13

Offshore Wind: Staying Ahead of the Curve

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13.1 Introduction

Wind energy accounts for 15% of the electricity consumption in the EU for 2019 with 205 GW cumulative installed capacity. The wind industry contributes €36 billion to EU’s Gross Domestic Product, supports 263,000 jobs and generates €8 billion exports. The European Commission recognises the important role of wind energy towards a climate-neutral Europe by 2050. Its long-term decarbonisation strategy foresees that wind energy will have a dominant role in 2030 and beyond in driving EU decarbonisation. The European Commission has set a target for 2030 for at least 32% of final energy consumption in the EU coming from renewables as part of the Energy Union strategy. Under this vision, Member States will collectively deliver on the EU’s Climate and Energy objectives. Meeting these objectives will require an ambitious
legislative framework for member states beyond 2020 and offshore wind is an important ingredient for meeting these objectives. This new source of clean, sustainable energy has been on the rise in the past three decades. Offshore wind has moved from few demonstration projects in the early 90s to a mainstream energy provider covering electricity consumption for millions of citizens. Europe is at the forefront of offshore wind developments with more than 20 GW of cumulative installations by the end of 2019, covering approximately 80% of global installations. The largest rotating machines the world has ever seen, are running offshore the European coasts in the North and the Baltic seas. However, in the past few years, offshore wind is taking big leaps in China, Taiwan, USA, Vietnam, Korea and Japan. Australia and India are two other nations that will soon join the offshore wind club. The 2020s will see the move of offshore wind from a European market to a global market. Can Europe stay at the forefront of future technological developments? What are the success stories to be shared and the challenges to be faced?

13.2 The Emergence of Onshore Wind

In order to gain a good understanding of offshore wind, it is necessary first to examine onshore wind. Offshore wind emerged in the 90s following onshore wind’s development a decade earlier, in the 80s, due to an unexpected event; the oil crises of 1973 and 1979 that led to significant increases in oil prices shocked all oil-dependent developed countries and led them to reconsider and re-plan their energy strategy and security of energy supply. One of the side effects of the oil crises was moving away from oil energy production and considering alternative sources of energy. Denmark and the state of California were pioneers at that time in research and development (R&D) for wind energy. During the 80s US renewable energy R&D funding grew from less than USD1.0 million per year in the early 1970s to over USD1.4 billion by 1980. This led to 12 GW of renewable power constructed in the USA during the 1980s (IRENA 2012). Following the oil crises, legislation was in parallel developed in the USA and Denmark encouraging the development of wind farms through tax incentives and subsidies. Denmark had a long
tradition using wind energy, and by the early 80s, several local manufacturers had emerged selling small turbines to local wind cooperatives. Energy legislation and subsidies scheme boosted developments in both sides of the Atlantic with Danish turbine manufacturers exporting to the USA. However, in the US, the tax incentives regime dropped following the reduction of oil prices in the 90s leading to a stall of new installations while in Denmark the political support continued by setting new targets up to 1350 MW of wind energy by 2000 (WindEurope 2020b). In parallel, many European countries from the mid to late 80s started creating a support regime for wind energy, including the UK, Germany, Spain, France and the Netherlands. To understand the technical advancements of onshore wind, it is worth following how the first wind farms looked like. The first wind farm in the USA started operation in 1980 at Crotched Mountain, consisting of $20 \times 30$ kW wind turbines, while in Europe the first wind farm, consisting of $5 \times 20$ kW turbines, started operations at the Greek island of Kythnos. By the early 90s, the size of a wind turbine grew from 20 kW to 450 kW, leading to a significant drop in costs and an increase in energy production per turbine. In parallel, the growth of commercial onshore wind in Europe during the 90s had begun moving from MW to GW scale in cumulative capacity. A decade later, average wind turbine sizes reached the MW scale.

13.3 The Birth of Offshore Wind and Its Technological Advancements

Offshore wind was born in the onshore wind’s transition period when it was moving to a more mature stage. The first offshore wind farm started operations in 1991 in Denmark. The Vindeby wind farm, consisting of $11 \times 450$ kW turbines, operated successfully for 26 years until it was decommissioned in 2017 (ORSTED 2017). The average wind turbine size in the EU expressed in MW has increased 10-fold within the same period of Vindeby’s lifetime, as presented in Fig. 13.1.

