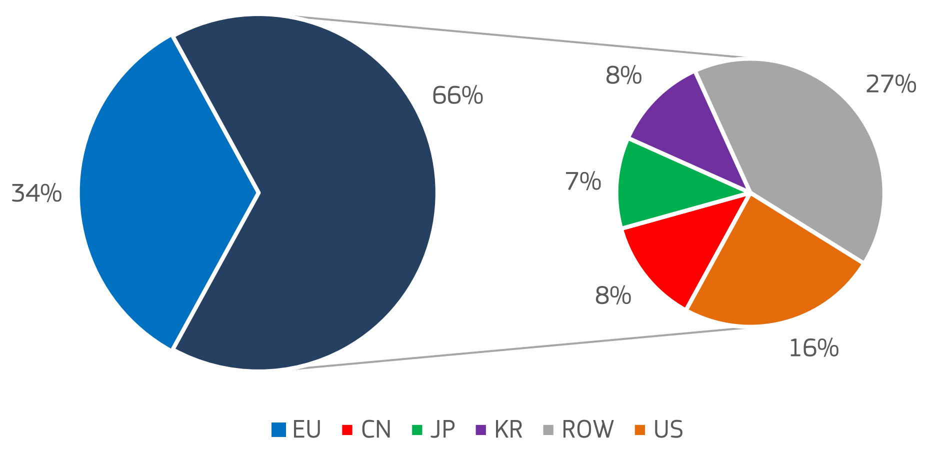
2.6 Patenting trends

Patenting trends are evaluated using the methodology developed by JRC (Fiorini et al., 2017; Pasimeni et al., 2019; Pasimeni et al., 2021; Pasimeni, 2019) and based on data derived from the PATSTAT database 2021 autumn version and based on patent codes Y02E 10/30 and Y02A 20/144.

Inventions (or patent families) can measure the inventive activity of a country or a region. Patent families include all documents relevant to a distinct invention (e.g. applications to multiple authorities), thus preventing multiple counting. A fraction of the family is allocated to each applicant and relevant technology. High-value inventions refer to patent families that include patent applications filed in more than one patent office. International inventions are the inventions that are protected in more than one countries and the flow of inventions indicates where inventions are filed and in which countries they are protected.

Globally, in the period 2010-2019 in total 3561 patent applications concerning ocean energy were submitted, of which 1677 were granted and 710 were high value. China alone accounts for the 49% of the patent applications from all entities, with 76% of those applications originating from Universities and Government/non-profit organisations. EU inventions amounts for 12% of the applications, originating predominantly (73%) from companies. However, this trend is not followed in high value inventions, where EU leads the way with 34% of the global high-value inventions, followed by the US with 16%. China and Korea account for approximately 8% of the total high value inventions (Figure 13). Compared to previous reports (Magagna D, 2020) the number of patents is smaller, Especially for Germany and China. This is attributed to the reclassification of patent codes by EPO. Earlier studies used patent codes that have since deleted. After the reclassification one of the codes is maintained (Y02E 10/30) and one newly introduced (Y02A 20/144).

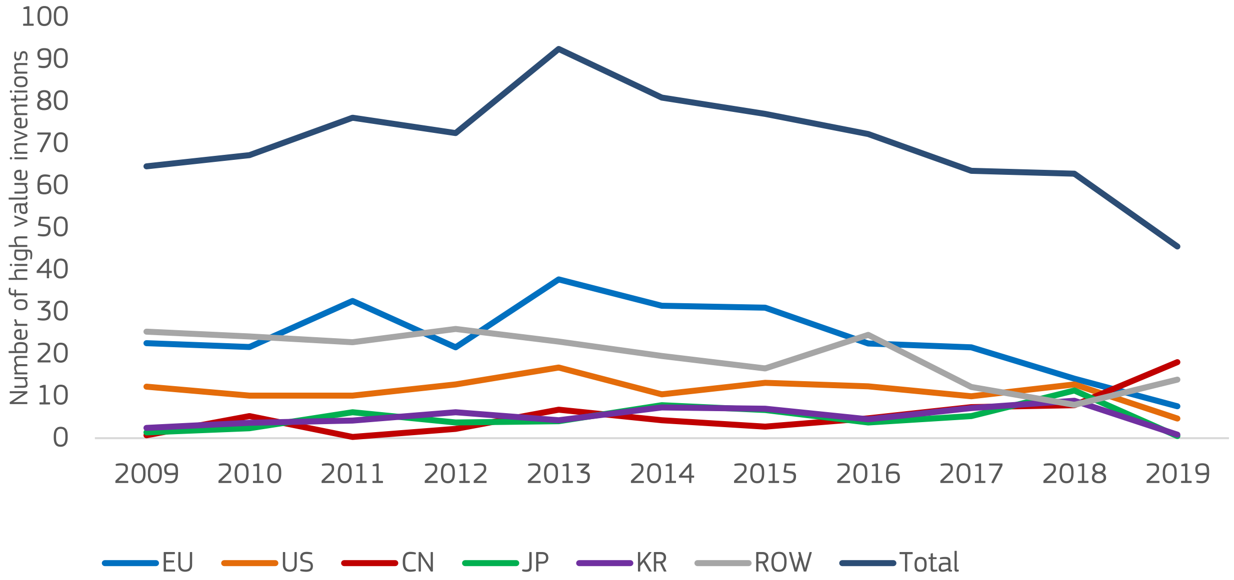
Figure 13. Share of global high-value inventions (2010-2019)



Source: JRC based on EPO Patstat, 2022

Over time, the number of high-value inventions globally peaked in 2013 and since then it has been steadily decreasing (Figure 14). EU high-value inventions have been following the global trend, but there is an increasing trend for China since 2015 which escalated in 2019.

Figure 14. Number of high-value inventions over time



Source: JRC based on EPO Patstat, 2022

The development of patenting data in the latest 3 years provide more insight about the development of the technology and the market, compared to the 10 year data aggregation. For the rest of the analysis the latest 3-year data (2017-2019) will be used to reflect to the current trends.

When considering data for years 2017-2019, EU is still leading the way in terms of high-value inventions (25%), but there is a noticeable increase in China's share (19%) meaning that there is an increase in China's interest in ocean energy technologies (Table 9).

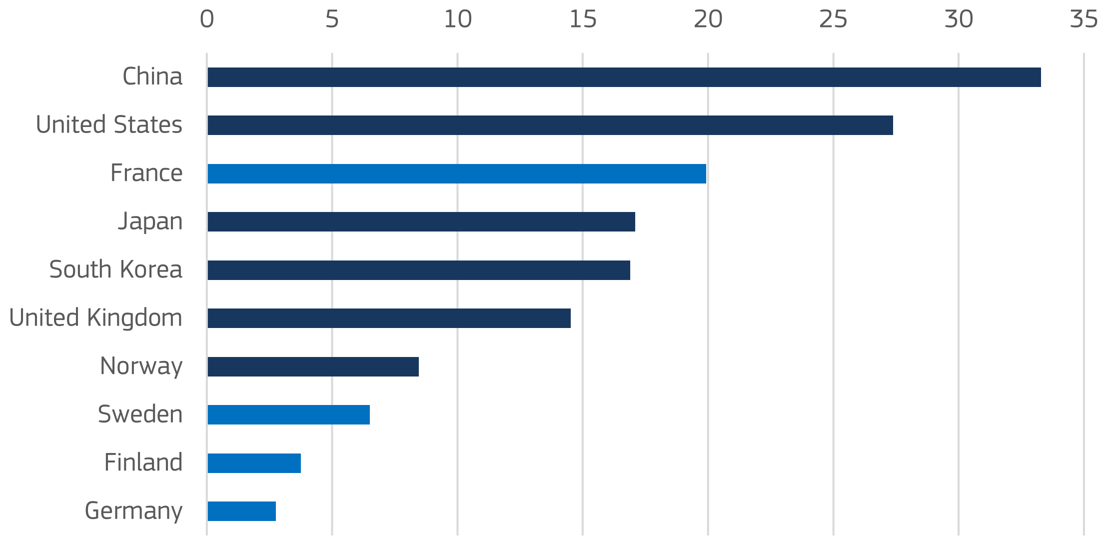
Table 9. Global distribution of high-value inventions (2017-2019)

Share of high-value inventions	
Country	High-value
European Union (EU)	25%
China (**CN**)	19%
Japan (JP)	10%
Korea (KR)	10%
Rest of the world	20%
United States (US)	16%

Source: JRC based on EPO Patstat, 2022

In terms of individual countries, China is leading the way followed by the US and France (Figure 15). Within the top 10 countries in terms of high-value inventions, 4 originate from the EU.

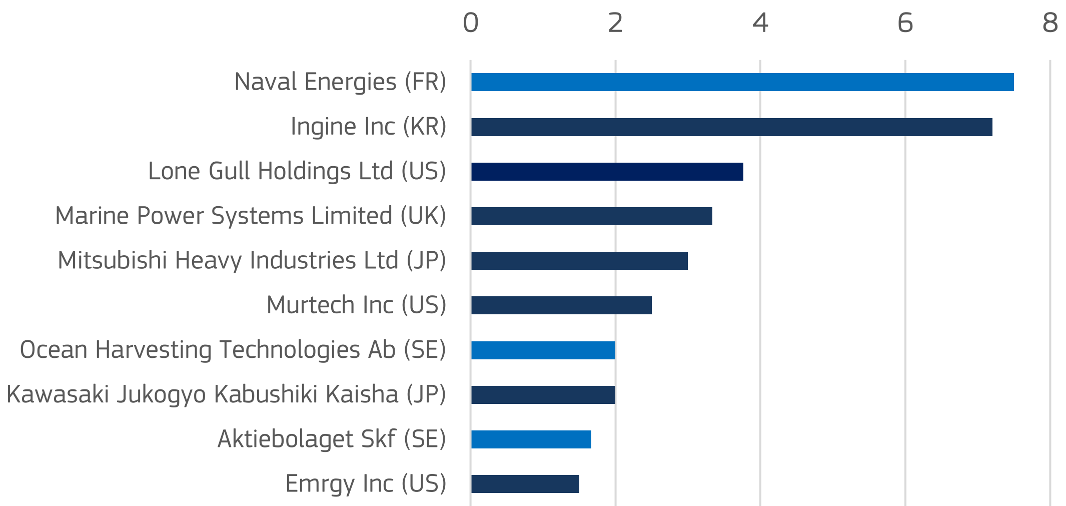
Figure 15. Number of high value inventions for the top 10 countries in the time period 2017-2019



Source: JRC based on EPO Patstat, 2022

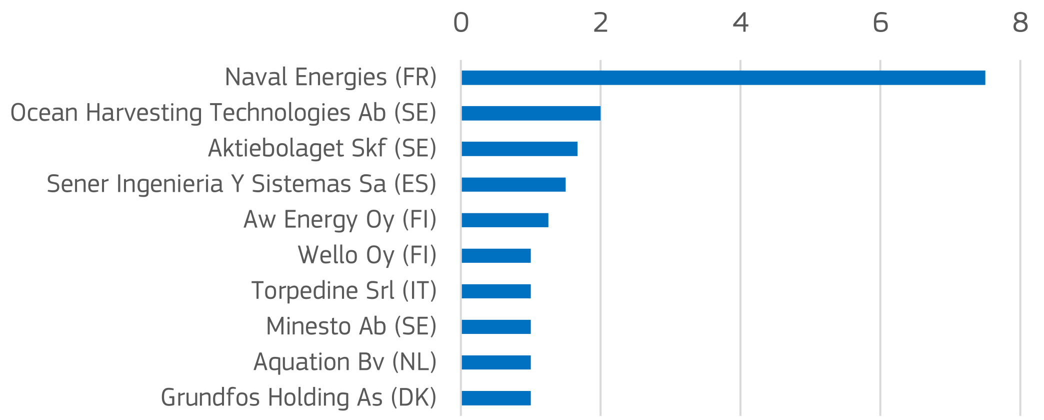
The globally top companies in terms of high-value inventions are presented in Figure 16, while the European top companies are presented in Figure 17. The French company Naval Energies, that is active mainly currently in OTEC technology and floating offshore wind, while in the past it was also active in the tidal energy, is leading both the EU, but also the global leader board in the category of companies.

