D2.1b. REEEM Innovation and Technology Roadmap

Renewable Energy Integration

Analysis of Wind, Solar PV and Ocean Energy

July 2018

About this report

In the framework of the REEEM project, the development of three technology and innovation roadmap is planned to highlight the role of innovation and technologies in the transition pathways toward a low carbon EU society. This report presents the second roadmap dedicated to renewable energy integration. The primary findings of this roadmap are consolidated in a stakeholder workshop in April 2018 in Brussels. The outcome of this report will provide a market outlook and techno-economic data projections for renewable energy technologies (i.e., wind power, solar PV power, and ocean power). It also provides inputs for the modelling activities in the REEEM project, particularly to model the EU transition to a low-carbon society according to a Base Pathway and two cases derived from it (one with high renewables penetration and one with expected breakthrough in floating foundation offshore wind and building-integrated PV). This report will be complemented by IRL reports, assessing and evaluate innovation readiness of selected renewable energy technologies

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REEEM partners

About REEEM

REEEM aims to gain a clear and comprehensive understanding of the system-wide implications of energy strategies in support of transitions to a competitive low-carbon EU energy society. This project is developed to address four main objectives: (1) to develop an integrated assessment framework (2) to define pathways towards a low-carbon society and assess their potential implications (3) to bridge the science-policy gap through a clear communication using decision support tools and (4) to ensure transparency in the process.

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Summary

Renewable energy *has the potential to play a big role in the transition pathways towards a low carbon society in Europe. The benefits of renewable energy are numerous and recognised, they diversify the European energy supply sources, reduce dependency on fossil fuels (e.g., oil, gas), delimit environmental impact of conventional energy sources and improve the European energy system security against fuel price volatility.*

Given these benefits, *renewable energy has been placed among the top priorities of the* ***European Union****. The integrated SET plan (Action No. 1 & 2) reveals Europe's ambitions to be the world number one in renewable energy. For that Europe needs to lead the development of new generation of renewable technologies and integrate renewable power successfully and cost-effectively onto the energy system. Currently, the share of renewable energy in the gross final energy consumption in EU-28 has increased from 8.5% in 2004 to 17% in 2017. The set targets and published EU legislatives request this number to reach 20% by 2020 and 32% by 2030.*

In order to realise these objectives, there is a need for technological ***innovation*** *and sustained market support not only for the development of the renewable energy but also finding approaches to fully integrate renewable energy into the energy system efficiently and effectively.*

This ***roadmap*** *studies the development and deployment of several renewable energy technologies in order to answer "What are technological innovations and market solutions necessary to achieve EU ambition for the 2050 and fully integrate renewable energy into the market?" This question underlines that this roadmap does not only focus on technological innovation but also market solutions (in terms of innovative regulations, business models, integration methods, customers & society requirements and value chain settings) in order to shift market gaps to opportunities and barriers to effective actions.*

The selected ***technologies*** *for this roadmap have a high potential for improving the performance of the European energy system and decarbonising it. The studied technologies are wind power (onshore and offshore), solar power (photovoltaic), and ocean power (wave and tidal) and the primary focus is on the electricity market. This roadmap explores the current position of these technologies in the market and identifies their road toward attaining the European targets and goals. Points in the technology development processes will be identified at which the technologies' value chain can be positively influenced to reduce costs and increase market deployment potential.*

In this roadmap, Chapter I sets the scene and sheds light on several EU directives and targets affecting the renewable energy industry. Chapter II-IV explore the development of the selected renewable energy technologies and propose several innovations and solutions to accelerate development of deployment of these technologies. Chapter V delineates the existing approaches toward the better integration of a large share of renewables into the European electricity systems. Finally, a ***summary*** *of the results and main actions are listed in Chapter VI.*

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I. Introduction: The Energy of the Future

I.1. Renewables energy and vision for deployment

Development of a low carbon society is among the top priorities of the European Union. In November 2016, the European Commission published its "Clean energy package for EU citizens" in which the clean energy transition is identified as the top priority of the European Commission. Renewable energy is discussed at the heart of this package and considered to play a significant role in the future of the energy industry. Renewable energy has benefits such as lowering greenhouse gas emissions, reducing European dependency on imported fossil fuels, diversifying the energy supply as well as job creation in new green industries. To promote the development of renewable energy, the European Union has introduced different instruments and targets. The importance and role of renewable energy are highlighted in Action 1 and 2 of Strategic Energy Technology (SET) plan Communication, which helps to structure European and national research programmes and triggers substantial investments on common priorities in low-carbon technologies.

- Action 1: "to sustain technological leadership by developing highly performant renewable technologies and their integration in the EU's energy system"; and
- Action 2: "to reduce the cost of key technologies" [1].

European Directive 2009/28/EC (known as 2020 package) mandates that by 2020, 20% reduction of greenhouse emission (in compare with 1990 level), 20% improvement in energy efficiency, and 20% of gross final energy consumption of European countries be from renewable energy sources. The country-level targets are set for the share of renewable energy in the gross final energy consumption of different member states. The targets are based on the member states' existing energy portfolio and economic status. Figure 1 illustrates 2020 targets for each European member states and the progress made in achieving those targets as of 2016. The analysed Renewable energy sources for the Figure 1 are wind power, solar power (thermal, photovoltaic and concentrated), hydropower, tidal power, geothermal energy, biofuels and the renewable part of waste [2]. As illustrated, while some countries have achieved their targets for 2020 and many others are on the right track to do so, some Member States (e.g. France, Luxembourg and the Netherlands) are slightly behind [3].

The targets for 2030 are also set. The targets aim at increasing the share of renewable energy to 32% in the final energy consumptions and improving energy efficiency to 32.5% by 2030 when compared with the 1990 level [4]. At the same time in 2030, 50% of all electricity production is planned to be from renewable energy sources [5]. The plans for 2050 are even more ambitious. The unbind plans aim at 80-95% reduction of greenhouse gas emissions, 50% share of renewable energy sources in gross final energy consumption and complete decarbonization of the electricity sector [6]. In order to meet these ambitious targets and plans, the European Union is actively engaged in different renewable energy projects and leads Research and Innovation (R&I) in this field.

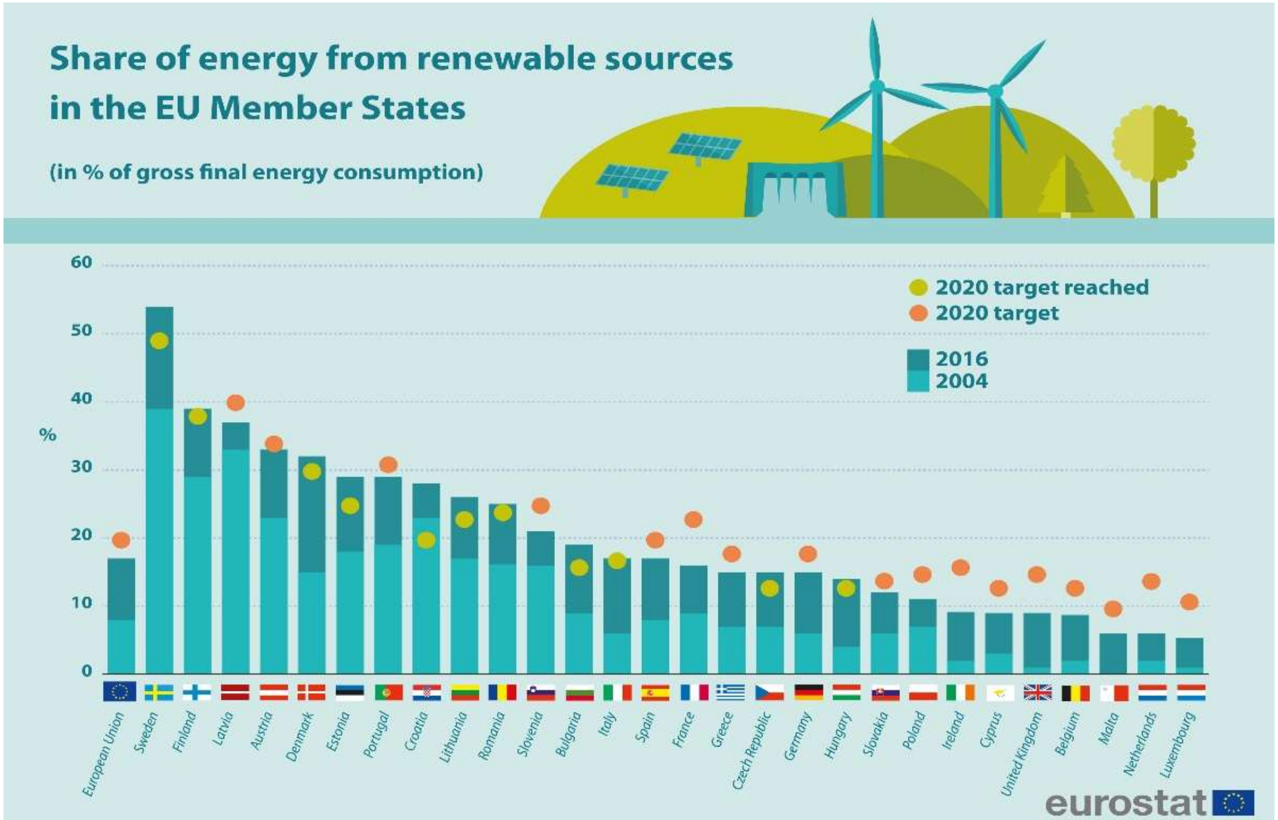


Figure 1- share of energy from renewable energy sources and 2020 targets [2]

Given the above discussion, renewable energy is expected to be at the centre of the European energy mix in the future, contributing to both small and large-scale electricity generation, centralized and decentralized generation. To do so, there is a need for technological innovation, advanced research, industrialisation of the supply chain and efficient policies and support scheme and cooperative society.

I.2. Roadmap and objectives

This roadmap studies the development of several renewable energy technologies in order to explore their positions and roles in the transition towards a low-carbon EU society. The results of this roadmap will provide input to the transition pathways developed and modelled in the REEEM project, in order to explore and assess different emerging futures. They will specifically feed into a so-called 'Base Pathway' representing one likely course towards the decarbonisation of the energy sector based on cooperation between groups of countries and current policies; they will additionally provide inputs for two cases derived from the former, one with 'High RES' penetration and one with expected 'RES Innovation' in offshore wind with floating foundation and building-integrated PV.

This roadmap studies wind power (onshore and offshore), solar power (photovoltaic) and ocean power (wave and tidal energy) based on their existing market share and potential for the future European electricity industry. The aim is to identify technological innovations or market solutions that could positively influence achieving EU 2050 ambitions. For each technology, the current market conditions are studied and technological limitations and existing market gaps are identified. Successively, market solutions and technological innovations are identified and discussed in details.

The roadmap also assesses the impact of the proposed innovations on renewable energy technologies' cost and provides cost projection for the studied technologies untill 2050. To do so, it utilises DELPHOS™, conducts literature study and consolidates the results with experts [1]. Note that the availability of natural resources for renewable energy production (i.e., wind, solar, water) is also an important factor influencing investors' decisions for the choice of renewable energy across the EU-28 countries. Although these factors are outside of the scope of this roadmap, in the REEEM models (e.g., TIMES Pan EU) the availability of natural resources and their influence on investment decisions for different renewable energy technologies across European countries are taken into account. The primarily findings and cost projections of this roadmap has been presented in a stakeholder workshop in April 2018. The collected inputs during the workshop have been addressed and incorporated in the final version of the roadmap.

In the following, Chapter II, III and IV are dedicated to the analysis of the selected renewable energy technologies. For each technology, a brief description of the technology and its historical development in Europe is provided. Next, market parameters and technological limitations related to each of the technologies are studied. Successively, scenarios for technological and market innovations are discussed that can improve the positions and costs of the technology. For offshore wind energy and solar PVs, two particular innovations are proposed as breakthrough scenarios and are discussed in details. Chapter V sheds light on existing innovations and solutions that facilitate the integration of renewable energy in the market. Finally, Chapter VI summarizes the findings of this roadmap, presents key facts and provides an action list in order to accelerate the development of renewable energy technologies and their integration in the European electricity industry (Figure 2).

This report also includes an appendix which provides an overview of the status and innovation potentials of the studied renewable energy technologies in this roadmap

[1] *Detailed description of Delphos could be found in the REEEM deliverable 2.3, later in this report in cost projection section and also in https://delphos.innoenergy.com/*

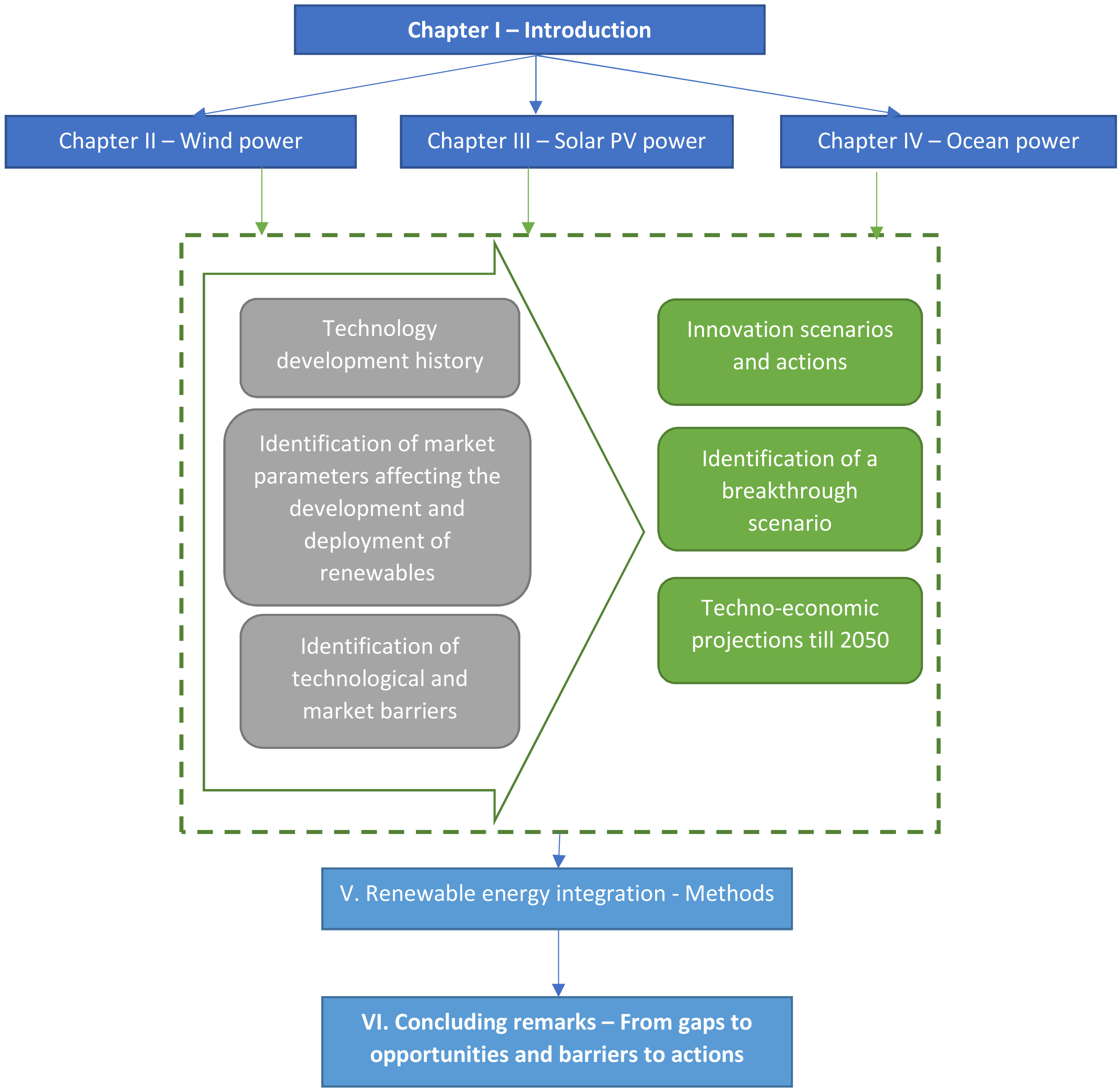


Figure 2 – Roadmap chapters and organisations

II. Wind Power

II.1. Description and history

In response to the oil crisis in the 1970s for the first time the development of wind power initiated in countries with a high dependency on fossil fuel. In Europe, Denmark was among the first countries which gained interests in the wind power as an alternative energy source. Wind power development was slow before the 1990s. It was from the beginning of the 21st century that global interests in reducing the GHG increased, which resulted in larger investments in wind power. The results of these large investments could be seen in the cumulative installation of onshore and offshore wind that has increased from 40.07 GW in 2005 to 168.7 GW in 2017 [7] (see figure 3).

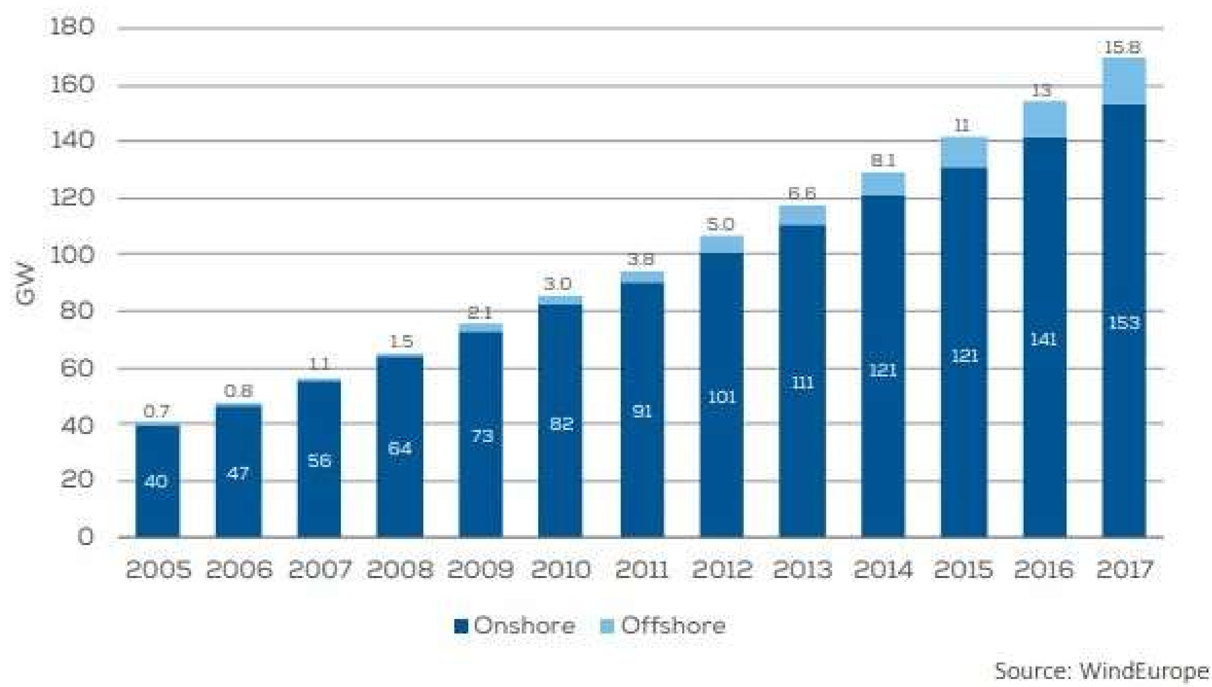


Figure 3- the Global cumulative growth of wind power capacity [8]

In Europe, the position of wind power is already prominent. In 2016, more than 50% of new installed power capacity was made in wind power. Different member states facilitate investments in new power capacities of wind power annually. As shown in Figure 4, Germany, France, followed by the Netherlands and the United Kingdom (UK) have made the largest investments in wind power. In 2016, Germany had the total capacity of 50 GW, Spain 23.1 GW, UK 14.5 GW and France 12.1 GW [9].

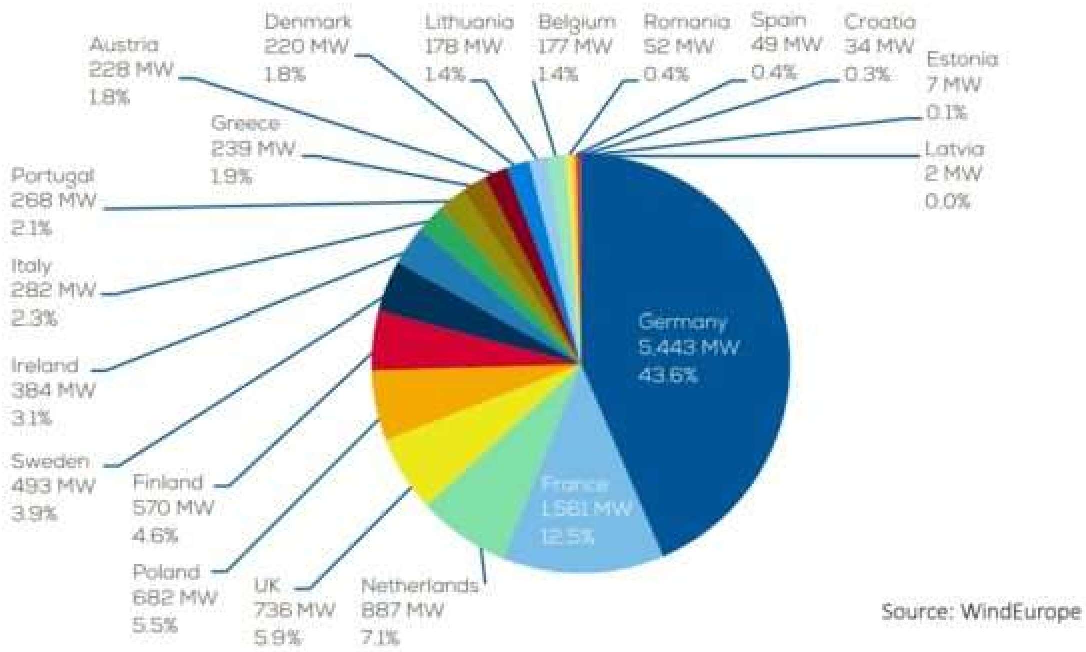


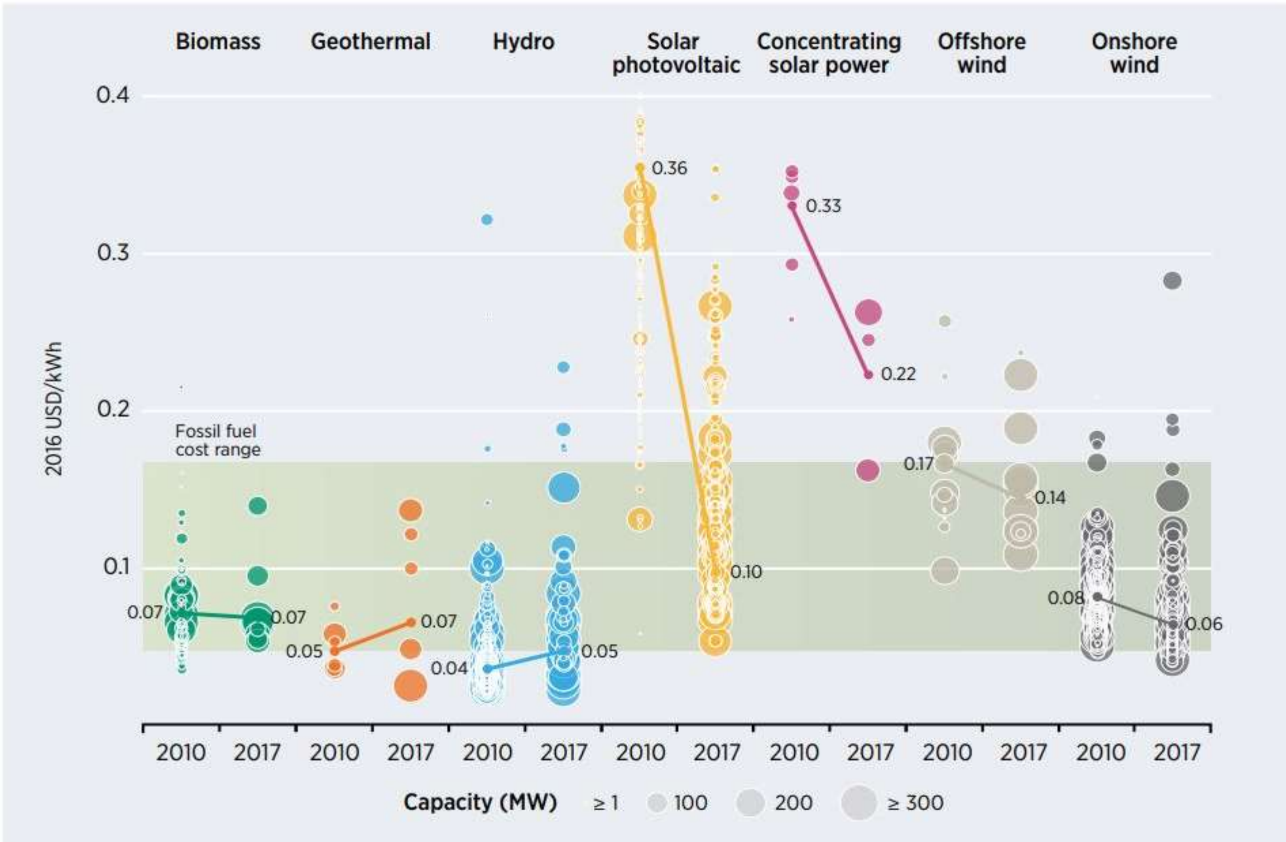
Figure 4 - EU market shares for new wind energy capacity installed during 2016. (Total 12,490 MW) [9],[10]

Investments are made in onshore or offshore wind, both technologies are explained below.

