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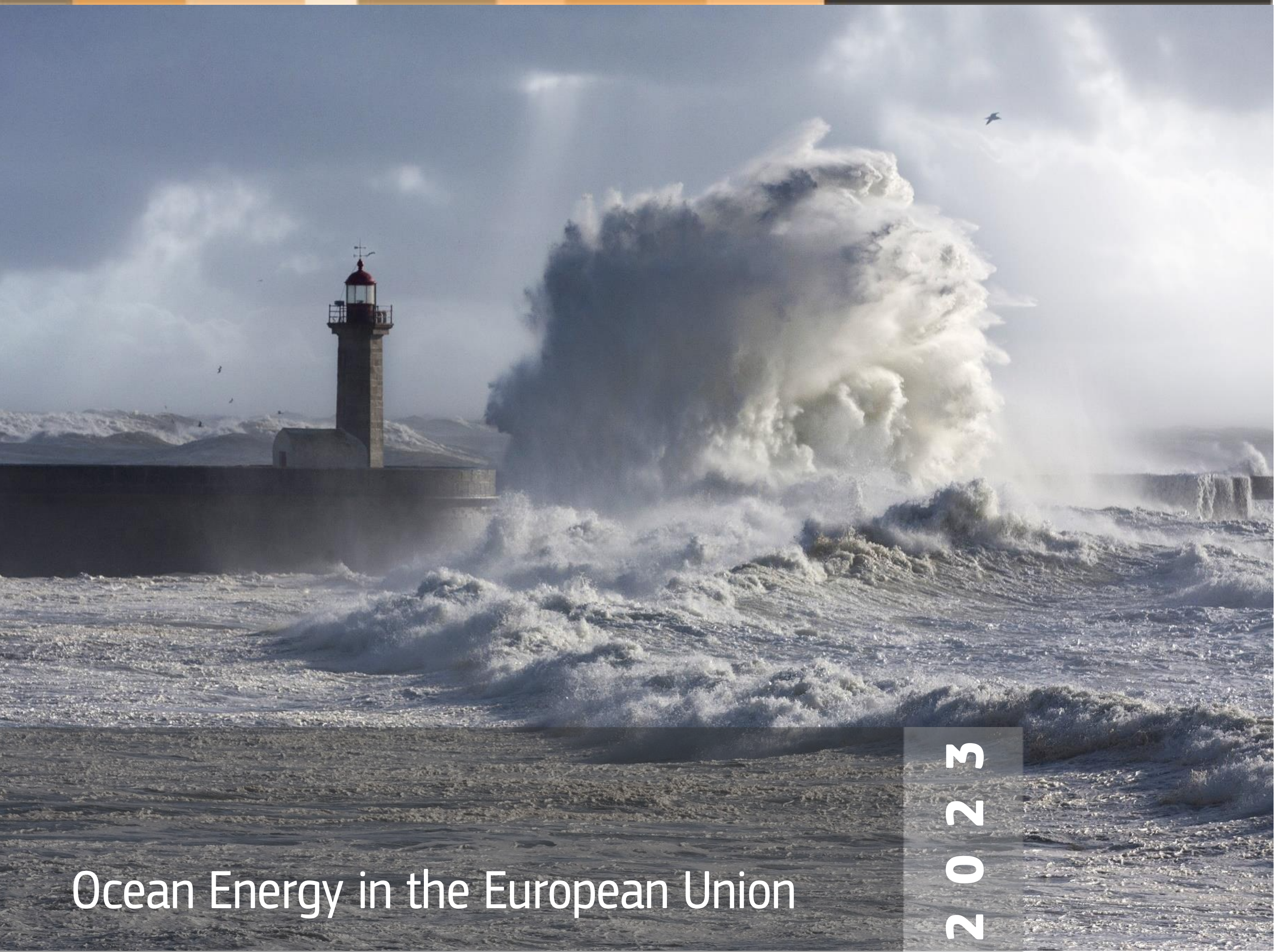

2023

Ocean Energy in the European Union

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

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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 trends focussing particularly on the technology progress made in EU-funded research until the end of 2022, in view of the SET-Plan targets. This report 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 on the Clean Energy Technology Observatory

The European Commission set up the Clean Energy Technology Observatory (CETO) in 2022 to help address the complexity and multi-faced character of the transition to a climate-neutral society in Europe. The EU's ambitious energy and climate policies create a necessity to tackle the related challenges in a comprehensive manner, recognizing the important role for advanced technologies and innovation in the process.

CETO is a joint initiative of the European Commission Joint Research Centre (JRC), who run the observatory, and Directorate Generals Research and Innovation (R&I) and Energy (ENER) on the policy side. Its overall objectives are to:

- monitor the EU research and innovation activities on clean energy technologies needed for the delivery of the European Green Deal
- assess the competitiveness of the EU clean energy sector and its positioning in the global energy market
- build on existing Commission studies, relevant information & knowledge in Commission services and agencies, and the Low Carbon Energy Observatory (2015-2020)
- publish reports on the Strategic Energy Technology Plan (SET-Plan) SETIS online platform

CETO provides a repository of techno- and socio-economic data on the most relevant technologies and their integration in the energy system. It targets in particular the status and outlook for innovative solutions as well as the sustainable market uptake of both mature and emerging technologies. The project serves as primary source of data for the Commission's annual progress reports on competitiveness of clean energy technologies. It also supports the implementation and development of EU research and innovation policy.

The observatory produces a series of annual reports addressing the following themes:

- Clean Energy Technology Status, Value Chains and Market: covering advanced biofuels, batteries, bioenergy, carbon capture utilisation and storage, concentrated solar power and heat, geothermal heat and power, heat pumps, hydropower & pumped hydropower storage, novel electricity and heat storage technologies, ocean energy, photovoltaics, renewable fuels of non-biological origin (other), renewable hydrogen, solar fuels (direct) and wind (offshore and onshore).
- Clean Energy Technology System Integration: building-related technologies, digital infrastructure for smart energy system, industrial and district heat & cold management, standalone systems, transmission and distribution technologies, smart cities and innovative energy carriers and supply for transport.
- Foresight Analysis for Future Clean Energy Technologies using Weak Signal Analysis
- Clean Energy Outlooks: Analysis and Critical Review
- System Modelling for Clean Energy Technology Scenarios
- Overall Strategic Analysis of Clean Energy Technology Sector

More details are available on the CETO web pages.

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1 Executive Summary

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 towards a transition to climate neutrality.

Wave energy and tidal stream energy are the two ocean sub technologies that dominate deployments, technological advancements and potential in the EU. In 2022 there were limited new installations in the EU, however there are multiple projects on the pipeline. Currently only 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 further refined in order to establish ocean energy as a reliable source of electricity generation. While for tidal energy there is a convergence in horizontal axis technology devices, for wave energy the sector is more fragmented with multiple devices being currently pursued. By refining the most promising technologies, increasing manufacturing capacities and overal increase the number of deployed devices, cost will be reduced as well. Currently costs are still high with average Levelised Cost of Electricity (LCoE) of 0.27 EUR/kWh for wave energy devices and 0.2 EUR/kWh for tidal energy devices. 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. According to the POTEnCIA model ocean devices' is projected to almost double from current levels to 460 MW of in 2050. This value is significantly lower than the target of the offshore renewable strategy of 1GW by 2030 and 40 GW by 2050, and highlights the need for a step change in the ocean energy sector in order to achieve the ambitious goals of the renewable energy strategy.

Public R&D has peaked in 2015, but then decreased ever since. In the last three reported years (2019, 2020 and 2021), the level of public R&D has been stable to around 23.31 million EUR in the EU

Financially, the EU has been supporting companies through public investments, leading the sector globally by contributing to 49% 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. Financial support in the EU leads 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 are necessary.

In 2022 there was a decrease in the absolute number of scientific publications both in wave and in tidal energy. For the first time, China overtook EU in the number of publications and is now leading both the wave and the tidal sectors. However, in the wave energy sector and for the period cummulatively in 2011-2022, EU is leading globally, having the largest number of total publications, largest number of highly cited articles, and h-index. For tidal energy, the majority of the publications comes from a single country, the UK, which holds the largest number of highly cited papers, and h-index. EU comes second behind the UK in all these metrics.

EU is highly competitive in the ocean energy sector with the majority of tidal stream projects (41%) presenting a Technology Readiness Level (TRL) higher than TRL 5 being located in the EU. Similarly, the majority of companies developing wave energy devices are located in the EU (52. 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**
• Tidal energy is a predictable source of energy, while wave can produce energy even under the mildest conditions • Reduced visual impact, leading to increased public acceptance • 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 costs (CAPEX) that need larger deployment levels to reduce • Maintenance can be costly/ difficult, leading to higher operational costs (OPEX) • Limited data on the length of lifetime leads to conservative assumptions when calculating levelised costs. • Geographically limiting factors. especially for tidal energy where most of the developed devices require strong tidal currents in order to operate.
Opportunities	**Threats**
• Large number of projects to be launched in the next years • Under favourable regulatory and economic conditions, ocean energy could contribute to around 10% of the EU's electricity demand by 2050. • Due to their capabilities, both for energy production but also for alternative uses (desalination, aquaculture, etc.) ocean energy technologies have the potential to drive the "blue" economy • EU companies are leading the field, so there are technology export opportunities • Co-development of ocean energy sources with other renewable sources of energy or other activities in common platforms, similar to energy islands	• The number of planned commercial projects has increased but more is needed to achieve ambitious targets and drive costs down. • Administrative barriers. Due to ill-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, 2023.

1.1 Scope and context

The ocean contains a vast renewable energy potential, which could support economically sustainable long-term development and could 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 reliable and stable electricity, as well as support other components of this economic sector, 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, to evaluate the value chains, 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.

The report analyses the status of the main technology indicators and their future development. Chapter 2 introduces the current technology readiness level (TRL) of the main technologies in the ocean energy sector. This is followed by an analysis of key indicators on deployment and an outline of modelling projections at EU and global levels. Chapter 2.3 analyses present and future cost developments in ocean energy with the latest estimates on LCoE, CAPEX, OPEX and WACC. Competitiveness indicators measuring public & private R&D funding, patenting trends and scientific publications are presented in chapters 2.4 to 2.7, followed by an analysis of the impact and trends of EU-supported research and innovation.
Chapter 3 focuses on the ocean energy value chain and includes an analysis of macroeconomic indicators (turnover, Gross Value Added (GVA), employment and production data) and a mapping of indicators on environmental and socioeconomic sustainability.

Chapter 4 gives an insight into the EU's global position and competitiveness by assessing the market shares of EU and global market leaders in ocean energy.

For the identification of the technology trends, needs and barriers, the technology roadmaps and reports from various organisations and initiatives have been used, 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).

This report is an update of the 2022 CETO report (Tapoglou et al., 2022).

1.2 Methodology and Data Sources

The report has been written following the CETO methodology that addresses three principal aspects:

a) Technology maturity status, development and trends

b) Value chain analysis

c) Global markets and EU positioning

The method to assess the Technology Readiness Level (TRL) of the technologies considered in this report follows the definition described in (European Union, 2014). 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 section, 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 though 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 as well as the need for raw materials for the development of ocean energy devices.

Annex 1 provides a summary of the indicators for each aspect, together with the main data sources. Annex 2 provides a list of the EU funded projects for ocean energy projects, while in Annex 3 there is a description of the POTEnCIA and POLES-JRC models.

2 Technology status and development trends

2.1 Technology readiness level

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, with a theoretical potential of about 2800 TWh for wave and 50 TWh for tidal energy annually (Magagna D, 2020). In Europe the largest potential exists along the Atlantic coast. OTEC, due to its nature, is only deployable in tropical seas and in EU overseas islands.

Tidal energy can be extracted in two main ways, by taking advantage of the water level between 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 pursued due to its limited site availability, large initial cost and environmental implications. Currently in the EU a 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, thereby producing electricity.
- Archimedes screw: 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 HAT. There, Both floating and bottom fixed HAT designs are considered, andcurrently there are multiple devices that have a high maturity level, whether 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 TRL 8-9, 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 licence for an array development reaching 80 MW.

As opposed to tidal devices, in wave energy there is a greater design variance with is no dominant sub-technology 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 device that encloses an eccentric weight of a gyroscope. As the device is moved by the waves, the weight rotates, producing electricity.
- Other: six more are identified, presenting unique characteristics and specific designs.

There are significant differences between the several types of wave energy devices, 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 show 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.

In **Table 2** the different wave energy technologies, together with their current TRL, are presented.

Table 2. Technological readiness level for different types of Ocean energy

	TRL (Technology Readiness Level)								
Sub-Technology	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Tidal energy									
Wave energy									
OTEC									
Salinity gradient									

Source: JRC, 2023

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.

A 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 to the Shetland Islands (Nova Innovation, 2019).

Similarly for wave energy, the sector is investigating 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 starting 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. Poseidon Wave and Wind system by Floating Power Plant combines 3 wind turbines and multiple wave energy devices in the same platform.

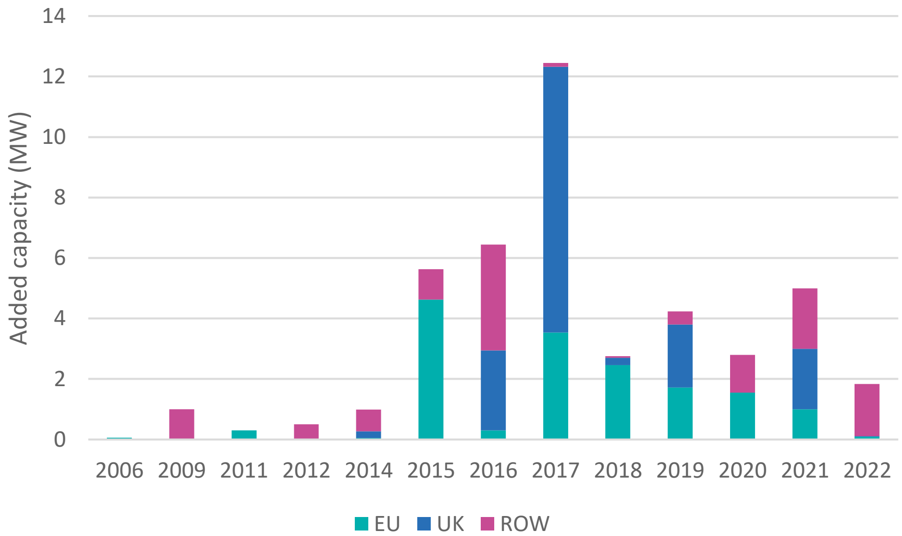
OES has identified six projects to demonstrate the capabilities of ocean energy in alternative markets, ranging from desalination and aquaculture applications to multi-use platforms (OES, 2021).