Until 2010 the offshore wind market followed the onshore wind market closely with turbine manufacturers adjusting onshore turbine models or providing upgraded models for offshore environments. After
2010, research and development of major onshore turbine manufacturers, together with market growth, created the foundations for the development of large dedicated offshore turbines which cut ties from the onshore wind turbines creating an exclusive offshore fleet. A fierce competition of turbine manufacturers commenced 10 years ago from a number of major industrial players that tried to grab a share of this emerging market. This competition continues today with a few major players MHI Vestas, Siemens Gamesa and GE competing on an international level. They are all providing commercial turbines currently exceeding 10 MW with Siemens Gamesa providing in mid-2020 the largest offshore wind turbine in the market, the SG 14-222DD, with a rotor diameter of 222 m. In 2019, the average size of an offshore wind turbine installed was 7.8 MW, which will exceed 8 MW in 2020. Turbine lifetime has also been extended the last few years from 20 years to 25+ years, lowering the offshore wind levelised cost of energy. As the turbine swept area is getting larger as depicted in Fig. 13.2, the turbine capacity factor, a measurement of turbines performance in maximum power has also increased with modern turbines having capacity factors exceeding 50% in the North Sea.
Technology advancements of wind turbine growth during this period was followed by the supply chain of the balance of plant. As turbines got larger so did wind farms which were located further offshore in deeper waters. Foundations got larger to accommodate larger and heavier turbines. Larger cables and substations were also developed to connect more powerful turbines to the onshore grid. Alternative current (AC) grid connection between the wind farms and the onshore grid has been the selection of choice for all countries apart from Germany due to the distance from shore where Direct Current (DC) connection is the preferred option as export cable lengths exceed 100 km. Installation vessels also got larger being able to accommodate more turbines and foundations per vessel and instal them faster with more powerful cranes. Cable vessels got larger as well as being able to carry more cables that will connect wind farms further offshore. In 2017 technological advancements continued with the successful installation of the first floating wind farm. Consisting of $5 \times 6$ MW wind turbines off the coast of Scotland, the Hywind project (EQUINOR 2020) earmarked a new era allowing turbines to be installed in water depths exceeding 100 m which unleashed the development of deepwater offshore wind farms close to coastal areas all over the world. Another 274 MW of seven floating wind projects will be connected in Europe by 2022 (WindEurope 2020a).
From the above summary, the technological trends for offshore wind farms are quite clear; moving to even larger turbines that can harness more energy, further offshore and in deeper waters. Future turbines are expected to have a nameplate capacity between 15 and 20 MW in 2030 with rotor diameters exceeding 250 m. As projects get larger and are developed further offshore, Direct Current technologies will increase their market share. More jacket foundations will be deployed compared to monopile foundations due to heavier turbines in deeper waters and floating foundations considered now novel will be well established. These technology advancements that have occurred the last few years had a huge impact on offshore wind costs. For every new 8 MW turbine which is currently installed it would require $4 \times 2$ MW turbines from a project that reached financial close in 2006 and $2 \times 4$ MW turbines from a project that reached a financial end in 2014. The amount of steel needed for the same energy produced under the same water depth conditions is massively reduced when moving to larger turbines with larger rotor diameters. Fewer turbines mean fewer foundations and cables and given installation times keep coming down, the overall project costs are reduced. Moving also to larger capacity cables optimises the energy production with lower electrical losses and fewer cables needed to be connected between the turbines and the offshore substation. A catalytic effect on cost reduction came from the size and continuation of projects being built. Thanks to the volume of continuous work occurring throughout European projects the last years, a significant cost reduction was possible, allowing innovation and industrialisation to take place. The decade of 2000 saw an average annual offshore wind installation rate below 100 MW with maximum one project constructed per year. Since 2011 it is stronger with a minimum of 1.1 GW offshore wind capacity installed per year. From 2017 this growth is even stronger with 2.5 GW minimum annual installations in the EU. The above developments have allowed the whole supply chain to move fast forward during recent years to cope with the size and volume of upcoming projects, in competitive bidding auctions. The technology advancements, the supply chain maturity, cheaper financing and the increased competition between developers and the supply chain led to a sharp price reduction in offshore wind costs, especially after 2016 when offshore wind auctions were
introduced. The Cost Reduction Monitoring Framework 2016 report (ORE Catapult) showed projects reaching a final investment decision in 2015–2016 achieved a levelised cost of energy (LCOE) of £97/MWh (EUR112/MWh). This compares to projects, which completed financing in 2010/2011 with an LCOE of £142/MWh (€164/MWh) at 2011 prices (Wind Power Monthly). The global weighted average cost of electricity for plants commissioned in 2017 was approximately €120/MWh corresponding to USD140/MWh (IRENA 2018). Auction results in 2016 and 2017, for offshore wind projects that will be commissioned in 2020 and beyond, signal a step-change, with costs falling to a range between €50/MWh and €83/MWh corresponding to USD60/MWh and USD100/MWh (IRENA 2018). These significant cost reductions continue with CFD auction prices announced in September 2019 in the UK falling below £40/MWh. All offshore wind auction results in 2019 ranged between €40/MWh and €50/MWh.