Figure 16. Number of high value Inventions for the top 10 companies in the time period 2017-2019



Source: JRC based on EPO Patstat, 2022

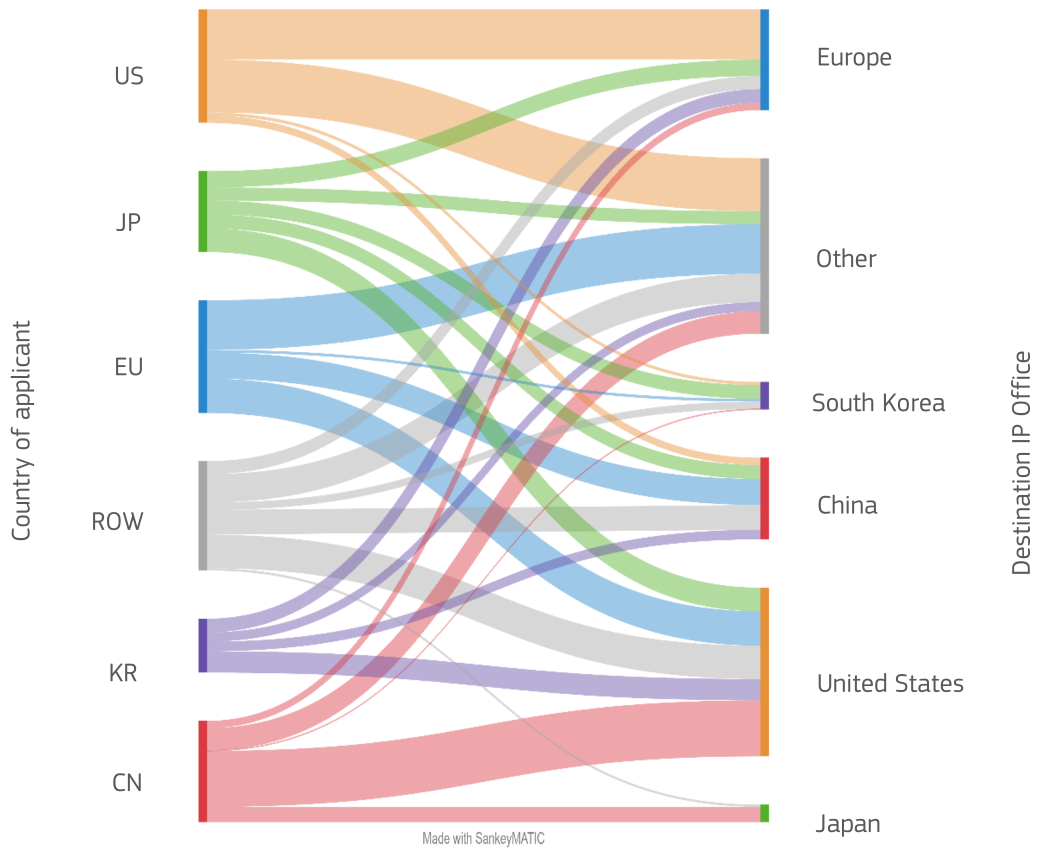
Figure 17. Number of high value Inventions for the top 10 EU companies in the time period 2017-2019



Source: JRC based on EPO Patstat, 2022

In terms of International protection, International activity inventions originating from the EU account for 18% of the total International inventions. Around 15% of the EU inventions are protected internationally, while for China, that's leading in terms of total and high-value inventions only 1% of them is internationally protected. The flow of inventions' international protection for all countries is presented in Figure 18.

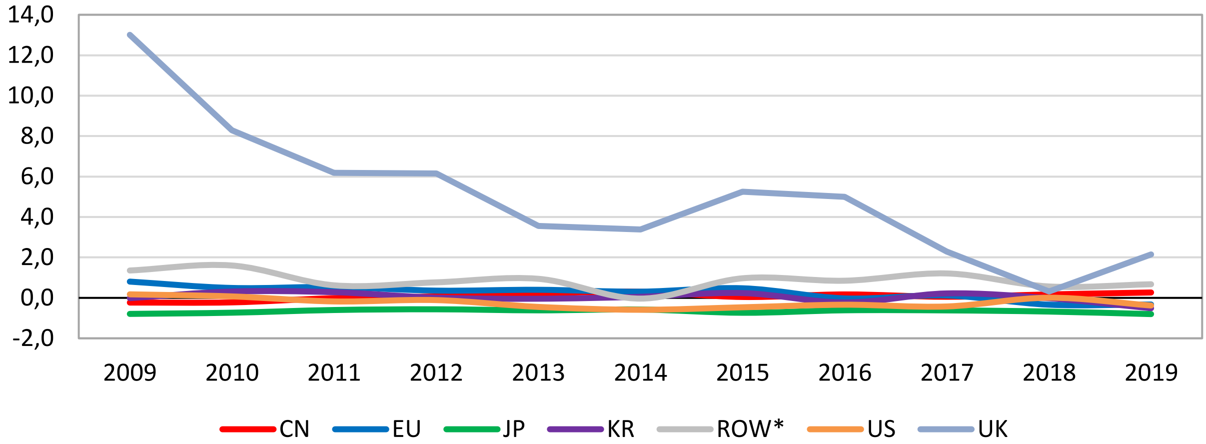
Figure 18. International protection of high value inventions for the time period 2017-2019



Source: JRC based on EPO Patstat, 2022

The Specialization Index (SI) represents the patenting intensity in a technology for a given country related to the rest of the world. When SI=0 the intensity of a given country is equal to the rest of the world, when SI<0, the intensity is lower than the world and when SI>0 the intensity is higher than the rest of the world. SI is calculated for each year separately and the index values for the technologically dominant countries is presented in Figure 19.

Figure 19. Specialisation index for the period 2009-2019.



Source: JRC based on EPO Patstat, 2022

Here the predominant trend is the decline of SI for the UK through the years, remaining however, ahead of the rest of the world (SI=2.16 for 2019). EU's SI fluctuates around zero, meaning that the intensity of ocean energy activities is similar to the rest of the world (average SI for 2009-2019 is 0.25). The remaining countries follow similar trend, with China displaying a positive trend but still having only slightly positive SI (0.27 for 2019).

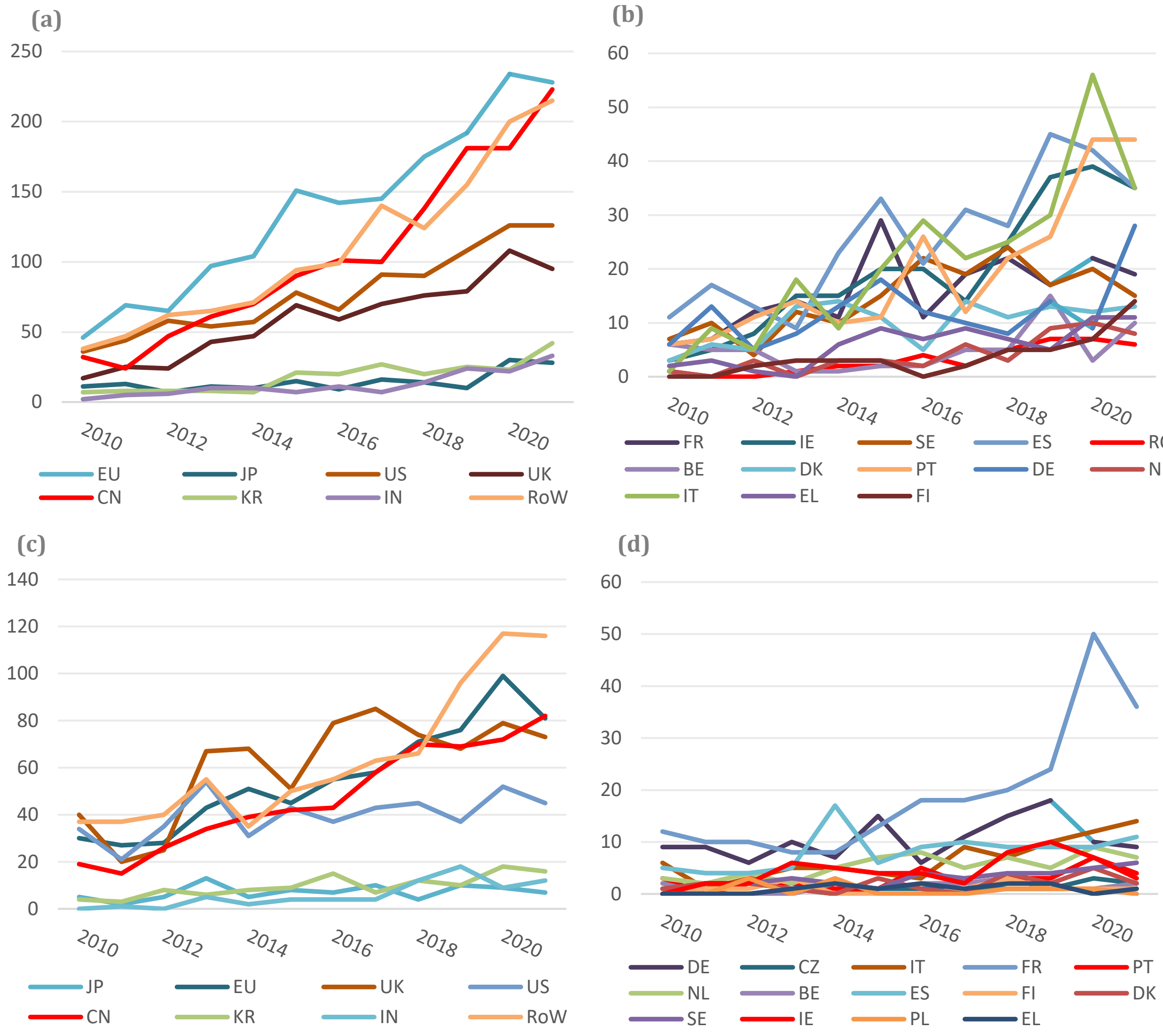
2.7 Bibliometric trends/Level of scientific publications

The level of scientific peer-review articles is a necessary analysis to understand the impact of a developing technology throughout the years. In order to assess the evolution of ocean energy technologies.

In the last decade, peer-reviewed publications in the field of wave energy have been growing steadily, both globally Figure 20(a) and in the EU Figure 20(b). Over time, publications originating for the EU dominate the wave energy accounting for 25% of the wave energy publications, while also leading the tidal energy sector (19%) together with the UK (21%). Countries that account to less than 1% of the total publications are not presented in the figure.

In EU level, Spain is leading the wave energy field accounting for 15% of the total EU publications, followed by Italy (13%), Ireland (11%) and Portugal (11%). Similarly for tidal energy, France is having a leading role producing 27% of the total publications in the period 2010-2021, followed by Germany (15%) and Spain (12%).

Figure 20. Peer-reviewed publication evolution for (a) wave energy related publications globally, (b) wave energy related publications in the EU, (c) tidal energy related publications globally and (d) tidal energy related publications in the EU



Source: JRC based on TIM, 2022

Other than the quantity, the quality of the publications is important for the assessment of the level of technology in a country or region. The quality is often assessed by using the number of highly cited papers as well as by using citation indices.

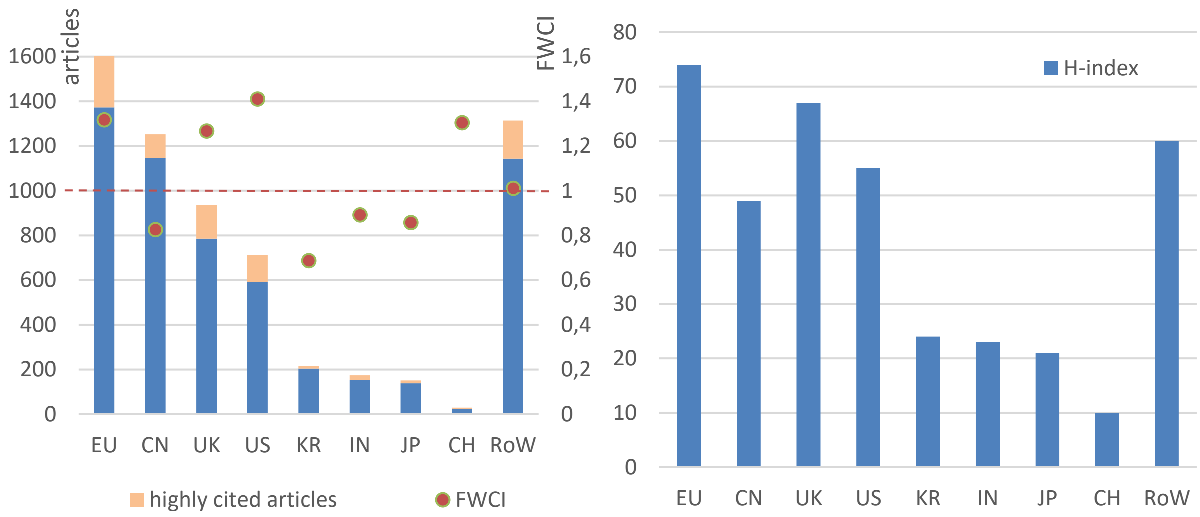
Highly cited articles defined as the articles that fall within the highest 1% based on the number of citations d when compared to articles published in the same field and year.

Citation indices are also commonly used. h-index is an index incorporates both the productivity and citation impact of publications. It is defined as the maximum value h, such as that the given country has published at least h articles that have at least been cited at least h times.

The Field-Weighted Citation Impact (FWCI) is the ratio of total citations received and the total citations that would be expected based on the average of the specific fields. FWCI values larger than 1 means that an article performed better than the average of its field, while values less than 1 corresponds to an underperforming publication.

In the wave energy sector, EU is leading globally, having the largest number of total publications m largest number of highly cited articles, and h-index. In terms of FWCI, EU ranks third following, the US and CH, both of which having considerably smaller total amount of publications (Figure 21). At an EU level Italy has the largest number of highly cited papers, followed by Spain and Ireland. In terms of h-index, the trend is swapped, with Spain leading the way followed by Italy and Ireland. In total 63% of the EU countries are above the LWCI=1 threshold, indicating a very good quality of research within EU (Figure 22).