Onshore wind power

The development and installation of onshore wind power started in the 1970s. In onshore wind power, wind turbines are installed on land, preferably where high potential sources of wind are available. During the last decade, onshore wind power has benefited extensively from innovatively designed turbines and learning curves, resulting in better system compatibility, higher power yield and longer operating hours. Onshore wind energy currently provides one of the cheapest sources of power in the electricity market (Figure 5).

As of 2017, there are 153.7 GW installed onshore wind power capacity available in Europe. Onshore wind power is the most deployed type of renewable energy in Europe. In 2016, 51% of new power capacity in the EU was in wind power, 141.1 GW of which onshore and 12.6 GW offshore [11]. The different European Member States have invested in wind power, among which Germany has made the largest contribution.



Source: IRENA Renewable Cost Database.

Note: The diameter of the circle represents the size of the project, with its centre the value for the cost of each project on the Y axis. The thick lines are the global weighted average LCOE value for plants commissioned in each year. Real weighted average cost of capital is 7.5% for OECD countries and China and 10% for the rest of the world. The band represents the fossil fuel-fired power generation cost range.

Figure 5 – Global LCoE from utility-scale renewable power generation technologies, 2010-2017[12]

Offshore wind power

Offshore wind power refers to the installation of wind turbines on the seabed, far from the shore. The market for offshore wind energy is less mature and younger than onshore wind power. The installation of offshore wind turbines in Europe dates back to 1991 in Denmark [13]. Currently in Europe after about 25 years 11 countries have offshore wind power installation (see figure 6), installed mainly in northern European waters [14].

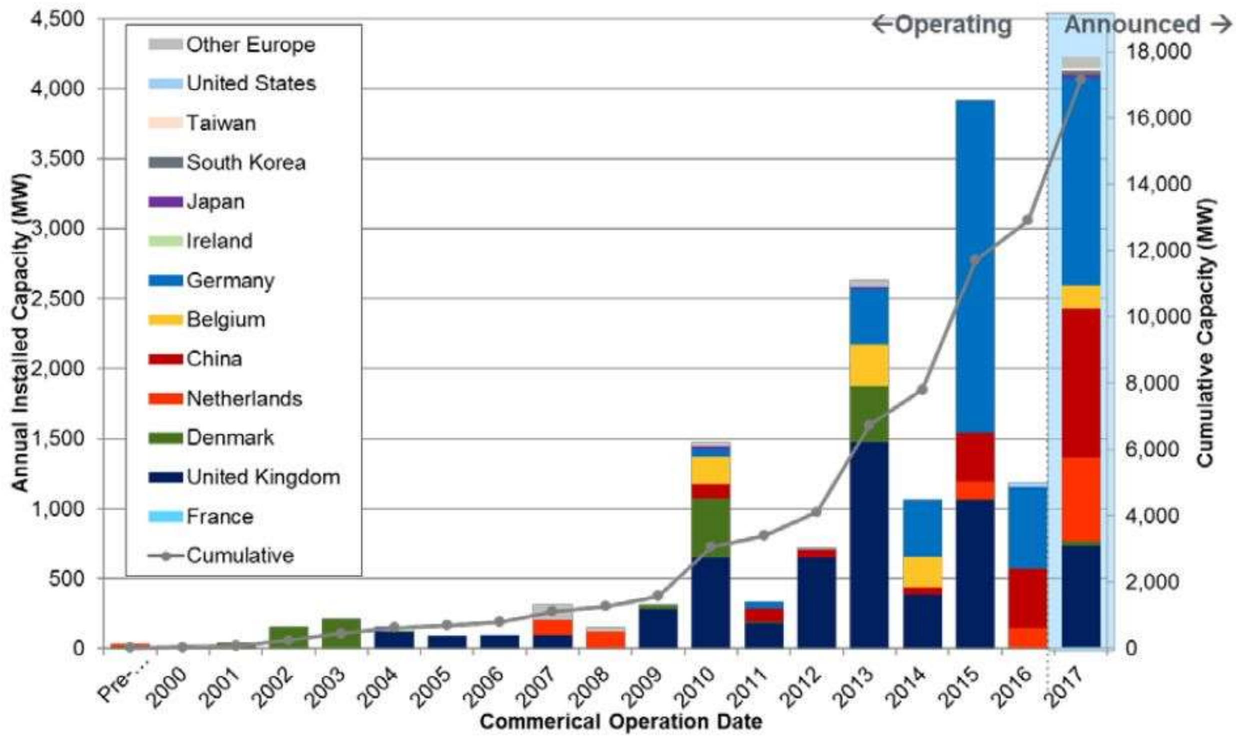


Figure 6 – Offshore wind power installed capacity by market [13, Page 7]

The two largest offshore wind farms worldwide are situated in Europe and together meet the electricity demands of more than 2 million people. The largest wind farm, called the Array, is situated off the Kent coast, England's south-eastern county. The turbine sizes are 3.6MW and they are spread over 90 square kilometres (km^2) area, with the total capacity of 630 MW. The first phase of this project was initiated in 2011[16].

The Gemini is the second largest offshore wind farm with 150 turbines of 4 MW size spread out over 70 km^2. The farm is situated in the North Sea 85 km off from the north coast of Groningen, the Netherlands. The large distance of the wind turbines from the shore assures that the farm is not visible from the coastline and accordingly is not affected by negative social opinion about the influence of the turbines on the landscape

Figure 7 shows the annual installation of onshore and offshore wind power. As shown, investments in onshore and offshore wind power plants have not been comparable and the wind power market is mainly comprised of onshore wind power so far. As illustrated, the investments in offshore wind power have increased annually until 2015 but these investments are small when compared with the investments in onshore wind power, mainly due to the higher cost of these technologies.

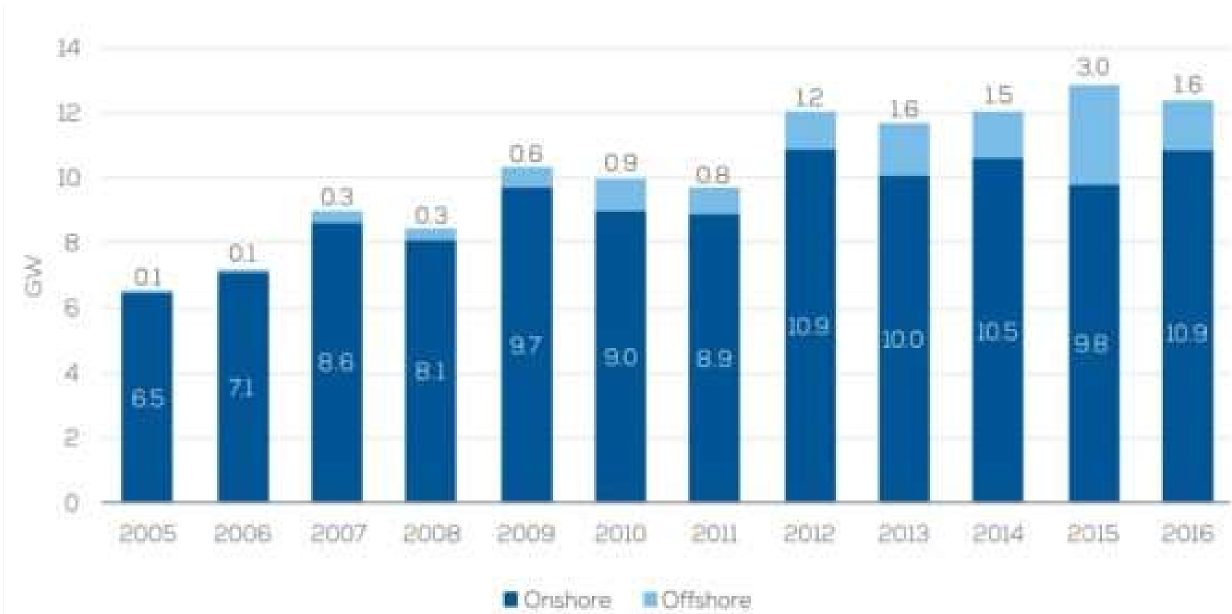


Figure 7- Annual onshore and offshore wind installations in the EU [10]

II.2. Wind power technology

Wind turbines consist of several components and parts from break and gearbox to yaw motor and wind blade. Through the years designs and manufacturing processes for these turbines have changed and contributed substantially to the technology cost reduction [17].

The improvement of wind turbine size has contributed significantly to the cost reduction of the technologies. The average size of the turbines has increased for onshore wind power from 0.3 MW in the 1990s to 1.4 MW in 2005 and 2-3 MW in 2015, and for offshore wind power from 1.8 MW in 2000 to 3MW in 2005 and 4.1 MW in 2015 [17]. The demand for larger wind turbines has increased over the years due to two reasons: (1) large-scale wind turbines have a more competitive LCoE; (2) land restriction is becoming more important than access to the grid. Accordingly, larger wind turbines could enable installation of fewer turbines with higher capacity at a lower cost of energy. Despite of the remarkable progress, the wind power market is expecting further cost reduction due to larger and better-designed wind turbine sizes. In 2030 for onshore wind power this size is expected to be 3-5 MW, and for offshore 10-12 MW.

Remarkably, the average size of wind turbines installed in Europe varies across different member states. This variation is on one hand due to varied regulations, project durations or wind speed and on the other hand, based on when the wind energy development was started in a country and on the largest available wind turbine size at the time. As shown in Figure 8, the average turbine power rating[2] in countries such as Sweden or Finland is more than 3 MW, when in the UK and Spain it is less than 2 MW.

[2] *A power rating is a measurement of the maximum amount of power that can be used with a specific tool or device.*

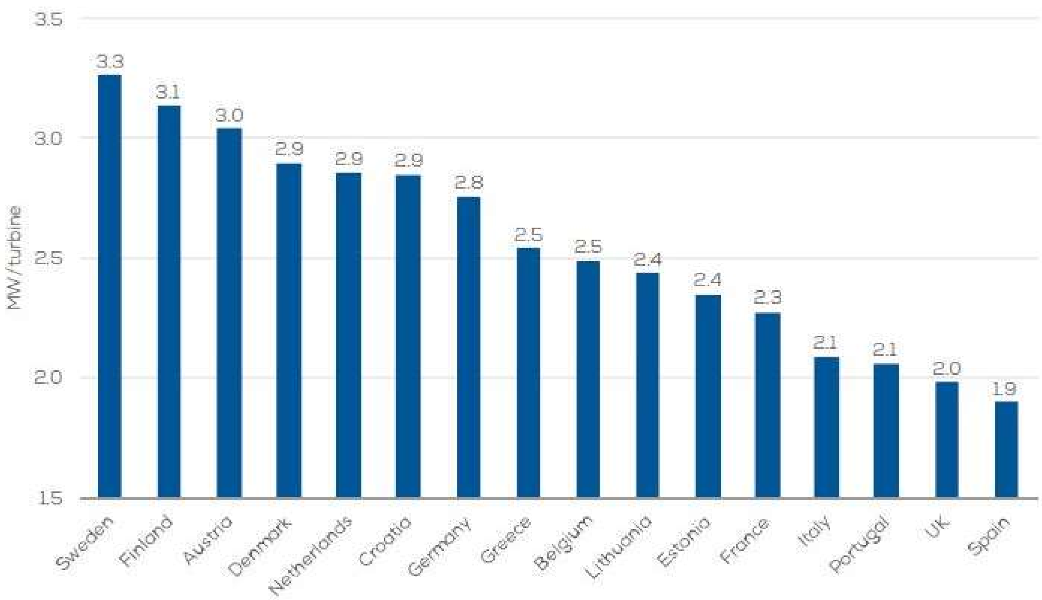


Figure 8- Average turbine power rating in different European member states in 2016 [10]

The height of wind power towers is another feature that directly influences the amount of produced wind power. Towers have different specifications for onshore and offshore wind power. When it comes to onshore wind power, the average height of the towers is about 100m in the European market [18]. An increase of another 20m, could potentially enhance power generation by 5%. Towers could be constructed from different materials and shapes such as lattice, tubular steel, concrete or hybrid metal-concrete.

For *offshore wind power,* both the tower and its foundation construction are more complicated due to their implementation on the seabed. The foundation for offshore wind farm could be categorized into the 5 groups of monopile, tripod or space farm, gravity-based foundation, jacket foundation or tri-pile structure[3]. So far, most of the foundations have a fixed bottom. As shown in Figure 9 monopile constitute the majority of the available foundation in the market followed by gravity-based foundation. These fixed offshore wind foundations are suitable for water depth up to a maximum of 50m. However, the wind power potential is on average higher in deeper sea water. In order to benefit from this potential, floating offshore wind power turbines have been introduced into the market. The floating options still need further development in order to be cost competitive and fully operational (discussed further in subsection II.5.1).

[3] *For further reading please refer for REEEM IRL report on renewable energy technologies*

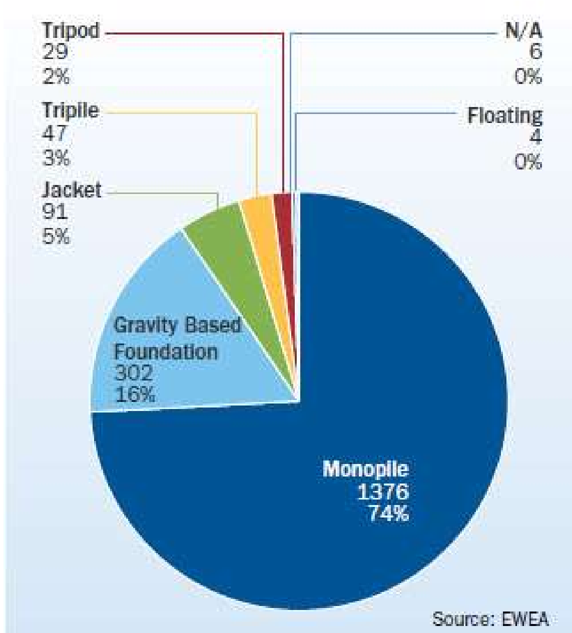


Figure 9 - share of substructure types for offshore wind farms by the end of 2012 [19]

II.3. Wind power market

Apart from technological development and availability of natural resources, the advanced deployment of wind power in the market is attributed to several market parameters. In this roadmap, we evaluate parameters related to policy and legislation, society and value chain in order to provide a holistic assessment of the wind market. Current market barriers related to these parameters are explained and potential solutions are discussed.

The overview of the studied parameters is presented in Table 1 and explained in details in the following.

Table 1 – Overview of the studied market parameters with an influence on the wind power deployment

	Evaluated parameters
Policy and legislation	- Policy support schemes, including both, pull (e.g., FIT, TGC, auction) and push policies - Stability of national policies - Relevant legislation (e.g., permitting procedure) - Issues related to grid connection - Engagement of both public and private players
Society	- Visual effect and land use - Additional cost for consumers - Job creation and loss - Society attributes - Higher cost for consumers - Consumers engagement and farm ownership - Environmental impact of wind power on nature
Value chain	- The strength of the European wind value chain - Trained human resources

Policy and legislation

Policy support schemes

The introduction of renewable policies into the energy industry has influenced the landscape of this industry massively during the past decades. In fact, policy support schemes are one of the main reasons behind the successful development of wind power. Initially, investments in wind power were costly and associated with high risk. Policy support schemes were therefore essential in order to motivate investment decisions of potential investors and make wind power cost competitive in the market. To do so, different European member states have introduced different types of pull and push support schemes for renewable energy. Being among the most developed and cost-competitive renewable energy resources, wind power has benefited greatly from these supports. Generally, the pull policy mechanism for the development of wind power in particular, and renewable energy, in general, could be categorised into 3 main groups of Feed-in tariffs (FIT), Feed-in Premium (FIP) and Tradable Green Certificates (TGC). Currently in Europe FIT followed by FIP are the most common policy supports [20].

In more recent years, the European governments tend to enforce market-based policies, in order to enhance competition in the renewable energy market. This has been the case for example in some member states (e.g., Germany) for the construction of offshore wind projects through the implementation of the auctioning system. In a round of auction, a project developer who requests the lowest amount of funding will win the auction. When a developer wins the auctioning, it will get access to the national grid. Interestingly, in Germany, for example, some developers value the connection to the grid so much that they even requested zero FIT or FIP for the development of their project [21]. On one hand, this policy support mechanism creates a competitive advantage for the technology. On the other hand, if a project developer does not win the auction, they could face an issue to connect their offshore wind production to the grid.

In addition to the pull policy mechanism, other policies and legislation are provided to support the development of wind power. Among these policies are push instruments which support the production of a technology through direct investments, financing incentives or R&D efforts. Examples of such policies are [22]:

- Selecting development zones contributing to site affordability. This has happened in Denmark where the governments issued a call for tenders for an offshore project near the shore (4-8 km).
- Sponsoring early-stage development and permitting activities. This has occurred in Denmark and the Netherlands, where the governments conducted early-stage development activities by defining development zones and conducted the initial environmental assessment, geotechnical and wind assessment. These activities have contributed to the permitting process and reduced the cost of wind projects.

National policy stability

Different types of policy instruments have been introduced in the European member states. These instruments have been changing their types and their amount of support through the years (e.g., in Spain). Some of these changes have delimited the trust of potential investors in policies and their supports [23]. Investors lack trust in the stability of policies which has resulted in a higher risk for their investment projects and delimited their interests to invest in wind projects.

Permitting procedure
Currently, in the market, there is legislation that hinders the development of wind farms [24]. Identifying and resolving the issues related to these legislations can accelerate the development of wind power. In Europe in order to build a wind farm and to connect it to the grid, project developers need to obtain a permit. The average total time for obtaining the permission for building and connecting a wind farm in Europe was estimated to be 54.8 months for onshore and 32 months for offshore in 2010 [24]. This long permission process, especially in countries such as France is an issue. While often the reasons for this long permission process are varied in different countries, environmental issues and constraints related to grid connections are identified as the main one.

Public and private investments/engagement
Market drivers especially energy policies should be adjusted in order to meet the objective of doubling the share of renewable energy by 2030 by engaging both the public and private sectors. "One-size-fit-all" policies might not have the optimum influence on the energy market [25]. Example of a one-size-fit-all policy is Tradable Green Certificate (TGC) enacted in Sweden that neither differentiate between different types of renewable technologies nor investors [26]. In more recent years, some European countries, set rules that target different sizes of renewable projects. This is for example the case in Germany that allows small players with plant sizes smaller than 100 kW to benefit from existing FIT system [27].

Society and environment

The European society is concerned about the environment and often hold a positive opinion about the technologies that contribute to the reduction of CO_2 emission. The positive society perspective has driven more investments in the wind power industry. This is especially because of wind power development not only restrain the CO_2 emissions but also enables electrification of remote areas (e.g., rural areas in Ireland). However, the development of wind power is not always supported by society due to several reasons explained below.

Visual effect and land use
The development of wind power is associated with unavoidable land use and visual influence on the landscape. Even if EU consumers hold a positive attitude towards renewable power generations (e.g., [28]), the wind turbines' visual influence on the landscape has made society in some regions to oppose the expansion of wind power in their surroundings. In addition, fear of infrasound has been found to have a negative impact on the acceptance [29]. Known Not In My Back Yard (NIMBY) situation can explain the hesitance for the development of onshore wind power in some regions. A study in the UK shows that respondents considered "out of sight" development of onshore wind power to be acceptable [30]. Interestingly, citizen have more negative view toward a higher number of installed wind turbines. This means that people prefer to reduce the number of turbines and bigger the trend to solve visual damage [31].

Several regulations and legislation are introduced into the market, since the society's opposition to having a wind farm near their own residential location, has slowed down the development of wind farms. In general, the legislation with regards to wind turbine distance and noise is done in relation to decibels (dB)level at the nearest habituated building.

When it comes to the offshore wind power the society is less concerned about the visual influence and potential disturbance (noise) of turbines as they are installed offshore. The longer is the distance between offshore wind turbines and the shore, the lower is its impact on the landscape. This, in turn, lowers the society opposition against the construction of offshore wind farms. This has been shown in a survey in the UK, showing that people favour offshore wind development [30].

Society attributes

It should also be noted that the acceptance of wind energy is affected by the personal attributes of society, such as knowledge, age, gender, income and experience with renewable energy [28,33]. People with more experience with wind power and higher information level are more likely to accept a renewable energy project [34,35].

Higher cost for consumers

*A*s discussed before in order to support the development of onshore wind power, different policies have been introduced to the market. An example of this case is a successful FIT in Germany or TGC in Sweden. While contributing to a decrease in the investment cost in wind power, these policies increase the price of electricity for consumers [36]. This increase has concerned electricity consumers and lowered their interest to support a larger share of wind power in the energy market. Figure 10 illustrates influence of these policy supports on consumers electricity bills.

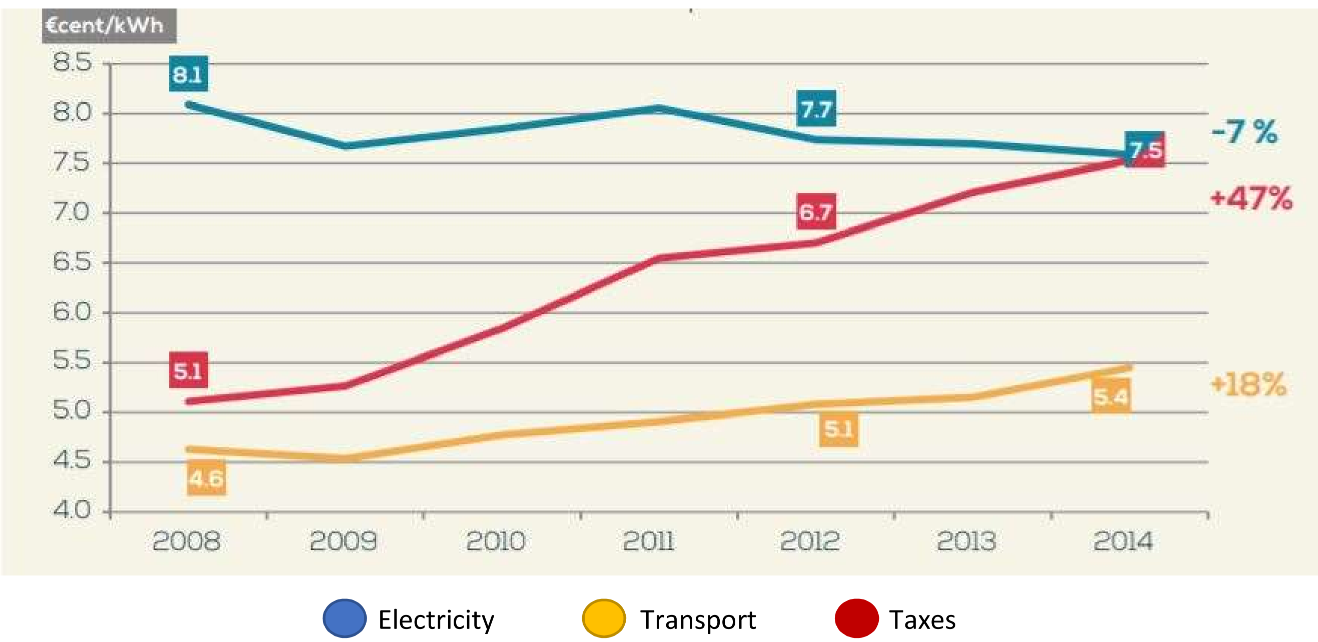


Figure 10 – Evolution of bill components 2008 – 2014 [37]

Job creation and loss

Wind power acceptance in the market is significantly influenced by the perception of its economic impacts [38]. So far, the development of the wind power industry has created jobs in Europe, which has a direct positive influence on the market. Overall in 12 European countries as of 2014, over 324,000 jobs were created, with a turnover of about €48 billion [39]. However, this development also had to some extent negative influence on other industries such as coal mining in Poland or Germany. Coal production among EU countries has been on the decline for 30 years. Only in Germany coal-mining employment is down to about 30,000 jobs, a tenth of the number three decades ago [40]. At the same time, within Europe, Germany was the number one per capita (labour force) employer of renewables (roughly one in 114 persons within the labour force was working in jobs related to renewable energy) [41]. Still, the job loss delimits partly the society's interest in renewable energy in general and wind power in particular.