13.4 Leading Countries in Offshore Wind Developments

The strong growth in offshore wind mentioned above would have never happened without a strong political regime to support the delivery of this volume. Offshore wind developments as large infrastructure projects have been intimately paired with government policies to exploit offshore wind as part of EU’s renewable energy targets. So which are the countries that are leading the way in offshore wind farm developments? As it has already been mentioned, Denmark was the real pioneer for the first ten years since the birth of offshore wind market and the first to install a 160 MW project, the Horns Rev, which became the largest true offshore project, located some 14–20 km offshore. Other countries that tapped into offshore wind and started installing small scale demonstration projects included the UK, Belgium, the Netherlands and Ireland. However, only the UK was consistent in delivering offshore wind farms from that time until today.
13.4.1 The UK

The UK, through leasing rounds over the last two decades, moved from a few demonstration projects of less than 100 MW each and close to shore to GW scale projects being constructed today far offshore. The UK is currently the largest offshore wind market in the world. Driven by the EU’s legally binding 2020 renewable energy targets of 30% of electricity coming from renewables, the UK government has implemented the Climate Change Act, which mandates an 80% cut in carbon dioxide emissions by 2050 compared to 1990 levels. This target in combination with the declining North Sea oil and gas industry and with 1/3 of old thermal power stations coming offline after 2020 led the UK government to focus on offshore wind for future power generation (FOWIND 2014). An industrial strategy was added in 2015 as a policy priority, with an obligation for a minimum UK content on wind farm total budget, examined during the consenting process, which has led several EU manufacturing companies to establish UK subsidiaries. The seabed within the Exclusive Economic Zone of UK’s continental shelf is owned and managed by the Crown Estate. Any developer needs to have secured a lease agreement with the Crown Estate to get exclusivity rights for site development. The first round of UK developments was published in 1999 by the UK government and was an open-door application process for projects limited to an area of 10 km$^2$ in size and with a maximum number of 30 turbines. Locations were chosen by potential developers, and 17 sites were granted a lease to exclusively develop offshore projects in April 2001, in what has become known as Round 1 of UK offshore wind development. Lessons learnt from Round 1 prompted the UK department of trade and industry to develop a strategic plan for offshore wind by selecting specific zones and pushing developments above 8 km offshore to reduce visual impact and avoid shallow feeding grounds for sea birds. The new areas were tendered to prospective developers in a competitive bid process known as Round 2 with 15 projects awarded with a combined power generating capacity of 7.2 GW. In June 2008 the Crown Estate launched the third round of site allocations by selecting 9 large zones further offshore for bidding with a combined capacity of
25 GW with successful bids announce 2 years later. A new allocation of the fourth round is currently ongoing with prospective bidders.

Once a developer has obtained a lease, a variety of permits need to be obtained together with a grid connection agreement. Once a project is constructed, generators are required to sell the transmission infrastructure through a competitive tender, to an Offshore Transmission Owner (OFTO) who receive a return on investment by charging transmission fees (FOWIND 2014). Up to April 2017, the government’s financial support for offshore wind farms used to be based on renewable energy certificates (ROCs), a green certificate mechanism paid on top of the electricity price. Since 2017, support is provided by contracts for difference (CfDs). CfDs are 15-year contracts agreed at a strike price (the generation price). Under the CfD system, a fixed revenue stream of a strike price is guaranteed to the generator independent of the fluctuation of the wholesale electricity prices. However, unlike other countries, when the wholesale price is above the strike price, the wind farm will pay back the difference to maintain cost-efficiency. The UK provides near and medium-term visibility through the size of the Levy Control Framework, a fixed government budget on the support available to energy technologies through the allocation of CfDs. The UK government has allocated funding to support 10 GW of total installed capacity by 2020 and committed following a Sector Deal agreed in March 2019 to support an additional 20 GW by 2030 leading to delivery of 30 GW offshore wind installed capacity by 2030. Recently these plans were pledged to increase installed capacity to 40 GW by 2030, which should materialise when the UK government passes the relevant legislation.