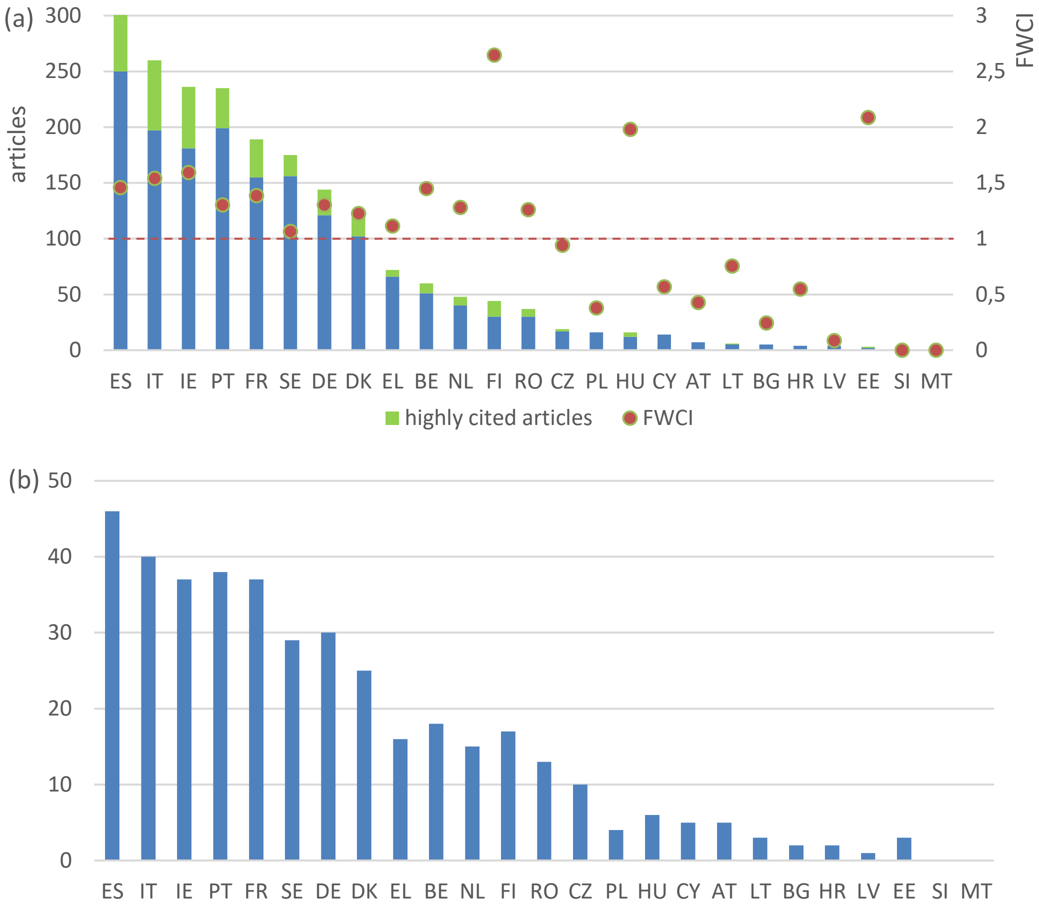
Figure 21. Global publication metrics for wave energy articles (a) Total publications, highly cited articles, Field-Weighted Citation Impact (FWCI) and (b) h-index



Source: JRC based on TIM,2022

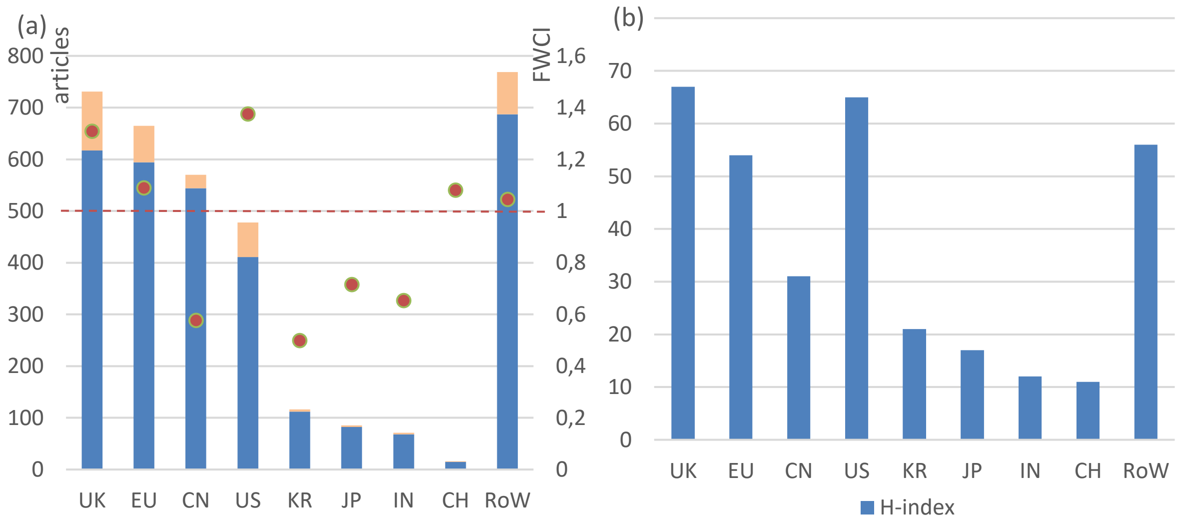
For tidal energy, the majority of the publications from a single country come from the UK followed by the EU, with UK having also the largest number of highly cited papers, FWCI and h-index. The majority of the publications in this field comes from an aggregation of countries not analysed in this report (Figure 23). In term of EU countries (Figure 24), France has the largest amount of highly cited articles and h-index, followed by Germany and Spain. In total 74% of the EU countries have a FWCI of above 1, highlighting the good quality of research conducted by member states.

Figure 22. Breakdown of publication metrics for wave energy articles per member state (a) Total publications, highly cited articles, Field-Weighted Citation Impact (FWCI) and (b) h-index



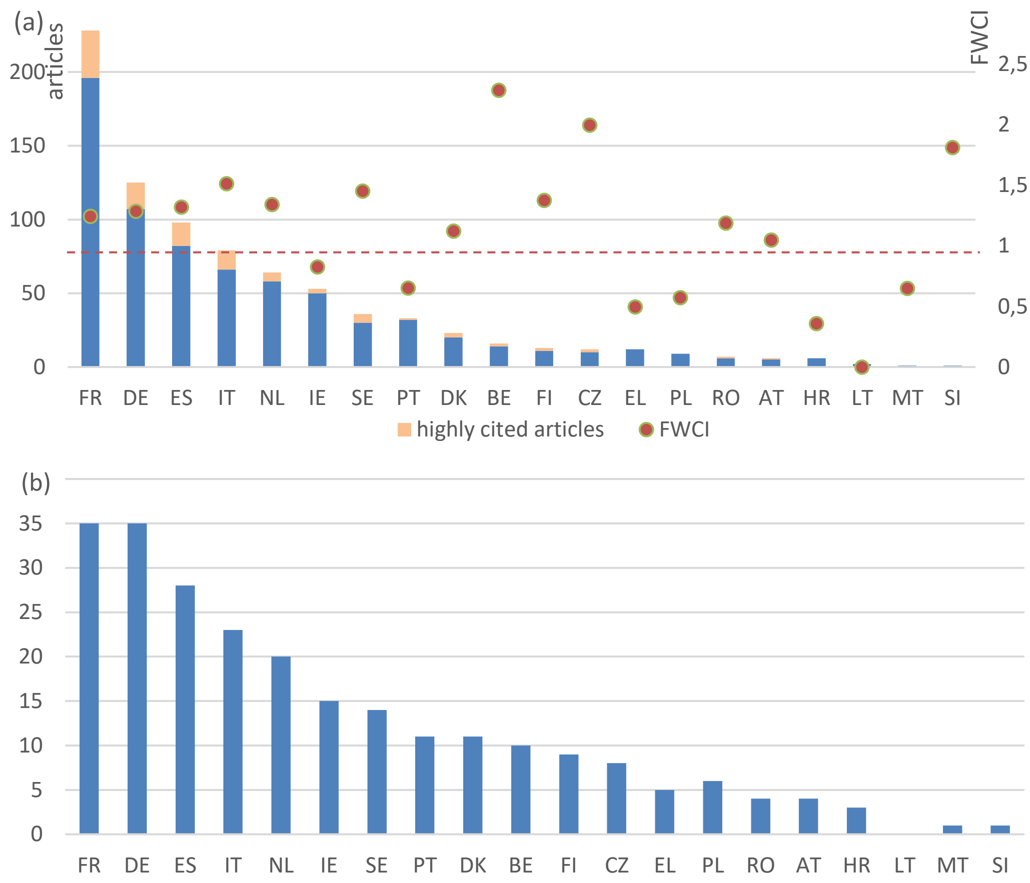
Source: JRC based on TIM, 2022

Figure 23. Global publication metrics for tidal energy articles (a) Total publications, highly cited articles, Field-Weighted Citation Impact (FWCI) and (b) h-index



Source: JRC based on TIM, 2022

Figure 24. Breakdown of publication metrics for tidal energy articles per member state (a) Total publications, highly cited articles, Field-Weighted Citation Impact (FWCI) and (b) h-index

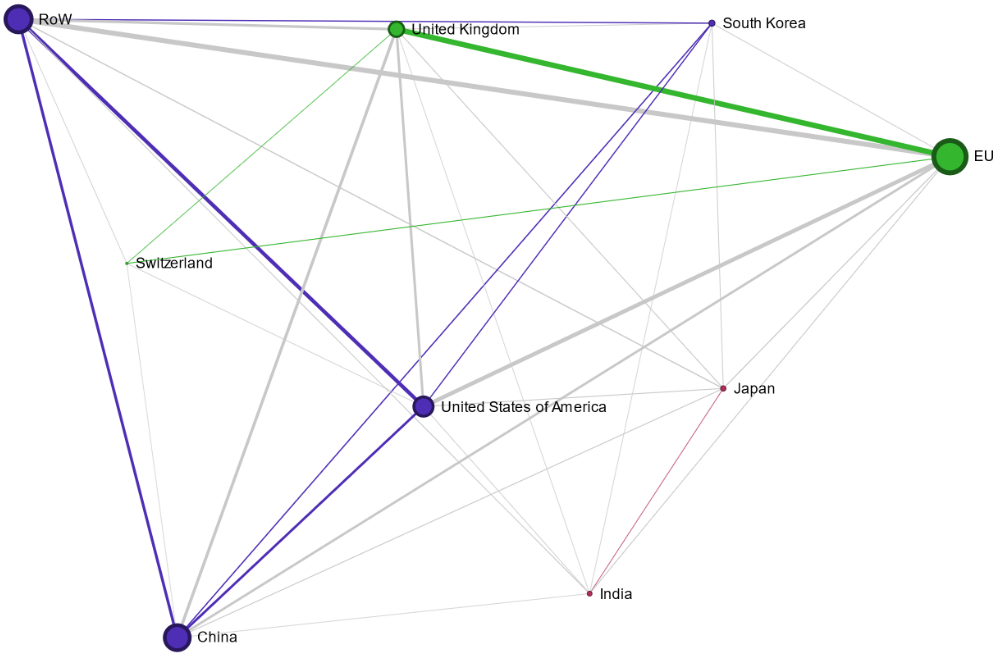


Source: JRC based on TIM, 2022

For wave energy the main collaboration countries are the UK and to a smaller extend Switzerland. This can be attributed to the close collaboration between parties in these countries. Especially for the case of the UK, funding for collaboration between UK and EU countries is still ongoing, leading in the co-authorship of multiple papers. This is furtherly reinforced by the presence of developed testing facilities in the UK, which help significantly in the deployment of new, scaled and testing devices. EU has also increased collaborations with the US. A second cluster of collaborations is also present between the US, China and South Korea. EU countries also collaborate with other countries with smaller individual impact in the field (Figure 25).

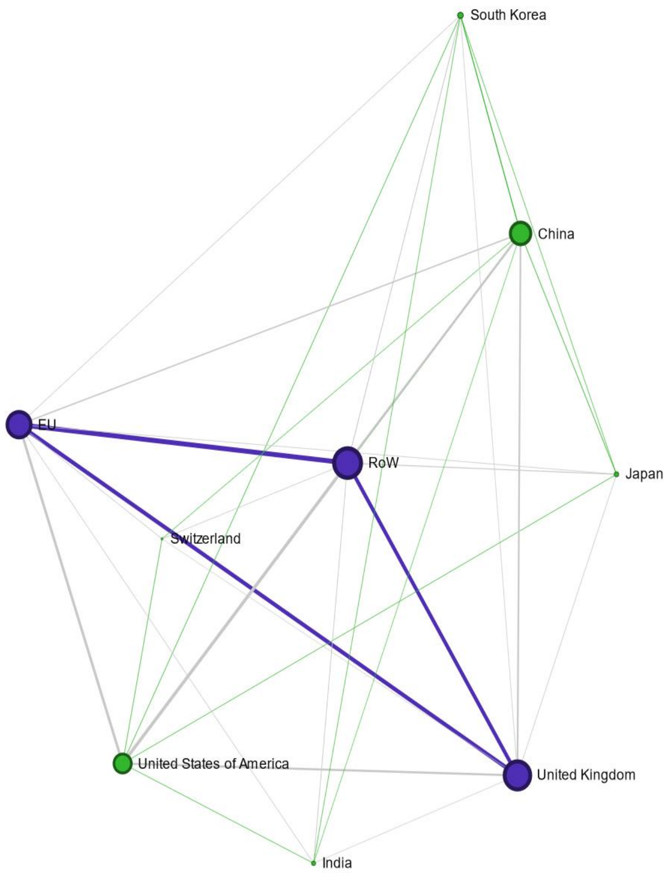
Similarly, for tidal energy (Figure 26), there are strong collaboration links between the EU and the UK. Moreover there is extended collaboration with EU countries and countries with smaller individual contribution.