Consumers engagement and farms ownership

The acceptance of wind power projects is also affected by ownership of the wind farms. For example, Waren and McFadyen (2010) [42] found that in Scotland attitudes are more positive when local communities have a direct involvement in the projects. Similarly, in Germany the historical development shows that community co-ownership leads to acceptance and also to a more positive attitude toward wind energy [43].

In a community investment project, citizens (private households, communities, etc.) own or participate in the generation of sustainable energy. The generated energy will be sold collectively and the profit will be split among the participating citizens. In these cases, the citizens could live close to one another in the same neighbourhood or live geographically distant from each other. This type of project has been applied in countries such as Germany and influenced the acceptance level of society effectively.

Influence on nature

Wind power could have negative influence on certain animal species. In particular, wind turbines could impose undesirable changes to birds and bats, or marine animals causing their death or changing their migration patterns and life. While measures have been taken to reduce the influence of wind power (e.g., painting the blades red), some impacts would be unavoidable.

Value chain

The strength of the European value chain

The strength of local value chain is identified as one of the main reasons enhancing the potential of an emerging market [7]. Likewise, the strong European wind value chain can effectively contribute to the growth and development of the wind power industry. The dominant position of European wind turbine manufacturers worldwide as well as component suppliers evidences on the success of the European power wind value chain. In a more recent year, the position of these manufacturers is threatened with increasing investment of Chinese industry in their wind power industry [44]. Figure 11 provides an overview of European value chain in wind power. Note that the list of companies could be extended and here is just to provide an overview.

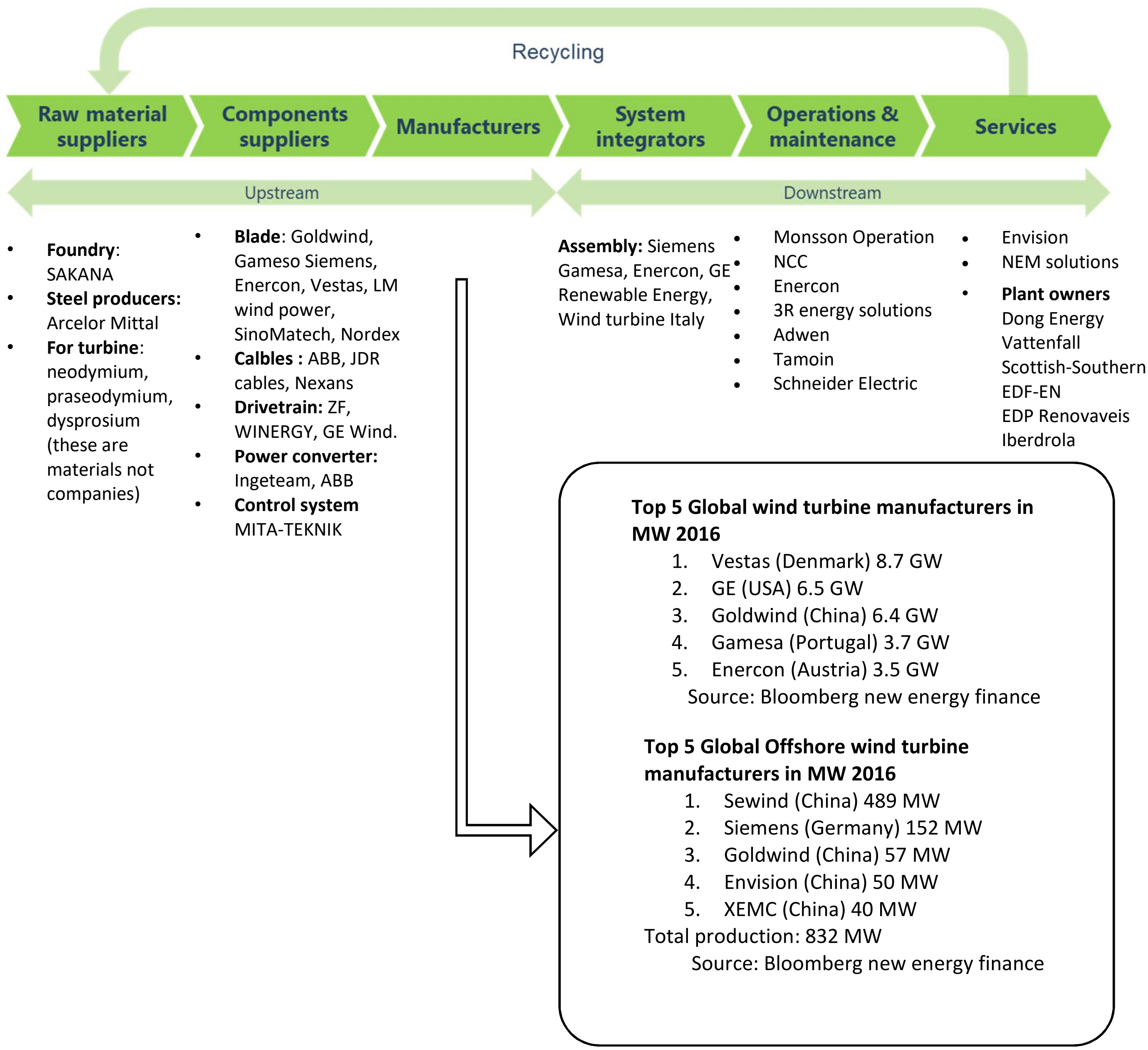


Figure 11 – European actors active in the wind power value chain[4] [44], [45]

Human resources and training

As the share of wind power is increasing in the electricity market, the need for skilled human resources is increasing in this market also increases. In 2016 the wind energy industry accounted – both directly and indirectly – for 262,712 jobs in the EU [46]. Figure 12 shows the share of human resources with different expertise in

[4] *For a more complete list please refer to https://windeurope.org/regional-map/*

different segments of the wind power market. These proportions should be considered for he future training programmes in order to have skilled human resources for the available jobs in the wind market.

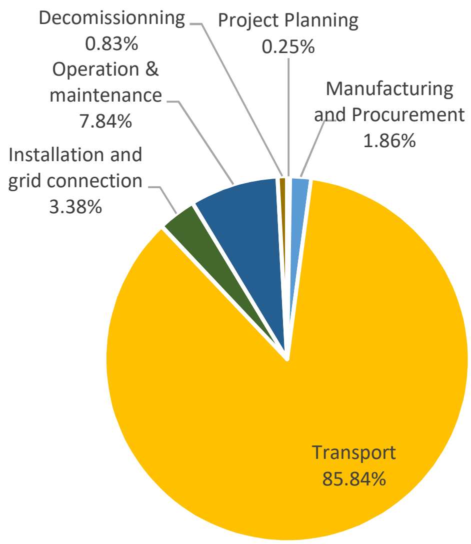


Figure 12 – Average working hours per wind farm installed

II.4. Additional barriers and bottlenecks

In addition to the above-mentioned barriers and bottlenecks related to the wind power market, other factors these could slow down the development and deployment of wind power [7]. Some of these barriers are specific to wind power type (onshore and offshore), site or region.

Barriers related to both onshore and offshore wind power:

- **Variability and intermittency of wind power**: Currently in the market, the cost of onshore wind power is competitive against fossil fuels, while the cost of offshore wind power is gaining competitiveness. Still, the variability of wind power delimits interest in large installation of wind power technologies. A large application of wind power and high dependency on this technology needs to be complemented by technologies such as energy storage or grid interconnection in order to balance variable wind power production.
- **Lack of low-speed wind turbine and parks**: The number of sites with access to high sources of wind power is becoming more limited. This calls for wind technologies that can capture low wind speed efficiently. As if yet, the development of this type of wind turbines has been limited.
- **Existing gap in digitalization of this technology**: Digitalization would allow better management of wind farms and maximisation of the output through a consistent planning. So far limited progress has been made in this regard.
- **End of life**: Currently limited attention is paid to what happens to wind turbines and systems after their lifetime, which is about 20 years. This issue is becoming more important since the installation of wind power on a large scale started around 20 years ago and therefore some farms might soon reach their end of life.

- **Wind turbine size and transportation**: As discussed, the size of the wind turbines has increased over the last year and this directly had a positive influence on the cost of energy. This increase in size, however, challenges the transportation of the wind turbine. Currently, the cost of transportation is increasing and there are even doubts about the possibility of transporting larger turbine sizes. This is negatively influencing the development of wind power.
- **Limited grid capacity**: the installation of wind power farms has proceeded in sites with access to grid connection. As the wind power market expands, sites with an access to the grid become more limited. The establishment of wind power in a location with no access to the grid (e.g., rural areas or mountains) means there is a need for investments in grid expansion and that could add substantially to the total cost of the project. This is especially important since in many cases the produced electricity by wind power needs to be transferred to regions with high electricity demand.
- **Conflict with other power sources and renewable energy**: Vested interests in other renewable technologies such as PV, and the promise of the emergence of cheaper and more reliable renewable energy sources lower the interests to invest in wind power. Moreover, dependency on existing technologies (often conventional sources) and lock-in effect lower the interests in investment in new wind power capacity.
- **Land use, site selection and accessibility**: Selecting a right site is important for a successful project implementation. This site selection is becoming more challenging as the number of sites with optimal conditions is decreasing. For offshore wind power, the location of the site is particularly important since the distance from the shore, water depth, wave heights, seabed morphology, soil conditions, ocean currents all impact the project costs.

Barriers specific to offshore wind power:

- **Offshore technology immaturity:** Several reasons encourage the installation of offshore wind turbines in deep water sites, such as access to high wind speed. However, the current offshore technology development status is only cost-competitive in shallow water sites. Even in these sites, there are risks such as ice floes or hurricanes that fully has not been tackled [47]. Accordingly, innovative solutions and further development of wind technologies are necessary to allow benefiting from the full potential of offshore wind technologies.
- **The high cost of offshore wind power**: The cost of offshore wind power is currently higher than alternative power generation sources such as onshore wind energy, but the gap is decreasing fast (Figure 5). This higher cost is due to parameters such as expensive support structure, electrical infrastructure, building and construction at sea, O&M cost, and the premium cost for marinization of turbines. High energy production of offshore wind power partly offset the cost and make offshore wind power a promising source for the future energy industry. Yet, offshore wind power cost needs to be reduced more before it becomes economically competitive in the European energy market. This is possible through further applications of offshore wind power in order to benefit from the learning curve by which product costs would decrease with higher production quantity.
- **High lead times:** the development of offshore wind power project is associated with long lead time for project planning. This means that the project investors need to wait long before making any revenue from their investments [48]. This has a negative influence on investors' interests to engage in the development of offshore wind technologies.
- **Risk adverse attitude**: Investments in offshore wind power is associated with high risk [47]. The project risk can be due to several reasons including 1) the uncertainty surrounding regulatory and permitting

issues, 2) high risk of construction and installation in water, 3) operational risks due to accurate energy production and long-term reliability. These risks have a direct impact on the cost of technology deployment and delimit interests to invest in them.

- **Physical constraints:** A successful development of offshore wind technologies is associated with installation of offshore wind turbines in long distances and in the harsh ocean environment. This means that, for installation of offshore wind technologies, several physical constraints must be tackled, including managing unpredictable weather changes, transportation and installation of turbines at far distances from shore.
- **Need for long-term planning by TSOs:** access to the grid by offshore wind technologies is among the main challenges and reasons for the high cost of offshore wind technologies. In order to successfully access to the grid and feed electricity into it, there is a need for long-term planning by TSOs.

II.5. Innovation outlook

In order to take advantage of the full potential of wind power and accelerate the technology development, the following actions are recommended. The actions can address the market or technology.

Market solutions

- **Long-term and reliable policies**: Securing long-term operation of policies supporting wind power (renewable energy in general) in order to lower the financial risk for investors in wind. Fixed-term contract and long-term national policies are examples of potential solutions.
- **Facilitating permission process**: Ease acquiring permission for the construction of wind farms in order to accelerate their deployment.
- **Motivate diversified investors including public and private**: Motivate engagement of both public and private investors to make sure that all potential investors are engaged and dedicated to the wind power market. For that there is a need for diversified policy frameworks, one-size-fits-all policies will not manage to targets all groups of investors.
- **Engaging local community in wind farm projects**: Engaging local consumers by promoting joint ownership of wind farms and increase the local employment rate, in order to increase their support for wind power and reduce their resistance toward the establishment of new farms.
- **Campaign or education programs to enhance knowledge on wind power environmental benefits:** Highlighting the benefits of wind technologies for the environment or its contribution to an independent European energy system in order to enhance social awareness of wind technology and potential.
- **Training human capital**: Training necessary human resources for the future market is necessary not only to meet the needs of the future energy market but also to compensate for the job loss caused by the energy transition.
- **Recycling and end of life:** The wind power industry in Europe started taking off about 20 years ago, and this means that many of the installed turbines would reach their end of life soon. There is a need for some efforts to address issues related to end of life of wind farms. This is possible for example through [44]:
    - how to separate different components and materials at a low cost;
    - high-quality recycling of the material;
    - reuse of the main component (e.g., foundations for offshore, towers).
- **Diversified support mechanisms**: Diversified types of support mechanisms should be applied in the marker in order to promote engagement of all potential types of investors in the wind market. This support mechanism should target leveraging both private and public capital.

- **Synergies with other markets (e.g., oil and gas, or ocean energy):** Offshore wind projects have similar operating environment as some other types of energy technologies including oil and gas, or ocean power technologies. Through better synergies between these technological chains, the deployment of offshore wind technologies and their deployment potential could be enhanced in the market.
- **Availability of cost-efficient value chain for offshore wind**: economy of scale and increasing deployment experience of project developers could result is a more effective and cost-efficient value chain for offshore wind technologies.
- **Availability of cross-border offshore wind capacity by TSO: The** possibility of transferring offshore wind capacity to where it is needed most through cross-border connections would enhance effectively the business of offshore wind projects. To do so, there is need for a centralised system for decision making and cooperation among neighbouring EU countries.
- **Hybrid technologies (wind power plus storage or other renewables):** the development of wind technologies is coupled with challenges such as variability or limited performance of these technologies under certain conditions. Coupling wind technologies with other available technologies in the market such as energy storage or wave energy technologies could enhance the position of wind technologies, by answering these challenges.

Technology innovations

Below several innovative solutions related to the development of wind technologies are provided.

1. Wind turbine and substructures (Rotor, nacelle, drive train (mech. /electrical) tower, foundation or offshore substructure

- **Improvement of wind turbine design:** This includes introducing new innovative conceptual design for wind turbines and components, including solutions such as new foundation concepts for the fixed turbine, different blade design or hydraulic drivetrain. The new designs should increase wind turbine output (e.g., by pitch optimization) or improve the turbines operability in extreme weather conditions such as desert or cold regions. The new design could introduce direct drive and mid-speed drivetrain [49].
- **Innovation in materials used in wind turbine technologies:** R&D should be conducted in order to find new materials for the wind turbine technologies. This is needed in order to reduce the dependency of the technologies on raw material and enhance their performance in harsh site conditions. The development of cheaper and more efficient materials would lead to technology cost reduction.
- **Innovation in drivetrain**: Geared drivetrain is currently a popular option in the market. But in the future, a geared drivetrain could potentially lose market share to direct drivetrain or hybrid and full hydraulic ones as they could lower the maintenance cost [49].
- **Improvement specific to offshore wind power turbines**: originally offshore wind turbines and their foundations were similar to onshore wind turbines. While onshore wind turbine already has an acceptable level of maturity, it is not an optimum design for the offshore environment. Several issues constraints the performance of normal onshore turbines in an offshore ocean environment, including corrosive seawater exposure, transportation and construction, harsh site condition and accessibility. In order to deal with these issues, innovative technological solutions are necessary for offshore turbines. Technology innovations could enhance reliability and energy output and lower system capital expenses. Also, the emergence of floating offshore wind power is promising solutions to boost the performance of

offshore wind power. Specifications and development of these foundations are discussed further in subsection II.5.3.

- **Tools for the management of wind turbine components and systems:** There is a need for the development of better management systems in order to enhance farms' safety factors and improve the farm performance (e.g., fatigue tool predictions for metallic and composites components together with systematic methodologies for material coupon testing).
- **Innovative materials and manufacturing processes:** Wind turbine components are key elements impacting OPEX. Designing better fatigue resistant materials and improving testing procedure can enhance O&M and reduce OPEX cost. Besides, industrial and manufacturing processes could be improved to reduce costs.
- **Development of new quality control systems:** The introduction of new automatic quality control such as FAT (Final Acceptance Test) and test bench (not accelerated) could effectively improve the quality of control system.
- **Scale-up prototype and test benches:** Scale-up prototypes and tests could improve and validate innovative concepts (e.g., new turbines). Test benches for different subsystems (e.g., pitch, yaw, lighting testing) can be used to monitor the performance and improvement in the field.

2. Wind farms

- **Wind turbine logistics and installation:** Developing innovative solutions to delimit the shock and transportation duration for wind turbines in order to improve the logistic cost. The analysis should be done to reduce installation risks. Examples of such risks are weather conditions that could postpone the installation; or availability of transportation facilities such as ships for offshore wind farms. Indeed, the onshore wind industry benefits from a relatively mature technology base that is now generally constrained by transport and planning limitations.
- **Reducing wind farm installation cost:** This could be possible through the development of equipment facilitating transport and installation of onshore and offshore wind turbines; access of equipment to offshore wind turbines under weather constraints.; and selection of best technologies and suitable ports for installation. Any delay caused by various weather conditions is an important factor adding to the installation cost.
- **Tools to control wind farm globally in order to optimise the annual energy production**: The tools should be developed to allow the optimisation of the annual energy production by mastering the numerical design tools and understanding their related uncertainties. This is necessary for robust designs of turbines and components. Such designs should last for 20 – 25 years.
  This is doable through calculation of capacity factor for different wind turbine ratings (rotor sweep area and installed power), development of short-term wind assessment chain and, improvement of sensors (e.g., nacelle Lidar).
- **Optimisation of wind farm layout under multiple constraints to reduce the cost of a farm:** Reducing the wind farm cost is possible through optimisation of the placement of the components, improving the output assessment tools (to predict wind sources), and improvement of the spatial, layout and geotechnical assessment tool.

See Table 2 for a comparison of offshore wind farm characteristics between 2001 and 2015.

Table 2 - Comparison of wind farm characteristics from example projects commissioned in 2001 and 2015 [49]

	The typical offshore wind farm, 2001	The typical offshore wind farm,2015
Water depth at lowest astronomical tide (m)	10	25
Distance from OMS port (km)	20	40
Wind farm capacity (MW)	60	300
Wind speed at 100 m above mean sea level (m/s)	9	9.8
Number of turbines	30	75
Turbine rating (MW)	2	4
Turbine rotor diameter (m)	80	130
Foundation	Monopile	Monopile

3. Operations and Maintenance (O&M): The onshore wind turbines are fairly mature which means there are less technological innovation opportunities for these technologies. Still, improvement in O&M can provide prospects for a further reduction of the technology cost. In offshore wind farms O&M is very costly (about 25-39% of the total LCOE of the wind farm) [50] and therefore any improvement in O&M can reduce the cost of offshore wind extensively. To improve O&M several approaches could be taken.

- Introducing responsive maintenance which requires an advanced monitoring system.
- Remote O&M which could reduce the cost of a wind project, while enhancing the safety of personnel.
- Improving the turbines and other related technologies in order to limit their need for maintenance.
- Development of new machinery sensors in order to control operability of wind farms from distance.
- Take necessary measures and action to improve monitoring performance of the field and testing the subsystems.
- Introducing condition-based maintenance instead of replacement and corrective maintenance. This requires implementation of monitoring systems that could control the status of critical components through the lifetime.
- Enhance weather prediction system in order to plan for suitable time windows for O&M. Particularly design of the mid-term wind and sea state assessment system which allow better predicting the mid-term weather/sea state weather conditions for offshore wind farms. The accurate prediction of could reduce the access cost to the turbines and improve health risk of human resources.

Advanced innovation scenario: the case of floating offshore wind foundation

Floating offshore wind foundation: a game changer

Due to reasons such as availability of wind with higher speed and limited visual effect on the landscape, the establishment of offshore wind power in deeper water sites has gained the interest of the industry. In Europe, more than 80% available wind power capacity is located in water sites deeper than 60m [22]. As discussed in section II.5, the current designs of wind power turbines and foundation allow the establishment of a wind farm in a water depth of about 50 meters. For deeper water sites, floating offshore wind foundation is being developed, a technology that is yet at a nascent stage of development. Commercialisation of floating foundation is expected between 2020 and 2025. The development of floating wind technology will require a new set of wind turbine design as well as floating cables.

In Europe between 2013 and 2015, there have been about 88 million Euro investments in R&D activities related to floating wind foundations. This number is still less than 245 million Euro made by Asia but more than 60 million Euro made by North America[22].

Floating foundations benefit the wind market in several ways [51]:

- cost reduction due to larger mass production opportunities,
- higher potential for full-system assembly at the shore;
- larger site availability and access wind sites with better wind speed,
- reduction of the impacts of human activities on marine ecosystems
- the cheaper foundation even for 50 meters depth water, and
- less damage to the seabed and marine life due to less aggressive installation.

Currently, in the market, there are different types of floating foundation being tested. These foundations could be categorized into three main groups of spar-buoy, semi-submersible and tension leg platform, explained below (Figure 13).

- **Spar buoy**: in this type, a cylinder with low water plane area is ballasted to keep the centre of gravity below the centre of buoyancy. The foundation is fixed to the seabed by catenary or taut spread mooring lines with drag or suction anchors. In this model the design is simple, the cost of installing a mooring line is little, and there is lower chance of critical wave induced motions. However, there is a need for heavy lifts vessels and is applicable only in water deeper than 100 meters.
- **Spar-submersible**: in this type, a number of large columns (often 3) is connected by bracing or submerged pontoon. The columns assure hydrostatic stability and the pontoon provides buoyancy. The foundation is connected to the seabed by catenary or taut spread mooring lines and drag anchors. This floating foundation type has benefits such as transportability by a draft below 10 meters or conventional tugs, or cheaper cost of mooring lines. On the other hand, they are more sensitive to critical wave-induced motions, the tendency to use more material and have complex fabrication compared with other types.
- **Tension leg platform**: in this type, a central column and arms are connected to tensioned tendons which secure the foundation to the suction/piled anchors. This model has a lower mass and could be assembled onshore and dragged offshore. On the negative side, the stability of this foundation is harder to maintain during installation and transportation. Besides this foundation have high mooring cost and high-frequency dynamic which could negatively affect the turbines.

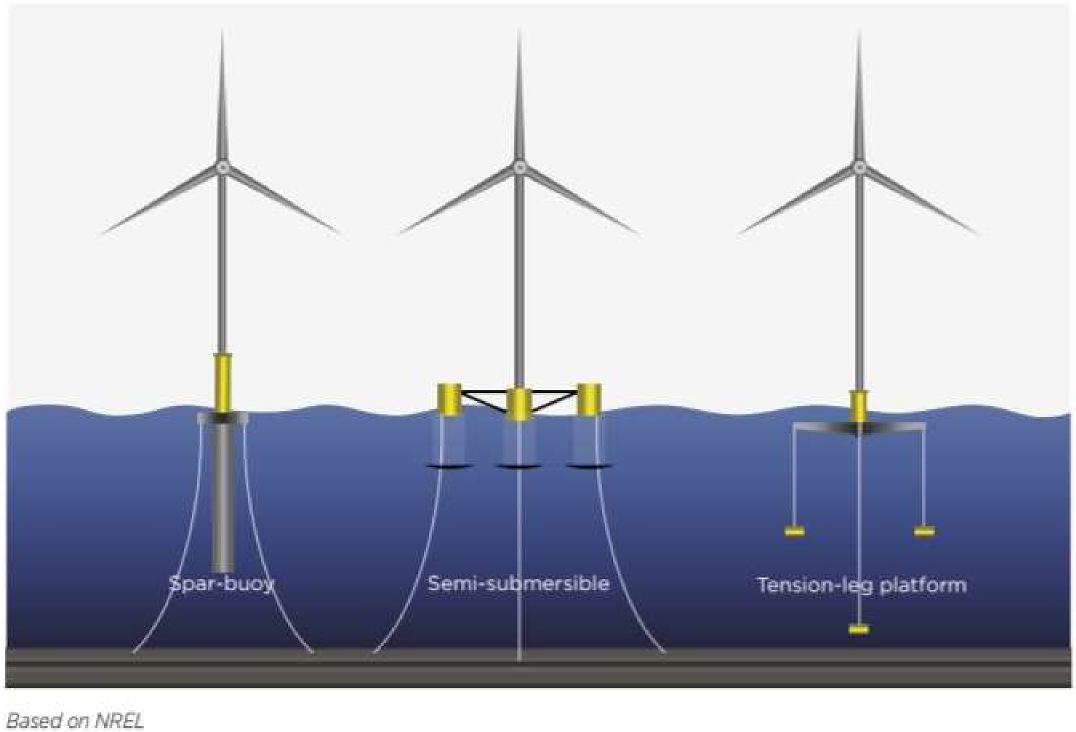


Figure 13 – Different types of floating foundation for offshore wind turbines [48, p.6]

Th above discussion indicated that the development of a floating foundation is needed in order to realise the full potential of offshore wind technologies in the market. Further development of the floating foundations necessitates the involvement of industry, researcher and policymakers in order for it to reach commercialisation and be successful. Some of the effective actions for the accelerated development of these foundations are listed below:

Actions

- The most significant innovations for floating offshore wind are improvements in support structure design and manufacture. These innovations reduce the cost of the support structure, which is the main source of the cost difference for floating farms.
- Innovations in the support structure can improve the balance of plant. Improvements in design and manufacturing, through holistic tower design, in which the tower and support structure are designed and optimised together will be important for floating structures.
- An increase in the turbine power rating should be made in order to reduce the cost of these technologies. Innovations in the turbine nacelle, the introduction of a number of next-generation drive trains, including improved direct-drive and mid-speed generator solutions, can reduce OPEX through greater reliability.
- Innovations in rotor components enable an increase in energy production. To do so, key innovations relate to improved blade aerodynamics and manufacture as well as the optimisation of turbine components.
- Improvement in lifting ability will be needed. Depending on the construction approach, this could impact dockside cranes or vessels.