2.2 Installed Capacity and 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 (since 1966) and a 20 MW station in Canada (since 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, Netherlands) are recently developed, but their application is limited geographically.

In terms of tidal stream and wave energy capacity, deployments' pace peaked in 2017 (**Figure 1**). In 2022 there were very limited new installations in the EU, while the global new installed capacity accounted for less than 2 MW.

Figure 1. Annual added capacity installation of tidal stream and wave energy plants in the EU, UK and rest of the world, 2006-2022

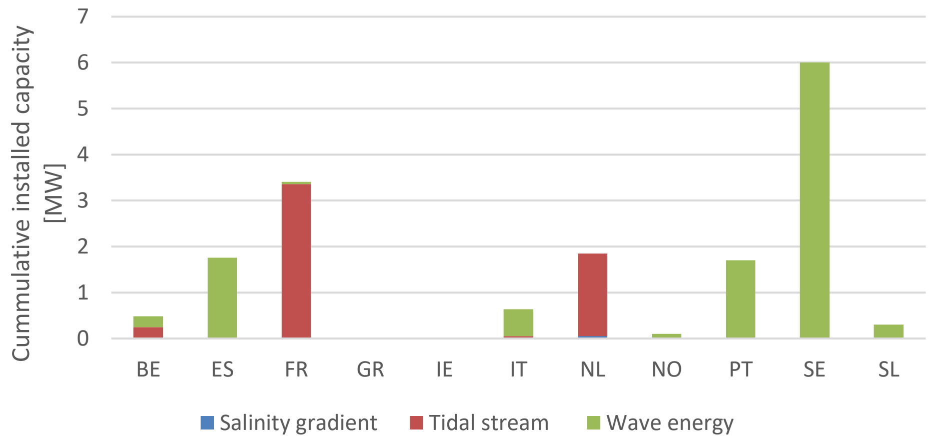


Source: JRC database, 2023

. For tidal devices, the Endeavour device with a capacity of 1.6 MW, was installed in Chinese waters, while in European waters there were three new devices: Evo25 (25 kW), EEL (30 kW) and Gkinetic (12 kW). In terms of wave devices, three devices were installed outside Europe, namely EWP-EDF WEC in Israel (100 kW), Drakoo in China (15 kW) and TigerRAY in the US (1 kW), while three more were installed in European Waters: In the EU, Sigma WEC in Slovenia (30 kW) and WEC10 in Belgium (3.5 kW); and in the UK, Archimedes Waveswing (16 kW).

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

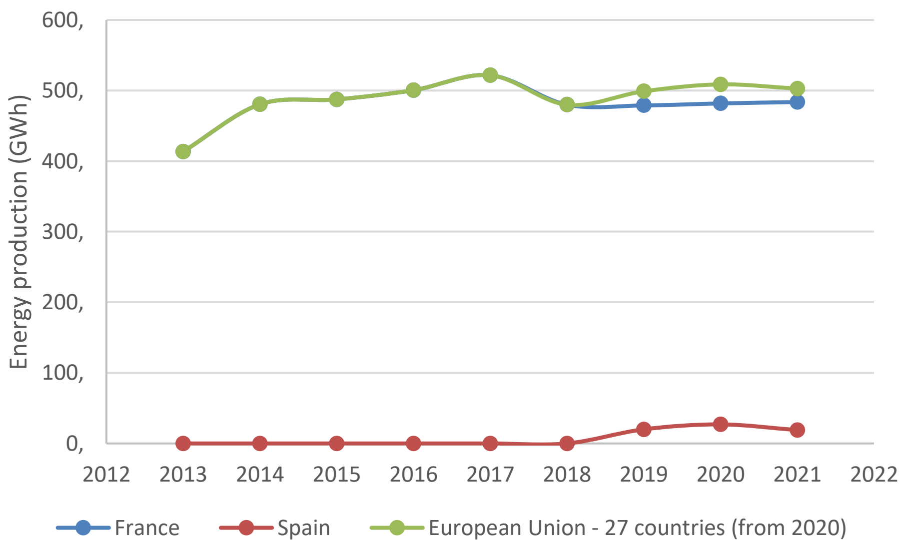
Figure 2. Ocean energy cumulative installed capacity in the EU in 2022



Source: JRC database, 2023

In Figure 3 shows 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 at demonstrationor level (TRL = 5-6), and do inject electricity in the not contribute to the networkgrid, hence their production is not taken into account in Figure 3. Most Member States with marine energy demonstrators or prototypes do not include them in the official capacity and production data communicated to Eurostat

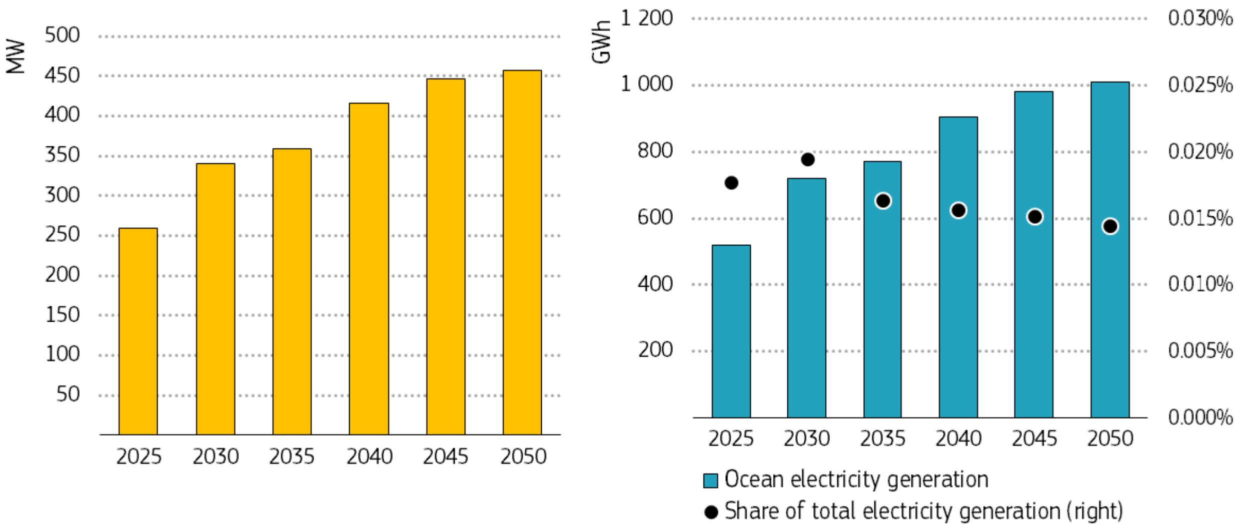
Figure 3. Annual ocean energy production in EU countries. The figure includes data for all types of ocean energy present in EU waters (i.e.tidal range, tidal stream, wave energy andsalinity gradient).



Source: Eurostat, 2023

Under the CETO Climate Neutrality Scenario (see Annex 3), the POTEnCIA model projects ocean devices' installed capacity to reach 340 MW in 2030 and then around 460 MW in 2050 in the EU, around 80% more than current capacity (**Figure 6**). In terms of electricity generation, POTEnCIA projections indicate that although ocean electricity is projected to almost double in 2050 compared to current levels, its contribution would remain limited to less than 0.1% of total electricity generation throughout the time horizon. This deployment level, which is mainly driven by the low competitiveness of ocean energy with other renewable sources, is significantly lower than the EC's target of the offshore renewable strategy of 1 GW by 2030 and 40 GW by 2050. This highlights the need for a step change in the ocean energy sector in order to rapidly reduce costs and enhance competitiveness vis-a-vis other technologies, as required to achieve the ambitious goals of the offshore renewable energy strategy.

Figure 4. Gross installed capacity (left) and gross electricity production (right) of ocean energy technologies in the EU according to POTEnCIA model.



Source: JRC, 2023

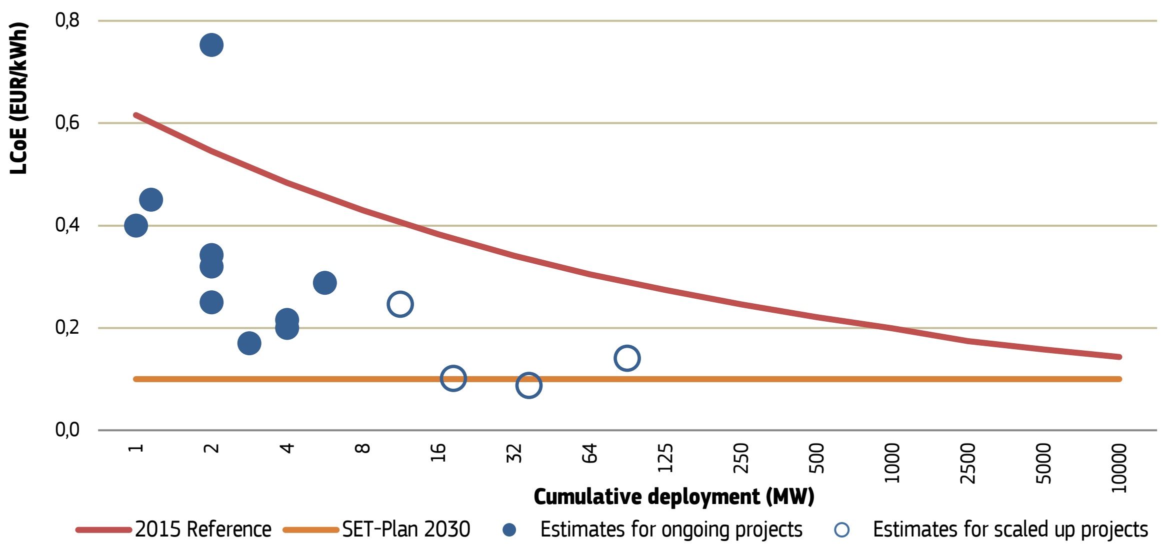
2.3 Technology Costs

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 consist 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**, and for wave energy projects in **Figure 5**.

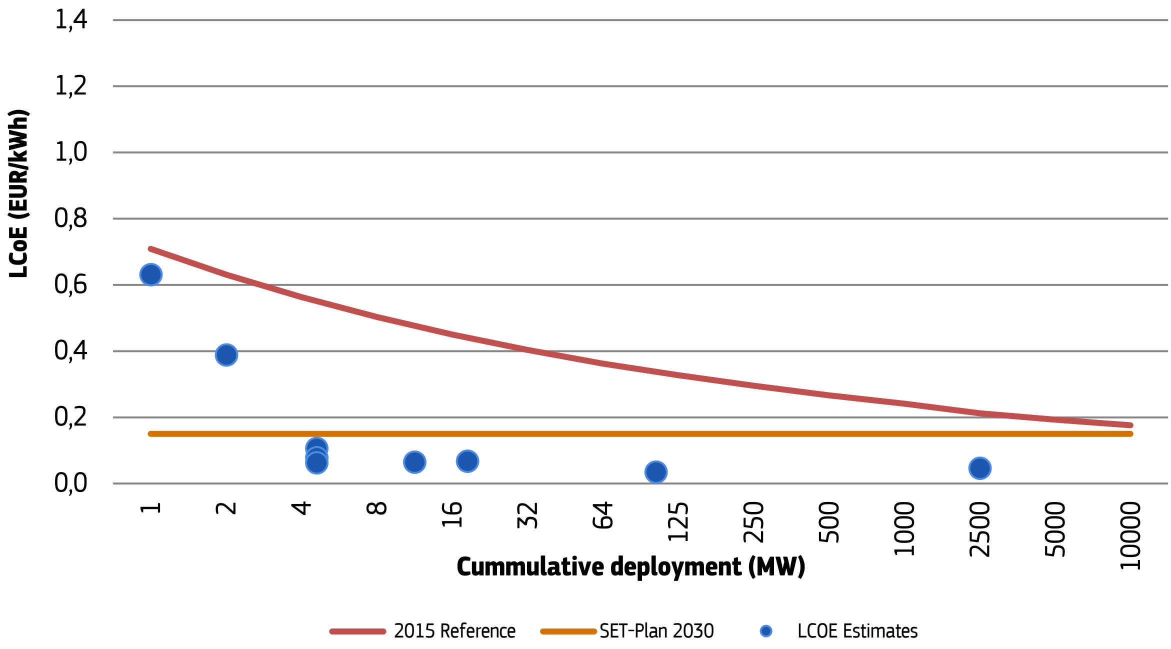
TIGER project (2022) calculated the current and the future trajectory of LCOE for tidal stream installations in the UK and France. They estimated a current LCOE equal to be around EUR 300±34 per MWh (GBP 259±30/MWh), while assuming a cumulative deployment of 877 MW in the UK and 783 MW in France by 2035. They project this value to drop to around EUR 90±39 per MWh (GBP 78±25/MWh) by 2035.

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



Source: Based on JRC database,2023 and IRENA, 2021

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



Source: JRC database, 2023

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 to 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 to reduce cost.

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 presented in **Table 3**. These key indicators for whole-system TRL 7-9 devices, for the wave and tidal ocean technologies, reflect the current status of ocean technologies.

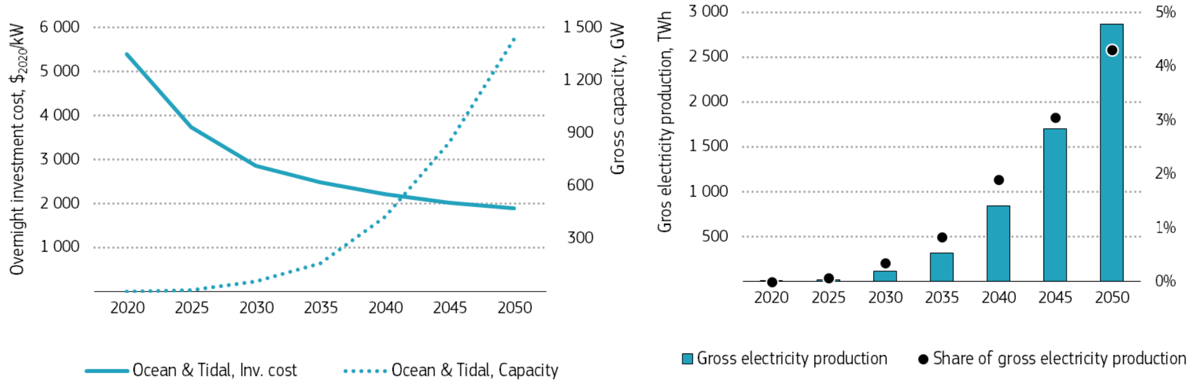
Table 3. Key indicator for whole-system TRL 7-9 devices, for the wave and tidal ocean technologies

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

Globally, the overnight investment cost is expected to drop to 2000 $\$_{2020}$/kW by 2050, while ocean energy technologies are expected to contribute around 4% of the gross electricity production (**Figure 7**).