Figure 25. International collaboration networks in wave energy



Source: JRC based on TIM, 2022

Figure 26. International collaboration networks in tidal energy



Source: JRC based on TIM, 2022

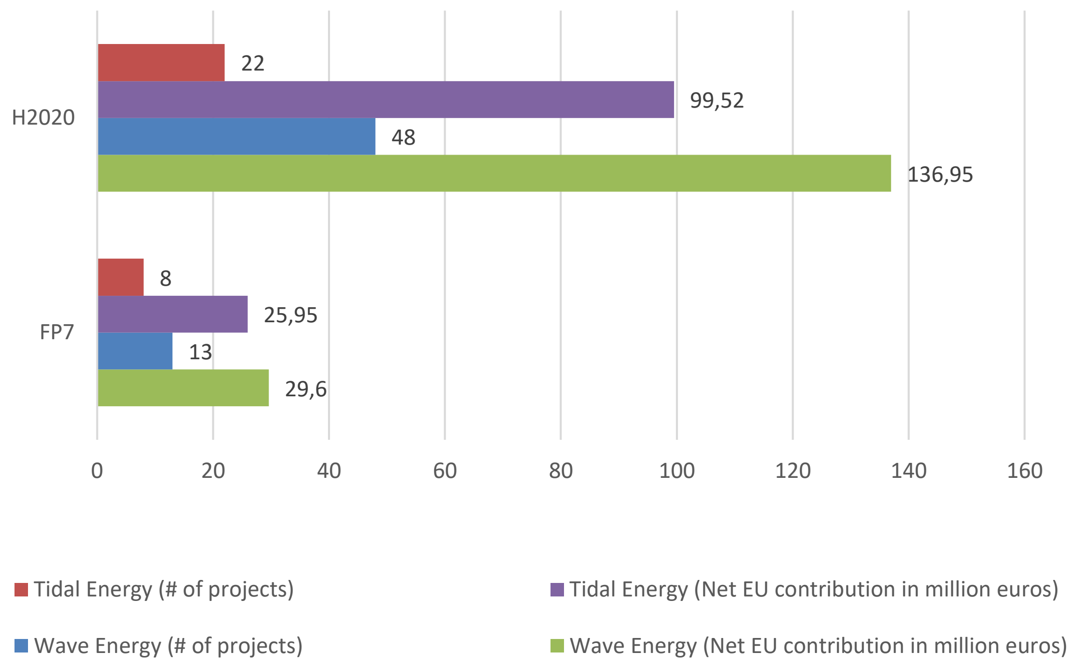
2.8 Impact and Trends of EU-supported Research and Innovation

The European Commission supports multiple activities addressing the development of ocean energy technologies and its subcomponents, as well as initiatives that are crucial for its advancement: professional networks, personal training, social opinion and policy advice, integration with other renewables. EU projects focused at the development of the technology have actively contributed to the progression of technologies and individual devices into higher TRL. In terms of tidal energy, in the last 5 years efforts have been put into demonstrating tidal device capabilities and refining of the technology, aiming at the reduction of the LCoE. In terms of wave energy the main focus is the development of the PTO, in order to increase the reliability and the survivability of the system.

Since 2010 almost 300 million EUR have been invested in projects involving different elements of wave and tidal energy through the 7th Framework Programme (FP7) and Horizon 2020 (H2020) Framework Programme. FP7, which concluded in 2013, funded 21 projects in the period 2010-2013 and 34 projects in its lifetime (2007-2013), while H2020 has already funded 69 projects.

Projects that include wave energy elements dominate both the amount of projects and the net EU contributions with 61 signed project agreements amounting for 166.56 million EUR. Tidal energy projects have received funding for 30 projects, amounting for 125.47 million EUR of net EU contributions (Figure 27).

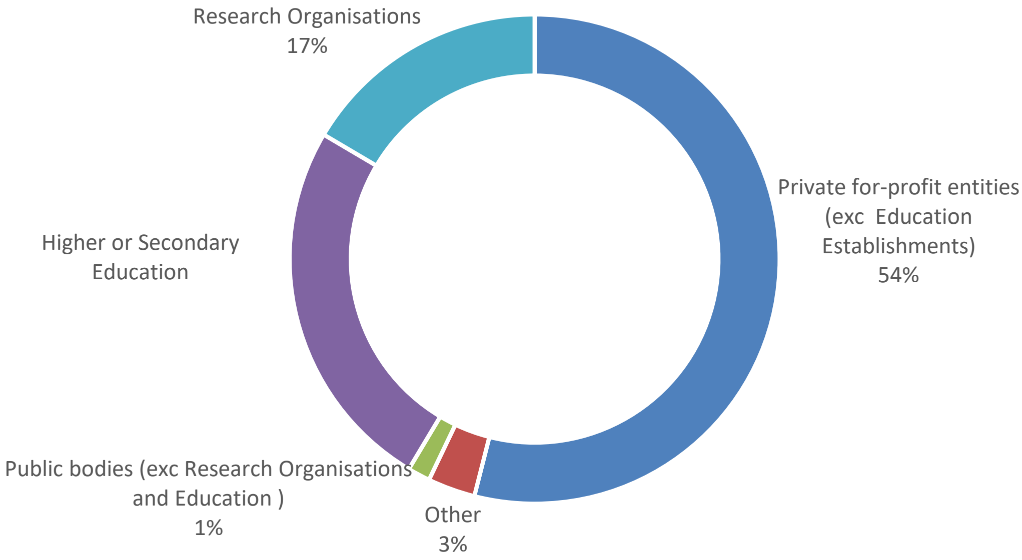
Figure 27. Number of project and total net EU contribution (in million EUR) for FP7 and H2020 frameworks, for tidal and wave energy



Source: JRC based on Cordis, 2022

The organizations participating in projects under these two frameworks (Figure 28) are predominantly private non-profit entities (54%), Education establishments (25%) and research organizations (17%). SMEs represent the 37.6% of private for-profit entities participating in FP7 and H2020 projects.

Figure 28. Participation in FP7 and H2020 projects per organization type



Source: JRC based on Cordis, 2022

The largest amount of net EU contributions in the period 2010-2019 was received by the UK, both as a coordinators and as participants in EU funded projects. This is due to the fact that within the study period UK was part of the EU and also due to the fact that in Scotland there are leading facilities for building and testing ocean energy devices. Spain, Denmark and Belgium are following in terms of net EU funds (Table 10).

Table 10. Top 10 funded by FP7 and H2020 countries in terms of net EU contributions

Country	Net EU contribution (million EUR)	Participation	Net EU contribution to coordination role (million EUR)
United Kingdom	86.3	139	39.9
Spain	28.6	73	7
Denmark	25.8	39	15.3
Belgium	21.7	19	0.984
France	20.6	49	0.478
Finland	17.96	13	3
Ireland	16.4	30	4.6
Italy	14.9	44	5.3
Sweden	13.1	30	6.293
Portugal	10.3	37	1.6

Source: JRC based on Cordis, 2022

The most fund awarded organizations under the H2020 scheme for wave and tidal energy are presented in Table 11 and respectively Table 12. In the case of Wave star AS and Marine current turbines limited the funds correspond to one project for each company, however these projects were terminated early and the funds were not spent in full.

Table 11. Top 10 fund awarded organisations for wave energy projects under H2020

Organisation	**Country**	**EU total contribution (million EUR)**
WELLO OY	Finland	11.9
WAVE STAR AS	Denmark	11.8 (Project terminated early)
JAN DE NUL NV	Belgium	4.9
GREEN MARINE(UK)LTD	United Kingdom	4.5
CORPOWER OCEAN AB	Sweden	3.2
WAVEPISTON AS	Denmark	2.5
FINCOSIT SRL	Italy	2.3
VGA SRL	Italy	2.2
THE UNIVERSITY OF EDINBURGH	United Kingdom	1.9
FUNDACION TECNALIA RESEARCH & INNOVATION	Spain	1.9

Source: JRC based on TIM, 2022

Table 12. Top 10 funded organisations for tidal energy projects under H2020

Organisation	**Country**	**EU total contribution (million EUR)**
ORBITAL MARINE POWER LIMITED	United Kingdom	17.6
NOVA INNOVATION LTD	United Kingdom	17
GEOSEA NV	Belgium	8.3
OPENHYDRO TECHNOLOGY FRANCE	France	7.9
MARINE CURRENT TURBINES LIMITED	United Kingdom	7.4 (Project terminated early)
BELGISCH LABORATORIUM VAN DE ELEKTRICITEITSINDUSTRIE LABORELEC CVBA	Belgium	4.5
SKF GMBH	Germany	4.1
MINESTO AB	Sweden	3.8
NAVAL ENERGIES	France	3.7
ATLANTIS RESOURCES (SCOTLAND) LIMITED	United Kingdom	3.4

Source: JRC based on TIM, 2022

Key projects funded by FP7 and H2020 are:

European Technology and Innovation Platform for Ocean Energy (ETIP Ocean 1-2): The ETIP Ocean project designed to engages all stakeholders and foster cooperation; align stakeholders to commonly agreed goals; find novel approaches to the development of technological and social processes related to the energy transition, and coordinate stakeholders in the context of the SET Plan Ocean Energy Implementation Plan.

Marine Renewables Infrastructure Network for Emerging Energy Technologies (MARINET): Funded in the period 2011-2015 to coordinate research and development at all scales (small models through to prototype scales from Laboratory through to Open Sea tests) and to allow access for researchers and developers into facilities which are not available universally in Europe. The linking together of facilities at different scales together with the incorporation of test facilities for components such as power take-off systems, grid integration, moorings, environmental tests will ensure a focusing of activities in this area. The majority (77%) of the MaRINET budget has been targeted in the areas most prioritized in the EC Call such as networking, training, dissemination and transnational access. This project was followed up by MARINET2 (2017-2021) and MARINERGI (2017-2019).

Support to the Realisation of the Ocean Energy Implementation Plan of the SET-Plan (OceanSET): Funded in the period 2019-2022, OceanSET focuses on assessing the progress of the ocean energy sector and will monitor the National and EU funded projects in delivering successful supports. Relevant data will be collected annually and will be used to inform MS and EU Commission on progress of the sector, it will also be used to review what works and what doesn't and to assess how to maximise the benefit of the funding streams provided across the MS, Regions and the EC.

Verification through Accelerated testing leading to Improved wave energy Designs (VALID): Funded in the period 2020-2023 VALID focuses on developing and validating a new test rig platform and methodology for accelerated hybrid testing that can be used across the wave energy sector. By improving the reliability and survivability of the components and subsystems that form WECs, the project aims to establish a standard for future use.

Floating Tidal Energy Commercialisation project (FloTEC): Funded in the period 2016-2021, FloTEC project will demonstrate the potential for floating tidal stream turbines to provide low-cost, high-value energy to the European grid mix. During this project a M2-SR2000 2MW by Orbital marine power Ltd was constructed and demonstrated.The core innovations being progressed were:

- 50% Increase in rotor swept area.
- All subsystems highly accessible for repair and maintenance
- Simplified superstructure redesign for series production
- Advanced, automated manufacturing techniques for blade manufacture:
- Enhanced power conversion with ability for energy storage integration;
- Mooring load dampers to reduce peak mooring loads.

Next Evolution in Materials and Models for Ocean energy (NEMMO): Funded in the period 2019-2022, NEMMO project aims to drive down costs by designing larger, lighter and more durable composite turbine blades. Researchers are working on ways to improve the hydrodynamic performance and active flow control of the turbine blade. They are also testing new composites and coatings that should increase resistance to fatigue, impact, cavitation erosion and biofouling. The ultimate aim is to reduce the levelised cost of energy for a 2-MW tidal turbine by 70 %.

Bridging the gap to commercialisation of wave energy technology using pre-commercial procurement (EuropeWave): Funded in the period 2021-2026 the EuropeWave project will build on the work of Wave Energy Scotland to help Europe's wave energy innovation community transition to commercial viability. To do this, the project will use an innovative 'pre-commercial procurement' approach to identify and fund the most promising wave energy technologies from developers across Europe. In the first stage, seven projects were selected to share 2.4 million EUR, to develop further their devices. Following completion of the first phase, five most promising technologies will then be selected to progress to a second phase, where project teams will undertake more extensive design, modelling and testing. The final phase of EuropeWave will select three devices for testing in real sea conditions off the coasts of the Basque Country and Scotland in 2025.

Fast-tracking Offshore Renewable energy With Advanced Research to Deploy 2030MW of tidal energy before 2030 (FORWARD-2030): Funded in the period 2021-2025 FORWARD-2030 project will accelerate the commercial deployment of tidal energy, which is in line with the European Green Deal. Specifically, the project will develop a multi-vector energy system that will combine predictable floating tidal energy, wind generation, grid export, battery storage and green hydrogen production. Ultimately, FORWARD-2030 will complete a supply chain plan, a societal cost of energy assessment tool, marine spatial planning and a life-cycle carbon reduction assessment.

A full list of the FP7 and H2020 projects for the period 2010-2021 is given in Annex 1.