- Innovation and development should aim at reducing the size of the floating wind power platform and improve its installation procedure. This reduction of floating foundations' size and of weight can contribute to the reduction of CAPEX [52]
- Development of floating transformer, better control system and improved mooring and anchoring could contribute to CAPEX saving,
- Supportive policies and financial schemes are needed to assure investors about the profitability of their investments in floating wind farms. Note that, any investment in offshore wind power reaches revenue generation after actual energy production. Therefore, any investments made at the beginning of the project should be considered as long-term investments. This calls for the development of long-term policy mechanisms to assure investors about the profitability of offshore wind projects. Lack of trust in the stability of policies has been noted a barrier to investments in floating offshore wind farms in some countries such as Scotland [52]
- Policymakers could contribute to floating foundation projects by facilitating private investments, extending support to the demonstration plants and contributing to the visibility of these technologies in the market.
- Floating wind power has limited environmental impact on the environment, due to its particular design below the water. Further research and publications about the actual impact of floating offshore wind farms on the marine life can enhance the technology position in the market [52].
- The industry should collaborate together and be transparent about the foundation's cost and risks in order to share the risk of investments in these immature technologies and to reach the optimum solution.
- Researchers can contribute to the development of floating offshore wind foundations through their focus on cost and risk reduction by using modelling and optimisation methods, assessing robustly varied site characters, wind potential and power output [51].
- The three biggest innovations in OMS are improvements in personnel access; the optimisation of blade inspection and repair and the introduction of condition-based maintenance for turbines.

II.6. Cost projections

The technological innovations discussed above will positively influence the technologies' performance as well as cost. Within the framework of the REEEM project, the cost projection for wind power is conducted using DELPHOS™, a platform developed by InnoEnergy in order to analyse the impact of innovations on energy cost and make it publicly available (see BOX I).

In DELPHOS™ the cost projections are provided till 2030. In this report, for projections after 2030, we made assumptions based on the opinion of InnoEnergy's experts. The projections are consolidated also with the data listed in the JRC technical report published in 2018 [53], and also during the stakeholder workshop held in April 2018.

BOX I. DELPHOS™

DELPHOS™ is developed by InnoEnergy in order to enable evaluating the effect of innovation on the LCOE across technologies by making a series of cost models. The platform allows industry, investors, researchers, and policy makers to make robust investment decisions at a project level as well as to feed their R&D strategy definition processes. DELPHOS™ is currently available for some renewable energy technologies including onshore and offshore wind power. Detailed description and assumptions of DELPHOS™ could be found online in InnoEnergy webpage and in Deliverable 2.3. of the REEEM project [100]. As explained in this report, DELPHOS™ studies the impact of innovation by considering its influence on the total cost based on the formula in Table 3:

Table 3- Formula for modelling the impact of innovation in DELPHOS

Impact / adjuster	Range	Value / formula
Maximum technical potential impact of innovation scenarios on each project element	[-100%;100%]	a%
Relevance to site type and tech type	[0;100%]	b%
Commercial readiness at FID date	[0;100%]	c%
Market share for Tech type at FID date	[0;100%]	d%
Anticipated impact	***[-100%;100%]***	***axbxcxd%***

Onshore wind power

Figure 14 depicts the cost break down of onshore wind power. The figure shows that the cost of wind turbine and operation and maintenance (O&M) constitute the highest costs of wind power. In order to estimate the cost of wind power until 2050, all the innovation cases discussed in the last section are considered and their influence on the final cost of technology is assessed.

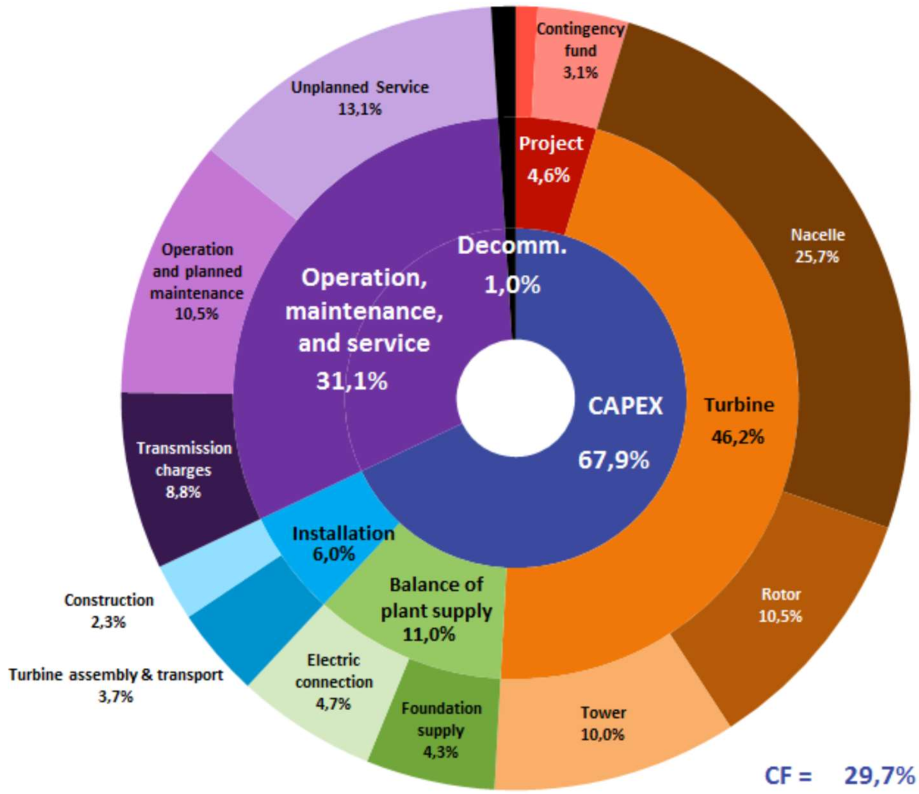


*Figure 14- Break down of LCOE for a typical onshore wind farm constructed in 2013**
**To better understand the figure, note that turbine, balance of plant supply and installation are the broke down parameters for CAPEX; and nacelle rotor and tower are the broke down parameters for turbine.*

Note that for cost projections in DELPHOS™ the following assumptions are made for onshore wind farm based on the most common conditions. Note that in DELPHOS™ the average EU site condition is considered for cost calculation. For onshore wind these assumptions are closest to the site conditions in the UK.

- Wind sites are divided into two groups of: 1) low wind site speed with average wind speed at hub height (m/s) 7.0 and wind shear exponent 0.14 or 2) High speed wind site with average wind speed 9.0 and wind shear exponent 1.10
- Air density is assumed to be 1.225 kg/m3
- Cost estimations are for a wind farm with average 50MW
- Initial operational lifetime is considered to be minimum 20 years
- Development and construction costs are endured by the project developer
- A multi-contract approach is used to contracting for construction

The assumptions made for the wind turbines are as the following:

- The turbine is rated at 3MW and certificated to international wind turbine design standard IEC 61400-1.
- The turbine used on the Low Wind Site is certificated to IEC Class III.
- The turbine used on the High Wind Site is certificated to IEC Class I.

Regarding the support structure and construction, the following assumptions are made:

- Hub height on the Low Wind Site is 120m, typical of IEC Class III Turbines and hub height on the High Wind Site is 100m, typical of IEC Class I Turbines. A concrete slab foundation with tower base embedment in good ground conditions (bearing pressure, chemical composition etc.).
- Three core 33kV AC cable is used.
- Transport is on a just-in-time basis, without significant holding area on site.
- Construction is carried out sequentially at each base, with tower, nacelle and rotor installed in a single visit.
- Operation and management system assumptions are Local service team with 7-day working within 'office hours' and remote access via SCADA system.

Several innovation assumptions are made for the projection of techno-economic data for wind power in DELPHOS™. The assumptions include almost all the features that are described in this roadmap relating to wind farm development, turbine nacelle and rotor, the balance of plants we well as O&M[5].

Table 4 and 5 illustrate techno-economic data for the two types of the wind turbine (class I and class III), each in low and high wind conditions. Note that in some cases the technology CAPEX increases due to innovations. This increase is associated with lower OPEX or higher AEP which means that the overall LCoE of the technology is improved.

Table 4- Techno-economic data for onshore wind in low wind and turbine IEC Class III till 2050

	Unit	2015	2020	2030	2040	2050
Technical lifetime	years	20	20	20	20	20
CAPEX	€/MWe	1458311	1485144	1505269	1300000	1000000
OPEX	€/MW/yr	36676	35469	34560	22366	15454
Net AEP	MWh/yr/MW	2676	2732	2877	3329	3942

Table 5- Techno-economic data for onshore wind power in high wind for turbine IEC Class I till 2050

	Unit	2015	2020	2030	2040	2050
Technical lifetime	years	20	20	20	20	20
CAPEX	€/MWe	1280000	1272320	1271680	1300000	1000000
OPEX	€/MW/yr	42282	40836	39690	25600	17662
Net AEP	MWh/yr/MW	3493	3566	3623	3942	4380

[5] *For full list of innovation please refer to Delphos webpage on: http://www.innoenergy.com/delphos/*

Offshore wind power

The cost breakdown of offshore wind is depicted in Figure 15. The cost projections for offshore wind power are taken from DELPHOS™. Also, in this case, all the technological innovative solutions and improvements suggested in the last section are considered.

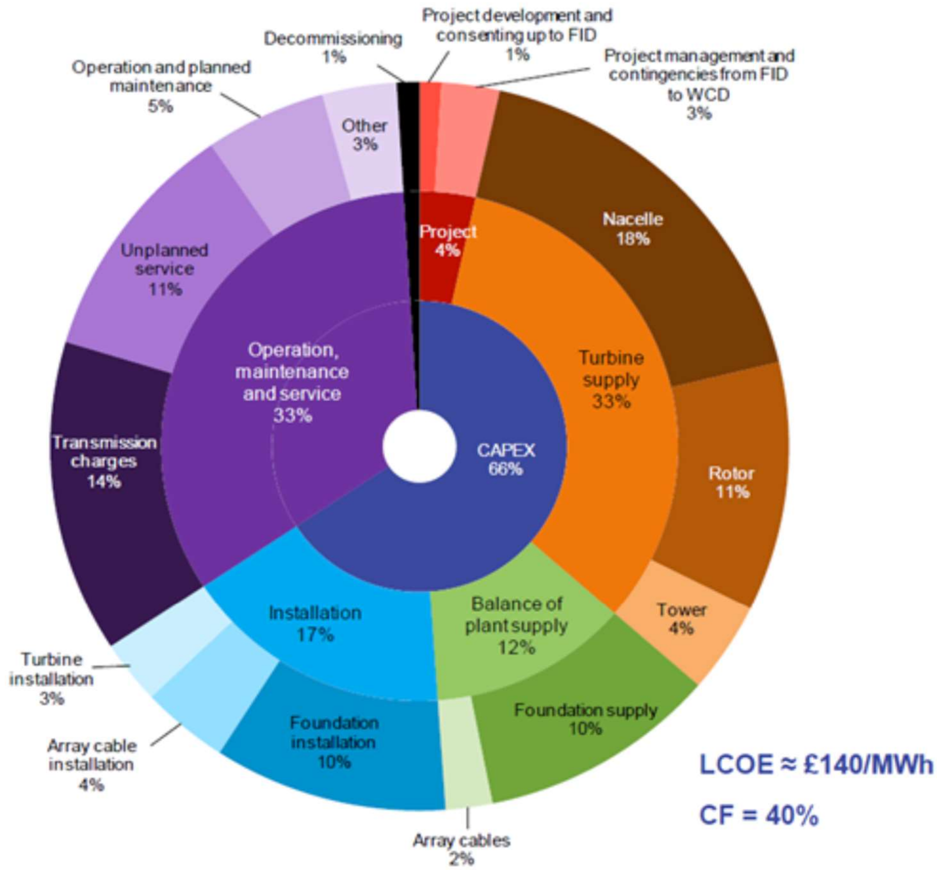


Figure 15- Break down of LOES for a typical offshore wind farm constructed in 2013

DELPHOS™ general assumptions for offshore wind sites are listed in Table 6. For the offshore wind technology, these site conditions are available and similar to the ones in the UK.

Table 6- Assumption for offshore wind sites in Delphos

	A	D
Wind speed (m/s)	9.0	10.0
Average water depth (m)	25	35
Distance to port (km)	40	125

DELPHOS™ assumes Four types of wind turbines are installed in each site: 6, 8, 10 and 12 MW.

Considered innovation scenarios for offshore wind farms in DELPHOS™ are related to the farm development, turbine nacelle and rotor, balance of plants, farm construction as well as O&M:

Based on the above-stated assumptions, Tables 7 to 14 illustrate techno-economic data for 4 types of offshore wind power for site A and site D separately. The cells are shaded in grey when the technology is phased out or has not yet entered the market in the specified year.

Table 7 – Techno-economic data for offshore wind power 6 MW in site A till 2050

	Unit	2015	2020	2030	2040	2050
Technical lifetime	years	25	27			
CAPEX	€/MWe	2054775	1987476			
OPEX	€/MW/yr	85237	82522			
Net AEP	MWh/yr/MW	3730	3758			

Table 8 – Techno-economic data for offshore wind power 8 MW in site A till 2050

	Unit	2015	2020	2030	2040	2050
Technical lifetime	years	25	27			
CAPEX	€/MWe	1975149	1911423			
OPEX	€/MW/yr	75386	72404			
Net AEP	MWh/yr/MW	3794	3838			

Table 9 – Techno-economic data for offshore wind power 10 MW in site A till 2050

	Unit	2015	2020	2030	2040	2050
Technical lifetime	years		27	30	30	30
CAPEX	€/MWe		1892470	1698316	1358652	1018989
OPEX	€/MW/yr		66240	57141	44836	33627
Net AEP	MWh/yr/MW		3901	4156	4323	4495

Table 10 – Techno-economic data for offshore wind power 12 MW in site A till 2050

	Unit	2015	2020	2030	2040	2050
Technical lifetime	years			30	30	30
CAPEX	€/MWe			1687752	1350201	1012651
OPEX	€/MW/yr			54425	44557	33417
Net AEP	MWh/yr/MW			4220	4389	4564

Table 11 – Techno-economic data for offshore wind power 6 MW in site D till 2050

	Unit	2015	2020	2030	2040	2050
Technical lifetime	years	25	27	30	30	30
CAPEX	€/MWe	2231157	2151199			
OPEX	€/MW/yr	101637	97674			
Net AEP	MWh/yr/MW	4237	4268			

Table 12 – Techno-economic data for offshore wind power 8 MW in site D till 2050

	Unit	2015	2020	2030	2040	2050
Technical lifetime	years	25	27	30	30	30
CAPEX	€/MWe	2122899	2048474			
OPEX	€/MW/yr	92747	88299			
Net AEP	MWh/yr/MW	4294	4344			

Table 13 – Techno-economic data for offshore wind power 10 MW in site D till 2050

	Unit	2015	2020	2030	2040	2050
Technical lifetime	years		27	30	30	30
CAPEX	€/MWe	7	2018024	1798070	1438456	1078842
OPEX	€/MW/yr		75820	63068	47469	35602
Net AEP	MWh/yr/MW		4402	4686	4874	5069

Table 14 – Techno-economic data for offshore wind power 12 MW in site D till 2050

	Unit	2015	2020	2030	2040	2050
Technical lifetime	years			30	30	30
CAPEX	€/MWe			1785527	1428421	1071316
OPEX	€/MW/yr			56475	47138	35353
Net AEP	MWh/yr/MW			4748	4938	5136

Breakthrough scenario: the case of offshore wind with floating offshore wind foundation entering the market in 2030

Table 15 illustrated the cost projection for the cost of the floating offshore wind power foundations.

Table 15 illustrates the cost projection for the cost of the floating offshore wind power foundations. In the REEEM project, we analyse a scenario where this type of offshore wind technology will enter the European electricity market by 2030 with a more competitive price than other types of offshore wind technologies fixed to the seabed. This projection is considered as modelling input for a 'RES Innovation' breakthrough scenario, assessing the potential role of offshore wind with floating foundation within the entire EU energy system.

Table 15 – Techno-economic data for offshore wind power in high innovation scenario with floating foundation till 2050

	Unit	2015	2020	2030	2040	2050
Technical lifetime	years			30	30	30
CAPEX	€/MWe			1674	1339	1004
OPEX	€/MW/yr			70000	58000	47000
Net AEP	MWh/yr/MW			4512	4738	4975

III. Solar Power: Photovoltaic

III.1. Description and history

Solar power, in particular, Photovoltaic (PV), is among the fastest growing renewable energy technologies with a total 104 GW installed capacity in Europe as of 2016 [54]. In several European countries, PV provides more than 5% of the annual electricity demand. Currently in the EU energy industry, PV supplies 3% of total electricity demand [55]. Solar PV account for more than half of global renewable energy investments in 2015, yet its overall contribution to the world energy generation remains low. This low share could be explained by factors such as the technology's low capacity factor, high initial investment costs, or variable electricity generation.

PV with different modular sizes allows different market segments, including individuals and small businesses, to invest in this technology [56]. In other words, PV provides a wide spectrum of investment options for both on and off-grid user, from small lighting system in villages to utility-scale projects. The short lead time of PV projects (from days to months depending on the plant size) and their modularity, which allows for scaling up are another reason making solar PV a desirable technology for power production [57].

PV is a fairly mature and proven technology which has already reached grid parity in some regions. Development and deployment of PV systems have contributed significantly to the reduction of the technology price. PV already provides a high share of electricity demand in some European countries such as 7% in Germany or 9% in Italy [57].PV's share is expected to grow in the future and provide 10-15% of electricity of EU by 2030.

Currently, in Europe, Germany with 35 GW and Italy with 18 GW installed capacity are the two biggest markets for PVs (Figure 16) [44]. Europe was considered as a leader of the PV market in the world. However, this role now is debatable as the share of Europe in the world's new PV installation has dropped from 74% in 2011 to 55% in 2012, and only 29% in 2013 [44]. Having said that PV has still a huge growth potential in Europe, given its possibility to be installed on different locations and scales.

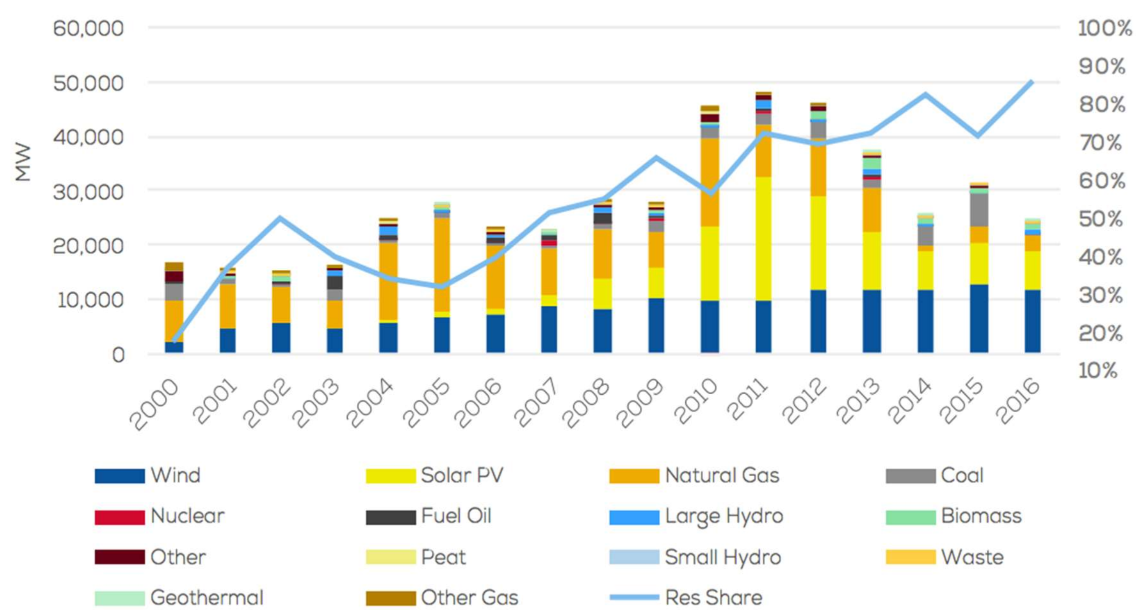


Figure 16 – Annual installed capacity and share of renewables in Europe [10]

III.2. Photovoltaic technology

PV types and components

There are different PV systems available in the market. The systems need to be adjusted based on consumers' requirement and site condition. A PV system generally includes a solar panel, inverter, breaker box, and meter. So far, different types of PV technologies are introduced to the market. The technologies are made of different materials and have diverse technical characteristics. Below the main types of PV technologies are explained and their market shares are discussed:

- ***Crystalline silicon (c-Si) technology**:* These so-called first-generation PV systems (fully commercial) use the wafer-based crystalline silicon (c-Si) technology, either single crystalline (c-Si) or multi-crystalline (mc-Si). Silicon is an abundant element in the earth's crust [57]. This technology entered the market around 50 years ago and still has the largest market share by far (about 93% market share in 2015, [57]). Before 2016, this market share was mainly multi-crystalline C-Si. However, this has changed in the recent years with a larger contribution of single- crystalline c-Si [58]. Commercial production of c-Si module began in 1963 [56] when the Japanese company Sharp Corporation installed 242 Watt on a lighthouse. In recent year the share of single and multi-crystalline The c-Si technologies are fairly mature with an efficiency of about 21-23%, having the theoretical efficiency limit of 29% [57]. In spite of the technology maturity, cost reduction is possible through technological innovation and economy of scale in the production phase.
- ***Thin film**:* the second commonly installed PV technology is a thin film, pertaining to the second-generation PV systems. It consist of three main groups: 1) amorphous Silicon (a-Si) (0.5% market share in 2015); 2) Cadmium-Telluride (CdTe, 4% market share in 2015); and 3) Copper Indium-Selenide (CIS) and Copper-Indium-Gallium-Diselenide (CIGS) (2.5% market share in 2015 [57], [56]. There is a long history of R&D research on thin films resulting in the production of thin films in larger quantities. Thin films potentially could offer a cheaper PV than c-Si PVs, but their efficiency would remain lower than c-Si. This film can be packed into the flexible and lightweight structure and easily be integrated into the buildings, suitable for Building Integrated PV (BIPV) application.
- ***Third generation PV technologies*****:** This type of technologies is in precommercial stage and still under development. There are four types of third-generation PV: 1) Concentrating PV (CPV); 2) Dye-sensitized solar cells (DSSC); 3) Organic solar cells; 4) advanced inorganic thin film and novel and emerging solar cell concepts. While some of these technologies are to be commercialised, their success depends on the market share which third-generation PV technologies manage to regain from the already established technologies.

III.3. Photovoltaic market

The European PV market has a long and successful development history. In recent years, this position has been threatened by a rising competition from Asian companies. This competition calls for a strategy to keep PV industry strong in Europe through re-launching cell and module manufacturing. The Set Plan implementation report [55] explains three reasons for keeping the European PV industry competitive: "*(1). There is the risk that once the central segment of the PV value chain is lost, soon after the upstream segment (i.e. equipment for manufacturing cells and modules) follows because of the continuous interaction and exchanges between the two industrial segments which generally requires logistic proximity; (2). All the analyses point to an ever-larger role for photovoltaics in the future global energy system. Ensuring a strong EU position in this industry provides a source of economic growth and for a continued important role in innovative energy technologies, and, importantly, increased energy independence; (3) The 'Clean Energy for All Europeans' proposal announced a Clean*

Energy Industrial Forum to support the EU manufacturing industry (included the photovoltaic industry) to take advantage of the growth opportunities arising as part of the energy transition".

Table 16 summarises the main parameters that influence the development of the European PV industry in terms of policy and legislation, society and value chain. The table illustrates the findings of this reports and its conducted analyses.