Figure 7. Global overnight investment cost and gross capacity (left) and Global gross electricity production of ocean energy technologies (right)



Source: JRC, 2023

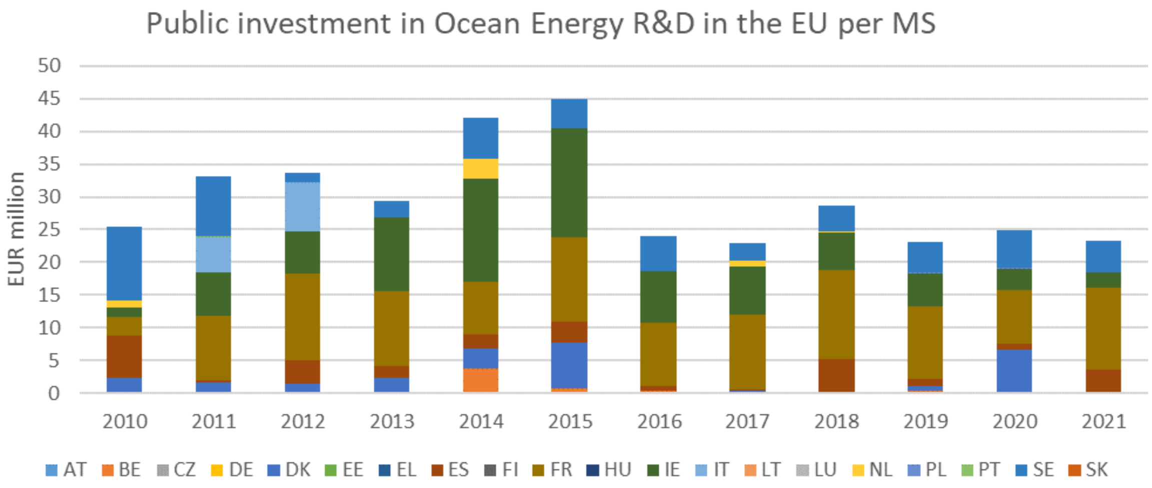
2.4 Public RD&I Funding and Investments

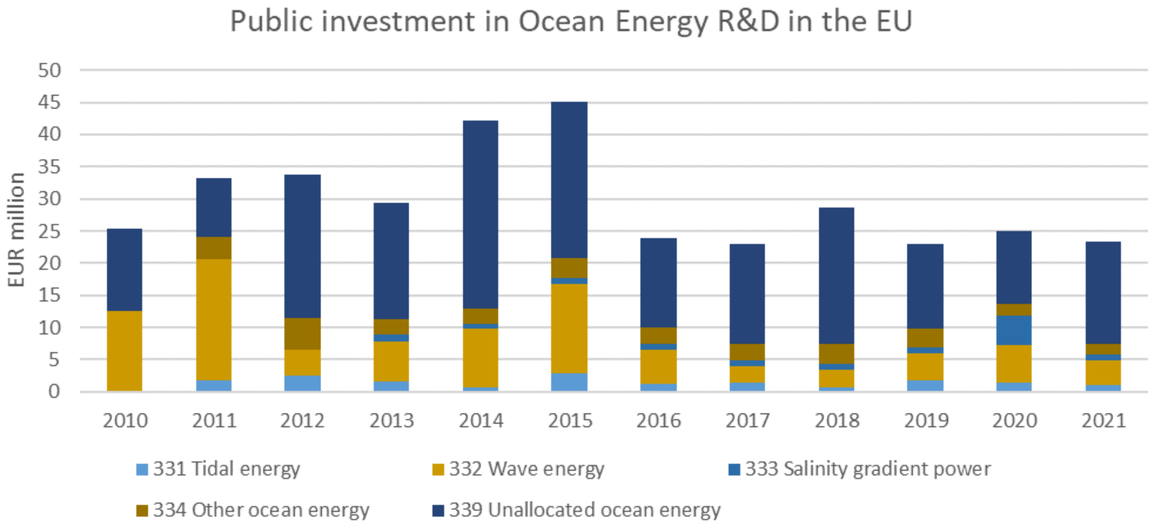
Public investment can have a significant positive effect on the development and deployment of a technology> It creates a positive environment for private initiatives, and affects among others the number of relevant publications and patent applications. As such, it is an important indicator of the level of development and competitiveness in a given technological area. The following information is based on JRC analysis with data from the IEA (IEA, 2023).

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 8**), followed closely by 2014. In 2021 there was a small decrease in public investments, however it remained to the same levels as previous years (23.31 million EUR in 2021 compared to 25 million EUR and 23 million EUR in 2020 and 2019 correspondingly). 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 (58.7%) of the public investments in the last decade fall in the unallocated ocean energy category.

Figure 8. Public R&D investments (in million EUR) in ocean energy in the EU by year and by MS (top graph) and Public R&D investments (in million EUR) in ocean energy in the EU by year and by technology (bottom graph)



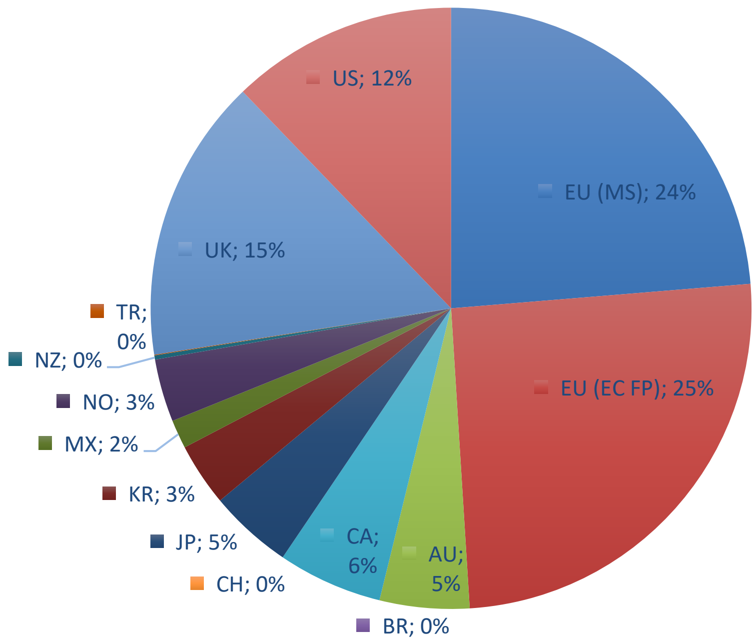


Source: JRC based on IEA, 2023

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 the EU is leading in R&D Investments, accounting for 49% of the worldwide public investments in the last decade (**Figure 9**). This is attributed both to direct investments by the Member States (24% of the total investments) but also to funding from EU framework programmes (25%). The UK (15%) and the US (12%) are following in ocean energy investments.

Figure 9. 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.



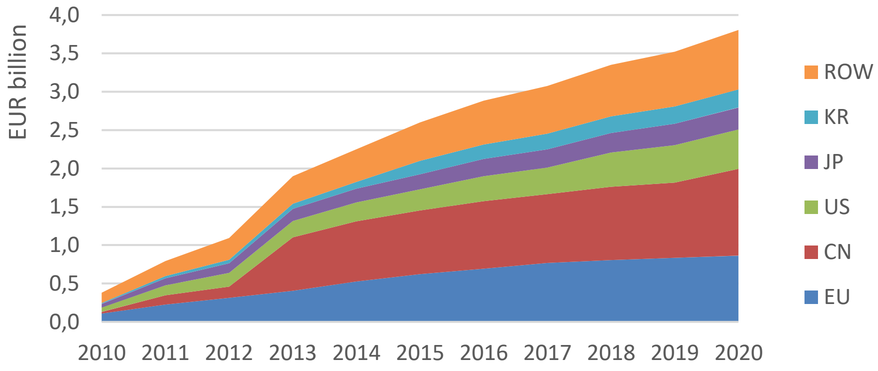
Source: JRC based on IEA, 2023

2.5 Private RD&I funding

The analysis presented in the following is based on the JRC methodology (Pasimeni, Fiorini, and Georgakaki, 2019; Fiorini A et al., 2017), with data referring to the period 2010-2020. 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. 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 second largest investor in ocean energy technologies, investing 862.9 million EUR (**Figure 8**). China is leading the sector with 1100 million EUR of investments. However, as will be seen in section 2.6, China has a considerable amount of patent applications Patents act as a proxy for private investments in this methodology, there is an inherited risk of overestimating investments in countries with larger amounts but less significant patents.

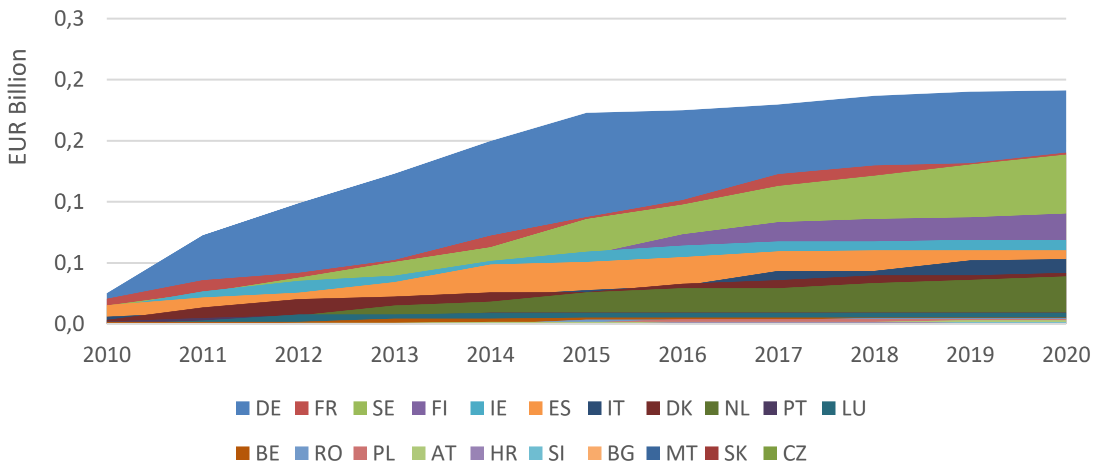
Figure 8. Cumulative global private R&I investments in ocean energy for the time period 2010-2020



Source: JRC SETIS according to Fiorini et al., (2017); Pasimeni, et al., (2019), 2023

In the EU, largest private investments for the period 2010-2020 were reported for Germany, followed by France and Sweden (**Figure 10**).

Figure 10. Cumulative private R&I investments per EU member state for the time period 2010-2020 (incomplete data for 2020)



Source: JRC SETIS according to Fiorini et al., (2017); Pasimeni, et al., (2019), 2023

Private investments in the EU peaked in 2014, accounting for 121 million EUR. In total, in the period 2010-2020, 863 million EUR have been privately invested. Top investors in the EU include Robert Bosch GMBH, AW

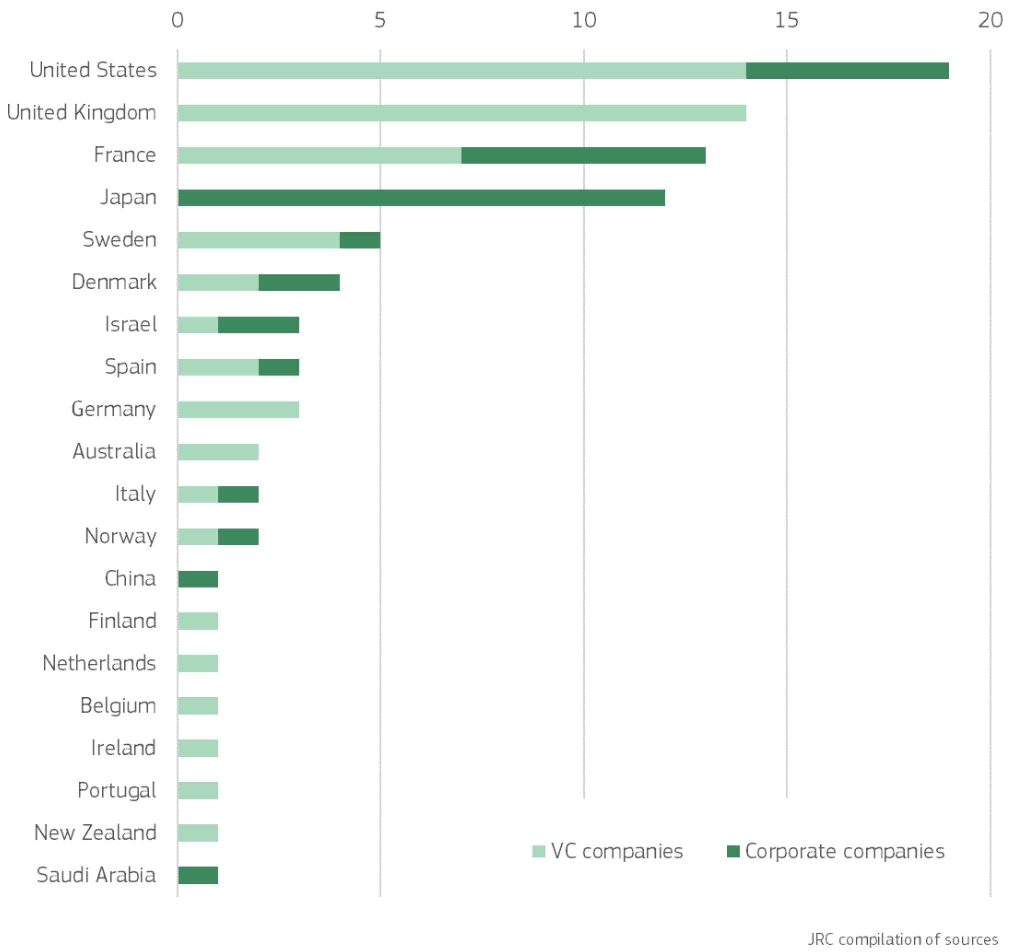
Energy OY and Ocean Harvesting Technologies AB. In the global leader board, the majority of the top investors originatefrom China, followed by Korea.