3 Value Chain Analysis

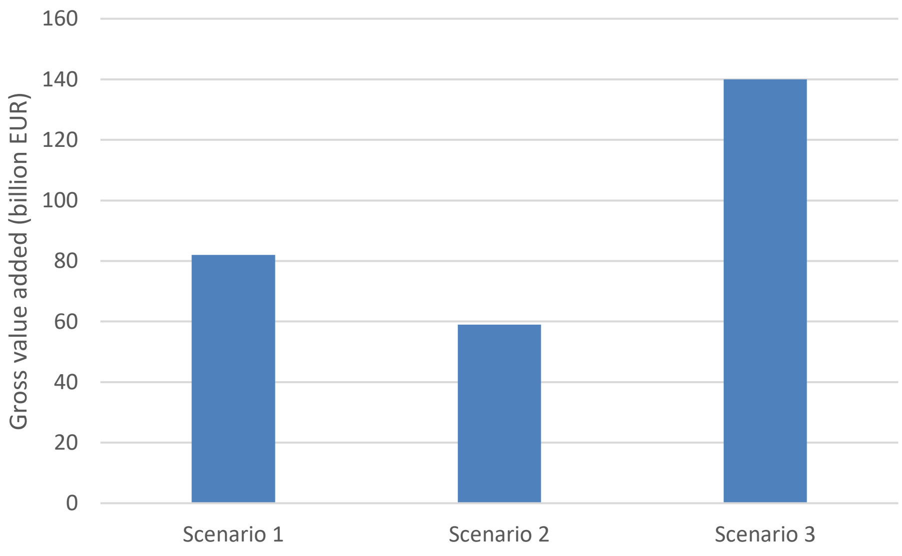
3.1 Turnover and Gross value added

Ocean energy technologies are still under development with only a handful of designs reaching high TRL, hence they cannot be considered as mainstream business. Reporting on market value and value chain are scarce and sometimes bundled together with other technologies in similar development status, or with other marine renewables. Overall, it has been reported (Market research future, 2021) that the global ocean energy market has a size of 2.17 billion EUR (2.28 billion USD), with a forecasted compound annual growth rate (CAGR) of approximately 28% for the period 2021-2027.
ETIP Ocean (2021) has evaluated the potential economic value offered to Europe from the development and deployment of wave and tidal energy to 2050, taking its account 3 scenarios:

- Achievement of the SET Plan: Based on achieving SET Plan targets, reaching net zero in Europe in 2050 and globally in 2070. Equal split between tidal stream and wave energy is assumed for Europe, while for the rest of the world this split is 40%-60%.
- Europe follows global market: Based on achieving net zero globally in 2050 rather than 2070 with a 40%-60% split between tidal stream and wave energy globally. In this scenario European supply chain is not strong and Europe is a market follower for ocean energy.
- Europe leads the global market: Based on achieving net zero globally in 2050 with a 40%-60% split between tidal stream and wave energy globally. In this scenario Europe is a market leader for ocean energy.

The total gross value added benefit to the European economy generated by supply chain activity servicing global deployments has a potential range of €59bn to €140bn across the three scenarios, as presented in Figure 29. The geographical scope of this study is the pre-Brexit European Union (EU-28)

Figure 29. Gross value added by 2070 in European economy for the 3 deployment scenarios (in billion EUR)



Source: ETIP Ocean, 2021

Therefore, there are significant economic benefits if Europe captures the high market share, goal achievable only through performance improvements, leading in cost reductions, and policy interventions (supporting European industrial activities and strengthening European export position) that would maximize the retention of value by the European economy.

3.2 Environmental and Socio-economic Sustainability

In an effort to progress and promote sustainable economy activities, EU has developed the ne new Taxonomy Regulation, to provide clarity on which economic activities are environmentally sustainable. The six environmental objectives of the Taxonomy are: climate change mitigation, climate change adaptation, sustainable use and protection of water and marine resources, transition to a circular economy, pollution prevention and control, and protection and restoration of biodiversity and ecosystems. For an activity pursuing one or more of the six objectives to qualify as sustainable it cannot cause significant harm to any of the other Taxonomy objectives. For each activity, technical screening criteria lay out thresholds to define compliance with the 'do no significant harm' principle.

Life cycle assessment (LCA) is a widely recognized and used tool for evaluating the potential environmental impact of products, processes and services. LCA of wave and tidal devices has been the subject of study in multiple scientific publications, however due to the diversity of technologies considered there is a large variation in their impact. Characteristically Paredes et al. (2019) have systematically reviewed 18 LCA studies in ocean energy technologies and concluded to a range of 10-106 kg CO2eq/kWh across them. According to the analysis the main source of environmental impacts are due to raw material extraction of structural components, manufacturing devices, energy consumption and mooring foundations. More specifically structure (particularly, steel manufacturing, in most cases), mooring and foundations, and the shipping operations have the greatest impact on total CO2 emissions (between 40–95% of the total emissions). Other raw materials necessary for the development of ocean energy technologies include copper and iron for cables, as well as potential magnets used in linear generators.

Ecosystem and biodiversity impacts assessment is necessary to ensure the environmental sustainability of ocean energy technologies. ETIP Ocean (2020) identified key environmental research needs and consenting challenges to facilitate the large scale roll out of ocean energy. The main environmental concerns included, amongst others, collision risk, noise, electromagnetic fields. However, it was concluded that there is no evidence of risk to local ecosystems, but it was also highlighted that long-term monitoring is essential. In the MaRVEN study (European Commission et al., 2016), the current norms and standards related to noise, vibrations and electromagnetic fields were reviewed. On-site measurements and field experiments to fill priority knowledge gaps and to validate and build on the results obtained in reviews were undertaken. In this way a programme for further research and development was outlined and priorities were identified. Similarly, The state of knowledge concerning the environmental effects of ocean energy devices in the marine environment and how these are driving the permitting process of projects was the subject of a report prepared for OES, concluding that he risks for deployment and operation of single devices and small arrays appear to be low, while for larger arrays further investigations are needed (Copping and Hemery, 2020). Tethys (2022) is a database with documents and information about the environmental impacts of marine renewable energy, supporting the OES-Environmental initiative.

The sea area used for these technologies varies significantly depending on the technology, its capacity and the PTO system. Depending on the conditions and the location the theoretical power capacity for tidal stream is 0.5 - 8 kW/m^2 and 17-50 kW/m^2 for wave energy. The energy return on energy invested (EROEI) ratio varies depending on the technology. It has been reported that ocean energy technologies are estimated to have EROEI equal to 3.25:1 (Capellán-Pérez et al., 2017), but real life application were also able to achieve better values (as an indication, Pelamis device, which is currently not pursued by any company, was estimated to have EROEI 15:1 (Beloglazov and Shabalov, 2017).

An internationally acceptable approach to technology development and evaluation is necessary to build confidence and transparency in the ocean energy sector. For this reason an international evaluation and guidance framework for ocean energy technology was developed by (Hodges et al., 2021), where 9 evaluation areas were identified (Table 13).

Table 13. Evaluation areas and their definitions

Evaluation area	Definition
Power capture	Power capture is the process of extracting energy from the natural resource by the interaction with a device and making it available as an input to a power take-off (PTO).
Power conversion	Power conversion represents the second step in the power conversion chain, whereby the mechanical power captured by the device is converted to electricity.
Controllability	Controllability is defined as the ability for control systems to be implemented to a subsystem or device and incorporates evaluation of the benefits control can deliver and the reliance of a subsystem or device on it.
Reliability	Reliability is defined as the "probability that an item can perform a necessary function under given conditions for a given time interval".
Survivability	Survivability is a measure of the ability of a subsystem or device to experience an event ('Survival Event') outside the expected design conditions, and not sustain damage or loss of functionality beyond an acceptable level, allowing a return to an acceptable level of operation after the event have passed.
Maintainability	Maintainability is defined as the "ability to be retained in, or restored to a state to perform as required, under given conditions of use and maintenance".
Installability	Installability is defined as is the ease with which a component, subsystem or device can be prepared, deployed at the operational open-water site and commissioned, resulting in a condition of operational readiness. Installability also includes the ease with which the component, subsystem or device can be recovered.
Manufacturability	Manufacturability is defined as the ability for the technology to be manufactured quickly, cheaply and with minimum waste, and therefore its compatibility with the supply chain's capability, readiness and maturity.
Affordability	Evaluation of Affordability relates to the cost of electricity generated from the wave or tidal stream resource.

Source: Hodges et al., 2021

Since ocean technologies are not mainstream yet, international standards are not yet been fully established. International electrotechnical commission (IEC) Technical Committee 114 since 2007 has developed international standards for marine energy conversion systems for wave, tidal and other water current converters, which are used to test and assess marine energy equipment. European marine energy centre (EMEC), that runs on of the main testing facilities in Europe (based in Orkney, Scotland), set the basis for the certification for marine energy converter units, including a basis for acceptance of operating bodies and mutual recognition of certificates.

3.3 Role of EU Companies

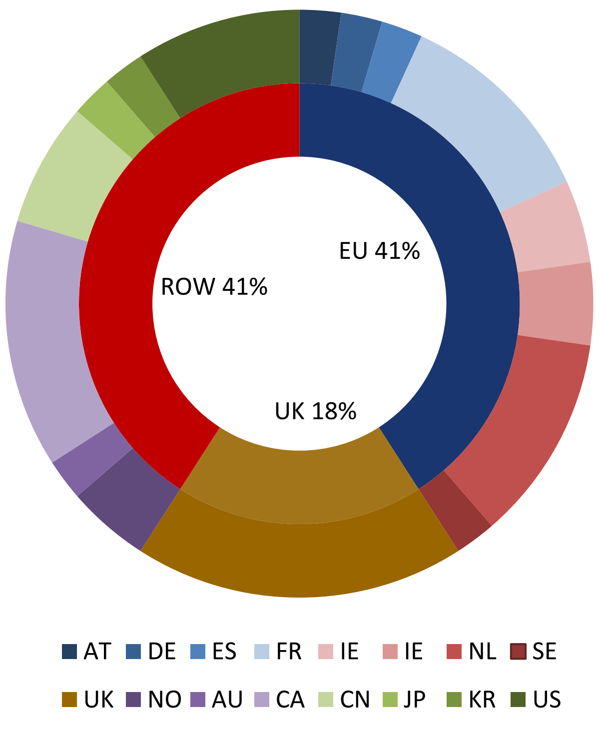
3.3.1 Tidal energy

Tidal energy is the most advanced form of ocean energy, with companies developing projects globally. 41% of the major the tidal energy developers are based in the EU, leading with Netherlands, France and Ireland. Non-EU players are predominantly based in the UK, Canada, USA and China.

Companies active in developing tidal stream devices with TRL>5 have been identified, with the majority (41%) of them located in the Europe (by Canada, Netherlands and France.

Figure 30). In terms of individual countries, UK has the largest number of companies, followed by Canada, Netherlands and France.

Figure 30. Distribution of tidal energy developers in terms of their originating region.



Source: JRC database, 2022

Through the years there have been an increasing focus on developing technology for niche markets, including off-grid application, river-stream applications and hydrogen-storage options. Tapping into niche markets offers a quick route-to-market for technology developers.

Some of the leading companies in the sector are presented in Table 14.

Table 14. Leading tidal energy developers with technology at TRL 6 or higher

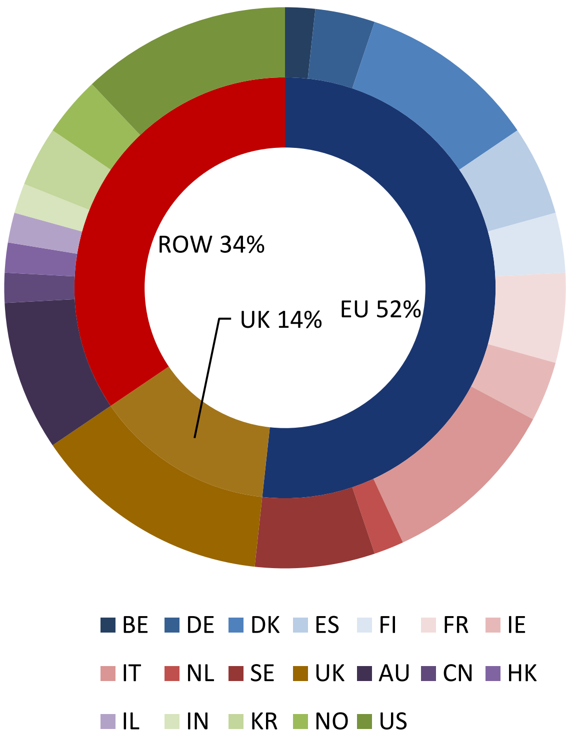
Name	Country	Website	Type
Andritz Hydro Hammerfest	Austria	www.andritzhydrohammerfest.co.uk	HAT
SABELLA	France	sabella.fr	HAT
Guinard Energies	France	www.guinard-energies.bzh/	DT
EEL GEN Energy	France	www.eel-energy.fr/en/	OH
SCHOTTEL	Germany	www.schottel.de/schottel-hydro/sit-instream-turbine/	HAT
Design Pro	Ireland	designprorenewables.com/	VAT
Kobold Turbine	Italy	www.seapowerscrl.com/ocean-and-river-system/kobold	VAT
GEM Ocean Kite	Italy	bluesharkpower.eu/	HAT
Tocardo	Netherlands	tocardo.com	HAT
Magallanes Renovables	Spain	www.magallanesrenovables.com/en/proyecto	HAT
Minesto	Sweden	minesto.com/	TK
Orbital	UK	orbitalmarine.com/	HAT
SIMEC Atlantis	UK	simecatlantis.com	HAT
Nova Innovation	UK	www.novainnovation.com/	HAT
Sustainable Marine Energy	UK	sustainablemarine.com/	HAT
Nautricity	UK	www.nautricity.com/	HAT
Oceanflow / Evopod	UK	www.oceanflowenergy.com/	HAT
Elemental Energy Technologies	Australia	www.mako.energy/projects	ET
Water Wall Turbine Inc	Canada	wwturbine.com/	HAT
New Energy Corporation	Canada	www.newenergycorp.ca/	VAT
Mavi Innovations	Canada	mavi-innovations.ca/project_post/remote-community-tidal-power-project/	HAT
Yourbrook Energy Systems	Canada	www.yourbrookenergy.com	HAT
ZHAIRUOSHAN Tidal Stream energy	China	From OES Report	HAT
Active-Controlled Tidal Current Power Generation System - KIOST	Korea	From OES Report	HAT
Tidetec	Norway	tidetec.com/	HAT
Ocean Renewable power Company	USA	www.orpc.co/	HAT
Verdant Power	USA	www.verdantpower.com/	VAT

Source: JRC database, 2022

3.3.2 Wave energy

Similarly to tidal energy, the majority of companies developing wave energy devices are located in the EU. In Figure 31 the distribution of wave energy developers worldwide with devices having TRL>6 is presented. 52% of active wave energy are located in the EU. Denmark has the highest number of developers, followed by Italy and Sweden. Outside the EU, countries with a large number of wave energy developers are the UK, the USA, Australia, and Norway.