Table 16 - Overview of the studied market parameters with an influence on the solar PV deployment

	Evaluated parameters
Policy and legislation	- *Policy support mechanisms* - *Diversified national policy frameworks* - *Policy stability* - *Stakeholder involvement and permits* - *End of life supports and policies*
Society	- *Social acceptance* - *Higher cost for consumers* - *Climate conditions* - *Consumers engagement and Community project* - *Lack of knowledge*
Value chain	- *The strength of the value chain*

Policy and legislation

Policy Support Schemes

Renewable policies are among the most effective means behind the development of the PV market. Policies such as FIT or TGC has managed to successfully promote investments in PVs and support a larger deployment of this technology in the market. Consequently, as the result of the economy of scale as well as learning-by-doing the system price is reduced by about 50-80% between 2005 to 2014. This cost reduction has opened the door for further growth of the PV sector even without the support of policy incentives which was necessary for the past. In fact, in southern Europe, the cost of electricity generated by PV systems are already below the residential electricity prices (meaning the technology has reached grid parity without incentives).

Diversified national policy frameworks

In several European countries, such as Germany, the enacted policies and regulations consider the diversity of solar PV investors (e.g., they differentiate between solar PVs installed at utility scales, energy companies or on small-scale by residential investors). This is an effective way of designing policies, as in the renewable energy market investors are different and have thereby different needs [25].

Policy stability

The policy supports are different in different member states. These support mechanisms have been changing their types and their amount through the years. In some countries, policies have been reversed and that has resulted in a lack of trust in available policies and created a barrier for investments in PV market. This has been the case in countries such as Italy and Spain, where retrospective reduction of FIT happened.

Stakeholder involvement and permits

During the policy-making process, it is important to involve all relevant stakeholders of PV projects in a region. Otherwise, lack of consent by some stakeholders could create barriers to acquire permits for the development of PV projects.

End-of-life supports and policies

Policies can improve resource and environmental impact of PV production though specific end-of-life management policies. Example of these policies is treatment standards and recycling requirements. Currently, Europe is the leader in adapting PV-specific waste regulations [57] when other countries such as China and Japan are only investigating these policies.

Society and Environment

Social acceptance

Solar energy typically has a positive image and is widely supported. Disturbance of solar panels is considered low as they do not generate noise, are not visible for long distances and are not harmful to environment or animals [59]. Several studied have indicated this social support for solar PVs. A study in the UK recorded the level of support for solar PV as high as 80% [60]. A study in the island areas of Greece shows that respondents considered solar energy as the most environmentally friendly form of energy [61]. Expert interviews in Finland similarly suggest that there is no actual opposition to solar energy [59].

Extra cost for consumers

The cost of PV systems is still higher than alternative options in some countries. Besides, in some cases supporting renewable energy market is often coupled with extra cost for consumers since they need to pay for the additional support provided by governments. This is particularly true since renewable technologies were more expensive 15 years ago and consumers are still paying for that cost. This higher cost in some regions has decreased electricity consumers' interests in renewable technologies.

Climate condition

The environmental factor is identified as one of the main parameters that could incentivise or demotivate investments in solar PV. While in some European countries undesirable climate conditions constrain the interests in solar PV, in other countries these parameters act as a driver

Consumer engagements and community projects

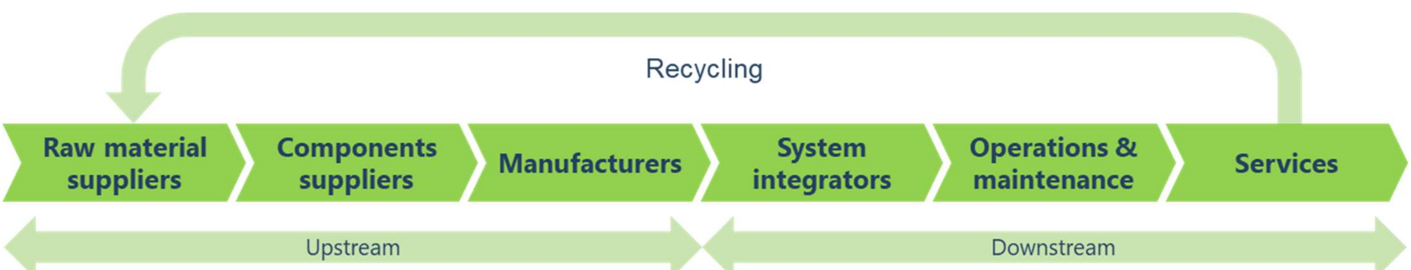
Society acceptance for solar power has been improved in Europe through the application of community projects. In this investment model, citizens (private households, communities, etc.) own or participate in the generation of sustainable energy. The generated energy will be sold collectively and the profit will be split among the participating citizens. In these cases, the citizens could live close to one another in the same neighbourhood or live geographically distant from each other.

The positive influence of community investment in solar power could be seen in Germany. The expansion of community solar project in Germany has led to the reduction of the technology prices and increased the attractiveness of these projects. In fact, 50% of all renewable energy generation in Germany are community-owned[6]. Community-owned renewable energy generation in Germany is supported by the government since the 1990s when the policies initiated to give priority grid connection for renewable energy and obliged grid operators to buy power from renewable energy generators. An example of a community-based solar project is in Freiburg, Germany, where solar PV is strongly supported. In this city, citizens are encouraged to invest in such projects using an online tool called "FREE-Sun". This tool identifies roof spaces available for solar PV and facilitates the planning process of community-based PV projects.

Lack of knowledge
Lack of knowledge about the benefits and services of solar PVs in the society has influenced the deployment of PVs in the market. For example, lack of knowledge of planners during construction of new buildings does not allow them to recommend PVs. In another example, adaptor improperly use or maintain PV technologies [62]. Note that, in some countries, unsuitable buildings architecture is the factor that constrains the interests of building planners and designers in solar PV. An example of this case is Scottish tenement buildings which offer limited roof space for solar cells [62].

Value chain

In the early 21st century, Europe was a pioneer in the production of PV modules and the development of new PV technologies. However, Europe lost its position in the global market share in wafer, cells and module production due to reasons such as overcapacity, shortage of silicon, or economic crisis. Europe still has a competitive position on some solar PV equipment, such as inverters (Solar PV value chain is shown in Figure 17). In 2016, there was more 81000 jobs in Europe available related to solar PV market. As shown in Figure 18, more than half of these jobs were related to O&M and installation of solar PVs.



1. Wacker Polysilicon AG (Germany)
2. GCL-Poly Energy Holdings Ltd. (China)
3. OCL Company Ltd. (Korea)
Top 3 companies own 45-50% Market Share as of 2016

1. Jinko Solar (China)
2. Trina Solar (China)
3. Canadian Solar (China)
Top 3 have 24% Market Share as of 2016

1. First Solar
2. SOLV
3. SolarCity
4. SunPOwer
5. MaxGen Energy Services

Major European Solar Portfolios :
1. Octopus Investments (Investor UK)
2. Enerparc AG (IPP/investor in Germany)
3. Foresight Group (Investor/asset Manager UK)

Figure 17 – Actors active in the PV value chain in Europe [63]

[6] *http://climatepolicyinfohub.eu/community-energy-projects-europes-pioneering-task#footnote1_3079twu*

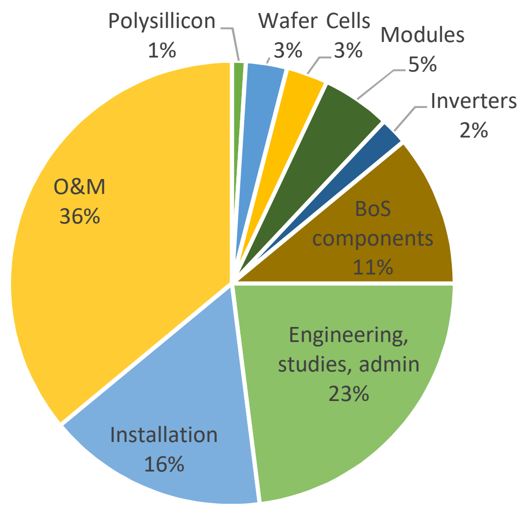


Figure 18 – share of jobs in the PV market in EU28 [64]

III.4. Additional barriers and bottlenecks

The following points summarize the technological barriers behind PV technologies:

- **Intermittent power generation/balance of system:** One of the main barriers behind the PV technology is their dependency on natural resources and thereby intermittent power generation which lowers their reliability as a source of power. A large installation of PVs as intermittent energy technologies could also challenge existing power mix and grid infrastructure.
- **Integration of solar PV in the system:** another issue with solar PV technologies is that the power from solar PV is not always produced where it is needed most. This means that measures need to be taken in order to fully and efficiently integrate solar PVs in the market. Examples of such measures are investments in storage technologies or enhancing grid capacity.
- **Uncertainty about who pays for the cost of flexibility: a** larger share of variable renewable power is associated with the need for investing in methods to enhance the flexibility of the power system. It is however still unclear who should bear this additional cost in the system. This further demotivates stakeholders to engage in the solar PV market.
- **Considering solar PV a luxury good rather than a necessity in power system:** Many consumers do not believe in the necessity of solar PV in the power system and only view this technology as a luxury good. This calls for the need for behavioural change.
- **Lack of suitable locations**: as of yet, solar PVs has been developed in locations with suitable environmental conditions to capture solar power. This means that further deployment of solar PV could be challenging as the number of available locations with the suitable condition is decreasing. This limited availability of locations calls for tighter collaboration with grid community, construction sectors as well as energy storage developers.
- **PVs specification and performance**: Different PV products with varied specifications and standards are available. Some of these specifications raise concerns about safety, durability or efficiency of PVs. The concerns and negative perspectives have created barriers for the further development of solar PVs.

- **Upfront cost**: Deployment of solar PV requires high initial costs for solar module and installations. Additionally, the investor endures others cost such as maintenance and repair costs. The perception of these costs by the investors with inadequate governmental supports or funding create barriers for the development of solar PVs. Besides, many available financial schemes are associated with high-interest rates. This is particularly true for residential solar PV, which is still costlier than utility scales ones.
- **Raw material and recycling**: solar PV technologies utilize different raw materials. This means that with a larger production of solar PV technologies availability of some raw material could become a problem in the future. This utilization of raw materials creates concerns regarding both resource depletion (raw material scarcity) as well as a dependency on countries with these raw materials.
- **Raising competition from Asia**: Currently, in the European market, the share of products of Asian competitors has increased in the industry (Jinka Solar, Trina solar), to the point that many of the European players have lost their market. This calls for policy schemes or business strategies to support the European PV market players and securing the sustainable supply chain (see Figure 17).

III.5. Innovation outlook

Market solutions

- **Stable policies**: Establishing a stable regulatory framework could have an influence on the development of the PV industry and motivate further investment in renewable energy technologies. This is because investment in renewable energy, including solar PV, is associated with high upfront cost and therefore vision for a long-term revenue is essential to reduce the risk of the technology.
- **Engagement of stakeholders in policy-making**: through this process policymakers become aware of the needs and requirements of different stakeholders and therefore can design more effective policies.
- **Improving end-of-life and recycling processes**: Among the main approaches that can reduce solar PVs' cost is recycling of PVs [57] or improving the processes that can reduce the production waste of these technologies (e.g., NexWafe). Through the recycling and waste reduction, many raw materials are recovered. The raw material recovery creates economic value and could be sold into global commodity markets to produce new solar panels. These benefits, call for innovation in collection, recovery and recycling of solar PVs. Currently in the market recycling of solar PV allows recovery of glass, aluminium and copper (about 85% of the mass). Enhancing recycling processes allows recovering of other materials, some even hazardous, such as cadmium and lead. With higher number of solar panel reaching their end of life, the importance of recycling and its potential effect on material availability is becoming more significant. The improvement of recycling processes could be supported through policies, advanced research and more industry investments
- **Grid integration:** in order to successfully integrate solar PV into the grid system there is a need for improvement of components enabling better integration of solar PV. This is possible through the development of devices and new services improving controllability and forecasting of PV system outputs or enhancing the lifetime and durability of integrated electronics. This improvement would reduce the Balance of System[7] (BOS) cost to about 10-15% [44]. This will result in a higher contribution of PV systems into the energy system and motivate further investments in these technologies.
- **Local community engagement across European countries**: This investment model actively engages citizens in renewable energy generation and hence increase social acceptance of renewable energy. Community-owned projects also have benefits such as increasing employment opportunity, harnessing natural resources and building social capital [65]. Community approaches have two types: bottom-up

[7] *The balance of system includes all the costs of the system other than the photovoltaic panels.*

and top-down. In the first case, citizens own the projects. In the second case, citizens are only partly involved in the projects, and they can buy a share in already established projects by actors such as utilities.

- **Increasing society knowledge and awareness about different types of solar PV**: this could motivate larger local investments in solar PV, ease acquiring permission process, and positively contribute to social acceptance.

  Training human resources: training necessary human resources for the future market is necessary not only to meet the needs of the future energy market but also to compensate for the job loss caused by the energy transition.
- **Creation of common financing scheme (cross-border) between all EU countries**: such financing schemes would motivate cross borer engagement in solar PV projects which not only increase the potential funding budget for these technologies but also enhance cross-border capacity exchange among EU member states. This would create a win-win situation for countries that are engaged in the development and deployment of PV technologies.
- **Creation of new business cases for solar PVs:** Investments in solar PVs could be taken by different groups of society as long as the projects are economically feasible. An example of new businesses is creating power-to-x cases in which power is produced by solar PVs. Developing business models which creates values for consumers could be also an effective way to increase the share of PVs in the power market.

Technology innovation

The technologies contained in the group of solar PV are fairly mature, yet, through technological innovation their performance could be improved, their cost reduced and their outdoor lifetime (e.g., >25 years) and efficiency increased. Below, several recommendations for potential technological innovation are listed. The recommendations are categorized by PV types.

- **Improvement of technologies' characteristics:**
  - **Wafer-based crystalline silicon (c-Si)** [44]**:**
    - **Improving the quality and usage of silicon materials in c-Si:** there is a need for innovation to improve the usage of materials in the c-Si PVs, in order to reduce the cost of technologies. Recycling and reusing materials could contribute to this improvement. Introduction of a new production method (e.g., new wafer production by NexWafe) can enhance production processes of c-Si PVs.
    - **Improving process and design needed for c-Si photovoltaic**: integration of better processes could result in optimising production yield, increasing efficiency and output. This is possible through the introduction of a control system for industrial processing equipment and quality insurance, or advanced cell architecture for losses reduction. Improvement of defect management systems could also contribute to the development of wafer-based c-Si PV.
    - **Improving module c-Si PV:** through different production methods, silicon PV module performance could be improved (cell to module power ratio even higher than 1). This could be for example through new encapsulation based on lighter and thinner materials, soiling and antireflective solutions, development of advanced interconnections for ultra-thin-cells. This assures higher energy output for the longer term. Overall, the CAPEX for module assembly lines should be reduced by 15%.
  - **Thin film photovoltaics**
    - **Technology improvement and cost-effective processes:** there is a need for improvement of material used in a thin film in order to replace/amend usage of some scarce and strategic

materials (e.g., Te, In, Ga, etc). This could result in a reduction of manufacturing cost per Watt and optimisation of production output. Moreover, there is a need for enhancing the lifetime and developing new predictive modelling tool in order to optimise the production output.
  - **Improving module efficiency:** it is recommended to improve model efficiency to average 12-17%, and increase the lifetime to more than 25 years. The CAPEX for manufacturing lines could be reduced by 30% in the next 5 years. To be cost-competitive in the market, module cost needs to be lower than 0.5 $/Wp. This is possible through different approaches including reduction of non-active interconnection Zones, reduction of degradation mechanism, improving efficiency by enhancing material, process and architecture, facilitating the lab to factory transfer through experimental and modelling studies, or replacement of glass back sheets [44].
  - **Antireflective coating:** development and improving antireflective, anti-soiling and anti-abrasive coatings that increase module efficiency.
  - **Improving encapsulation and modularization:** in order to improve the stability of PVs and assure their long-term output, there is need to develop encapsulates with improved properties for higher resistance to ambient conditions (temperature, humidity) decrease of module weight, suppression of at least one glass.
- **CPV**
  - **Cell efficiency:** There is need to improve the cell efficiency toward 50% [44] through approaches such as new cell architecture, enhancing industrial equipment, automated and optimised manufacturing processes, enhancing the reliability and the accuracy of the tracking system, developing automated systems to monitor the proper functioning of trackers and to detect failure.

- **Quality control**: monitoring of the quality of PVs' from production and installation to deployment can improve the performance of these technologies. This will reduce the PVs cost. For example in India, some identical equipment showed about a 20% performance difference due to varied installation quality [66]. Testing, modelling and demonstration of the technology could enhance the quality of the technology leading to an increase in overall system performance and improving their lifetime to more than 25 years at a low cost.
- **Hybrid technologies**: while solar PVs produce variable power, creating hybrid technologies through coupling of solar PV with other technologies such as storage could enhance solar PVs application in the market.
- **Flexibility in design and ease of installation**: currently solar PV development is limited to some locations. Development of various and flexible design for PV products can lead to a larger development and deployment of solar PV. Production of diverse products for different regional markets and various applications enable engaging different industries in the PV market. Deployment of solar PVs for the different application could result in value generation from PVs in new markets, e.g., benefiting from a dynamic electricity pricing environment by delivering ancillary services to the grid. A promising and recent example is the application of solar PV in buildings known as Building Integrated PV (BIPV). This is discussed in detail in the next section.

Advanced innovation scenario: the case of BIPV

Buildings are responsible for more than one-third of the final energy consumption of EU and about the same of electricity consumption. Hence, enhancing the efficiency of the EU building stock can contribute significantly to attaining the EU Energy and climate objectives.

BIPV can contribute to the improvement of energy efficiency in buildings. BIPV serves not only as a method for generating electricity but also as a building envelope [67]. BIPV could influence the PV market greatly, by expanding the suitable sites for installation of solar PV. BIPV can be integrated into buildings' exterior materials in several ways:

- They could be integrated into the building facade. They can replace or complement traditional view or glasses,
- They could be integrated into rooftops and replace batten and seam metal roofing, or traditional asphalt,
- They could be incorporated in the saw-tooth design of building façade, which increases access to the sunlight,
- They could be used in skylight system.

A recent study provides insights into the most common applications of BIPV in Europe. The findings show that one-third of the applications are realised in renovation projects and two third in new buildings. The highest share of BIPV applications is realised in residential buildings and public infrastructure [68].

The BIPV development is currently slow due to several barriers that are blocking its development [67]. The most known barriers are related to the technical specifications as well as its high upfront cost and long payback time. BIPV technologies are new and fairly immature in the renewable energy market and therefore they need further development in order to reduce their cost and reach their optimal performance. In order to improve the position of BIPV in the market several approaches could be taken:

- **Innovative material**: To find new material and system solutions that allow integrating PV into the existing building materials, while reducing their cost,
- **Varied product design**: Establishment of the flexible product line for a variety of products in different scales allows larger contribution of BIPV in the market,
- **Diverse energy system**: Development and installation of the smart junction box in order to integrate DC-DC or DC-AC conversion devices and protection devices,
- **Development of high voltage modules**: this innovation in technology would enhance the performance of solar PV,
- **Development of multifunctional PV products:** this would allow installation of PVs in approved construction materials for PV installation,
- **Varied manufacturing processes**: Development of automated low-cost manufacturing and control processes, including the development of new flexible equipment for different production lots with different geometries (e.g. small or large production lots, flexible compounds),
- **Specific policy designs for BIPV**: BIPV market is on early stage and still costlier than the other competitive options in the market. During this time, policymakers need to support and accelerate the development of BIPV market by enacting supportive policies and legislation,
- **Setting codes and standards**: although it is a complex process, the harmonisation of code and standards for performance and safety of BIPV could contribute to the faster development of this industry by reducing the cost and increasing the number of skilled workforces through right training programmes. Code and standards shall be applied during installation, safety and testing procedures.

III.6. Cost projections

Similar to the analysis of wind power, the influence of innovation on the cost of solar PV is studied using DELPHOS™. The cost projections are done for c-Si PV and thin film separately, because of the differences between the maturity levels of the technologies. Given the limited applications of the third generation of PVs, no cost projection is made for this type of PV technology. Note that, the capital cost of a PV system is composed of the PV module cost and the Balance Of System (BOS) cost. The PV module is the interconnected array of PV cells and its cost is determined by the costs of raw materials (especially silicon prices), cell processing/manufacturing and module assembly. The BOS cost includes the cost of the structural system (e.g. structural installation, racks, site preparation and other attachments) and, the electrical system costs (e.g. the inverter, transformer, wiring and other electrical installation costs). In the case of hybrid technologies, the battery or other storage system cost will be added to the overall system cost. Figure 19 shows the cost break down of solar PV.

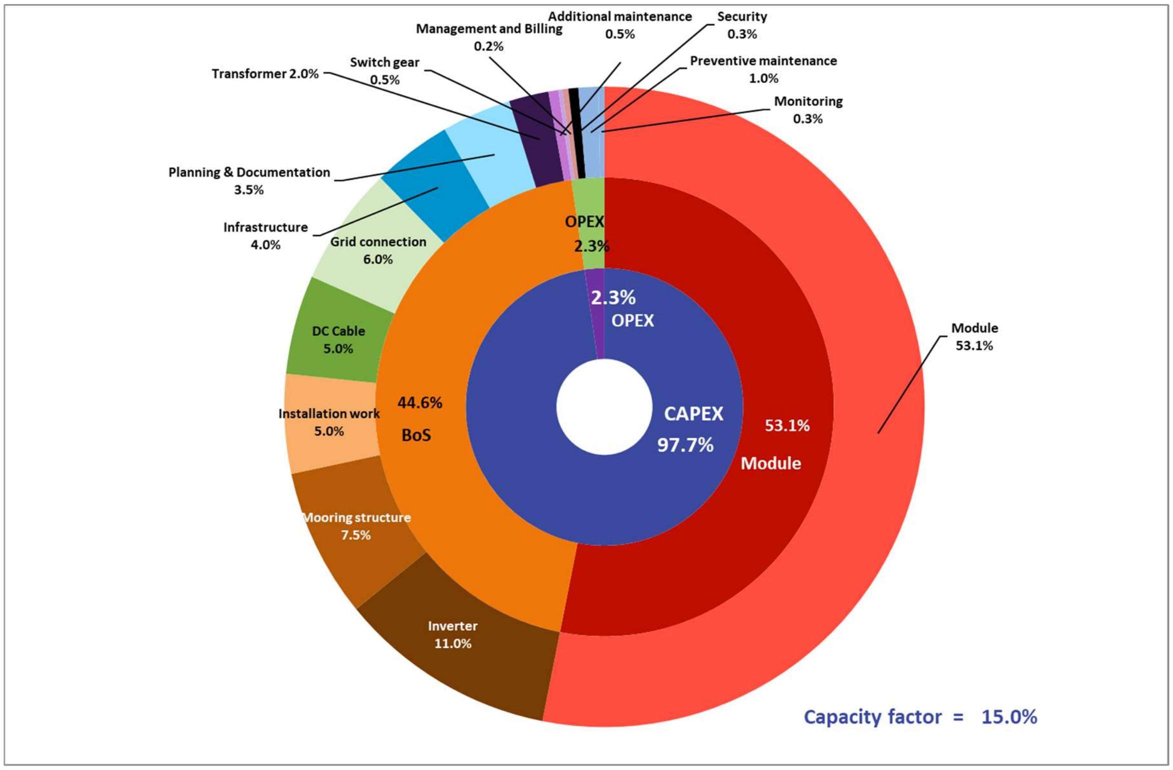


Figure 19- Cost breakdown of solar LCoE. This figure does not consider a complete lifetime, capacity factor, and capital interest on the OPEX [69]

Note that for Solar PV cost projections, similarly to wind power, DELPHOS™ provides projections till 2030. In this report, for projections after 2030, a number of assumptions are made based on InnoEnergy network of experts. The data are also consolidated with the data published in the JRC technical report in 2018 [53].

The general assumptions used in DELPHOS™ modelling of Solar PV technologies are listed below. Note that in DELPHOS™ the average EU site condition is considered for cost calculation. For solar PV technology, these assumptions are closest to site condition in Slovenia or Austria.

- General assumptions
  - 5 MW installed capacity for ground and <100 kW for roof-top C-Si
  - Global radiation (kWh/m2/yr) is 1320
  - Type of support is ground mounted and roof mounted
  - Depreciation time is minimum 25
  - EPC contract is used for contracting construction
  - The following module technology is utilized:
    - Conv c-Si: multi-crystalline silicon technology, average cell efficiency in the range of 17%, module efficiency in the range of 15,5% in 2015 (245 Wp/module)
    - High-efficiency c-Si: monocrystalline with average cell efficiency in the range of 19 to 20%, module efficiency in the range of 17 to 18% in 2015 (270 Wp/module)
    - Thin Film: average module efficiency in the range of 13 to 14% in 2015 (100Wp / module)
  - For inverters, 500 kW range is used in ground-mounted site type and 20 kW range is used in the building mounted site types.
  - For support structures, for ground-mounted installations, fixed aluminium structure with concrete foundations is used and for rooftop installations, roof racking is used.
  - For array electrical for ground-mounted installations medium voltage wiring for the collection system is used, and for Rooftop installations, low voltage wiring for the collection system is used.
  - For O&M of ground-mounted PVs, local service team is assumed within 1-hour driving distance, with 7-day working within office hours and remote management control room with data access via SCADA system.
  - For Rooftop installations, low-cost O&M strategy and no remote access.