The development of ocean energy technologies appears to be mostly driven by venture capital companies (representing 64 % of identified innovators).

The US (1st), the UK (2nd) and France (3rd) all rely on a very strong base of venture capital companies. On the other hand, Japan, ranked 4th in the number of innovating companies, only hosts corporate companies (**Figure 11**).

Supported by innovators in several Member States, the EU accounts for 39 % of identified innovators and is well positioned to develop a leadership.

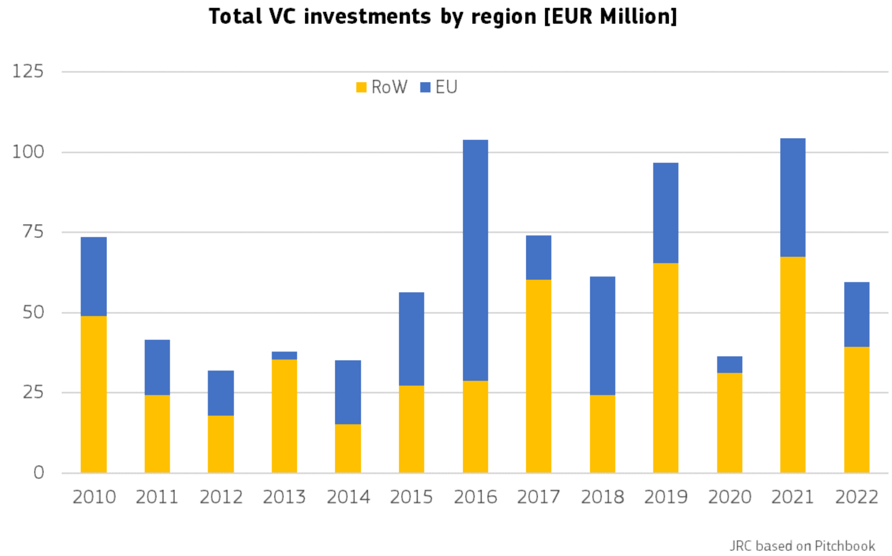
Figure 11. Number of innovating companies in the ocean energy sector (2017-2022) by country of origin

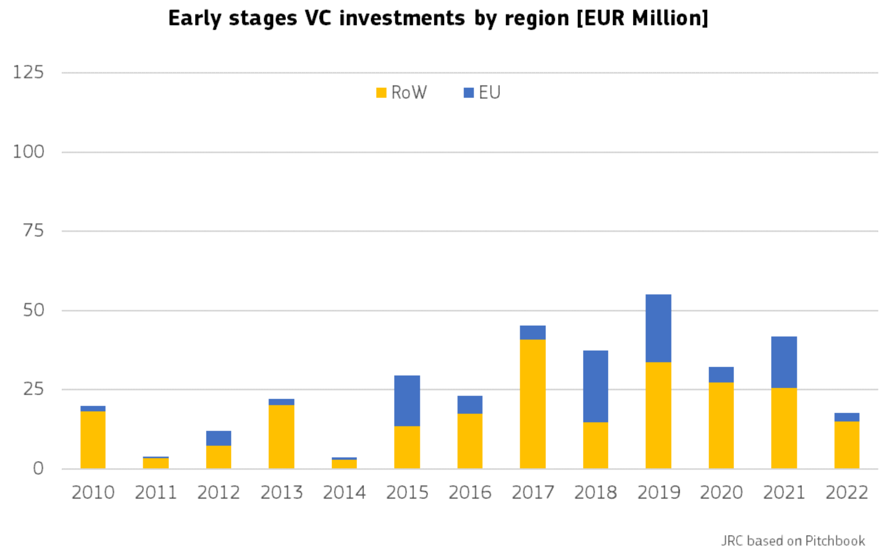


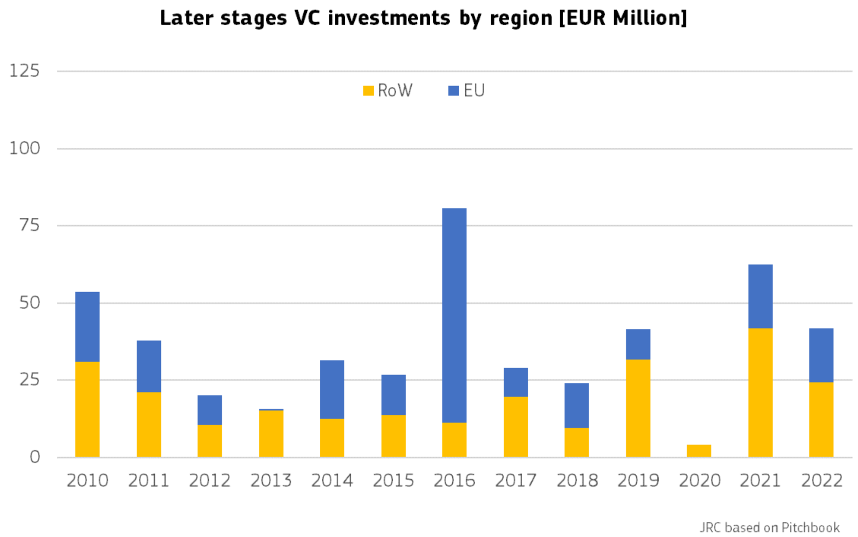
Source: JRC, 2023.

Venture Capital (VC) early and later stage investments are considered. 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 12** 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 2017-2022 compared to 2011-2016), investments seem to stagnate. Early stages still account for a large share (53 %) of global VC investments outside of the EU, while later stages investments are largely predominant in the EU.

Figure 12. Venture Capital investments in Ocean energy Total investments (top), Early stages investments (middle) and Later stage investments for the EU and the rest of the world (bottom)



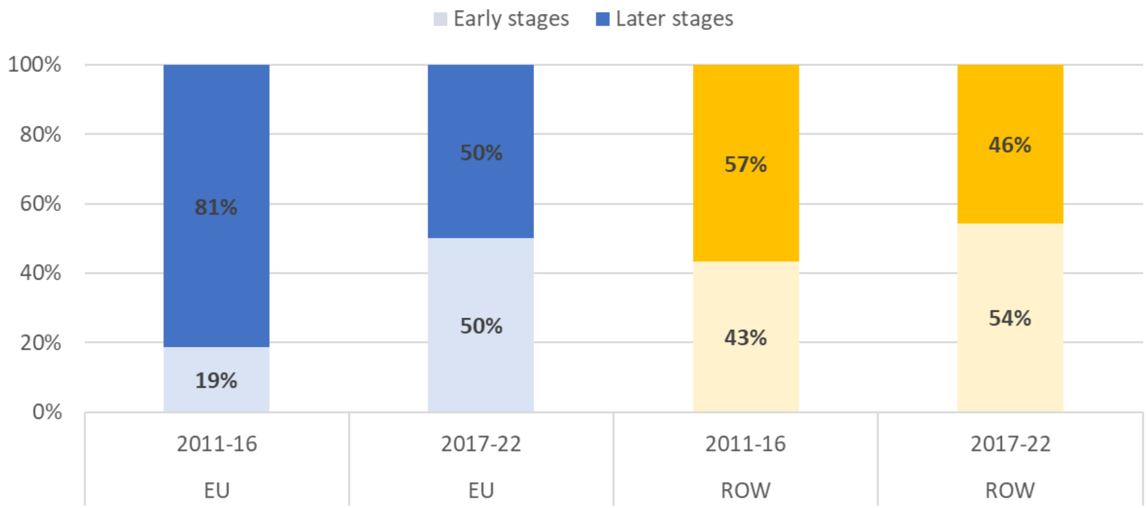




Source: JRC based on Pitchbook, 2023.

Overall, as seen in **Figure 13**, VC investments in the EU are dominated by investment in later stages, accounting for 81% and 50% of the total investments in period 2011-2016 and 2017-2022 correspondingly. Compared to the period 2016-2021, the period 2017-2022 had a notable decrease in later stage investments in the EU. This willingness to invest more in earlier stages of development shows an increase in the confidence in the technologies currently being developed. In the rest of the world for the period 2011-2016 later stage investments dominated the investments (57%), while for the period 2017-2022 there was a change in the trend, with 46% of the total VC investment happening at an earlier stage.

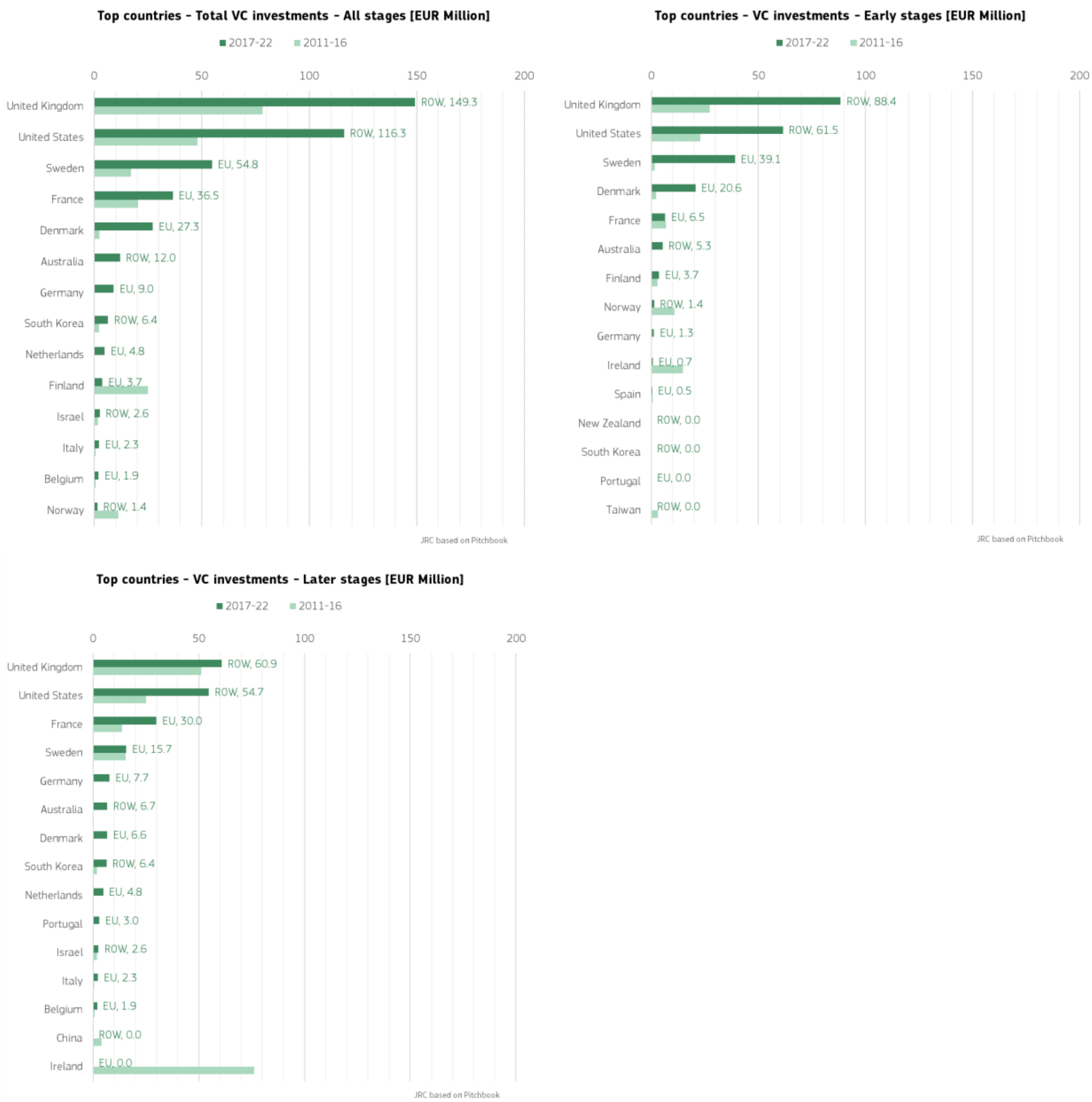
Figure 13. Investments by stage and region (Share of capital invested)



Source: JRC based on Pitchbook, 2023

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 14**). In terms of EU countries, Sweden is leading in total and early stage investments, while France is leading in the later stage investments.

Figure 14. Venture Capital investment by country for total investments (top left), Early stages investments (top right) and Later stage investments (bottom)



Source: JRC based on Pitchbook, 2023

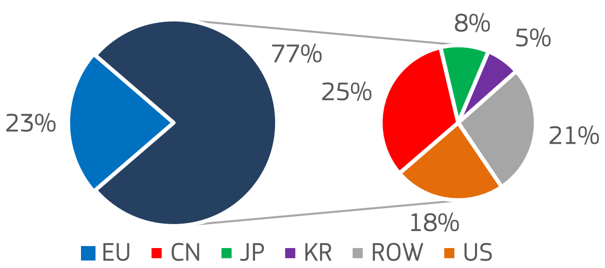
2.6 Patenting trends

Patenting trends are evaluated using the methodology developed by JRC (Fiorini A et al., 2017; Pasimeni, 2019; Pasimeni, Fiorini, and Georgakaki, 2019; Pasimeni, Fiorini, and Georgakaki, 2021) and based on data derived from the PATSTAT database 2022 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. 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 (2018-2020) will be used to reflect the current trends.

Globally, in the period 2018-2020, a total of 1355 patent applications concerning ocean energy were submitted, of which 432 were granted, 202 were high value and 79 were international. China alone accounts for 72% of the patent applications from all entities, with 56% of those applications originating from Universities and Government/non-profit organisations. EU inventions amounts for 6% of the applications, originating predominantly (52%) from companies. However, this trend is not as strong in high value inventions, where EU and China have similar number of inventions (23% and 25% of the global high-value inventions correspondingly), followed by the US (17%) and Japan (8%) (**Figure 15**). 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 been deleted. After the reclassification, one of the codes was maintained (Y02E 10/30) and one newly introduced (Y02A 20/144).