Figure 31. Distribution of tidal energy developers in terms of their originating region



Source: JRC database, 2022

Currently the sector of wave energy is having quick progress with a large amount or devices in lower TRL, but also an increasing amount of devices in higher TRL and pre-commercial stages. In Table 15 the most prominent wave energy device developers is presented.

Table 15. Leading wave energy developers with technology at TRL 6 or higher

Name	Country	Website	Type
Laminaria	Belgium	http://www.laminaria.be/	Other
Wave Dragon	Denmark	http://www.wavedragon.net/	OT
Wave Piston	Denmark	https://www.wavepiston.dk	Other
RESEN Waves	Denmark	www.resenwaves.com/	PA
AW-Energy / WaveRoller	Finland	http://aw-energy.com/	OWSC
Wello	Finland	https://wello.eu/	RM
SBM	France	https://www.sbmoffshore.com/what-we-do/our-products/renewables/	BW
SINN Power	Germany	https://www.sinnpower.com/	PA
Ocean Energy Ltd	Ireland	http://www.oceanenergy.ie/	OWC
SeaPower Ltd.	Ireland	http://www.seapower.ie/	ATT
CETO Wave Energy Ireland	Ireland	https://www.carnegiece.com/ceto-technology/	PA
40South Energy	Italy	http://www.40southenergy.com	OWSC
Wave for Energy	Italy	http://www.waveforenergy.com/tech/iswec	RM
Wedge	Spain	https://www.wedgeglobal.com/en/waveenergy	PA
CorPower	Sweden	http://www.corpowerocean.com/	PA
Seabased	Sweden	https://www.seabased.com/	PA
Waves4Power	Sweden	https://www.waves4power.com/projects/	PA
Mocean Energy Ltd	United Kingdom	https://www.mocean.energy/	ATT
Seatricity	United Kingdom	http://seatricity.com/	PA
AMOG Consulting Limited	Australia	https://amog.consulting/products/wave-energy-converter	PA
BioWave	Australia	http://bps.energy/projects	OWSC
Bombora	Australia	http://www.bomborawave.com/	Membrane
Carnegie	Australia	https://www.carnegiece.com/	PA
Aquanet Power	Hong Kong	https://www.aquanetpower.com/	OWC
EcoWavePower	Israel	https://www.ecowavepower.com/	PA
Fred Olsen	Norway	http://boltseapower.com	PA
Resolute Marine Energy	USA	http://www.resolutemarine.com/	OWSC
Atmocean	USA	https://atmocean.com/	PA
Ocean Power Technologies	USA	https://www.oceanpowertechnologies.com/	PA
Columbia Power technologies	USA	https://columbiapwr.com/	PA
Oscilla Power	USA	https://oscillapower.com/imec-technology/	PA
NWEI - Azura Wave	USA / New Zealand	https://azurawave.com/projects/hawaii/	PA

Source: JRC database, 2022

3.4 Employment in value chain

Since ocean energy technologies represent a small fraction of the energy sector and are still not commercially widespread, value chain data are often reported aggregated with other sources of energy or are missing. According to IRENA and ILO (2021), 1288 jobs in ocean energy globally in 2020. However the database estimating the employment is limited, presenting only 4 countries globally with ocean energy employment. The majority of employment in ocean energy is in UK (928 jobs) followed by Spain (350 jobs). These numbers are not represent the reality closely, since as seen in section 3.4 multiple companies are operating in various EU countries and beyond. However, they are representative of the trend in the ocean energy sector, as seen in the previous chapters of this report, where UK with EU are leading in the development and deployment of ocean energy devices.

According to ETIPOcean (2020) future trends in employment will depend on the uptake of ocean energy in Europe and Globally. Assuming that EU targets will be reached in 2050 and the wave/tidal energy proportional split is 60%/40%, if Europe follows the global market 205.000 new direct and indirect jobs will be created for the European economy by 2050. If Europe leads the global markets 505.000 new direct and indirect jobs will be created.

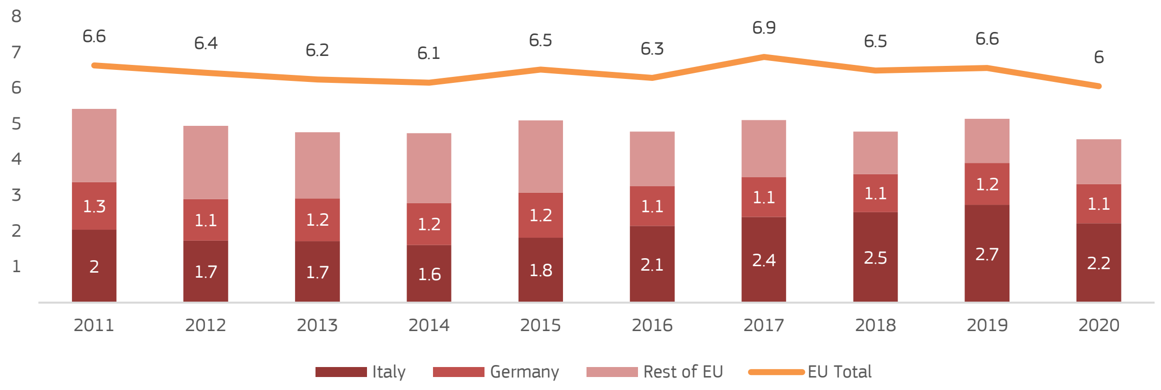
3.5 EU production Data

Ocean energy technologies are still under development with only a few commercial applications. Accordingly, manufacturing, installation, and trading activities are currently at a small scale and are usually divided into smaller sub-systems. Until reaching large, commercial scale installations, the ocean energy sector relies heavily on vehicles, machinery, and products used by other sectors, like offshore wind. The most prominent examples are the cables and the installation vehicles. Consequently, no production or trade codes are directly and exclusively linked to ocean energy technologies. However, equipment related to the manufacturing or installation of ocean energy devices can potentially act as a proxy for understanding the trends in technology development. Therefore, the selected production and international trade codes are related to lifting equipment (prodcom 28221470, HS 842699) and insulated electric conductors (prodcom 27321400, HS 854460).

The production codes used are primarily applicable in multiple other industrial applications, so in absolute numbers their production has high values. As seen in Figure 32 the production value of the two mentioned production codes has been relatively steady in the past ten years. The maximum value in 2017 reached EUR 6872 million. Italy and Germany are the main producer countries in Europe. Given the different uses of these products and the limited deployment of ocean energy

From the information available it is not possible to ascertain the use of the equipment and materials represented in these trade codes. However, based on the information presented in this report and due to the limited deployment of ocean energy technologies it is however reasonable to assume that most, if not all the equipment is mainly utilized by other sea users.

Figure 32. Total production value in EU in million EUR and Top Producer Countries



Source: JRC based on PRODCOM data, 2022

4 EU position and Global competitiveness

4.1 Global & EU market leaders (Market share)

The most competent market players for ocean energy were identified in 3.3. The majority of the companies have not announced the value of the project they are involved in. Along with this, the companies are involved in a wide range of stages across the overall value chain so it is challenging to derive a market share.

4.2 Trade (Import/export)

No dedicated trade code for ocean energy equipment and services has been located up to now. However, due to the limited deployment of ocean energy devices globally and due to the leading position of EU in the sector, in terms of the global annual market it is likely that trade doesn't represents a significant share.

4.3 Resources efficiency and dependence in relation to EU competitiveness

Resource efficiency and critical material dependency are topics that have gained little or no attention in the ocean energy sector. While numerous studies assess the materials needed for ocean energy device deployment under the prism of LCA, material availability is rarely mentioned.

Similar to other properties mentioned in other sections of this report, device types differ considerably in terms of design and structural components. This also means that some components and materials are found in certain device types only and are not applicable or not used for others.

The main materials present in all devices in different amounts are steel (mainly in the structure and moorings), cement (mainly for foundations and anchor points of the moorings), magnets (for linear generators), copper and iron (mainly for electrical connections and export cables).

Depending on the device characteristics other materials and metals are present. Various composite materials (for tidal blades), polymers (for oscillating hydrofoil designs) and polyurethane (for buoys designs) may also be present in large amounts. Uihlein (2016) presented an assessment of materials present in different types of devices as a percentage of their total weight

Table 16. Share of material used to produce ocean energy device in % of total weight

	Device Type	Steel	Other metals	Electronics	Plastics	Concrete	Sand	Water
Tidal	Horizontal axis turbine	50.2	6.4	0.9	6.9	32.7	0.8	2.1
	Vertical axis turbine	88.4	5.5	1.5	4.6	0	0	0
	Oscillating hydrofoil	77	9.7	1.8	11.2	0.3	0	0
	Enclosed tips	77.8	8	2.8	10.9	0.5	0	0
	Archimedes screw	54.5	12.5	0.4	7.6	25	0	0
	Tidal kite	64.3	2.6	1.5	5.6	25	0	0
	Other tidal	64.5	3.3	0.6	7.1	24.5	0	0
Wave	Attenuator	46.2	7.0	1	6.6	6.3	9	23.9
	Point absorber	50.5	3.8	0.9	11.9	13.6	5.3	14
	Oscillating wave surge	55.1	7.9	3	12.9	8.3	3.5	9.3
	Oscillating water column	60.6	3.1	0.6	4.1	31.6	0	0
	Overtopping	36.7	0.9	0.2	0.9	55.5	1.6	4.2
	Submerged pressure differential	63.1	3.4	0.9	11.2	21.3	0.02	0.05
	Rotating mass	46.1	2.8	0.3	4.9	20.6	6.9	18.4
	Other wave	65.5	3.6	0.5	4.8	25.6	0	0

Source: Uihlein (2016)

The supply risk of raw materials is assessed based on the fourth technical assessment of critical raw materials for the EU (European Commission. Directorate General for Internal Market, Industry, Entrepreneurship and SMEs., 2020). Particularly rare earth elements used in the permanent magnets of the turbine generators are identified as critical raw materials in the ocean energy sector. Dysprosium, Neodymium, Praseodymium, Terbium and Borate show a high supply risk).

5 Conclusions

In the last decade ocean energy technologies have been progressing rapidly. However significant cost reductions are required in order to be competitive, in line with other mainstream renewable energy sources. In the long term, it is expected that ocean energy could contribute up to 10% of the EU energy needs.

The key take away messages and trends from this report are the following:

- Ocean energy technologies have progressed fast in the last decade. Multiple devices have improved in maturity and some designs becoming commercially available recently. For tidal energy, the most prominent sub-technology that have reached TRL 9 are horizontal axis devices, followed by tidal kites (TRL 8). On the contrary, wave energy sector is more fragmented with multiple designs currently being pursuit. Point absorbers and OWC devices have currently reached TRL 9.
- Technological challenges faced by the ocean energy sector have been identified and are (i) design and validation of the devices, (ii) foundations, connections and mooring, (iii) logistics and marine operation, (iv) integration in the energy system and data collection, (v) analysis and modelling tools.
- Installed capacity is increasing and multiple projects are on the pipeline, but more is needed to achieve ambitious targets
- Wave and tidal energy costs are still high but expected to fall when deployments increase. Currently the average LCoE for wave energy devices is 0.27 EUR/kWh and for tidal energy devices 0.2 EUR/kWh. According to SET plan, by 2030, LCoE for tidal energy should reach 0.1 €/kWh, whilst for wave energy the target is of 0.15 €/kWh.
- In the decade (2010-2020), largest public investments have been awarded in France, Ireland and Sweden. The majority of the disclosed investments consider wave energy. Globally, EU is leading in R&D Investments, accounting for 46% of the worldwide public investments in the last decade.
- In terms of private investment, EU companies are the second largest investor in ocean energy technologies, with China is leading the sector having triple the amount of investments. VC investments in the EU are dominated by investment in later stages accounting for 77% and 74% of the total investments in period 2010-2015 and 2016-2021 correspondingly.
- In the period 2010-2019, China is leading in the number of patent application submitted, accounting for 49% of global applications submitted, with EU inventions accounting for 12% of the applications. However, EU is leading in the field of high value inventions, accounting for 34% of the total number of high value inventions.
- Scientific publications originating for the EU dominate the wave energy sector accounting for 25% of the wave energy publications, while in the tidal energy UK is leading the sector (21%), followed closely by EU (19%).
- The European Commission supports multiple activities addressing the development of the ocean energy sector. Since 2010 almost 300 million EUR have been invested in projects involving different elements of wave and tidal energy through the 7th Framework Programme (FP7) and Horizon 2020 (H2020) Framework Programme. Projects funded had a broad scope, from developing networks to advancement of subcomponent of devices and testing of individual devices. This funding was key for the development of the sector and the advancement of individual devices into higher TRLs. Further funding is necessary for the development of market-ready wave and tidal devices.
- Market value and chain value has been underdefined, however there will significant economic benefits if Europe captures the high market share, goal achievable only through performance improvements, leading in cost reductions, and policy interventions.
- Companies active in developing tidal stream devices with TRL>5 have been identified, with the majority (41%) of them located in the Europe. In terms of individual countries, UK has the largest number of companies, followed by Canada, Netherlands and France. Similarly the majority of companies developing wave energy devices are located in the EU (52%).
- Main materials present in all ocean energy devices in different amounts are steel (mainly in the structure and moorings), cement (mainly for foundations and anchor points of the moorings), magnets (in the case of linear generators), copper and iron (mainly for electrical connections and export cables). Particularly rare earth elements used in the permanent magnets of the turbine generators are identified as critical raw materials in the ocean energy sector.