Solar PV – C-Si

The innovation scenarios considered in DELPHOS™ modelling are related to c-Si cell manufacturing, module manufacturing, innovation in inverters and O&M costs. Based on the above assumptions, the calculation of DELPHOS™ until 2030 are shown in Table 17 to 20. The techno-economic analyses are conducted for two site conditions separately: ground installation and rooftop installation.

Table 17 – Techno-economic data for solar PV, convectional c-Si ground mounted technology till 2050

	Unit	*2015*	*2020*	*2030*	*2040*	*2050*
Technical lifetime	*years*	30	30	30	30	30
CAPEX	*€/MWe*	879550	818421	697307	483753	307843
OPEX	*€/MW/yr*	30800	28310	25400	17780	12700
Efficiency	*%*			*Cell 17% - Module 15.5*		
Net AEP	*MWh/yr/MW*	1320	1335	1359	2311	2719

Table 18 – Techno-economic data for solar PV, convectional c-Si roof mounted technology till 2050

	Unit	*2015*	*2020*	*2030*	*2040*	*2050*
Technical lifetime	*years*	30	30	30	30	30
CAPEX	*€/MWe*	1317800	1245189	1063069	724790	461230
OPEX	*€/MW/yr*	20000	17996	15590	10913	7795
Efficiency	*%*			*Cell 17% - Module 15.5*		
Net AEP	*MWh/yr/MW*	1320	1355	1406	2390	2812

Table 19 – Techno-economic data for solar PV, high-efficiency c-Si ground mounted technology till 2050

	Unit	*2015*	*2020*	*2030*	*2040*	*2050*
Technical lifetime	*years*	30	30	30	30	30
CAPEX	*€/MWe*	998287	880389	880389	598972	399315
OPEX	*€/MW/yr*	30200	27170	23940	16758	11970
Efficiency	*%*	*Cell 19-20% - Module 17-18%*				
Net AEP	*MWh/yr/MW*	1320	1341	1368	2326	2736

Table 20 – Techno-economic data for solar PV, high-efficiency c-Si roof mounted technology till 2050

	Unit	2015	2020	2030	2040	2050
Technical lifetime	years	30	30	30	30	30
CAPEX	€/MWe	1411099	1268437	1268437	846659	564440
OPEX	€/MW/yr	20000	17752	15296	10707	7648
Efficiency	%	Cell 19-20% - Module 17-18%				
Net AEP	MWh/yr/MW	1320	1362	1410	2397	2820

Solar PV – Thin Film

Innovation scenarios considered in DELPHOS™ are related to the module, inverters and O&M of the thin film. Based on the above assumptions, Table 21 and 22 summarise the results of DELPHOS™ for thin film techno-economic data:

Table 21 - Techno-economic data for solar PV, thin film technology ground mounted till 2050

	Unit	2015	2020	2030	2040	2050
Technical lifetime	years	30	30	30	30	30
CAPEX	€/MWe	819890	719044	556459	491934	368951
OPEX	€/MW/yr	33300	30480	27210	20408	13605
Efficiency	%			13%		
Net AEP	MWh/yr/MW	1320	1339	1379	2344	2758

Table 22 - Techno-economic data for solar PV, thin film technology roof mounted till 2050

	Unit	2015	2020	2030	2040	2050
Technical lifetime	years	30	30	30	30	30
CAPEX	€/MWe	1295827	1156785	937920	777496	583122
OPEX	€/MW/yr	21300	19308	16929	12697	8465
Efficiency	%			13%		
Net AEP	MWh/yr/MW	1320	1349	1399	2378	2798

Breakthrough scenario: The case of BIPV entering the market in 2030

In this report, BIPV development and deployment in the market is discussed as a case of breakthrough innovation. Tables 23 shows cost projections for this technology. These projections are considered in the REEEM project as modelling input for a 'RES Innovation' breakthrough scenario, together with the assumptions on offshore wind with floating foundation presented in the previous Chapter. We consider that PV technologies suitable for BIPV application will enter the market at a competitive price around 2030.

Table 23- Techno-economic data for solar PV technology suitable for BIPV application till 2050

	Unit	2015	2020	2030	2040	2050
Technical lifetime	years	25	25	25	25	25
CAPEX	€/MWe	1900000	1500000	390000	310000	260000
OPEX	€/MW	38000	30000	7800	6200	5200
Efficiency	%			Up to 30%		
Net AEP	MWh/yr/MW	1000	1000	2000	2700	3500

IV. Ocean Power

IV.1. Description and history

Development of ocean energy in Europe dates back to 1966 when a 240 MW tidal project was built in La Rance, France. This development, however, remained limited before 1999 and the testing of wave energy devices in Portugal [70]. Projections show that ocean energy has the potential to generate 350 TWh of electricity in Europe by 2050, which can meet 10% of the European demand [70].

Ocean energy together with others forms of renewable energy enable generating electricity at different time periods. According to National Renewable Energy Action Plans (NREAPs) signed by the member states, the total ocean energy capacity should reach 2253 MW by 2020 in the EU [71]. This is when by mid-2016 there is only 14 MW wave energy capacity available in the EU. This wave capacity together with tidal and salinity gradient technology sums up to 254 MW of ocean energy in Europe [72]. The pipeline of announced European projects promises the development of 600MW tidal energy and 65 MW of wave energy [72].

IV.2. Ocean power technology

Wave power

There are different types of wave energy technologies available in the market. The diversity of these technologies implies lack of market converge and technology immaturity. Wave technologies could be installed onshore, nearshore or offshore. Each type requires certain technical specifications. Onshore devices are mounted on a natural rock or breakwater. On the positive side, these devices are close to the utility network and benefit from low cost and easy maintenance. However, due to their proximity to the shore, the potential resources to be captured is less than the other types of wave energy. Nearshore devices are located in shallow water areas and are fixed to the seabed with pinned pile foundation or gravity mass. This type of wave energy has the advantage to provide a suitable stationary base against which an oscillating body can work. Offshore devices are located in deep water and are tethered to the seabed using tight of slack moorings mass. While the potential resources are much greater in the offshore area, the location increases the cost of the project due to the complication of construction, and O&M.

Generally speaking all types of wave energy include a number of components [73]: 1) The main structure and mover that harness wave energy; 2) Mooring lines or foundation which keep the structure in place; 3) The power take-off in order to convert mechanical energy into the electrical energy 4) The control system which optimise the performance of the technology in different operating conditions.

Tidal power

Similar to wave energy, different tidal energy technologies are available in the market. Generally, there are two different groups of tidal energy technologies available in the market. First, tidal stream which produces energy through the differences in sea level between high and low tides. Second, tidal range (or barrage) which has similar principles as hydropower and necessitates a barrage (dam or barrier) to impound a large body of water and drive turbines to generate electricity. This type of technology is more developed than other ocean energy and has several functioning projects across the world. The largest and newest tidal barrage in the world is the Sihwa dam in north-eastern South Korea, built in 2011 and with a capacity of 254 MW [74].

Tidal technologies have four primary components: 1) A **barrage** which is used to convert ocean energy to electricity in tidal range technology; 2) A **tidal turbine** (vertical or horizontal) which is used to transfer the kinetic energy of stream to electrical energy; 3) Mooring line or foundation that keeps a tidal technology in place when there is a need for supporting lines or foundation. Currently in the market, 56% of all the projects and concepts uses rigid connection (mostly seabed), 36% uses a mooring, and 4% monopiles [74]; 4) **Electrical cable**: this component connects the ocean energy technologies to the shore. They are normally installed in a trench at the seabed, below the beach on shore.

IV.3. Ocean power market

Similarly, to the case of wind and solar PVs, market parameters affecting ocean market are studied. A summary of these parameters explored in this report is presented in Table 24.

Table 24- Overview of the studied market parameters with an influence on the ocean power deployment

	Evaluated parameters
Policy and legislation	- Policy support schemes, both pull and push mechanism - Grid connection
Society	- Resource availability - Social acceptance - Environmental impact
Value chain	- The strength of the value chain

Policy and legislation

Policies have supported the development of ocean energy in the past years. This has been conducted through both pull and push policies.

Policy support schemes: Pull mechanism

Different national policies support the development of renewable energy. Examples of such pull policies are FIT in Germany or France; supporting market tariff mechanism in Ireland or Denmark; Feed-in-premium in the Netherlands, or renewable obligation in the UK. These policies though often target the whole group of renewable energy, and only in a few member states, there is a dedicated pull mechanism for ocean energy. Ocean energy could not yet benefit significantly from these support mechanisms. This is because cost of most of these projects are still high and thereby these technologies do not have the chance to compete with other renewable energy technologies (e.g., in auctions for building new capacity).

Policy support schemes: Push mechanism

The establishment of push mechanism enables ocean technologies to gain competitiveness in the European energy market. An example of this framework is Smart Specialisation Platform on Energy (S3PEnergy) established by the European Commission. Within this framework, ocean energy is acknowledged as a key area planning to harmonise regional efforts and to match business needs with innovation strength. In accordance, support mechanisms have been introduced on national-level by the Swedish Energy Agency, or other national agencies in Belgium, France, Ireland, the Netherlands, Portugal, Spain and the UK[8] [72].

[8] *http://oceaneranet.eu/*

Besides, there are available funds for ocean energy in Ireland, France, Portugal, and the UK (the latter with the highest contribution of 285 million Euro) [72]. Some of these funding schemes are under the NER 300 programme, the European Investment Bank (EIB) InnovFin scheme, or the European Regional Development Fund (ERDF) [72]. The availability of public funding from programs dedicated to low-carbon projects has incentivized the development of a number of wave energy projects at pre-commercial or demonstration projects in Europe.

Grid connection

Ocean energy resources are often located in areas far from shore. Due to that, there is a need for an extension of power lines which add extra cost for project developers. In order to tackle this issue, in some member states (e.g., Germany and Denmark) this extra cost is mutualised among all the grid users, including electricity producers and consumers. This ensures that the first movers do not carry the whole burden of grid upgrades and share the investment risks among all the market players. This strategy also would allow the project developers to use innovation fund for focusing on the innovative parts of the project rather than non-innovative technology such as cables.

Society and environmental

Availability of resources

The large availability of ocean power in different countries worldwide is among the most important drivers behind the social support for ocean energy. This support increases due to the technologies' limited environmental and visual impact [73]. Therefore, there is a need for better and accurate picture of existing and future ocean energy resources and conditions (e.g., wind speed, temperature, wave height, and tidal flow) in order to better plan future projects and understand ocean energy potential in different European member states.

Social acceptance

The positive society perspective on ocean energy has been noted as a driver for the development of ocean energy technologies. A survey has been carried out in 25 EU member states to assess the public opinion. The outcomes showed that 60% of respondents have a positive perspective and 24% have a neutral attitude about the utilization of ocean energy [75]. In the UK as the international leader of ocean energy, the level of support for ocean energy is even higher: 73% of people support wave and tidal energy, which is higher than biomass (65%), onshore (66%) or offshore wind energy(73%) [60]. This number, however, is lower than solar energy which is 80% [60].

The social acceptance of ocean energy is increased by promises such as reduced dependence on fossil fuels or energy imports. Besides, economic and employment benefits for the hosting regions are expected, through parameters such as job creation [76].

Still, studies suggest that some concerns exist about the visual and environmental impacts of ocean energy [77]. These concerns are stronger in fishing and surfing community since they are not sure how ocean technologies affect their market and products. The adverse effects of ocean energy are, however, considered less serious than those of offshore wind farms.

Environmental impact

The environmental impact of both wave and tidal technologies on underwater marine life should be studied and further evaluated to ensure that it will not have a critical influence on the sea. This knowledge could positively influence society perspective about the ocean energy technologies.

Value chain

More than 52% of the companies developing tidal energy devices worldwide are located in Europe. These companies are 88% technology component suppliers and 12% technology developers [72]. Among these companies, a higher number of developers are located in the UK, the Netherlands and France [72].

Similarly to tidal energy, about 60% of wave energy developers are located in Europe [78]. The UK and Denmark host the highest number of project developers between all the EU countries.

IV.4. Additional barriers and bottlenecks

Although the potential is high, the development of ocean energy has been slow. Several barriers to the market can explain this slow development process. Below a list of main barriers is provided.

- **No dominant technology:** currently in the market, there are more than a hundred concepts available for wave energy technologies. As the result of the lack of a dominant technology, supply chain does not work toward a common goal and create a barrier for accelerated development wave power technologies.
- **High technology and upfront cost**: ocean energy technologies are immature and their projects are capital intensive. This means that in order to invest in these technologies there is a need to access a high level of funding before any revenue is generated. This is unlike conventional or mature technologies (e.g., gas-fired power station), for which the cost of construction of the plant itself is not as high or revenue generation happens during the payment for the fuel and energy production. Ocean technologies need to significantly and urgently reduce their cost in order to become competitive.
- **High project risks**: Energy projects are often coupled with high risk due to reasons such as limited technological development, regulatory and market uncertainties. The greater the risk, the higher is the cost of financing the project. When it comes to ocean energy this risk is higher due to technology immaturities and particular marine environment. This high project risk delimits interests in investments in ocean energy.
- **Planning and licencing framework**: In the ocean energy market, procedures for consenting and licensing are often recognized as barriers. This is due to a lack of clarity of dimensions and conditions on which licencing decisions are based. Such clarification can enhance the planning and licensing procedure.
- **Accessibility and grid cost**: resources for ocean energy are often located in a remote area with long distance to the main power line. This means for project development there is also a need for investments in grid connection and cable infrastructure which add costs up to 40% of the total project cost. Adding this cost to the total cost of ocean energy projects further delimit the interests of potential investors and increase the risk of projects [70].
- **Limited standards and compatible results of technology deployment**: Deployment and testing of ocean energy technologies have been conducted in different countries with the different seabed and shore conditions. This hinders the comparison between projects and as the results create barriers for investors to select the most suitable technology and foresee the outcomes.
- **Limited RD&D supports**: the total investments in ocean energy RD&D worldwide is less than investments made in other renewable energy sources [75]. This limited support could be related to the limited maturity of ocean energy when compared with other renewable energy sources.
- **Environmental impact:** due to limited deployment of ocean energy, the influence of these technologies on ocean natural environment is yet unknown or unclear. This result in resistance and some barriers to the large application of these technologies.

IV.5. Innovation outlook

Market solutions

- **Push and pull policy mechanisms**: ocean energy technologies are less mature when compared with other renewable energy technologies such as wind or solar PV. Further development of ocean technologies necessitates focused push policy mechanism and consistent R&D support in order to reach a level that allows them to compete in the market. Existing means of support are explained in chapter IV.2 such as EIB funding or InnovFin products, but further supports still are needed.
- **Enabling framework for ocean projects:** currently, in the market, there are several incentives available favouring more mature types of renewable power technologies. This calls for support and policy frameworks tailored to new technologies which are still capital intensive. The support frameworks can facilitate demonstration projects of emerging ocean technologies.
- **Synergies among ocean energy with other sectors**: In the ocean power sector cost reduction can be reached through collaboration with other sectors such as offshore wind. Both industries operate in the ocean environment and share synergies with regards to grid infrastructure, equipment, operations and maintenance procedures, project development, permitting processes, or R&D actions. Based on the analysis by JRC, common components and projects of offshore wind and wave and tidal projects could be up to 40% [79]. This means that through cost reduction in the offshore wind industry and synergies among these two sectors, there is a high potential also for cost reduction in the ocean energy sector. The common efforts can focus on 1) design consensus on off-the-shelf technologies, 2) Installation, operations and maintenance procedures (e.g. specialised station-keeping/ cable-handling capability) 3), optimisation and standardisation of serial manufacturing of converters and materials [79],[73].
- **Mutualising grid costs**: The deployment of ocean energy is associated with a high cost for grid connection. Suitable and different approaches should be taken to decrease the cost of connection to the grid for project developers. To exemplify, in some Member States (e.g., Germany and Denmark) this extra cost is mutualised among all the grid users, including electricity producers and consumers. This ensures that the first movers do not carry the whole burden of grid upgrades and share the investment risks among the market players. This strategy also allows the project developers to use innovation fund for focusing on the innovative parts of the project rather than non-innovative technology such as cables.
- **Improvement of Maritime Spatial Planning (MSP)[9]:** Currently in Europe, there is a need for the improvement of the MSP Directive. In order to reduce conflict, encourage investment in ocean energy by creating predictability and transparency, increase cross-border cooperation and protect the environment. The results would have an impact on ocean energy development in Europe [70].
- **Studies on environmental impacts**: exploring the potential environmental impact of ocean energy on ocean environment can improve the position of these technologies in the market. Uncertainty about the actual environmental impacts of these technologies is coupled with society's and investors' hesitance toward them. This is particularly effective in the case of ocean technologies since the seen influence of these technologies on the ocean has been marginal and, in some cases, even positive.
- **Standardisation and clarification on the consenting process**: standardisation and implementation of EU-wide projects lead to the generation of comparable data and accumulating knowledge across the value

[9] *Due to the raising Competition for maritime space – for renewable energy equipment, aquaculture and other uses – Maritime spatial planning (MSP) has been developed to ensure human activities at sea take place in an efficient, safe and sustainable way across borders. In accordance, European Parliament and the Council have adopted legislation to create a common framework for maritime spatial planning in Europe.*

chain. This in turn leads to a faster development of the ocean industry, since the industry players can learn from their network for example by sharing guideline about optimal devices and farm layouts requirements [70].

- **Harmonization of technologies**: As discussed, different types of ocean technologies and prototypes have been introduced into the market. Harmonisation of these technologies and collaboration among the technology developers can lead to faster development of ocean technologies in the market.
- **Improving weather forecasting techniques**: improving the techniques that allow a better understanding of the potential of ocean technologies, would enhance potential and performance of ocean energy technologies in the market.

Technological innovation

Below several innovation solutions are provided which could improve the cost and status of the ocean technologies.

- **Improvement in subsea electrical infrastructure:** (inter)connection of wave converters and tidal turbines to the grid is among the biggest challenges and creates the highest cost for the project. Several approaches could be taken to reduce the cost associated with this interconnection:
    - Development and establishment of a device or array in order to improve interconnectedness of different ocean energy technologies to each other and facilitate their connections to the onshore grid. This interconnection could reduce the total cabling cost of different devices to the shore. Note that in this case, it is important to be able to retrieve individual devices without compromising the performance of the whole system and to avoid the higher cost and unnecessary risks.
    - In order to deliver grid compliant electricity, a key technology is central power electric hub which could collect and transmit electricity from several devices to shore (including offshore wind power). This technology is a base for the development of ocean energy and could contribute significantly to the development of ocean energy.
    - Development and installation of effective low-cost cable protection for tidal sites or other sites requiring protection (e.g., rocky bottoms, surf zones, etc.). So far there is limited experience with the installation of cables for a high tidal flow that reduces cable damages and secures a longer lifetime (20-25 years). Existing and traditional solutions are expensive and have a significant impact on the project CAPEX.
    - Improving the inspection and monitoring of fatigue handling or the controlling of dynamic electrical cables of converters in order to extend their lifetime to 20-25 years.
    - Agreeing on standards for wet-mate medium voltage connectors in 100-150m water depth (3.3kV, 6.6kV, 33kV). Wet-mate connectors accelerate the separation of electrical cabling without placing a strain on the cable.
- **Operation & Maintenance**
    - The economic and commercial viability of ocean energy depends significantly on the O&M cost. O&M is specific to the technology and location, yet the following points could help to reduce the cost of O&M in most occasions:
        - Improving the technology design to reduce its need for O&M,
        - Optimizing the duration of any O&M operation,
        - Considering weather restrictions that can influence O&M activities,
        - Improving the tools and methods for inspection and monitoring, for example in order to better manage weather windows,

        - Improving underwater connectors in order to reduce the time required for the maintenance,
        - Improving remote system monitoring to better understand the interaction of the ocean devices with the sea in real condition, and also reduce the cost.
- **Foundations and Moorings:**
    - Development of fixing devices and systems to secure tidal turbines and wave foundations. The reasons for this development is that the foundation and its installation and decommissioning constitute a remarkable part of the project cost. The cost for the structure itself could be even lower than the installation. Accordingly, great saving can be made by reducing the time needed for the installation of vessels.
    - There is a need for improving environmental impacts of mooring arrangements for wave energy converters. This is in particular important when there is a farm with a range of hundreds of MWs. In such farm, there is a need for several hundred km of mooring lines (e.g., for 400WM offshore wave farms there is a need for up to 300 km mooring lines). These long mooring lines have environmental impacts, inspection requirements and reliability issues that could threaten the position and development of wave energy.
    - New mooring systems could enhance the safety and interaction with the converters [73].
- **Power take-off components**
    - There is a need for reliable and efficient power electronics, auxiliary and control systems within the submerged turbines and wave converters. This is because accessing these parts and their maintenance is very difficult and costly. Accordingly, the development and enhancement of these parts are necessary to reach a higher level of reliability than normally achieved.
    - The development of control system can lead to the improvement of interaction between the device and the sea, for example by adjusting pitch or yaw.
    - As both tidal and wave energy are Variable Renewable Energy (VRE), development of storage facility alongside renewables can, therefore, improve the continuous and smooth supply of power.
    - The development and improvement of tidal turbine components (blades, sealing, etc), based on growing operational experience and a better understanding of the working environment can reduce the cost of the project.
    - Development of innovative and generic power take-off systems for wave energy converters. One example is the development of a system based on electro-active materials for point absorbers instead of electro-mechanical components. This alteration could be a game changer in the wave energy industry by enhancing the tolerable fatigue cycle. Another example is the development of negative spring system, which reacts opposite to common springs and thereby reduce hydrostatic spring thereby limiting resonance frequency[73].
- **Materials**
    - Integration of new material in tidal and wave energy resulting in weight reduction or introduction of auto-regenerative, auto-sensorial, fatigue resistant and corrosion resistant materials. Such new materials can reduce CAPEX and OPEX of ocean technologies. For example, the utilisation of materials other than steel for structure (e.g., Steel Reinforced Concrete, rubber or Fibre Reinforced Polymer) can reduce the technology's weight thereby improve its performance.
    - Coatings can, on one hand, contribute to the improvement of materials to fix deforms and adjust shapes. On the other hand, they enhance the material resistance to extreme weather condition.

- **Installation and logistic**
  - The development of ocean technologies can benefit from the marine industry's facilities and knowledge. Several years of the marine industry development have resulted in the establishment of harbours, vessels, grids and cables that can facilitate the development of ocean power projects. In addition, there are pre-established procedures for safety and health are useful for ocean projects. Note that still new methods for infrastructure and sub-sea solutions are needed to reduce the cost of ocean energy technologies [70].

IV.6. Cost projections

Ocean energy technologies are less mature in comparison with other renewable energy technologies studied in this roadmap. Due to their limited development history, it is not possible to study the future cost of ocean energy technologies with DELPHOS™.

Accordingly, in this roadmap, the data for these technologies are collected through a literature study and primarily are obtained from the analysis of the JRC report on ocean energy technology [72]. Table 25 and 26 present the cost projections for tidal and wave power technologies. Note that, it is assumed that the site conditions used for making the cost projections for wave and tidal technologies are comparable with the site condition in Spain[10].

Table 25 - Techno-economic data for tidal energy wave [72]

	Unit	*2015*	*2020*	*2030*	*2040*	*2050*
Capacity factor Max (Ave.)	*%*	*36 (29)*	*45 (33)*	*47 (40)*	*47 (42)*	*50 (45)*
Technical lifetime	*years*	*20*	*20*	*20*	*20*	*20*
CAPEX	*€/kWe*	*10668*	*5010*	*3100*	*2585*	*1897*
FOM	*% CAPEX*	*6.2*	*6.5*	*5.6*	*6.3*	*4.9*
Ave. Capacity factor	*%*	*29*	*33*	*40*	*42*	*45*
Max. capacity factor	*%*	*36.3*	*45.2*	*47.1*	*47.1*	*50*
Net electrical power	*MWe*	*10*	*10-20*	*20-30*	*30-40*	*50-400*

Table 26 - Techno-economic data for wave energy [72]

Wave Energy	*Unit*	*2015*	*2020*	*2030*	*2040*	*2050*
Capacity factor Max (Ave.)	*%*	*34 (25)*	*41 (28)*	*43 (31)*	*43 (34)*	*46 (0)*
Technical lifetime	*years*	*20*	*20*	*20*	*20*	*20*
CAPEX	*€/kWe*	*10500*	*6636*	*5267*	*2650*	*2300*
FOM	*% CAPEX*	*4*	*4.3*	*4.2*	*5*	*5.5*
Ave. Capacity factor	*%*	*25*	*28*	*31*	*34*	*40*
Max. capacity factor	*%*	*34*	*41*	*43*	*43*	*46*
Net electrical power	*MWe*	*1-3*	*3-10*	*10*	*40*	*75*

[10] We are conducting further analyses to made sure that right site conditions are assumed.