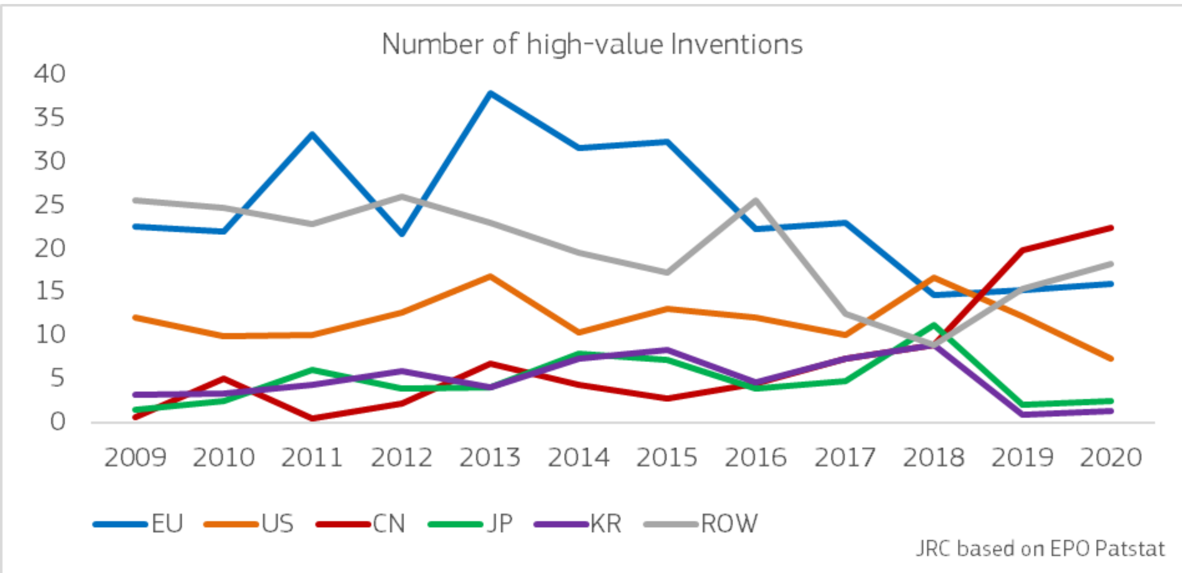
Figure 15. Share of global high-value inventions (2018-2020)



Source: JRC based on EPO Patstat, 2023

The number of high-value inventions globally peaked in 2013 and since then it has been steadily decreasing (**Figure 16**). EU high-value inventions have been following the global trend. On the other hand, there is an increasing trend for China since 2015, which accelerated in 2019.

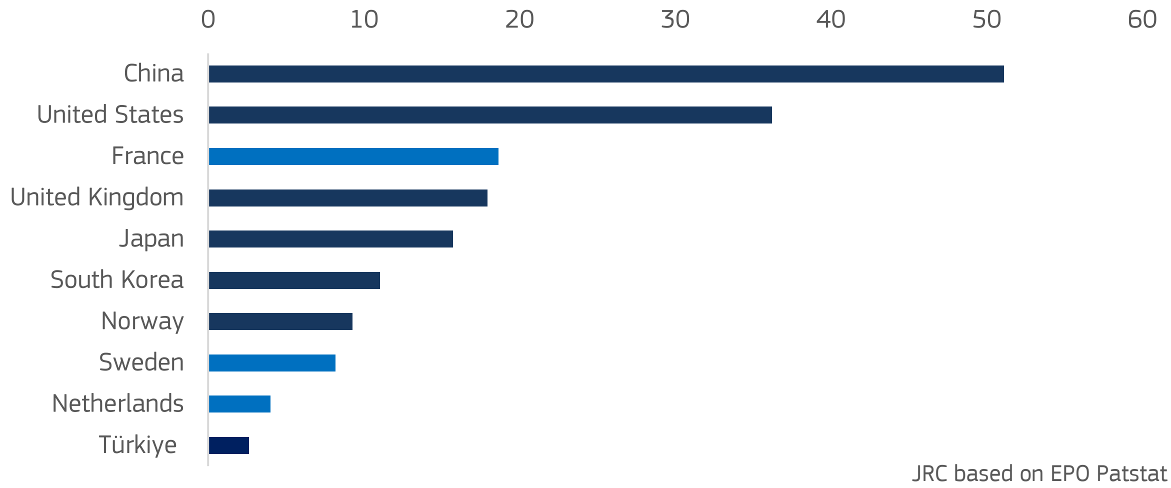
Figure 16. Number of high-value inventions over time



Source: JRC based on EPO Patstat, 2023

In terms of individual countries, China is leading the way, followed by the US and France (**Figure 17**). Within the top 10 countries in terms of high-value inventions, 3 originate from the EU.

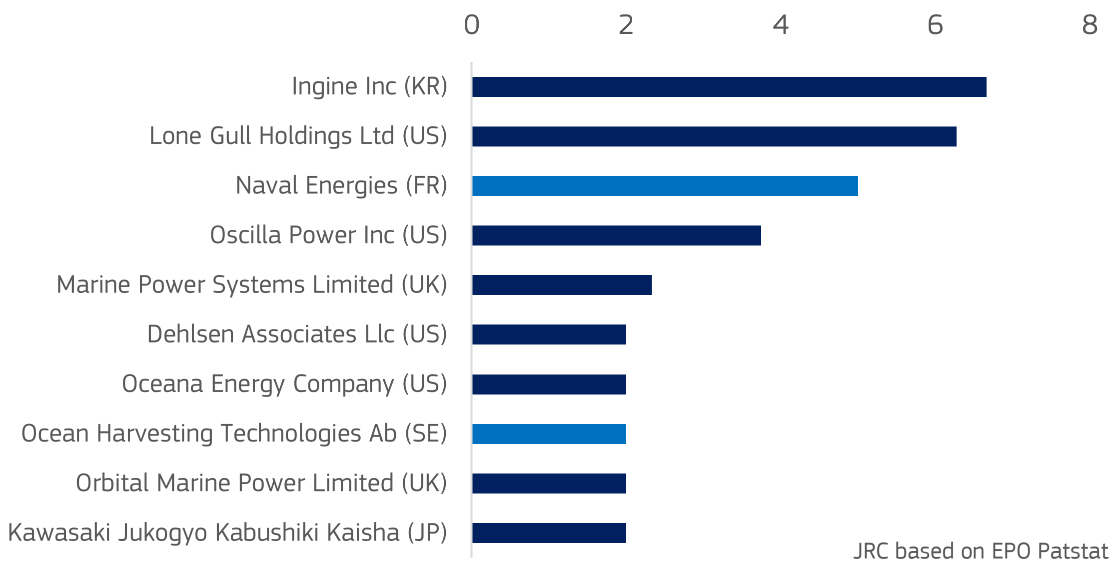
Figure 17. Number of high value inventions for the top 10 countries in the time period 2018-2020



Source: JRC based on EPO Patstat, 2023

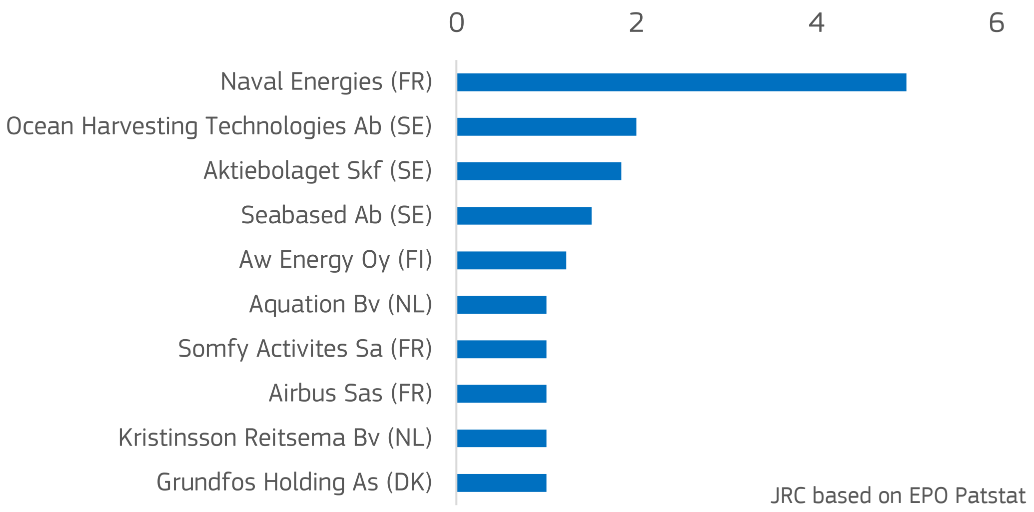
The global top companies in terms of high-value inventions are presented in **Figure 18**, while the European top companies are presented in **Figure 19**. The French company Naval Energies, that is currently mainly active in OTEC technology and floating offshore wind, while it was also active in the tidal energy.

Figure 18. Number of high value Inventions for the top 10 companies in the time period 2018-2020



Source: JRC based on EPO Patstat, 2023

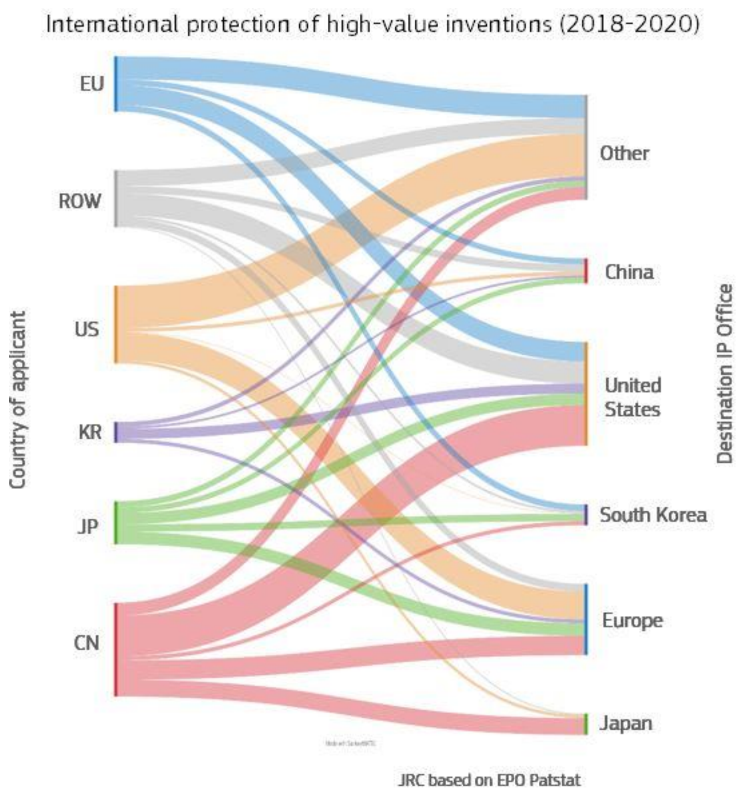
Figure 19. Number of high value Inventions for the top 10 EU companies in the time period 2018-2020



Source: JRC based on EPO Patstat, 2023

In terms of International protection, international activity inventions originating from the EU account for 14% of the total International inventions. Around 16.8% of the EU inventions are protected internationally. The flow of inventions' international protection for all countries is presented in **Figure 20**.

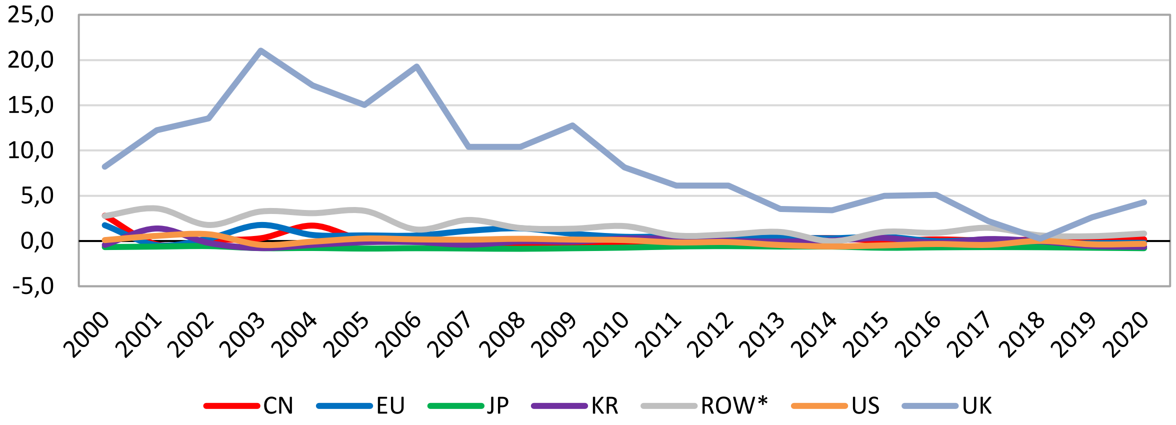
Figure 20. International protection of high value inventions for the time period 2018-2020



Source: JRC based on EPO Patstat, 2023

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 are presented in **Figure 21**.

Figure 21. Specialisation index for the period 2000-2020.