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List of abbreviations and definitions

ATT	Attenuator
BiMEP	Biscay Marine Energy Platform
CAGR	Compound Annual Growth Rate
CAPEX	capital expenditure
CORDIS	Community Research and Development Information Service
EC	European Commission
EMEC	European Marine Energy Centre
EU	European Union
EROEI	Energy Return On Energy Invested
ET	Enclosed Tips
ETIP Ocean	European Technology and Innovation Platform for ocean energy
EU	European Union
EPO	European Patent Office
FP7	Seventh Framework Programme
FWCI	Field-Weighted citation impact
H2020	Horizon 2020
HAT	Horizontal Axis Turbine
IEA	International Energy Association
IEC	International Electrotechnical Commission
JRC	Joint Research Centre
KPI	Key Performance indicator
LCA	Life cycle analysis
LCoE	Levelised Cost of Energy
OEE	Ocean Energy Europe
OES	Ocean Energy Systems
OH	Oscillating Hydrofoil
OPEX	Operational Expenditure
OTEC	Ocean thermal energy conversion
OWC	Oscillating Water Column
OWSC	Oscillating water surge Converters
PA	Point absorber
PLOCAN	Plataforma Oceanica De Canarias
PRO	Pressure retarded osmosis
PTO	Power Take-off
R&D	Research and Development
RED	Reversed Electro dialysis
ROW	Rest of the World
RM	Rotating Mass
SET-Plan	Strategic Energy Technology Plan
SWOT	Strengths, Weaknesses, Opportunities and Threats
TRL	Technological readiness Level
VAT	Vertical Axis Turbine

List of figures

List of tables

Annex 1

Table 17. EU Funded Projects under FP7 and H2020

Project Title	Project Acronym	Thematic Priority	Net EU Contribution	Total Cost	Participation	Type of Action	Topic Code	Topic Description	Project Number
Wave Energy Transition to Future by Evolution of Engineering and Technology	WETFEET	Secure, clean and efficient energy	EUR 3,456,883	EUR 3,657,509	14	RIA	LCE-01-2014	New knowledge and technologies	641334
WAVe Resource for Electrical Production	WAVREP	Marie-Sklodowska-Curie Actions	EUR 165,599	EUR 165,599	1	MSCA	MSCA-IF-2017	Individual Fellowships	787344
Low price wave energy conversion through force cancellation.	Wavepiston	Secure, clean and efficient energy	EUR 50,000	EUR 71,429	4	SME	SIE-01-2014-1	Stimulating the innovation potential of SMEs for a low carbon energy system	663466
Competitive Wave Energy on Islands	Wavepiston	Innovation in SMEs	EUR 2,499,999	EUR 3,844,949	1	SME	EIC-SMEInst-2018-2020	SME instrument	830036
Advanced Braking Module with Cyclic Energy Recovery System (CERS) for enhanced reliability and performance of Wave Energy Converters	WaveBoost	Secure, clean and efficient energy	EUR 3,988,744	EUR 3,988,744	9	RIA	LCE-07-2016-2017	Developing the next generation technologies of renewable electricity and heating/cooling	727598
Bringing wave	Wave Scale	Innovation in	EUR	EUR	1	SME	EIC-SMEInst-2018-	SME	867793

power to a cost competitive level and commercial scale		SMEs	50,000	71,429			2020	instrument	
Development of a novel wave tidal energy converter (WATEC) to lower renewable electricity generation costs.	WATEC	Secure, clean and efficient energy	EUR 50,000	EUR 71,429	1	SME	SMEInst-09-2016-2017	Stimulating the innovation potential of SMEs for a low carbon and efficient energy system	773606
Demonstration of the economic feasibility of a wave-powered desalination system	W2O	Food security, sustainable agriculture and forestry, marine and maritime and inland water research and the bioeconomy	EUR 50,000	EUR 71,429	1	SME	SMEInst-08-2016-2017	Supporting SMEs efforts for the development - deployment and market replication of innovative solutions for blue growth	789695
New combined solution to harness wave energy full renewable potential for sustainable electricity and fresh water production	W2EW	Cross Theme	EUR 3,000,000	EUR 5,296,090	4	IA	EIC-FTI-2018-2020	Fast Track to Innovation (FTI)	831041
Verification through Accelerated testing Leading to Improved wave energy Designs	VALID	Secure, clean and efficient energy	EUR 4,993,651	EUR 4,993,651	15	RIA	LC-SC3-RES-32-2020	New test rig devices for accelerating ocean energy technology development	101006927
Demonstration of a	UPWAVE	Secure, clean	EUR	EUR	9	IA	LCE-03-2015	Demonstratio	691799

1-MW wave energy converter integrated in an offshore wind turbine farm		and efficient energy	20,722,490	28,866,788				n of renewable electricity and heating/cooling technologies	
Tidal Turbine Power Take-Off Accelerator	TIPA	Secure, clean and efficient energy	EUR 4,401,565	EUR 4,500,480	9	RIA	LCE-07-2016-2017	Developing the next generation technologies of renewable electricity and heating/cooling	727793
Tidal Demonstration for Energy Scheme	TIDES	Energy	EUR 8,002,735	EUR 13,432,210	7	CP	ENERGY.2012.2.6.1	Demonstration of first ocean energy farms	322428
Demonstration of a Condition Monitoring System for Tidal Stream Generators.	TIDALSENSE DEMO	Research for the benefit of SMEs	EUR 1,621,900	EUR 2,949,380	13	CP	SME-2011-3	Demonstration action	286989
Health Condition Monitoring of Small Scale Tidal Generators Using Miniature Torque Sensors	TidalHealth	Secure, clean and efficient energy	EUR 50,000	EUR 71,429	2	SME	SIE-01-2014-1	Stimulating the innovation potential of SMEs for a low carbon energy system	663953
Tidal Energy Converter Cost Reduction via Power Take Off Optimisation	TIDAL-EC	Research for the benefit of SMEs	EUR 1,041,000	EUR 1,349,050	7	BSG	SME-2013-1	Research for SMEs	605987
Development and demonstration of	The Blue Growth Farm	Food security, sustainable agriculture	EUR 7,602,873	EUR 9,890,328	17	IA	BG-04-2017	Multi-use of the oceans marine space,	774426

an automated, modular and environmentally friendly multi-functional platform for open sea farm installations of the Blue Growth Industry		and forestry, marine and maritime and inland water research and the bioeconomy						offshore and near-shore: Enabling technologies	
TEMPERATE WELDING	TEMPERATE CO2	Secure, clean and efficient energy	EUR 50,000	EUR 71,429	2	SME	SIE-01-2014-1	Stimulating the innovation potential of SMEs for a low carbon energy system	672626
Smart and Networking UnderWAter Robots in Cooperation Meshes	SWARMs	Information and Communicatio n Technologies	EUR 6,389,046	EUR 17,168,627	31	JTI	ECSEL-01-2014	ECSEL Key Applications and Essential Technologies (RIA)	662107
Subsea socket for offshore Platforms based on Tide turbines	SUBPORT	Secure, clean and efficient energy	EUR 50,000	EUR 71,429	1	SME	SMEInst-09-2016-2017	Stimulating the innovation potential of SMEs for a low carbon and efficient energy system	775337
Stemming the rising tide: The protective role of saltmarshes	STORM	Marie-Curie Actions	EUR 309,235	EUR 309,235	1	MC	FP7-PEOPLE-2013-IIF	Marie Curie Action: International Incoming Fellowships	623720
Structured Training and Advanced	STARMAS	Marie-Sklodowska-Curie Actions	EUR 158,010	EUR 158,010	1	MSCA	MSCA-IF-2014-EF	Marie Skłodowska-Curie	657539

Research in Marine Active Structures								Individual Fellowships (IF-EF)	
Ground-breaking retractable ship bow foils for unbeatable cost-saving, emission reduction and motion stabilization	SmartWings	-	EUR 2,110,092	EUR 3,014,418	1	SME	H2020-EIC-SMEInst-2020-4	H2020-EIC Accelerator pilot –SME Instrument - Green Deal	101010259
Power quality in coastal smart grids	SMARTWAVE	Marie-Curie Actions	EUR 194,047	EUR 194,047	1	MC	FP7-PEOPLE-2013-IEF	Marie-Curie Action: Intra-European fellowships for career development	622428
Next generation short-sea ship dual-fuel engine and propulsion retrofit technologies	SeaTech	Smart, green and integrated transport	EUR 4,999,243	EUR 6,478,472	8	IA	LC-MG-1-8-2019	Retrofit Solutions and Next Generation Propulsion for Waterborne Transport	857840
Smart Efficient Affordable Marine Energy Technology Exploitation using Composites	SEAMETEC	Secure, clean and efficient energy	EUR 50,000	EUR 71,429	2	SME	SIE-01-2014-1	Stimulating the innovation potential of SMEs for a low carbon energy system	651752
Grid connection of Wave Energy Converters: investigation on storage requirements and solutions	SEA2GRID	Marie-Curie Actions	EUR 166,566	EUR 166,566	1	MC	FP7-PEOPLE-2010-IEF	Marie-Curie Action: Intra-European fellowships for career development	272571

SEA-TITAN: Surging Energy Absorption Through Increasing Thrust And efficieNcy	SEA-TITAN	Secure, clean and efficient energy	EUR 3,890,342	EUR 3,890,342	13	RIA	LCE-07-2016-2017	Developing the next generation technologies of renewable electricity and heating/coolin g	764014
Development of screw anchors for floating Marine Renewable Energy system arrays incorporating anchor sharing	SAFS	Marie-Sklodowska-Curie Actions	EUR 195,455	EUR 195,455	1	MSCA	MSCA-IF-2016	Individual Fellowships	753156
Risk Based Consenting of Offshore Renewable Energy Projects	RiCORE	Secure, clean and efficient energy	EUR 1,393,533	EUR 1,393,533	6	CSA	LCE-04-2014	Market uptake of existing and emerging renewable electricity, heating and cooling technologies	646436
Demonstration of the Next Generation Wave Energy Device – POWERMODULE	PowerModule	Secure, clean and efficient energy	EUR 2,499,999	EUR 3,991,875	1	SME	SMEInst-09-2016-2017	Stimulating the innovation potential of SMEs for a low carbon and efficient energy system	783535
PowerKite - Power Take-Off System for a Subsea Tidal Kite	PowerKite	Secure, clean and efficient energy	EUR 5,074,364	EUR 5,537,389	10	RIA	LCE-02-2015	Developing the next generation technologies of renewable electricity and	654438

								heating/cooling	
Forecast of time-varying effects of post-GFC monetary policy + a novel computing application	Post-GFC Monetary Policy	Marie-Sklodowska-Curie Actions	EUR 158,122	EUR 158,122	1	MSCA	MSCA-IF-2014-EF	Marie Skłodowska-Curie Individual Fellowships (IF-EF)	657182
New mechanisms and concepts for exploiting electroactive Polymers for Wave Energy Conversion.	POLYWEC	Energy	EUR 2,059,156	EUR 2,620,590	6	CP	ENERGY.2012.10.2.1	Future Emerging Technologies	309139
LARGE MULTIPURPOSE PLATFORMS FOR EXPLOITING RENEWABLE ENERGY IN OPEN SEAS	PLENOSE	Marie-Curie Actions	EUR 281,400	EUR 281,400	3	MC	FP7-PEOPLE-2013-IRSES	Marie Curie Action International Research Staff Exchange Scheme	612581
PivotBuoy - An Advanced System for Cost-effective and Reliable Mooring, Connection, Installation & Operation of Floating Wind	PivotBuoy	Secure, clean and efficient energy	EUR 3,960,065	EUR 3,992,878	12	RIA	LC-SC3-RES-11-2018	Developing solutions to reduce the cost and increase performance of renewable technologies	815159
Nonlinear Rock and Roll - Modelling and Control of Parametric Resonance in Wave	ParaResWEC	-	EUR 151,851	EUR 151,851	1	MSCA	WF-01-2018	Widening Fellowships	867453