V. Renewable Energy Integration: Market design and flexibility options

The European Union aims at increasing the share of renewable energy in the total energy consumption by up to 32% by 2030 [4], which requires about a 50% share of renewables in the electricity market. This is while the current European market is not designed to accommodate this large share of Variable Renewable Energy (VRE). For a successful integration of renewable energy, there is a need for enhancing market flexibility options both on supply and demand side.

Currently, in the market, the share of decentralized energy generation is increasing and in parallel, the interest on renewables is increasing. Consequently, it is a large number of investors in Variable Renewable Energy (VRE) that need to meet the energy demand of small and large consumers. The European electricity market needs to adapt to this new reality through findings approaches to integrate all the market players and improve market flexibility.

A more flexible European electricity market could be achieved through the modification of existing market design [80]. Below several approaches to enhance the flexibility of the market are discussed. A set of actions is recommended accordingly.

Improving grid interconnection in Europe

The share of VRE is increasing in the electricity markets of European countries. In this situation, it is essential to transmit electricity with no restrictions from where it is generated to where it is most needed and valued. This will enhance the market competitiveness and incentivize investment in renewable power technologies.

Existing grid interconnection between different member states can facilitate import and export leading to a higher renewable electricity use. Studies demonstrate that already now the electricity exchange between member states could work partly similar to energy storage [81]. It is, for instance, the case of the exchanges between Germany and Austria. In periods of high generation from wind and solar, Germany exports electricity to Austria, where this is stored in pumped hydro-storage facilities. On the contrary, in periods of higher demand and lower renewable generation, Germany imports the stored energy from Austria. The fundamentally different energy supply mix of the two countries drives these dynamics. Such mechanisms can happen also between non-neighbouring countries, where other countries in between serve as transit countries. Finally, the European market interconnection ensures long-term stability for investment in energy sectors and resources and this motivates larger investments in new renewable power plants and decommissioning of the units when overcapacity recorded [80].

In an integrated market, the role of cross-sector interconnections should not be overlooked. In many energy systems, flexibility in the market could be achieved through synergies between different sectors, such as the heating and power sectors. For example, the district heating sector can provide a buffer for adjusting the heat output of combined heat and power (CHP) plants. This flexibility for CHP plants can help them to adjust the electricity generation of VRE in the market.

Enhancing market interconnection is possible through investments in infrastructure, but also improved regulation of cross-border flows: it is the case that cross-border electricity transmission bottlenecks at times happen because the transmission between countries is capped even though the physical transmission limits are not met. In such cases, electricity price differentials between countries arise, too. Enhanced market interconnection can be achieved also by stronger intra-day trading and market coupling'[11], discussed in the next subsection.

Actions:

- Enhance grid transmission capacity between different European countries.
- Increase grid transmission capacities between different EU countries to enable transmitting electricity to where is needed most, during extreme weather conditions such as cold and icing, and warm weather.
- Enhance grid transmission through new technologies. This is possible for example through point to point HVDC, MultiTerminal HVDC, and others.
- Adjust regulations and harmonize electricity markets across European countries to allow for easier cross-border electricity trades.
- Considering the possible contradicting impacts due to similar power production mix, similar demand pattern, or correlation between availability of renewable energy in neighbouring countries when supporting cross-border interconnections [82]
- New market designs that can mobilize the untapped potential of the District Heating (DH) systems and heat storage for providing flexibility for the power sector [83]

Empowering the short-term electricity market

Design and development of a market that considers short-term electricity planning at its core can effectively facilitate the integration of a larger share of renewable energy. Currently, in the European electricity market, producers can sell their electricity on the spot market when the trades are done via day-ahead auctions. The market price is determined based on supply and demand. Changing this market from a day-ahead auction to a minute before consumptions could facilitate the full integration of VRE. This is because renewable energy is dependent on weather conditions and therefore there is uncertainty associated with projecting their energy production one day ahead. In some European countries currently, a local intraday market (as short as 15-minute) is available (Figure 20). Expanding the intraday market to EU-level can contribute to an effective integration of the larger share of VRE.

[11] *Market Coupling uses so-called implicit auctions in which players do not actually receive allocations of cross-border capacity themselves but just bid for energy on their Exchange. The Exchanges then use the available cross-border transmission capacity to minimize the price difference between two or more areas.*

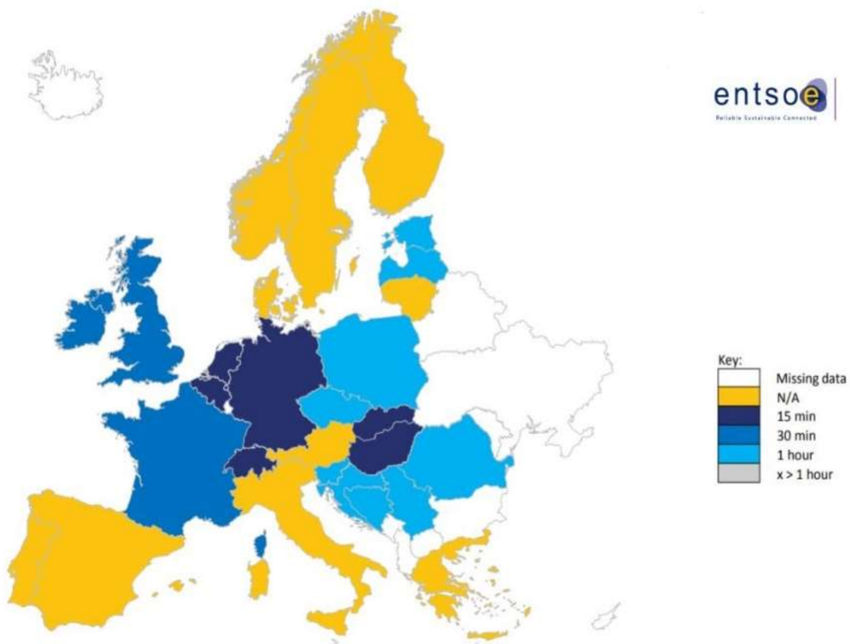


Figure 20 - Intraday auctions in EU member states [84]

Action:

- Constraints on pricing should be removed, intraday lead times and trading intervals should be shortened and gate closure times should be brought closer to real time between different EU countries.
- Development of simulation and monitoring tools enabling better forecasting techniques in order to improve overall flexibility of the system.
- Establishing a European harmonized system for handling congestion to improve the flexibility of the market.
- Establishing a mechanism to pay for available capacity, instead of the payment for delivered electricity. This can motivate the establishment of reserve capacity in the market.
- Value the development of flexibility options (ramping capability etc.) and the importance of it in systems with a high share of VRE

Facilitating demand response and enabling active consumers

Improving demand response would enhance the flexibility of the electricity market that is required for a larger integration of VRE. Currently, consumers are not properly incentivised to adapt their consumption patterns due to several reasons:

- The static pricing and fixed tariffs do not reflect the scarcity in the supply side nor the abundance of electricity from VRE to call for consumers response.
- The share of electric energy is a small fraction of the whole bill paid by consumers. For example, the wholesale electricity price accounts for less than 20% of the electricity bill for end users in Northern Europe [85]. The rest of the bill constitutes of taxes, transmission and distribution grid fees, and

renewable taxes due to subsidies. Therefore, any variation in the wholesale electricity prices, even if reflected in the bill has a minor economic impact for the consumers.
- The technical and regulatory requirements for the participation of end users in many intraday and balancing markets are either undefined or difficult to fulfil for the majority of small demand response providers.
- The potential of demand-side management in industry is typically overestimated due to the focus on adjusting production-rather than consumption.
- In some markets, the peak prices do not truly reflect the scarcity or oversupply. This can be due to the intervention of regulatory bodies, like setting a cap price or an inefficient interlinkage between markets in different time scales. In many cases, the locational grid bottlenecks are not reflected in prices, making it difficult to identify the potential contribution of end users through demand response.
- The socio-environmental benefits of integrating renewable energy are not completely identified and internalized in power prices. Considering these externalities will give a more realistic view of the benefits of demand-side management [86].

There are several technologies available in the market enabling consumers to participate in the energy market and facilitate the integration of renewable energy. Examples of new technologies and services include but are not limited to smart grids, smart metering and smart-home. According to an analysis by the European Commission's DG Energy and JRC, in 2014 already 45 million smart meters were installed in three European Member States (Italy, Finland and Sweden) and the EU was set on a course to roll-out 200 million smart meters for electricity and 45 million smart meters for gas by 2020 [87]. This indicates a great step towards enabling active consumers.

Self-generation and storage equipment are empowering citizens to take ownership of the energy transition, using these new technologies to reduce their bills and participate actively in the market. Note that, many consumers in the electricity market lack knowledge base in energy supply, demand and pricing matters, making it complicated for them to engage in the market and drafting bidding strategies. In light of the above discussion, to incentivize residential and industrial consumers to participate in the market, the following actions are recommended.

Action:

- Linking more closely wholesale and retail prices to motivate end-users' engagement. Removing price regulation that prevents consumers' response to major short-term price signals and incentivizes demand response.
- Establishment of network tariffs that motivate demand response in areas with grid bottlenecks
- Enable new market players to enter the market in order to provide value for the consumers through services such as arbitrage, while reducing the energy demand. This will help to ensure delivering a new deal for consumers.
- Facilitating the entry of aggregators and virtual power plants that can act on behalf of a large number of small-scale end users.
- Introducing dynamic taxation schemes that follow the variations in wholesale electricity prices, instead of a fixed tax premium on top of wholesale prices.
- Considering the risk of productivity loss associated with demand-side management in the industry when drafting proposals for attracting demand response from industry [88].
- Allowing consumers, particularly industrial ones, to participate in the market by introducing regulations that reduce the need for interventions such as capacity mechanism [80].

- Development of new technologies and services that higher awareness and drive a change in behaviours and a more active role of consumers. Examples of such technologies are smart meters. Note that further development of some of these technologies calls for an adjustment in policies and regulations to enable deployment of these technologies in the market [89].
- Provide incentives for power generation at peak times through time-of-delivery payments.
- Provide incentives for self-consumption during peaks through time-of-use electricity rates.
- Improve forecasts and reform energy-only electricity markets for better synchronisation of supply and demand.
- Considering externalities such as socio-environmental benefits of demand-side management when defining remuneration schemes.
- The digitisation of various sectors and components to allow for real-time demand-supply management.
- Encourage crowd-funding and enable citizens to be the investors of renewable energy.

Development and deployment of reserve capacity and storage technologies

With a larger share of VRE, it is fundamental to include technologies and services that can balance the generation curve of renewables. One approach for this would be the utilisation of reserve capacity, in terms of a backup power generation with fast ramping time. Natural Gas generation can play a big role as a backup for VRE and facilitate the transition to a low-carbon energy system. The importance of natural gas generation in the future electricity market is clearly stated in Energy Technology Perspectives 2014. In this report, the New Policies Scenario shows an almost constant share of gas in the global power supply (including Europe) in the next decades [90]. This role could be further enhanced by CCS, to reduce emission associated with this fossil-based power generation. Overall, Natural Gas power plants could represent a complementary enabler for VRE, although their deployment could face challenges due to:

- The existence in of capacity remuneration mechanisms to financially support fast ramping controllable generation to back up the intermittency of renewables. The remuneration is another distortion of the market [81].
- The fact that in some countries a large part of the overcapacity is constituted by Natural Gas power plants (e.g., in Italy).

Renewable energy production along with local storage can smooth renewable energy production by storing energy when is not needed and allowing its use during demand peaks. Energy storage technologies enable changing the role of consumers to independent prosumers. The REEEM roadmap on energy storage applications shed light on different types of storage technologies and actions that could accelerate their development [91]. Inputs from the roadmap have been used in REEEM for a model-based analysis of the impacts of the transition to a low-carbon energy system in the EU. The results, available in [92], suggest that storage technologies are potential enablers if the right actions are taken to bring the technology prices down. A list of key actions can be found in REEEM roadmap on energy storage applications [91]. The findings of this roadmap are aligned with other research works [81] that analyse the role of storage as an enabler for variable renewables in the EU.

Energy storage together with renewables can create stronger business cases as storage allows storing renewable power when there is a surplus and prices are low and release that power when the price is higher. However, existing rules make this process complicated, therefore provide limited value for consumers to participate in the market.

Action:

- Establish backup generation with fast ramping time in order to support the power market with a large share of VRE. Natural gas power generation is among promising energy sources to act as reserve capacity.
- Integrating energy storage into the renewable energy plants (e.g., wind power parks) and grid system for balancing transmission and grid systems. Energy storage does not directly reduce the cost of energy but will increase the penetration degree of renewable energy in the grid and thereby improve their business cases.
- Removing market barriers to the participation of energy storage in several marketplaces and providing multiple services simultaneously [93].
- Cross-sectoral projects like the Power-To-X are required to make competitive sector-coupling available and improve transition toward a low-carbon society. Such technologies are aiming to use surplus electricity directly or even indirectly by producing syn-gas or -fuels for when electrification is not an alternative, e.g. aviation and marine transport.

Encouraging old and new players

The integration of renewable energy in the market requires the introduction of new business models, engagement of a broader range of players and introduction of new incentives to the market [80]. This is particularly important as renewable investors are not anymore old traditional investors, but rather a diverse group of players with different experiences and backgrounds.

Actions:

- Grid expansion and better management will play a crucial role in the future energy industry since renewable energy is often decentralized and locally produced.
- Local producers shall find appropriate approaches to incentivize Distribution System Operator (DSO) to use local flexibility options and answer challenges in a cost-effective manner. DSOs need to be neutral market players to encourage the development of market-based services to consumers by the third party.
- It is necessary to revisit the revenue framework of Transmission System Operators (TSO) and ensure that there are right incentives available for all TSOs in the market. Acknowledging the role aggregators and establishing a position for then in the market can strengthen the business cases of renewable energy. For example, an aggregator can be a third party who can get access to disposing of the electricity for consumer's flexible consumption and/or generation in the electricity market. The aggregator can pool flexibility from consumers and converts it into electricity market services.
- New energy-intensive industries, such as data centres, have an enormous potential for helping the electricity market to integrate VRE. This potential is not fully exploited due to the existing technical and market barriers. To tap the flexibility potential of new energy-intensive services/industries such as data centres, a more transparent scheme is needed when drafting agreements. This is possible through efficient and easily understandable indicators and metrics [94].
- Setting up a framework that allows utilities to act as an aggregator if they deem it beneficial.

Introduction of new services and hybrid technologies improving the competitiveness of renewable energy

Development of new services or hybrid technologies that can strengthen business cases of renewables and encourage further investments in these power resources. Below some actions that can enhance the potential services of renewable technologies are listed.

Action:

- Design and implement new services for renewables (e.g., new-built PV systems or wind farms) which would positively improve their contribution to the electricity supply system and create a business case for them. An example of such types of services is providing ancillary services.
- Create a regulatory framework to facilitate the operation of the electric vehicle (EV) charging stations that run on renewables.
- Combining installation of the hybrid renewable technologies (i.e., renewables together with storage,) to improve their position in the market.

VI. From Gaps to Opportunities and Barriers to Actions: Concluding remarks

Renewables are moving to the centre of the low-carbon energy mix in Europe, through the transition from small-scale to large-scale technologies and centralised to decentralised energy production (Figure 21). Besides, renewable energy is changing the landscape of the energy market by empowering different groups of investors with diverse industrial background and allowing the development of new business models.

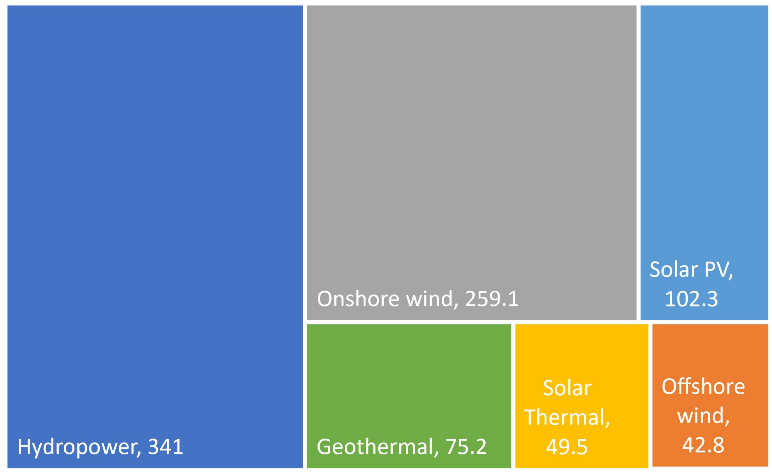


Figure 21 – Primary production of renewable electricity in EU in 2015 (TWh) (source: Eurostat)

This roadmap analysed the development and deployment of 3 groups of renewable energy, namely wind, solar PV and ocean with a focus on the electricity market. The analyses of this roadmap shed light on different technological and market barriers that slow down the development and deployment of renewable energy technologies. The findings result in a list of actions that can accelerate the development of the renewable energy industry. Below the main findings of this roadmap are summarized.

Market outlook

Wind Power

- In 2016, 153.7 GW of wind power was installed in the EU. Germany is the EU Member State with the largest share of installed wind capacity. Spain, the UK, France and Italy have the highest share of wind power after Germany.
- In 2017, there was 15.8 GW of cumulative offshore wind capacity in Europe (11 wind farms being built in during 2018, adding 2.9 GW) [95]. This capacity represents about 13% of the annual EU wind energy market.
- By 2030, IRENA ReMap scenario estimates 327 GW of installed wind power capacity in Europe. Scenarios developed by WindEurope present fairly similar results (Figure 22) [96]
- By 2030, 50-100 GW of offshore wind power capacity is expected [96]. Offshore wind is expected to produce 7% to 14% of the EU's electricity demand by 2030 [96].
- By 2030, wind power market creates 569k jobs in Europe [96]. For the offshore industry, jobs are estimated to reach a number between 170k and 204k (Figure 23) [96]
- Europe is the home for top 10 wind power manufacturers. This strong position of Europe in the wind power value chain creates jobs in manufacturing, R&D efforts, management, sales and others. Interestingly, 46 % of the Vestas employees in Europe were involved in "sales and services " in 2016.
- Europe is the biggest market for the offshore wind industry and leads its development. As of 2017, Europe hosts the highest number of offshore wind developers worldwide.

- Technological innovation in the onshore wind industry will be incremental as the technologies are already mature.
- In the onshore wind industry, innovative approaches for O&M are expected to reduce the cost of this technology.
- Technological innovation in the offshore wind industry is expected as the floating foundation technology is entering the electricity market with a competitive price. The development of floating wind turbine foundation may be a breakthrough scenario in this market.
- Offshore wind power is now cheaper than natural gas and nuclear in the UK (170€/MWh in 2014, 65€/MWh expected in 2022-2023).

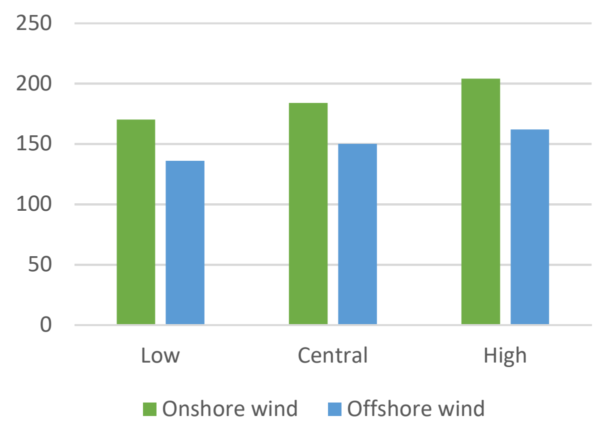


Figure 22- Wind power installed capacity scenario by 2030 [96]

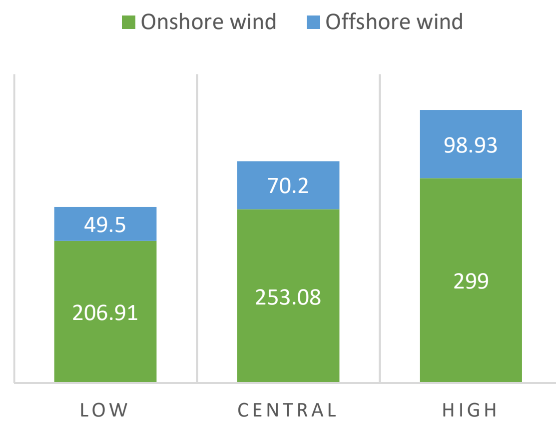


Figure 23- Potential employment in the wind power sector by 2030 (1000 jobs) [96]

Solar PV power

- By 2016 there was 104 GW of accumulated solar PV capacity in Europe.
- By 2030, IRENA ReMap scenario projections estimate 270 GW of solar PV installed in Europe.
- IEA projections are less ambitious and suggest that solar PVs capacity will reach 192 GW by 2030 and 229 GW by 2050 in Europe [97].
- By 2030, the share of solar PV in the European electricity mix will be at least between 10-15%
- In 2016, there was 81 000 jobs related to Solar PV in Europe. This number is expected to be more than double by 2021 (compared to 2016). While the job growth will be throughout the value chain, more job is particularly expected in downstream value chain in O&M services and engineering, studies and admin [64]
- Europe is competitive on some parts of the value chain. On the upstream value chain, the strength of Europe lies in its leadership on equipment and Inverter/BoS, despite a weak cell manufacturing production capacity. On the downstream value chain, Europe has a strong competitive advantage because of its early move on Solar PV and its prior experience in managing ageing solar power plants. Cells manufacturing is the weakest part of the value chain, Europe representing only 4% of global production. Most of the value of Solar PV is located in the downstream part of the value chain (40% on project development, 18% on installation, 25% on O&M. Wafers, cells and modules represent only 5.1% of the gross value added).

- Opportunity for Europe is to consider exporting its extensive project development capabilities (engineering and know-how to export), on O&M and new services.
- Solar PV, particularly c-Si technology, is a mature type of renewable energy technology and therefore any further innovation in this technology will be incremental. Still, further R&D can improve the efficiency of this technology and reduce its cost for example through better utilisation of raw materials.
- Introduction of new types of solar PVs, for example with a flexible design suitable for BIPV, can be considered as a breakthrough scenario. Such PV technologies enable the installation of PVs on any surfaces thereby significantly improve site availability.

Ocean power

- In 2016, there was 245 MW of installed ocean energy available in Europe.
- By 2020, the NREAP suggests installation of 2253 MW ocean energy in the EU, 10 times more than today's installation [98].
- Europe is a leader in the ocean energy market and is the home for 52% of tidal and 60% of wave energy project developers [99].
- Due to the diversities of ocean technologies, it is difficult to summarize the impactful technological innovation needed to realise the full potential of ocean technologies in the European electricity industry. Yet, completion of testing and demonstration projects, proving the feasibility of ocean projects (viability of their electrical infrastructure as well as foundation and mooring systems) can enhance the position of these technologies in the market.
- The current LCoE of ocean energy is between 60-110 cEUR/kWh. According to the SET plan, this cost should decrease to about 10-15 cEUR/kWh by 2030 [72].

Key findings

- Renewable energy technologies are an inseparable part of the future EU electricity industry and a must for a successful energy transition toward a low carbon EU society.
- Renewable energy technologies have the potential to reduce energy relate emission from the industry in a cost-effective manner.
- The costs of electricity generation from renewables will be reduced at a different rate for wind, solar and ocean energy till 2050 (See Appendix I).
- Wind is a dominant source of power in Europe and onshore wind power energy is the most deployed type of renewable power in Europe. In Denmark alone, over 26% of electricity demand is already supplied by wind power. This variable wind power in the Danish electricity industry has been managed successfully by the grid operator. The Danish government aims for meeting 50% of Denmark's electricity demand from wind power by 2025.
- Development in wind turbines sizes has contributed significantly to the cost-competitiveness of wind power industry. However, this increase in size at the same time has created challenges for the transportation and installation of turbines.
- From 2010 onward, the largest share of investments in new power capacity in Europe has been made in wind and solar technologies.
    - In 2017, more than 80% of wind power investments European-wide was made in Germany, France and the UK. This means that, some European countries have made larger investments in renewable power capacity than others.
    - In 2017, more than 11% of the total electricity demand in Europe is met by wind power.
    - In 2016, in Europe, solar power meets about 3% of the total electricity demand.