Source: JRC based on EPO Patstat, 2023

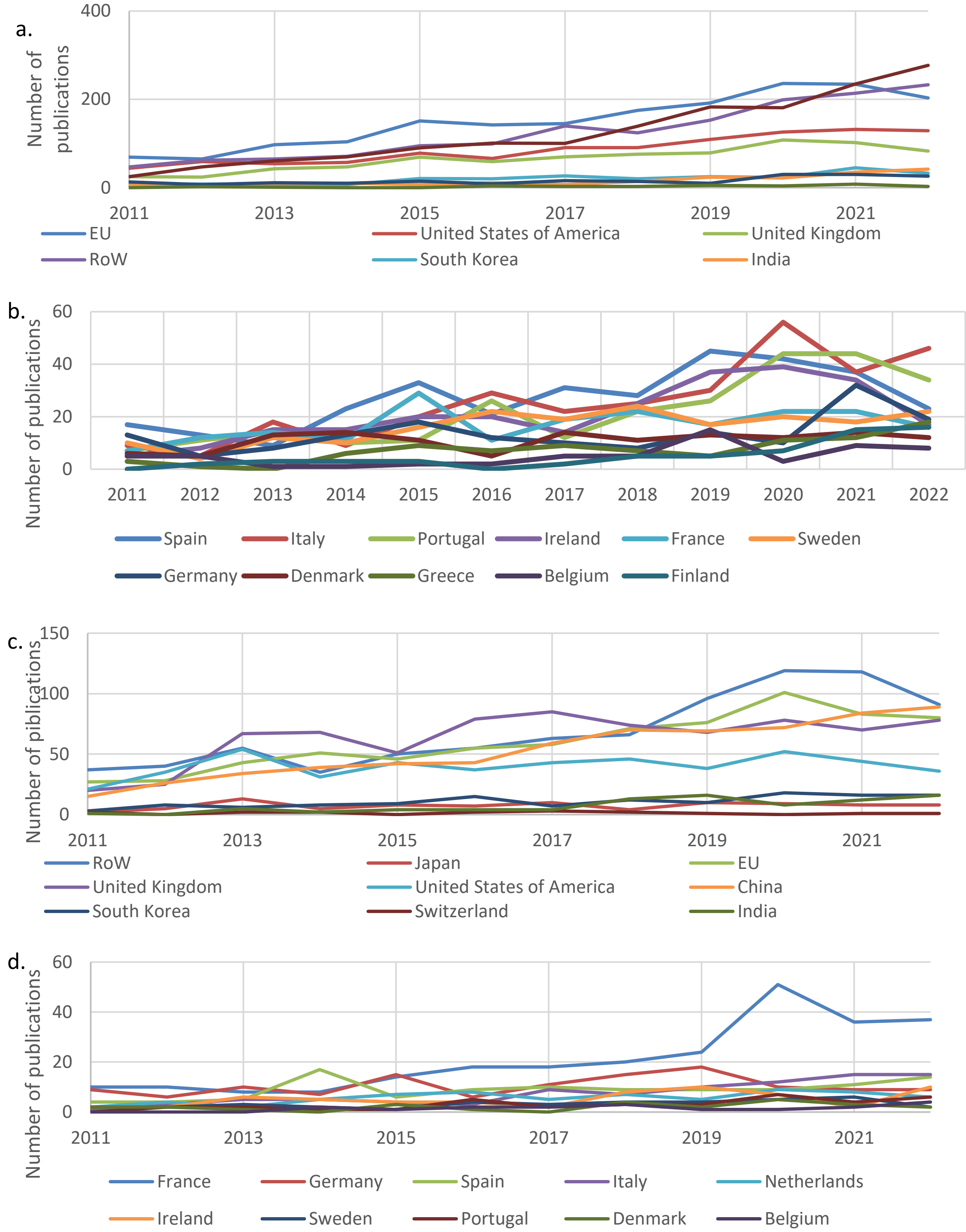
Here the predominant trend is the decline of SI for the UK through the years, remaining however, ahead of the rest of the world (SI=4.27 for 2020). EU's SI fluctuates around zero, meaning that the intensity of ocean energy activities is similar to the rest of the world (average SI for 2010-2020 is 0.17). The remaining countries follow a similar trend, with China displaying a positive trend but still having positive SI (0.12 for 2020).

2.7 Scientific publication trends

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

In the last decade, peer-reviewed publications in the field of tidal energy have been growing steadily, both globally and in the EU (**Figure 22**). In 2022 there was a decrease in the absolute number of publications both in wave and in tidal energy. China overtook the EU in the number of publications and is now leading both the wave and the tidal sector. EU is performing second in both ocean energy categories, followed closely by the UK. In the EU Italy took over the lead from Portugal in 2022 in number of wave energy related publications, while France is leading in the tidal energy sector. Countries that account to less than 1% of the total publications are not presented in the figure.

Figure 22. 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, 2023

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.

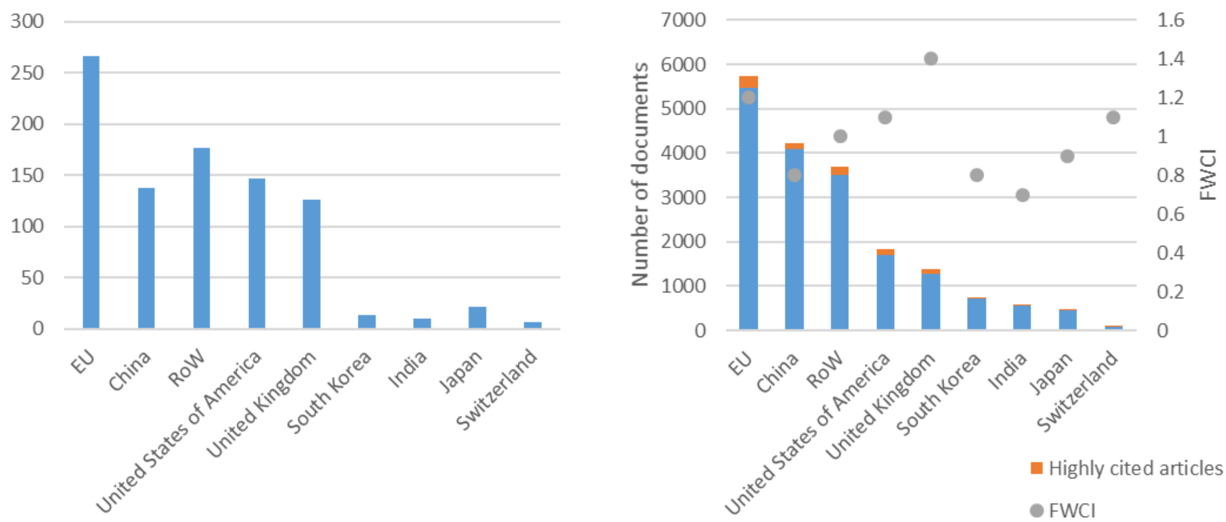
Highly cited articles are defined as the articles that fall within the highest 1% based on the number of citations when compared to articles published in the same field and year.

Citation indices are also commonly used. h-index is an index that 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 and for the period 2011-2022, EU is leading globally, having the largest number of total publications, largest number of highly cited articles, and h-index. In terms of FWCI, EU ranks second following the UK, which has a considerably smaller total amount of publications (**Figure 23**). At an EU level Italy has the largest number of highly cited papers and h-index, followed by Spain and Ireland. In total 60% of the EU countries are above the FWCI=1 threshold, indicating a very good quality of research within the EU.

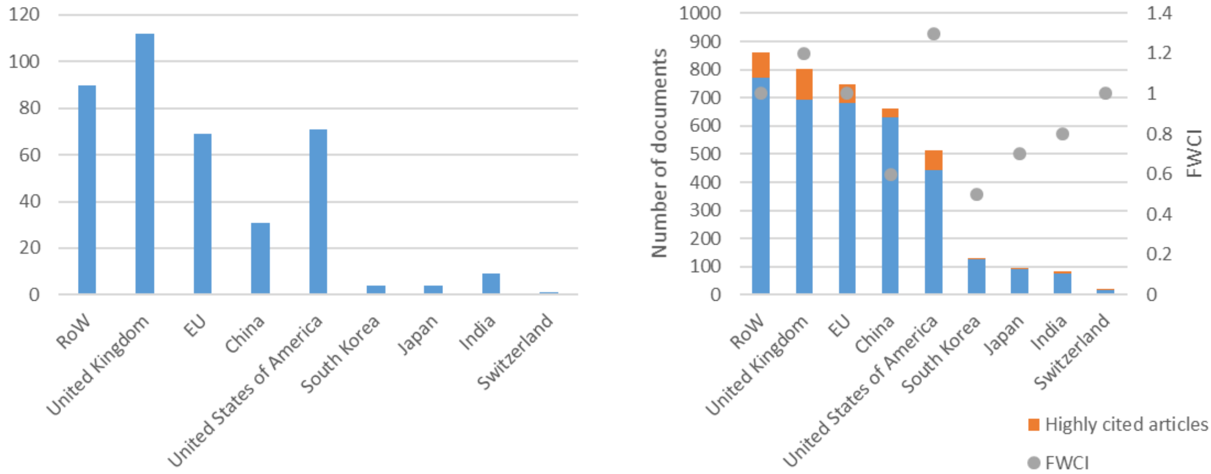
Figure 23. Global publication metrics for wave energy articles: h-index (left) and total publications, highly cited articles, Field-Weighted Citation Impact (FWCI) (right)



Source: JRC based on TIM, 2023

For tidal energy, the majority of the publications from a single country come from the US followed by the EU, with UK having also the largest number of highly cited papers, and h-index. Considering FWCI, the US are leading the field, followed closely by the UK and the EU. The majority of the publications in this field comes from an aggregation of countries not analysed in this report (**Figure 24**). In term of EU countries, France has the largest amount of highly cited articles and h-index, followed by Germany and Spain. In total 62% of the EU countries have a FWCI of above 1, highlighting the good quality of research conducted by member states.

Figure 24. Global publication metrics for tidal energy articles: h-index (left) and total publications, highly cited articles, Field-Weighted Citation Impact (FWCI) (right)

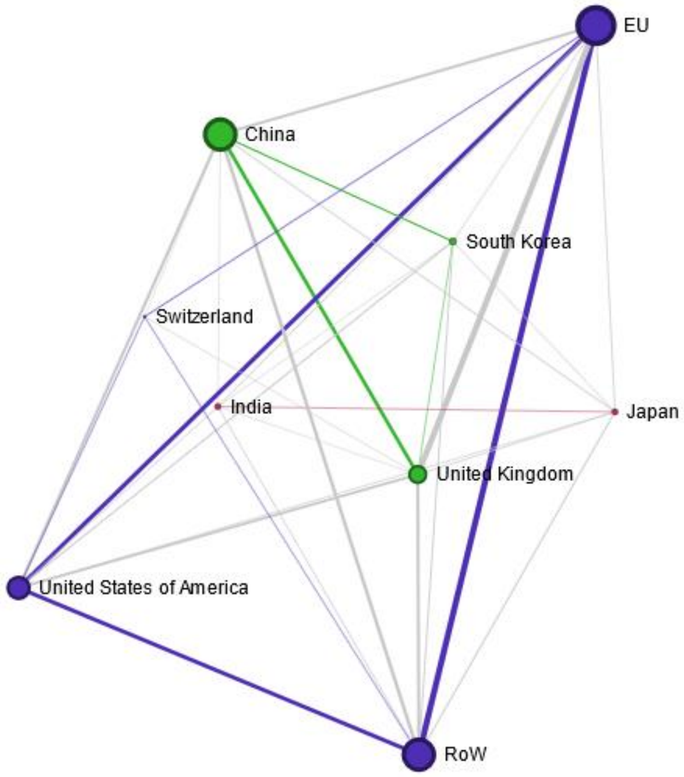


Source: JRC based on TIM, 2023

For wave energy the main collaboration countries are the UK and to a smaller extent 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 UK, China and South Korea. EU countries also collaborate with other countries with smaller individual impact in the field (**Figure 25**).

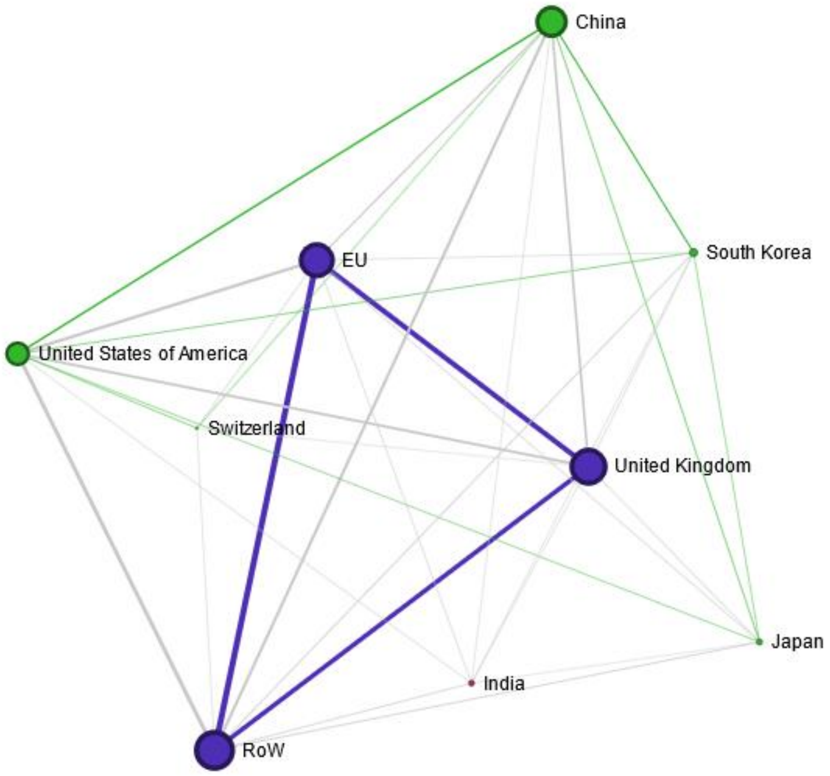
Similarly, for tidal energy (**Figure 26**), there are strong collaboration links between the EU and the UK. Moreover there is extended collaboration with EU countries and countries with smaller individual contribution.