Energy Converters									
Optimum Power Extraction of Wind Energy by Small to Medium Scale Wind Turbines	OPTIWIND	Research for the benefit of SMEs	EUR 1,159,875	EUR 1,494,530	9	BSG	SME-2012-1	Research for SMEs	315563
Optimisation of Tidal energy Converter Arrays	OpTiCA	Marie-Sklodowska-Curie Actions	EUR 148,636	EUR 148,636	1	MSCA	MSCA-IF-2016	Individual Fellowships	748747
Open Sea Operating Experience to Reduce Wave Energy Cost	OPERA	Secure, clean and efficient energy	EUR 5,741,264	EUR 5,741,264	13	RIA	LCE-02-2015	Developing the next generation technologies of renewable electricity and heating/cooling	654444
Validation and Optimization of an Open-Source Novel Nonlinear Froude-Krylov Model for Advanced Design of Wave Energy Converters	OpenWave	Marie-Sklodowska-Curie Actions	EUR 171,473	EUR 171,473	1	MSCA	MSCA-IF-2018	Individual Fellowships	832140
A hydraulic collection tower, with a novel energy storage device for wave energy arrays	OHT	Secure, clean and efficient energy	EUR 50,000	EUR 71,429	1	SME	SMEInst-09-2016-2017	Stimulating the innovation potential of SMEs for a low carbon and efficient energy system	775250
Open-Centre Tidal Turbine Industrial Capability	OCTTIC	Cross Theme	EUR 2,990,158	EUR 4,271,655	5	IA	FTIPilot-01-2016	Fast Track to Innovation Pilot	730659

Scaling up to the Normandie Hydro Open-Centre Tidal Turbine Pilot Array	OCTARRAY	Secure, clean and efficient energy	EUR 15,000,000	EUR 124,331,410	6	IA	LCE-15-2016	Scaling up in the ocean energy sector to arrays	745855
OceaNET	OCEANET	Marie-Curie Actions	EUR 3,420,099	EUR 3,420,099	10	MC	FP7-PEOPLE-2013-ITN	Marie-Curie Action: Initial Training Networks	607656
Wave Energy Technology Made Mainstream	NextWave	Innovation in SMEs	EUR 50,000	EUR 71,429	1	SME	EIC-SMEInst-2018-2020	SME instrument	826910
Next Evolution in Materials and Models for Ocean energy	NEMMO	Secure, clean and efficient energy	EUR 4,981,008	EUR 5,212,863	13	RIA	LC-SC3-RES-11-2018	Developing solutions to reduce the cost and increase performance of renewable technologies	815278
NEARshore geological CONTROL on coastal morphodynamics: monitoring and modelling in high-resolution	NEARCONTROL	Marie-Sklodowska-Curie Actions	EUR 203,200	EUR 314,673	2	MSCA	MSCA-IF-2014-GF	Marie Skłodowska-Curie Individual Fellowships (IF-GF)	661342
Multi-Use in European Seas	MUSES	Secure, clean and efficient energy	EUR 1,982,104	EUR 1,987,604	10	CSA	BG-03-2016	Multi-use of the oceans' marine space, offshore and near-shore: compatibility, regulations, environmental and legal issues	727451

Mooring of floating wave energy converters:numerical simulation and uncertainty quantification	MoWE	Marie-Sklodowska-Curie Actions	EUR 200,195	EUR 200,195	1	MSCA	MSCA-IF-2016	Individual Fellowships	752031
Innovative Multi-purpose off-shore platforms: planning, Design and operation	MERMAID	Transport (including Aeronautics)	EUR 5,483,411	EUR 7,376,568	29	CP	OCEAN.2011-1	Multi-use offshore platforms	288710
Developing the PTO of the first MW-level Oscillating Wave Surge Converter	MegaRoller	Secure, clean and efficient energy	EUR 4,946,769	EUR 4,946,769	10	RIA	LCE-07-2016-2017	Developing the next generation technologies of renewable electricity and heating/cooling	763959
Marine Renewables Infrastructure Network for Emerging Energy Technologies	MARINET	Research Infrastructures	EUR 8,999,998	EUR 11,045,266	29	CP-CSA	INFRA-2010-1.1.23	Research Infrastructures for offshore renewable energy devices: ocean-, current-, wave- and wind energy.	262552
Marine Renewable Energy Research Infrastructure	MARINERGI	Research Infrastructures	EUR 1,999,799	EUR 2,048,294	14	RIA	INFRADEV-02-2016	Preparatory Phase and support to early phase of ESFRI projects	739550
Improved magnets for energy generation through	MAGNETIDE	Research for the benefit of SMEs	EUR 1,131,700	EUR 1,457,244	7	BSG	SME-2011-1	Research for SMEs	284578

advanced tidal technology									
Development of a novel wave energy converter based on hydrodynamic lift forces	LiftWEC	Secure, clean and efficient energy	EUR 3,404,730	EUR 3,556,230	12	RIA	LC-SC3-RES-1-2019-2020	Developing the next generation of renewable energy technologies	851885
Non-linear, control-informed optimisation of innovative wave absorbing structures using highly-efficient numerical methods	InWAS	Marie-Sklodowska-Curie Actions	EUR 184,708	EUR 184,708	1	MSCA	MSCA-IF-2018	Individual Fellowships	842967
Demonstration of Integrated Solution for offshore Tocardo Tidal power plants.	InToTidal	Cross Theme	EUR 2,000,000	EUR 2,891,524	5	IA	FTIPilot-01-2016	Fast Track to Innovation Pilot	730799
Maximising the technical and economic performance of real wave energy devices	INNOWAVE	Marie-Sklodowska-Curie Actions	EUR 804,637	EUR 804,637	2	MSCA	MSCA-ITN-2015-EID	Marie Skłodowska-Curie Innovative Training Networks (ITN-EID)	676061
Innovative Methods for wave energy Pathways Acceleration through novel Criteria and Test rigs	IMPACT	Secure, clean and efficient energy	EUR 3,342,938	EUR 3,342,938	5	RIA	LC-SC3-RES-32-2020	New test rig devices for accelerating ocean energy technology development	101007071
Innovative Method	IMAGINE	Secure, clean	EUR	EUR	6	RIA	LCE-07-2016-	Developing	764066

for Affordable Generation IN ocean Energy		and efficient energy	3,761,205	3,761,205			2017	the next generation technologies of renewable electricity and heating/coolin g
European Industrial DoCtorate on Offshore WiNd and Wave ENergy	ICONN	Marie-Sklodowska-Curie Actions	EUR 845,838	EUR 845,838	5	MSCA	MSCA-ITN-2015-EID	Marie Skłodowska-Curie Innovative Training Networks (ITN-EID)	675659
The development of a modular 'stepping locomotion' system for installation on subsea trenching machines used for subsea energy cable burial	HEXATERRA	Research for the benefit of SMEs	EUR 1,198,998	EUR 1,571,697	9	BSG	SME-2013-1	Research for SMEs	605420
Making wave energy competitive with wind and solar energy	HACE	Innovation in SMEs	EUR 50,000	EUR 71,429	1	SME	EIC-SMEInst-2018-2020	SME instrument	815590
Development of a wind-wave power open-sea platform equipped for hydrogen generation with support for multiple users of energy	H2OCEAN	Transport (including Aeronautics)	EUR 4,525,934	EUR 6,501,859	19	CP	OCEAN.2011-1	Multi-use offshore platforms	288145
Geotechnical design solutions for the	GEOWAVE	Research for the benefit of	EUR 1,129,100	EUR 1,456,241	10	BSG	SME-2011-1	Research for SMEs	287056

offshore renewable wave energy industry		SMEs							
Floating Tidal Energy Commercialisation project (FloTEC)	FloTEC	Secure, clean and efficient energy	EUR 9,782,380	EUR 22,200,080	15	IA	LCE-03-2015	Demonstration of renewable electricity and heating/cooling technologies	691916
Development, engineering, production and life-cycle management of improved FIBRE-based material solutions for structure and functional components of large offshore wind enerGY and tidal power platform	FIBREGY	Advanced materials	EUR 6,499,590	EUR 8,361,441	14	IA	LC-NMBP-31-2020	Materials for off shore energy (IA)	952966
Bridging the gap to commercialisation of wave energy technology using pre-commercial procurement	EuropeWave	Secure, clean and efficient energy	EUR 11,351,057	EUR 22,752,113	3	PCP	LC-SC3-JA-3-2019	European Pre-Commercial Procurement Programme for Wave Energy Research &Development	883751
Enabling Future Arrays in Tidal	EnFAIT	Secure, clean and efficient energy	EUR 14,914,600	EUR 21,175,063	13	IA	LCE-15-2016	Scaling up in the ocean energy sector to arrays	745862
Electric Motor And	EMAS	Joint Technology	EUR 138,900	EUR 189,600	1	JTI	JTI-CS-2009-1-SGO-02-010	Engine Thrust Reverser	255811

Sensor design and manufacture		Initiatives (Annex IV-SP1)						Actuation System (ETRAS) electric motor & resolver	
Energy from Limited Velocity Estuaries and Rivers	ELVER	Innovation in SMEs	EUR 50,000	EUR 71,429	1	SME	EIC-SMEInst-2018-2020	SME instrument	887603
Effective Lifetime Extension in the Marine Environment for Tidal Energy	ELEMENT	Secure, clean and efficient energy	EUR 4,984,623	EUR 5,179,548	15	RIA	LC-SC3-RES-11-2018	Developing solutions to reduce the cost and increase performance of renewable technologies	815180
eForcis and BeForcis, Wave Energy Generators for marine buoys and devices.	eForcis	Secure, clean and efficient energy	EUR 50,000	EUR 71,429	1	SME	SMEInst-09-2016-2017	Stimulating the innovation potential of SMEs for a low carbon and efficient energy system	736343
Erosion Control Oscillating Wave Energy Converter	ECOWEC	Innovation in SMEs	EUR 50,000	EUR 71,429	1	SME	EIC-SMEInst-2018-2020	SME instrument	888528
Advanced Design Tools for Ocean Energy Systems Innovation, Development and Deployment	DTOceanPlus	Secure, clean and efficient energy	EUR 6,689,077	EUR 8,420,818	21	IA	LCE-16-2017	2nd Generation of design tools for ocean energy devices and arrays development and	785921

								deployment	
Optimal Design Tools for Ocean Energy Arrays	DTOCEAN	Energy	EUR 4,178,232	EUR 6,181,700	19	CP	ENERGY.2013.2.6.1	Design tools, enabling technologies and underpinning research to facilitate ocean energy converter arrays	608597
Feasibility study for an innovative direct drive tidal turbine	Direct Drive TT	Secure, clean and efficient energy	EUR 50,000	EUR 71,429	1	SME	SIE-01-2014-1	Stimulating the innovation potential of SMEs for a low carbon energy system	651505
Deep Green Island Mode 2	DGIM2	Innovation in SMEs	EUR 2,499,995	EUR 6,464,875	2	SME	EIC-SMEInst-2018-2020	SME instrument	872404
Deep Green Island Mode	DG Island Mode	Innovation in SMEs	EUR 50,000	EUR 71,429	1	SME	EIC-SMEInst-2018-2020	SME instrument	827525
Moment-based nonlinear energy-maximising optimal control of wave energy systems to secure a renewable future	DESTINY	Marie-Sklodowska-Curie Actions	EUR 183,473	EUR 183,473	1	MSCA	MSCA-IF-2020	Individual Fellowships	101024372
DEMOnstration for Tidal Industry DErisking	DEMOTIDE	Secure, clean and efficient energy	EUR 20,301,150	EUR 47,999,417	6	IA	LCE-03-2015	Demonstration of renewable electricity and heating/cooling technologies	691925
Direct Drive Tidal	D2T2	Secure, clean and efficient	EUR 2,250,266	EUR 3,214,666	1	SME	SMEInst-09-2016-2017	Stimulating the innovation	734032

Turbine (D2T2) Accelerator project		energy						potential of SMEs for a low carbon and efficient energy system	
Control parametric resonance of wave energy conversion systems	CONPARA	Marie-Sklodowska-Curie Actions	EUR 196,591	EUR 196,591	1	MSCA	MSCA-IF-2018	Individual Fellowships	841388
CommerciaL Energy ARray for Widespread Acceleration of Tidal European Resources	CLEARWATER	Energy	EUR 7,736,317	EUR 22,630,102	4	CP	ENERGY.2012.2.6.1	Demonstration of first ocean energy farms	321751
Clean energy from ocean waves	CEFOW	Secure, clean and efficient energy	EUR 16,998,022	EUR 25,021,614	11	IA	LCE-03-2014	Demonstration of renewable electricity and heating/cooling technologies	655594
DEVELOPMENT AND MARKET UPTAKE OF INNOVATIVE SYSTEM TO OBTAIN ELECTRICAL ENERGY FROM OCEAN WAVE RESOURCES	BUTTERFLY	Food security, sustainable agriculture and forestry, marine and maritime and inland water research and the bioeconomy	EUR 50,000	EUR 71,429	1	SME	SMEInst-08-2016-2017	Supporting SMEs efforts for the development - deployment and market replication of innovative solutions for blue growth	774021
Coral Reef wisdom to capture Wave Energy	ARRECIFE	Secure, clean and efficient energy	EUR 50,000	EUR 71,429	1	SME	SMEInst-09-2016-2017	Stimulating the innovation potential of SMEs for a low carbon	807148

								and efficient energy system	
Development of cost-effective, water based power take-off system for marine energy applications	AQUAGEN	Research for the benefit of SMEs	EUR 1,736,951	EUR 2,346,533	10	BSG	SME-1	Research for SMEs	262315
Advanced Coatings for Offshore Renewable ENergy	ACORN	Research for the benefit of SMEs	EUR 1,036,000	EUR 1,342,124	7	BSG	SME-2013-1	Research for SMEs	605955

Source: JRC based on Cordis, 2022

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