    - In 2016, Europe's contribution to the worldwide amount of PV installation was 33%.
  - Realising the full potential of renewable energy is more probable when different types of renewables are developed together. This is because the combination of renewable energy technologies provides a more balanced electricity generation curve. Wind resources are stronger during winter time, while there are more sunny days available in summer. In another example, offshore wind and wave power complement one another electricity production by capturing wind power at different time periods.
  - Impactful technological innovation in all renewable technologies is possible through the development and utilisation of new materials for the technologies' production. New materials can improve the technologies' performance and sustainability as well as their resistance toward harsh environmental conditions. In additions, all renewables can benefit from new innovative methods for O&M services or recycling facilities that enhance their sustainability (see Table 27).
  - The development and commercialisation of ocean technologies are in progress. Europe is a leader in the ocean industry. In particular, the UK and France have made large investments in this industry.
    - Availability of different types of wave and tidal technologies illustrate immaturity of ocean technologies and lack of a dominant design in the wave or tidal markets,
    - High cost and limited technical features of tidal and wave technologies hinder their further deployment in the market. Instruments like the EIB's InnovFin Energy Demo Project exist to decrease this risk and support the development of innovative technologies,
    - France possesses the largest share of tidal energy capacity in the world.
- The general European political trend for renewable energy is to support their market expansion, by reducing the financial and technological risks of renewable projects.
    - Renewable policies have financially supported the development and deployment of different renewable technologies. For example, solar PV has been deployed largely as the result of supportive policies. This large deployment has resulted in a reduction in the price of this technology to the point that it has reached grid parity in some regions.
    - In more recent years, European countries tend to introduce market-based policies in order to enhance competition in the market. This is while well-managed FITs is shown to be effective in stimulating deployment of renewable energy (e.g., in Germany)
    - SET Plan targets direct and orient development of the renewable technologies by providing performance and cost targets for 2030.
    - Finding approaches that enable the transmission of the renewable electricity from where it produced to where is needed most European-wide.
- Societal factors are identified to be determining for the development of renewable energy.
    - Community projects in several European countries have positively influenced society perspective about renewable projects, particularly PV projects. This positive perspective has further motivated investments in different renewable technologies.
  - Strong European value chain in wind, solar and ocean industries has contributed to the further growth of these industries in Europe. However, a rising competition from outside of Europe threatens parts of the European value chain. Measures should be taken to maintain and to recapture strength of the European value chain.

Key barriers:

- High upfront cost of projects in the renewable power industry delimits interest of potential investors in renewable technologies.

- Deployment of renewables in some remote areas necessitates not only investment in these technologies, but also an investment in grid expansion. The latter will increase the overall cost of the project and that lowers the interests of potential investors.
- Unstable national policy frameworks (in terms of both type and timeframe) supporting renewable energy technologies have demotivated investors to engage and invest in these technologies.
- Currently, in the market, some renewable technologies are more mature than others. The more immature technologies such as wave and tidal are costlier and this creates barriers to investments in these emerging technologies when market-based support mechanisms are enacted.
- Renewable energy technologies depend on natural resources which suffer from variability. The variability of wind, solar, and ocean energy is one of the biggest challenges for the future European electricity market. To overcome this variability all the flexibility options, including grid interconnections, demand-side response, short-term markets, storage technologies, as well as new business cases and new players need to be considered and developed. Only after such development, realizing the full potential of renewable energy would be possible.
- Limited development of options and methods that allows better integration of renewable energy in the European electricity market negatively influences the position of this variable energy sources in the electricity market. Example of such methods is demand response or deployment of storage technologies (see chapter V).
- Renewable energy technologies have an influence on both the environment and landscape. This influence has affected the society acceptance negatively and slowed down the deployment of renewable energy.
- The position of European value chain in the renewable energy industry has lost its competitiveness due to the raising competition especially from Asian companies.
- The end-of-life and recyclability of renewable energy technologies are still open issues and unresolved in the market. Renewable technologies consist of raw materials which question their long-term sustainability without taking actions about recycling of these technologies.
- There is a lack of O&M players in the market, particularly in the offshore wind power industry. This calls for more focused education and training programs.
- A number of technical characteristics of renewable energy technologies constrain their performance and position in the market. Improvement of these technical characteristics can, therefore, accelerate the technologies' development and deployment processes. To improve these characteristics, several innovation suggestions are provided in this report in Chapter II to IV. A summary of these innovation assumptions is listed in Table 27.

Market solutions -integration of renewable energy:

- Enhancing the grid interconnection between EU countries can allow renewable electricity to be transmitted from where it is produced to where it is needed most.
- Electricity trading between EU countries is currently based on a day-ahead auctioning system. An intraday market exists in some European countries (e.g. Germany). Establishment of the European-wide intraday market can facilitate a larger integration of renewable energy.
- Capacity markets and reserves capacity are recommended for the European power industry to assure the availability of backup power generation in the time when renewable energy production is insufficient.
- Currently, the role and contributions of storage technologies are limited in the power market. This role could become more dominant in the coming years through larger investment in these technologies. The

status and potential of storage technologies are listed in the REEEM roadmap on energy storage application.

- Development of methods and approaches that facilitate the involvement of consumers in the electricity industry (e.g., through demand response)
- Encouraging old and new players to enter the electricity market in order to improve the business cases of renewable technologies (see Table 27).

Key actions

Table 27 summarises the key actions suggested throughout this roadmap to accelerate the development and deployment of the studied renewable energy technologies in the European electricity market. Some of the suggested actions can also lead to a faster development of renewable technologies that are outside of the scope of this report and are not studied (e.g., biomass, hydropower).

Table 27 – Summary of the key actions to support the development and deployment of renewable technologies

Sector	*Action*	*Timeline*

Wind Energy (Chapter II)	• *Wind power technology can be developed through* ***technological innovation****:*
	    ○ *Incorporation of new designs and concepts for wind turbine and its structure*
	    ○ *Innovation in drivetrain*
	    ○ *Development of tools for the better management of wind turbine components and systems*
	    ○ *Innovative materials and manufacturing processes to reduce the technology cost*
	    ○ *Development of new quality control systems to improve the technology's quality*
	    ○ *Scale-up prototypes and test benches*
	    ○ *Findings solutions and innovative processes for recycling wind turbines at their end-of-life*
		2020-2025

	• *Finding approaches for* ***improving the performance of wind farms****. This includes:*
	    ○ *Enhancing wind turbine logistics and installations. This could reduce the wind farm installation cost*
	    ○ *Development of tools to control wind farm globally in order to optimize annual energy production*
	    ○ *Optimizing wind farm layout under multiple constraints to reduce the cost of a farm*
		2020-2025

	• *In both onshore and offshore wind power, remarkable cost-saving potential could be made through finding* ***innovative solutions for O&M*** *services. Examples of new solutions are:*
	    ○ *Introducing responsive or condition-based maintenance*
	    ○ *Remote O&M*
	    ○ *Improve weather prediction tools*
		2020-2030

	• ***Assessment of the impact of offshore wind on the environment*** *in order to prevent damages and resolve doubts about their potential influence on the ocean environment.*	*2020-2022*
	• *Development of* ***floating offshore wind power foundation*** *with competitive prices can make a breakthrough scenario in the wind industry. This breakthrough enables access to large sources of wind power, while reducing the wind impact on the landscape.*	*2030-2040*

Sector	*Action*	*Timeline*
Solar PV (Chapter III)	• ***Improvement of technological characteristics of PVs:*** o *Improving the quality control processes during the production of all types of PV technologies in order to enhance their performance.* o *For the c-Si, it is possible to improve the technology through better utilization of silicon materials, enhancing processes and designs that can result in a higher production yield, or improving PVs' energy efficiency and output through innovation in modules.* o *For the thin film, technological development is possible through better utilisation of materials or substitution of scarce materials used in this technology. It is also possible to improve thin films' efficiency through approaches such as reduction of non-active interconnections zones, reduction of degradation mechanism, or developing antireflective coating. Lastly, thin film performance could be improved by encapsulation and modularization to ensure their long-term output.* o *Continuous R&D efforts for the development of third-generation PV technologies in order to improve their performance and enable them to regain market shares from already established PV technologies.*	*2020-2030*
	• ***Improving the recycling processes of solar PV*** *in order to enhance their sustainability throughout their life-cycle and improve their total value in the market. Recycling is not restricted to end of product life, but also important already in production through the utilisation production processes that reduce the waste (e.g., wafer production through NexWafe).*	*2020-2025* *2020-2025*
	• ***Monitoring and controlling the quality of PV technologies*** *during their manufacturing, in order to improve their performance and lifetime.*	*2025*
	• *Development of devices and services that could* ***enhance controllability and predictability of distributed solar power generations****.*	*2020-2025*
	• *The utilisation of methods to* ***enhance society engagement in*** *solar PV projects.*	*2020*
	• *Improving the* ***flexibility of PVs' designs and manufacturing processes****. This can considerably increase the number of available sites with suitable conditions for installation of PVs which will drive larger investments in the PV market.* o *Through the emergence of PVs with a flexible design, a market for BIPV will be formed. Europe has the chance to become the leader of this emerging market, especially because currently the competition in this market is limited.* o *In this roadmap, the development of the BIPV market is considered as a breakthrough the scenario. We assume that this market will become competitive by 2030.*	*2030-2050*

Sector	*Action*	*Timeline*
Ocean power (Chapter IV)	• *Mutualise **cost of the grid** between all grid users of ocean energy in order to ensure that first movers do not carry the whole financial burden.*	*2030-2050*
	• *Finding solutions for improving **interconnection of wave converters and tidal turbines to the grid.***	*2025-2030*
	• *Development of **new approaches for O&M services** can improve the economic viability of ocean energy technologies by bringing down their cost.* o *Improving system monitoring from a remote location can enhance O&M services while reducing their cost for both ocean energy and offshore wind power.*	*2030*
	• *Development of **new fixing devices to secure tidal and wave turbines** to ocean seabed. This can notably reduce the project cost while improving the technology performance. Note that installation and decommissioning of ocean technologies constitute a large share of the total cost of ocean projects.*	*2030-2050*
	• *Improving **installation processes of vessels** (e.g., fast-setting, non-spilling grout, pin piling techniques). This will result in great saving made by for example a reduction of time needed for the installation.*	*2030*
	• ***Development of components that are resistant to the harsh ocean environment** in order to reach longer life and better performance. This will positively influence the overall cost of ocean projects.*	*2025-2030*
	• ***Utilization of new material or coating** for ocean energy technologies in order to improve their resistance to extreme weather conditions. This will reduce both CAPEX and OPEX of these technologies.*	*2025*
	• ***Standardisation and harmonisation of EU wide ocean projects** create the conditions for improving learning processes, sharing guidelines, and reaching optimal services in a shorter time. Harmonisation of ocean technologies could allow faster development of the technologies and facilitate the emergence of a dominant design. Reaching a dominant design for ocean technologies are associated with their larger deployment, consequently cost reduction based on learning-by-doing*	*2020-2025-2030*
	• *Assessing the **impact of ocean energy on the environment** in order to prevent damages and resolve doubts for their potential influence on the ocean environment and biodiversity.*	*2025-2030*
	• *Improving **synergies between the ocean and offshore wind sectors**. This is possible through common R&D projects or improving synergies with regards to grid infrastructure, equipment, O&M procedures, project development, and permitting processes. Based on JRC analysis, common components and projects of offshore wind and wave and tidal projects could be up to 40%.*	*2025-2030*

Sector	*Action*	*Timeline*
Market design (Chapter I and V)	• *Support attaining **EU targets** for 2030, and 2050 in order to orient the European electricity market toward sustainability. SET plan targets provide a good guideline for the development and deployment of wind, solar and ocean energy.*	*2020-2030-2050*
	• *Enacting **supporting policies** in order to improve the position of renewables in competition with other available energy technologies. Renewables need policy supports due to their higher costs and variable electricity productions.*	*2020-2030-2040*
	• ***Foster long-term markets** to encourage investments in renewables. For that, it is essential to develop stable regulatory frameworks that encourage the decisions to invest in renewable energy technologies, in spite of their high up-front cost.*	*2025*
	• *Introduction of financing structures that encourage the **engagement of both public and private investors** in the development of renewable energy. It is only then that the full potential of renewable energy will be realized.*	*2020-2025*
	• ***Grid expansion and better grid management** will play a crucial role in the future electricity industry, particularly because renewable power is often decentralized and produced locally.*	*2025-2030*
	• *Promote **priority connection to the grid for renewable technologies** in the electricity industry in order to reduce the risk of these projects*	*2025*
	• *Set **right priorities** between electricity generation and environmental targets*	*2020*
	• ***Mutualise the cost of the grid** at least for projects such as ocean and offshore wind power to assure that the first movers do not endure all the costs*	*2020-2025*
	• *Establish a **European database covering available wind, solar and ocean energy resources** in order to promote business cases of these resources and direct investments in regions with high energy resources.*	*2020-2025*
	• *Support the development of methods and options that **facilitate the integration of renewables in the electricity market**. This includes the development of short-term electricity market, enhancing grid interconnection between different EU countries, establishing methods for encouraging demand response, and developing new market designs encouraging the involvement of both old and new players with a capacity to enhance the electricity market's flexibility.* ○ *Harmonize electricity markets across European countries to allow for easier cross-border electricity trades.* ○ *Constraints on pricing should be removed, intraday lead times and trading intervals should be shortened and gate closure times should be brought closer to real time.* ○ *Establishing a mechanism to pay for available capacity, instead of payment for delivered electricity in order to motivate establishment of reserve capacity in the market.* ○ *Linking more closely wholesale and retail prices to motivate end-users' engagement. In other words, removing price regulation that prevents consumers from responding to short-term price signals.* ○ *Establish network tariffs that motivate demand response in areas with grid bottlenecks.*	*2020-2030-2050*

- *Enable new players to enter the market in order to provide value for the consumers through services such as arbitrage that is possible using renewable technologies.*
- *Provide incentives for renewable power generation at peak times through time-of-delivery payments,*
- *The digitalization of various sectors and components to allow for better, real-time demand-supply management.*
- *Encourage crowd-funding and enable citizens to be the investors of renewable energy.*
- *Integrate a larger share of energy storage technologies in the electricity market and grid system. Storage would enhance the integration of the renewable power in the grid and improve their business cases.*
- *Design and implement new services for renewables (e.g., new-built PV systems or wind farms) that can positively improve renewables' contribution to the electricity supply system. An example of such services is providing ancillary services.*
- *Acknowledging and establishing a position for aggregators in the market in order to strengthen renewables' business cases and to carry out new services in the market.*
- *Create a regulatory framework to facilitate the operation of the electric vehicle (EV) charging stations that run on renewables.*

List of abbreviations

AEP	*Annual Energy Production*
CAPEX	*Capital Expenditure*
DH	*District Heating*
DSM	*Demand Side Management*
DSO	*Distribution System Operator*
EU	*European Union*
FIT	*Feed-in Tariff*
FOM	*Fixed Operation & Maintenance*
GW	*Gigawatt*
kWh	*Kilowatt Hour*
LCoE	*Levelised cost of energy*
MWh	*Megawatt Hour*
OPEX	*Operational Expenditure*
O&M	*Operation and Maintenance*
PV	*Photovoltaic*
R&I	*Research & Innovation*
SET Plan	*Strategic Energy Technology (SET) plan*
TGC	*Tradable Green Certificate*
TSO	*Transmission System Operators*
VRE	*Variable Renewable Energy*
VOM	*Variable Operation & Maintenance*

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Appendix I. Fact sheet

Below for each renewable energy technology studied in this roadmap, a factsheet is presented. The fact sheet focuses on the technology's current status as well as innovation potential. It also highlights the strength and weaknesses of the technology's value chain and put forward a list of actions with top priority.

BOX II. Guideline for the fact sheet figures and notes

- *Deployment potential* indicates the deployment potential of the technology in the future European market (e.g., in terms of GW installed capacity by 2050)
- *Innovation and solution potential* for:
  - *technology* illustrates the potential of the technology development as the results of activities such as R&D efforts (e.g., related to technology development and TRL level)
  - *market* shed lights on potential of market solutions (e.g., emergence of new business models, new actors) that positively influence the deployment rate of the technology in Europe
- *Selected innovation scenarios* highlight a number of actions that can accelerate innovation processes of the technology.
- *Value chain* explores main strengths and weaknesses of the European value chain related to the technology.
- *Cost projection* illustrates the techno-economic data for the studied technologies in this roadmap. Note that, in this roadmap for some technologies cost projections are provided for different types of a renewable energy technology (e.g., solar PV ground-mounted and roof mounted). In those cases, the cost projection for the cheapest type of a technology only is provided in the factsheet below. For the full list of cost projections, please refer cost projections listed within each chapter in the roadmap.

Onshore wind power

Deployment Potential in Europe

Low *Medium* *High*

Market fact and outlook:

- In 2016 there is 153.7 GW of wind power installed in Europe, 141.1 GW of which is onshore wind power.
- Wind power is installed more than any other form of power generations in Europe in recent years. It covered 10.4 % of the EU's electricity demand in 2016.
- IRENA's ReMap scenario projects 327GW installed wind power by 2030 in EU-28
- Germany has 44% of the total EU installations in new wind power capacity.
- By 2030 wind power market will create 569k jobs in Europe
- Europe is the home for top 10 wind power manufacturers. Europe should maintain the same position in recycling facilities of wind.

Cost projections:

High wind - Turbine ICE class I	**2015**	**2030**	**2050**
CAPEX (€/kWe)	1280	1300	1000
OPEX (€/kW/yr)	42	39	17
Lifetime (years)	20	20	20
Net AEP (MWh/yr/MW)	3493	3622	4380

Development status

Mature

Innovation and Solution Potential:

Low *Medium* *High*

Selected Innovation Scenarios:

- Improving O&M using responsive maintenance, advanced monitoring systems, improving quality of the equipment, and enhancing weather prediction systems
- Community project could encourage investment decision of locals in onshore wind power
- Optimize farm layouts and improve the output assessment tools
- Investments in recycling facilities for wind turbines to separate their components at low cost, ensure high quality recycling or reuse main components.

Value chain:

EU strength

- In 2015, top 4 EU companies (Vestas, Siemens, Gamesa and Enercon) together own 30% of wind turbine supply market.
- Strong European value chain in wind create jobs in activities such as manufacturing, R&D, management and sales

EU weaknesses:

- Raising Chinese competition in this market.
- Limited investments in end-of-life recycling facilities.

Offshore wind power

Deployment Potential in Europe

Low *Medium* *High*

Market fact and outlook:

- In 2017, there was 15.8 GW of cumulative offshore wind capacity in Europe (11 wind farms being built in February 2018, adding 2.9 GW). This capacity represents about 13% of the annual EU wind energy market.
- Total of 2.9 GW of offshore wind capacity was traded in 2017: 1,891GW by power producers and 1,033 GW by financial investors
- By 2030 there would be 50-100 GW installed offshore wind capacity. This is expected to produce 7% to 14% of the EU's electricity demand in 2030.
- Europe is the biggest market for offshore wind and leads its market development.
- Offshore industry is estimated to create between 170k and 204k jobs by 2030.

Cost projections:

10 MW turbine - Site A condition	**2020**	**2030**	**2050**
CAPEX (€/kWe)	1892	1698	1018
OPEX (€/kW/yr)	66	57	33
Lifetime (*years*)	27	30	30
Net AEP (*MWh/yr/MW*)	3900	4156	4495

** The cost projections for 10 MW offshore turbine are provided from 2020 as this technology will enter the market by 2020.*

Development status

Deployment & Mature

Floating foundation are at commercialisation

Innovation and Solution Potential:

Low *Medium* *High*

Recommendations and Innovation scenarios:

- Designing turbines adapted and resistance to harsh weather conditions
- Improving O&M using responsive maintenance, advanced monitoring systems, improving quality of the equipment, and enhancing weather prediction systems
- Investment programs and/or incentives to improve the grid infrastructure in offshore areas.
- Need for long-term markets and policy framework.
- Launch a climate impact measurement of offshore wind installations on the ecosystem
- Supporting development and commercialisation of floating wind power foundations
- Measuring environmental impact of offshore wind in ocean environment.

Value chain:

EU strength

- 18.27% of all offshore wind turbines are produced by Siemens, a European company.
- Large investments in European offshore wind turbine manufacturing
- Opportunity to export services, knowledge and innovation of European players

EU weaknesses:

- Raising competition by Asian companies

Solar PV power

Deployment Potential in Europe

Low *Medium* *High*

Market Fact:

- In 2016 there is 104 GW of total accumulated Solar PV capacity in installed in Europe.
- Installed capacity is expected to reach 196 GW by 2030 and 229 GW by 2050. IRENA ReMap scenario projects 270 GW of installed solar PV.
- Solar PV constitutes 4% of the electricity mix in Europe (9% in Italy and 7% in Germany and Greece).
- PV has proven to have a high market potential due to the possibility of its installation on different scales and by different actors (i.e., from residential to utilities).
- Share of solar PV in the final electricity mix in Europe needs to be between 10-15% by 2030.
- In 2016, 81k jobs is created in Solar PV in Europe and this number is expected to be more than double by 2021.

Cost projections:

Convectional c-Si PVs Ground mounted	**2015**	**2030**	**2050**
CAPEX (€/kWe)	879	697	307
OPEX (€/kW/yr)	30	25	12
Lifetime (years)	30	30	30
Net AEP (MWh/yr/MW)	1320	1359	2718
Efficiency (%)	Cell 17% - Module 15.5%		

Development status

Mature

BIPV are at development

Innovation and Solution Potential:

Low *Medium* *High*

Recommendations and Innovation scenarios:

- Improving quality and usage of raw material, for example silicon, in solar PVs.
- Improving module efficiency through enhancing the materials, manufacturing processes, designs, or development of antireflective coating.
- Development and designing flexible solar PV that can increase available sites for PVs, and ease their installation process (BIPV)
- Improving recycling processes in order to enhance PVs' sustainability and business cases.

Value chain:

EU Strength:

- Europe is competitive in upstream value chain. the strength of Europe lies in its leadership in equipment and Inverter/BoS.
- EU has competitive advantages due to its early move on solar PV

EU Weaknesses:

- European value chain is weak in cell manufacturing production capacity
- Early 2010's, EU market shares in wafer, cells and module plummeted, due to overcapacity, shortage of silicon, aftermath of economic crisis.

Tidal power

Deployment Potential in Europe

Low *Medium* *High*

Market Fact:

- In 2016 there is 240 MW of tidal barrage in France available.
- The NREAP projection estimates 2253 MW of ocean energy installation by 2020, 10 times more than today installation.
- Number of different available tidal energy technologies indicate their immaturity.
- Europe's technological leadership in the sector has been strengthened. Europe accounts for 52 % of tidal stream and 60 % of wave energy developers.
- The current LCoE of ocean energy is between 60-110 cEUR/kWh . This cost should decrease to about 10-15 cEUR/kWh by 2030 according to the SET plan.

Cost projections:

Tidal power	**2015**	**2030**	**2050**
CAPEX (€/kWe)	10668	3100	1897
FOM (% CAPEX)	6.2	5.6	4.9
Lifetime (years)	20	20	20
Net Electrical Power (MWe)	10	20-30	50-400
Average capacity factor (%)	29	40	45

Development status

Development & Commercialisation

Innovation and Solution Potential:

Technology

Low *Medium* *High*

Market

Recommendations and Innovation scenarios:

- Harmonization of technologies in order to benefit from the learning effect
- Finding synergies with other energy sectors such as offshore wind
- Reducing the technology cost through new technology's design and innovation and by learning-by-doing.
- Improvement at the subsea level infrastructure.
- Improving O&M using advanced monitoring system, new processes and technologies such as under water robots.
- Development of optimal and resistance foundations and mooring systems for ocean energy technologies.

Value chain:

EU strength

- More than 52% of the companies developing tidal energy devices worldwide are located in Europe.
- 88% of the tidal companies located in EU are component suppliers and 12% are technology developers.

EU weaknesses:

- Limited investments due to the high risk of investments in the tidal technology.

Wave power

Deployment Potential in Europe

Low *Medium* *High*

Market Fact:

- There is 14 MW of wave energy available in the market and this rate is expected to increase to 37 MW till 2020.
- The NREAP projection estimates 2253 MW of ocean energy installation by 2020, 10 times more than today installations.
- Most of the known companies in the field of wave energy are active in Europe
- There are no existing convergence in wave energy technologies, which indicates their immaturity
- The current LCoE of ocean energy is between 60-110 cEUR/kWh . This cost should decrease to about 10-15 cEUR/kWh by 2030 according to the SET plan.

Cost projections:

Wave power	**2015**	**2030**	**2050**
CAPEX (€/kWe)	10500	5267	2300
FOM (% CAPEX)	4	4.2	5.5
Lifetime (years)	20	20	20
Net Electrical Power (MWe)	1-3	10	75
Average capacity factor (%)	25	31	40

Development status

Development & Commercialisation

Innovation and Solution Potential:

Low *Medium* *High*

Recommendations and Innovation scenarios:

- Harmonization of technologies in order to benefit from a higher rate of learning effect
- Reducing the technology cost through new technology's design and innovation and as the result of learning-by-doing
- Improvement of subsea level infrastructure
- Improving O&M using advanced monitoring system, new processes and technologies such as under water robots
- Development of optimal and resistance foundations and mooring systems for ocean energy technologies.

Value chain:

EU strength

- Majority of the companies who are active in the wave power industry are located in Europe.
- The UK and Denmark host the highest number of technology developers among all the EU countries.

EU Weaknesses

- Limited investments due to technologies' high cost and risk associated with that.
- limited cooperation between companies active in this industry.