Figure 25. International collaboration networks in wave energy



Source: JRC based on TIM, 2023

Figure 26. International collaboration networks in tidal energy



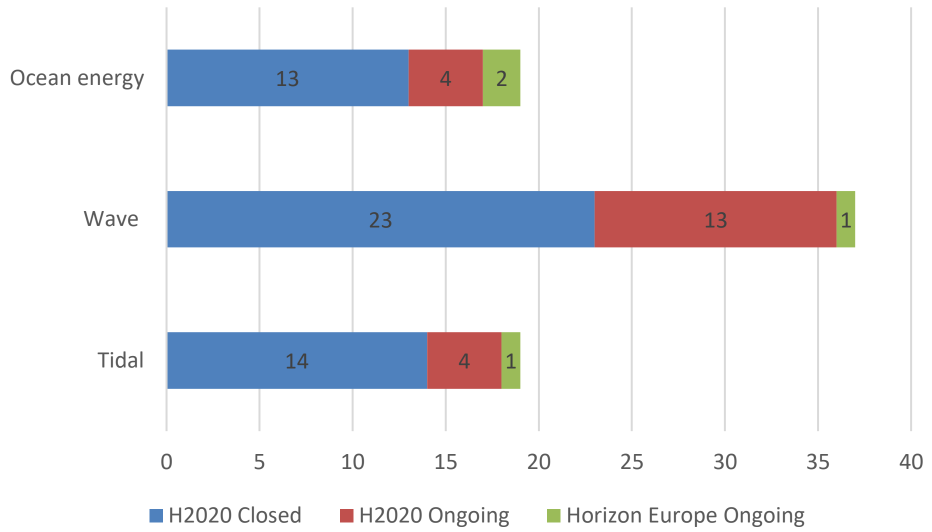
Source: JRC based on TIM, 2023

2.8 Assessment of R&I project developments

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 EUR 300 million have been invested in projects involving different elements of wave and tidal energy through the 7th Framework Programme (FP7), Horizon 2020 (H2020) Framework Programme and Horizon Europe. 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 71 projects. Horizon Europe has been active since 2022 and 4 projects have been so far funded under the scheme. In **Figure 27** the breakdown between the 2 different funding schemes, as well as the number of projects funded relevant to each ocean energy sector are presented. Ocean energy category includes projects that can benefit both wind and tidal energy sectors.

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, 2023

New projects funded under Horizon Europe focus on damage detection in marine structures (EnDorSE), demonstration of wave energy device (WEDUSEA) and improvement of tidal device blades design, reliability and control (MAXBlade).

A full list of the FP7 and H2020 projects for the period 2010-2021 is given in Annex 2.

3 Value Chain Analysis

3.1 Turnover and Gross value added

Ocean energy technologies are still in the development phase, with only a few designs reaching high Technology Readiness Levels (TRL). Consequently, the sector is not yet considered mainstream business, and information regarding market value and value chain is limited. However, according to Market Research Future (2021), the global ocean energy market was estimated to be around EUR 2.17 billion (2.28 billion USD) in size, with a projected compound annual growth rate (CAGR) of approximately 28% for the period 2021-2027.

ETIP Ocean (2021) conducted an evaluation of the potential economic value that the development and deployment of wave and tidal energy could offer to Europe until 2050. Three scenarios were considered:

- Achievement of the SET Plan: Assumes Europe and the world reach net-zero emissions in 2050 and 2070, respectively, with an equal split between tidal stream and wave energy in Europe and a 40%-60% split for the rest of the world.
- Europe follows the global market: Assumes global net-zero emissions by 2050 with a 40%-60% split between tidal stream and wave energy worldwide. In this scenario, Europe is not a market leader but follows global trends.
- Europe leads the global market: Assumes global net-zero emissions by 2050 with a 40%-60% split between tidal stream and wave energy worldwide. In this scenario, Europe takes a leading role in the ocean energy market.

The total potential gross value added benefit to the European economy, resulting from the supply chain activity supporting global ocean energy deployments, ranges from €59 billion to €140 billion across the three scenarios. The study focuses on the pre-Brexit European Union (EU-28). To capture a high market share, Europe must achieve performance improvements, cost reductions, and implement policies that support European industrial activities and strengthen the region's export position. These actions would maximize the economic benefits retained by the European economy.

3.2 Environmental and socio-economic sustainability

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 result. Characteristically Paredes et al. (2019) have systematically reviewed 18 LCA studies in ocean energy technologies and concluded to a range of 10-106 kg CO_2eq/kWh across them. According to the analysis the main source of environmental impacts is from 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 CO_2 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 potentially 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, while it was concluded that there is no evidence of risk to local ecosystems, 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 the 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 (2023) 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).

Since ocean technologies are not mainstream yet, international standards have 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. The European marine energy centre (EMEC), that runs one of the main testing facilities in Europe (based in Orkney, Scotland), sets 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

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

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

Some of the leading companies in the sector are presented in **Table 4.**

Table 4. 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, 2023

Similarly to tidal energy, the majority of companies developing wave energy devices are located in the EU. 52% of active wave energy companies 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.

Currently the sector of wave energy is showing 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 5** the most prominent wave energy device developers are presented.

Table 5. 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, 2023

3.4 Employment

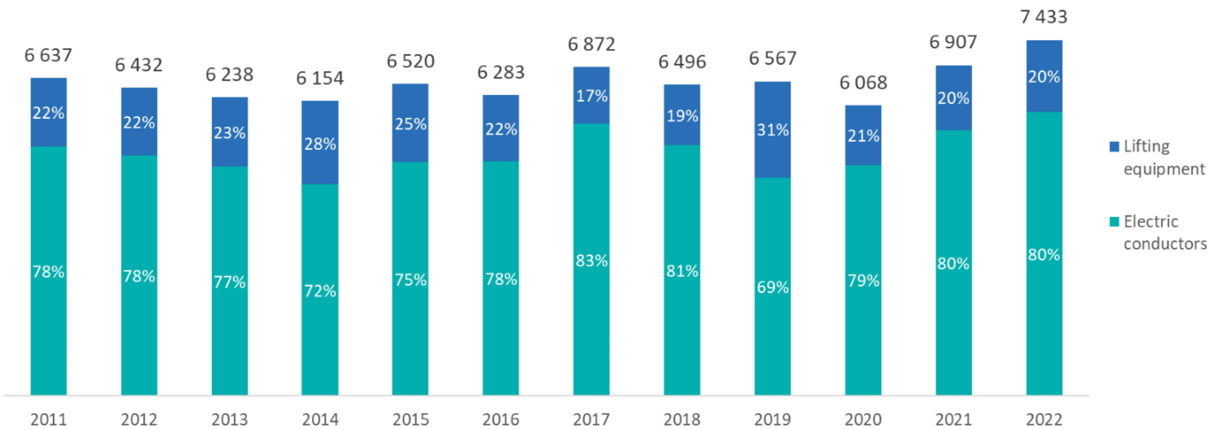
Since ocean energy technologies represent a small fraction of the energy sector and are still not commercially widespread, value chain data are often reported aggregated with other sources of energy or are missing. According to IRENA and ILO(2021), there were 1288 people employed in the ocean energy sector 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 the UK (928 jobs) followed by Spain (350 jobs). These numbers do 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 are reached in 2050 and the wave/tidal energy proportional split is 60%/40%, and 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 adapted form other industries. 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.
Figure 28 shows the EU production in value. Over the past ten years (2013-2022), the overall production value had a 19% increase with an annual compound growth of 2% and an average value of EUR 6.6 billion. In 2022, the total value had an 8% increase compared to the previous year, reaching EUR 7.4 billion. Insulated electric conductors hold the grand majority of the EU production value. Italy and Germany were the top EU producers, holding 32% and 17% of the total EU production respectively. Germany had a balanced production of both commodities, while 80% of Italy's production was about insulated electric conductors.

Figure 28. EU production value per commodity [EUR Million]



Source: JRC based on PRODCOM data

4 EU Market Position and Global Competitiveness

4.1 Global & EU market leaders

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) and trade balance

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 Resource 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 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 6**).

Table 6. 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 Critical Raw Material Act. 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 haveprogressed rapidly. However significant cost reductions are required in order to be competitive, in line with other mainstream renewable energy sources.

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 have become commercially available recently. For tidal energy, the most prominent sub-technology that has reached TRL 9 is the horizontal axis device, followed by the tidal kite (TRL 8). On the contrary, the wave energy sector is more fragmented, with multiple designs currently being pursuied. Point absorbers and OWC devices have currently reached TRL 9.

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 2021 there was a small decrease in public investments, however it remained broadely at the same levels as previous years (23.31 million EUR in 2021 compared to 25 million EUR and 23 million EUR in 2020 and 2019 respectively). In 2021 largest public investments have been awarded in France, Sweden and Spain

Globally, the EU is leading in public R&D Investments, accounting for 49% of the worldwide public investments in the period 2012-2021. This is attributed both to direct investments by the Member States (24% of the total investments) but also to funding from EU framework programmes (25%).

The development of ocean energy technologies appears to be mostly driven by venture capital companies (representing 64 % of identified innovators).

Globally, in the period 2018-2020, EU and China have similar number of inventions, 23% and 25% of the global high-value inventions correspondingly.

In 2022, there was a decrease in the absolute number of scientific publications both in wave and in tidal energy. For the first time, China overtook EU in the number of publications and is now leading both the wave and the tidal sector. However, in the wave energy sector and for the full period spanning from 2011 to 2022, EU is leading globally, showing the largest number of total publications, largest number of highly cited articles, and largest h-index. For tidal energy, the majority of the publications, the largest number of highly cited papers, and the highest h-index all come from the UK.

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), Horizon 2020 (H2020) Framework Programme and Horizon Europe. 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 71 projects. Horizon Europe has been active since 2022 and 4 projects have been so far funded under the scheme.

Market value and chain value has been underdefined, however there will be significant economic benefits if Europe captures the high market share, a goal achievable only through performance improvements, leading in cost reductions, and policy interventions.

Companies active in developing tidal stream devices to TRL>5 have been identified, with the majority (41%) of them located in /the EU. In terms of individual countries, UK has the largest number of companies, followed by Canada, the Netherlands and France. Similarly the majority of companies developing wave energy devices are located in the EU (52%).

The 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

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Annexes

Annex 1 Summary Table of Data Sources for the CETO Indicators

Theme	Indicator	Main data source
Technology maturity status, development and trends	Technology readiness level	JRC analysis
	Installed capacity & energy production	JRC database
	Technology costs	JRC, IRENA
	Public and private RD&I funding	JRC based on IEA
	Patenting trends	Patstat
	Scientific publication trends	CORDIS
	Assessment of R&I project developments	JRC based on Pitchbook
Value chain analysis	Turnover	EurObserv'ER
	Gross Value Added	EurObserv'ER
	Environmental and socio-economic sustainability	JRC analysis
	EU companies and roles	JRC database
	Employment	EurObserv'ER
	Energy intensity and labour productivity	IRENA and ILO
	EU industrial production	PRODCOM
Global markets and EU positioning	Global market growth and relevant short-to-medium term projections	JRC
	EU market share vs third countries share, including EU market leaders and global market leaders	JRC
	EU trade (imports, exports) and trade balance	COMEXT
	Resource efficiency and dependencies (in relation EU competiveness)	JRC

Annex 2 EU Funded projects

Tidal	Wave	Both wave and tidal
CRIMSON	IMAGINE	DTOceanPlus
D2T2	ARRECIFE	ETIP OCEAN
DEMOTIDE	BUTTERFLY	ETIP OCEAN 2
DG Island Mode	CEFOW	FIBREGY
DGIM2	CONPARA	LINCOLN
Direct Drive TT	DESTINY	MARINERGI
ELEMENT	ECOWEC	MARINET2
ELVER	eForcis and BeForcis	MUSES
EnFAIT	EuropeWave	NEPTUNE
FloTEC	HACE	OCEANERA-NET COFUND
InToTidal	ICONN	OceanSET
NEMMO	IMPACT	RiCORE
OCEAN_2G	INNOWAVE	SAFS
OCTARRAY	InWAS	SUBPORT
OCTTIC	LiftWEC	SWARMs
OpTiCA	MegaRoller	TAOIDE
PowerKite	MoWE	WATEC
SEAMETEC	NextWave	EnDorSE
TidalHealth	OHT	SEETIP Ocean
TIPA	OpenWave	
MAXBlade	OPERA	
	ParaResWEC	
	PivotBuoy	
	POSEIDON	
	PowerModule	
	SeaTech	
	SEA-TITAN	
	SmartWings	
	Space at Sea	
	The Blue Growth Farm	
	UPWAVE	
	VALID	
	W2EW	
	W2O	
	Wave Scale	
	WaveBoost	
	Wavepiston	
	Wavepiston	
	WETFEET	
	WEDUSEA	

Annex 3 POTEnCIA and POLES - JRC Model overview

A3.1 POTEnCIA Model overview

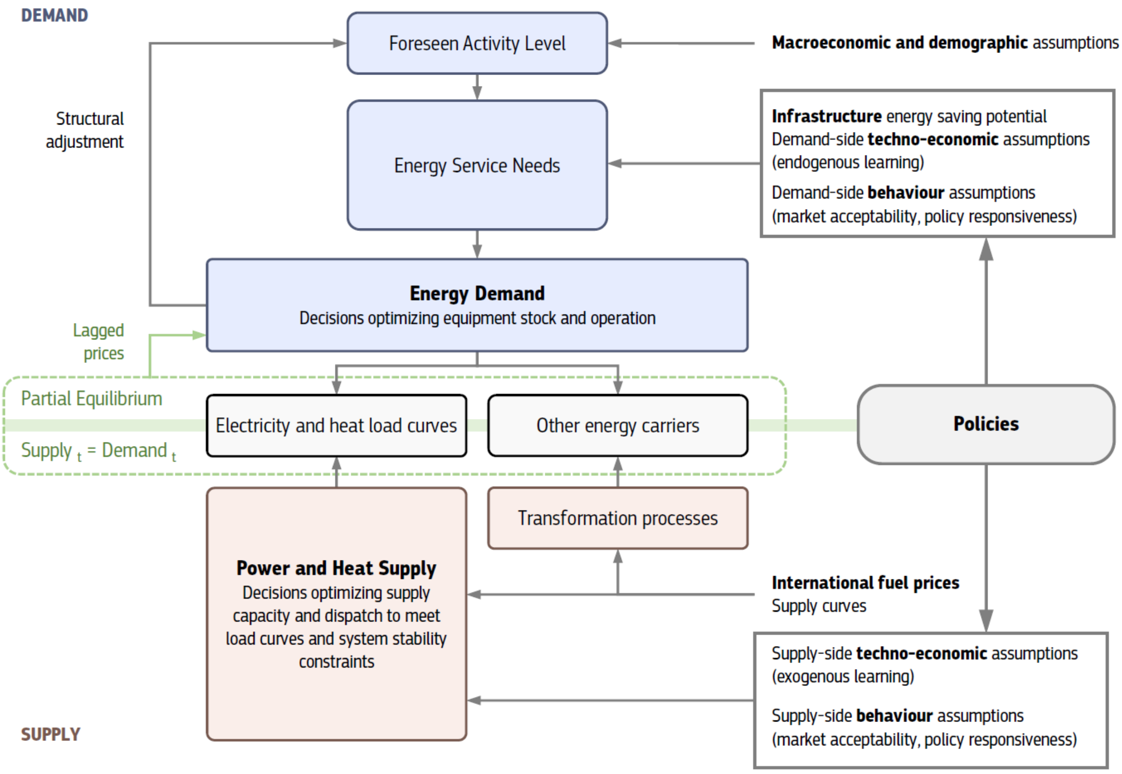
The Policy Oriented Tool for Energy and Climate Change Impact Assessment (POTEnCIA) is an energy system simulation model designed to compare alternative pathways for the EU energy system, covering energy supply and all energy demand sectors (industry, buildings, transport, and agriculture). Developed in-house by the European Commission's Joint Research Centre (JRC) to support EU policy analysis, POTEnCIA allows for the joint evaluation of technology-focused policies, combined with policies addressing the decision-making of energy users. To this end:

- By simulating decision-making under imperfect foresight at a high level of techno-economic detail, POTEnCIA realistically captures the adoption and operation of new energy technologies under different policy regimes;
- By combining yearly time steps for demand-side planning and investment with hourly resolution for the power sector, POTEnCIA provides high temporal detail to suitably assess rapid structural changes in the EU's energy system;
- By tracking yearly capital stock vintages for energy supply and demand, POTEnCIA accurately represents the age and performance of installed energy equipment, and enables the assessment of path dependencies, retrofitting or retirement strategies, and stranded asset risks.

The core modelling approach of POTEnCIA (Figure 29; detailed in Mantzos et al., 2017, 2019) focuses on the economically-driven operation of energy markets and corresponding supply-demand interactions, based on a recursive dynamic partial equilibrium method. As such, for each sector of energy supply and demand, this approach assumes a representative agent seeking to maximize its benefit or minimize its cost under constraints such as available technologies and fuels, behavioural preferences, and climate policies. This core modelling approach is tailored to each sector, for instance to represent different planning horizons and expectations about future technologies under imperfect foresight. In particular, power dispatch modelling uses a high time resolution with full-year hourly dispatch to suitably depict the increasing need for flexibility from storage and demand response, and the changing role of thermal generation in a power system dominated by variable renewable energy sources. Within this sector modelling framework, investment decisions of the representative agents are simulated with discrete-choice modelling. The model then finds an overall equilibrium across different sectors using price signals for resources such as traditional and renewable energy carriers while accounting for efficiency and environmental costs.

This core modelling approach is implemented individually for each EU Member State to capture differences in macroeconomic and energy system structures, technology assumptions, and resource constraints. The national model implementation is supported by spatially-explicit analyses to realistically define renewable energy potentials and infrastructure costs for hydrogen and CO2 transport. Typical model output is provided in annual time steps over a horizon of 2000-2070; historical data (2000-2021) are calibrated to Eurostat and other official EU statistics to provide accurate initial conditions, using an updated version of the JRC Integrated Database of the European Energy System (JRC-IDEES; Mantzos et al., 2018). Developed in parallel to POTEnCIA, an updated release of this database is planned by 2024 to ensure the transparency of POTEnCIA's base-year conditions and to support further research by external stakeholders.

Figure 29. The POTEnCIA model at a glance



Source: JRC adapted from Mantzos et al., 2019

A3.1.1 POTEnCIA CETO Climate Neutrality Scenario overview

The technology projections provided by the POTEnCIA model are obtained under a Climate Neutrality Scenario aligned with the broad GHG reduction objectives of the European Green Deal. As such, this scenario reduces net EU27 GHG emissions by 55% by 2030 versus 1990, and reaches the EU27´s climate neutrality by 2050 under general assumptions summarized in Table 7. To suitably model technology projections under these overarching GHG targets, the scenario includes a representation of general climate and energy policies such as emissions pricing under the Emissions Trading System, as well as key policy instruments that have a crucial impact on the uptake of specific technologies. For instance, the deployment of bioenergy and renewable power generation technologies to 2030 is consistent with the EU's Renewable Energy Directive target (42.5% share of renewables in gross final energy consumption by 2030). Similarly, the adoption of alternative powertrains and fuels in transport is also promoted by a representation of updated CO_2 emission standards in road transport and by targets of the ReFuelEU Aviation and FuelEU Maritime proposals.

Table 7. General assumptions of the POTEnCIA CETO Climate Neutrality Scenario

General scenario assumptions	Modelled scenario and policy assumptions
GDP growth by Member State	GDP projections based on EU Reference Scenario 2020, with updates to 2024 from DG ECFIN Autumn Forecast 2022
Population by Member State	Population projections based on EU Reference Scenario 2020, with updates to 2032 from EUROPOP 2019
International energy markets	Natural gas import projections consistent with REPowerEU targets for supply diversification and demand reduction. International fuel price projections to 2050 aligned with REPowerEU

A3.2 POLES-JRC model overview

POLES-JRC (Prospective Outlook for the Long term Energy System) is a global energy model well suited to evaluate the evolution of energy demand and supply in the main world economies with a representation of international energy markets. POLES-JRC is hosted at the JRC and is particularly adapted to assess climate and energy policies.
POLES-JRC covers the entire energy system, from primary supply (fossil fuels, renewables etc.) to transformation (power, biofuels, hydrogen) and final sectoral demand. International market and prices of energy fuels are simulated endogenously. Its high level of regional detail (66 countries & regions covering the world with full energy balances, including all detailed OECD and G20 countries) and sectoral description allows assessing a wide range of energy and climate policies in all regions within a consistent global frame: access to energy resources, taxation policy, energy efficiency, technological preferences, etc. POLES-JRC operates on a yearly basis up to 2050 and is updated yearly with recent information.

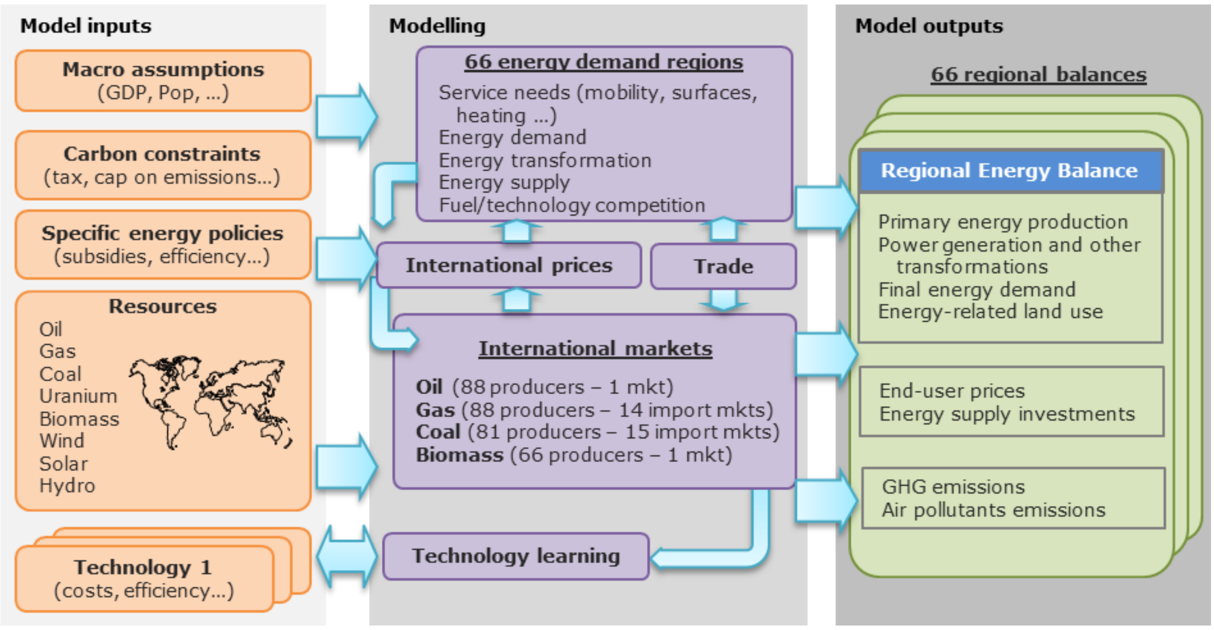
The POLES-JRC model is used to assess the impact of European and international energy and climate policies on energy markets and GHG emissions, by DG CLIMA in the context of international climate policy negotiations and by DG ENER in the context of the EU Energy Union.

POLES-JRC has also been applied for the analyses of various Impact Assessments in the field of climate change and energy, among them: the Proposal for a revised energy efficiency Directive (COM(2016)0761 final) and The Paris Protocol – A blueprint for tackling global climate change beyond 2020 (COM(2015) 81 final/2).
Moreover, POLES-JRC provided the global context to the EU Long-Term Strategy (COM(2018) 773) and formed the energy/GHG basis for the baseline to the CGE model JRC-GEM-E3.

POLES-JRC forms part of the Integrated Assessment Modelling Consortium (IAMC) and participates in inter-model comparison exercises with scenarios that feed into the IPCC Assessment Reports process.

POLES-JRC results are published within the series of yearly publications "Global Climate and Energy Outlooks – GECO". The GECO reports along with detailed country energy and GHG balances and an on-line visualisation interface can be found at: https://ec.europa.eu/jrc/en/geco

Figure 30. Schematic representation of the POLES-JRC model architecture



A3.2.1 POLES-JRC Model description

Power system

POLES-JRC considers 37 power generating technologies existing technologies as well as emerging technologies. Each technology is characterised by its installed capacity, cost parameters (overnight investment cost, variable & fixed operation and maintenance cost), learning rate and other techno-economic parameters (e.g. efficiencies). The cost evolution over time is taken into account by technology learning driven by accumulated capacity.
For renewable technologies maximum resource potentials are taken into account. Similarly, the deployment of CCS technologies is linked to region-specific geological storage potential.
In addition to these technical and economic characteristics, non-cost factors are applied to capture the historical relative attractiveness of each technology, in terms of investments and of operational dispatch.
With regard to the clean energy technologies covered by CETO, the model includes power generation using photovoltaics (utility and residential), Concentrated Solar Power (CSP), on-shore and off-shore wind , ocean energy, biomass gasification and steam turbines fuelled by biomass, geothermal energy as well as hydropower. CCS power technologies are considered as well. Moreover, electricity storage technologies such as pumped hydropower storage and batteries are also included.

Electricity demand
The total electricity demand is computed by adding the electricity demand from each sector (i. e. residential, services, transport, industry and agriculture). The evolution over time of the sectoral electricity demand is driven by the activity of each sector and competition between prices for electricity and fuels.
POLES-JRC uses a set of representative days with an hourly time-step in order to capture load variations as well as to take into account the intermittency of solar and wind generation. The usage of representative days also allows to capture hourly profiles by sector and end-uses.
With a view to CETO demand side technologies, the model includes heat pumps in the residential and service sector, batteries for electric vehicles and electrolysers.

Power system operation and planning
The power system operation assigns the generation by technology to each hour of each representative day. The supplying technologies and storage technologies must meet the overall demand, including grid imports and exports.
The capacity planning considers the existing structure of the power mix (vintage technology), the expected evolution of the load demand, the production cost of technologies.

Hydrogen

POLES-JRC takes into account several hydrogen production routes: (i) low temperature electrolysers using power from the grid or power from solar and wind, (ii) steam reforming of natural gas (with and without CCS), (iii) gasification of coal and biomass (with and without CCS), (iv) pyrolysis of coal and biomass as well as high temperature electrolysis using nuclear power.
Hydrogen is used as fuel in all sectors. Moreover, hydrogen is used to produce fertilisers as well as to produce fuels used in the transport sector (i.e. gaseous and liquid synfuels and ammonia). POLES-JRC models global hydrogen trade and considers various means of hydrogen transport (pipeline, ship, truck, refuelling station).

Bioenergy

POLES-JRC receives information on land use and agriculture through a soft-coupling with the GLOBIOM model[1]. This approach allows to model bioenergy demand and supply of biomass adequately
by taking into account biomass potential, production cost and carbon value. Moreover, the emissions from land use and forestry (CO2) as well as agriculture (CH4 and N2O) are derived from GLOBIOM.
Power generating technologies using biomass considered are biomass gasification (with and without CCS) and biomass fuelled steam turbines.
Hydrogen can be produced from biomass via gasification and pyrolysis. Moreover, the production of 1st and 2nd generation of biofuels for gasoline and diesel is considered.

Carbon Capture Utilization and Storage (CCUS)

POLES-JRC uses CCUS technologies for:

- Power generation: advanced coal using CCS, coal and biomass gasification with CCS, and gas combined cycle with CCS.
- Hydrogen production: Steam reforming with CCS, coal and biomass gasification with CCS, and coal and biomass pyrolysis.
- Direct air capture (DAC) where the CO2 is stored or used to produce synfuels (gaseous or liquid).

Model documentation and publications:
A detailed documentation of the POLES-JRC model and publications can be found at:
https://ec.europa.eu/jrc/en/poles

A3.2.2 POLES-JRC Global *NDC-LTS CETO* Scenario

The global scenario data presented in the CETO technology reports refers to a NDC-LTS CETGO scenario modelled by the POLES-JRC model.
The *NDC-LTS CETO* scenario takes into account the latest emission pledges found in the Nationally Determined Contributions (NDCs) and Long-Term Strategies (LTSs) announced by the signatory countries of the Paris Agreement. The *NDC-LTS CETO* scenario considers the policies of NDCs in the medium term and the LTSs in the longer term.
This scenario assumes that the objectives in the NDCs (including conditional objectives) are reached in their relevant target year (2030 in most cases). To this end, carbon values and other regulatory instruments are put in place on top of existing, legislated measures. Beyond 2030, the objectives of the countries' LTS, where they exist, are pursued; if the country has not announced an LTS, it is assumed that no additional decarbonisation effort is made, and carbon values, if any, are kept constant to their 2030 level. This scenario includes the net zero targets announced by many countries. The *NDC-LTS CETO* scenario also considers decarbonisation proposals related to international aviation and maritime transportation sectors (international bunker fuels).

The *NDC-LTS CETO* scenario has been developed within the CETO project with a view to provide each technology report with specific scenario data. The scenario implemented up-to-date techno-economic parameters provided by authors of the CETO technology reports.
The *NDC-LTS CETO* scenario is very similar to the *NDC-LTS* scenario of *the Global Climate and Energy Outlook 2023*, which is currently under development.

[1] Global Biosphere Management Model (GLOBIOM) model description. International Institute for Applied Statistical Analysis, Laxenburg, Austria. http://www.globiom.org

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