13.4.2 Germany

Another success story of offshore wind is Germany. Germany has been the front runner in promotion of green energy policies for wind and solar energy for decades, however, due to its deeper waters and limited coastline, it saw its first offshore wind demonstration project, the Alpha Ventus start installation in 2009, many years after other EU countries.
Following a slow start though it has emerged to become the second-biggest market in Europe. Driven by its industrial strategy to become a world leader in clean energy together with the EU’s legally binding 2020 renewable energy targets, the German government has implemented the ‘Energiewende’ legislation. This new energy legislation aims to transition away from fossil fuels and nuclear power after the nuclear accident in Fukushima, Japan, in 2011. The Renewable Energy Sources Act (EEG 2017) mandates an 80% renewable electricity consumption by 2050 with a significant part of it expected to be borne by offshore wind. (FOWIND 2014). The Federal Maritime and Hydrographic Agency (BSH) is the federal agency overseeing licensing for renewable energy projects in the German Exclusive Economic Zone. A thorough marine spatial plan and grid plan were developed that identified potential zones for offshore wind development where developers were able to submit applications within these zones in an open-door approach until 2017. BSH released such zones for offshore wind developments where developers, after securing exclusivity rights, submitted a consent application which was examined by the BSH. After award of a lease, the developer moved to site investigations and further site development until full consent was granted. At the same time, the Transmission System Operators (TSO) was required to develop, acquire permits and fund all offshore wind grid connection works up to an offshore connection point, with the developer responsible for connecting to this connection point. In 2017 and 2018 there was a transition period with auctions released for securing certain capacity of eligible projects.

From 2018 onwards (for projects to be commissioned after 2026) the model has changed to a more centralised approach with sites selected in advance by BSH according to the nationally coordinated marine spatial plan and offshore grid plan, with a schedule of when these sites will be auctioned. Then site investigations are conducted by BSH and site information is passed on to developers before the official auction. Winning bidders will get a subsidy contract, grid permits and the guarantee that the TSO will build and operate the transmission assets. Developers are still required to obtain full consent by BSH following the auction process. The government’s financial support for offshore wind farms until 2017 was based on a feed-in tariff mechanism based on water depth and
distance from shore to allocate such tariff. The tariff could be provided at a fixed price for 8 or 12 years with reduced tariff for a prolonged period. Since 2017, the support for new projects is based on a flexible market premium on top of the spot market electricity price granted through a 20-year contract. The German Offshore Wind Act has set targets of 6.5 GW by 2020 and 15 GW by 2030. The act provides visibility for future auctions and includes 500 MW per year tendered between 2021 and 2022, 700 MW between 2023 and 2025 and 840 MW annually from 2026 onwards (IEA 2017). The government has passed new legislation in May 2020 to raise Germany’s 2030 offshore wind target to 20 GW by 2030.

13.4.3 The Netherlands

The Netherlands was one of the first EU countries to develop and operate large-scale commercial wind farms before 2010 with an installed capacity of 247 MW. However, despite the strong start, the Netherlands has had a stop–start history. In 2011, a change of government led to a cut in renewable energy support and stagnation in the offshore wind industry. In 2014, the market took a huge leap forward with the signing of the Dutch Energy Agreement between the government and key industry players. The financial close of the largest project to be financed by banks, the EUR2.8 billion Gemini project was another positive development (FOWIND 2014). Driven by the Energy Agreement’s targets of 16% of electricity coming from renewables by 2023, the Dutch government has implemented the Energy Act, with a target to reach 4.45 GW of offshore wind capacity by 2023. Beyond 2023 a climate agreement passed in 2018 seeing additional 1 GW offshore wind installation per year between 2023 and 2030 unveiling a roadmap of 11.5 GW installed capacity by 2030. Until 2014, the Netherlands used to have an open-door approach to offshore wind development with developers securing exclusivity of sites and moving to consent by applying to the Ministry of Infrastructure and Water Management. Following extensive public consultation by the Dutch government, the Offshore Wind Energy Law came into force in 2015, where the National Water Plan allocated designated offshore
wind farm zones within the Dutch EEZ. In these areas, the Netherlands Enterprise Agency (RVO.nl) acts as a one-stop-shop for offshore wind development and consultation with developers. RVO undertakes the selection of specific project sites, conducts the necessary site investigations and obtains full consent and grid permits. The Dutch transmission system operator is responsible for developing, constructing and operating the offshore transmission grid where the projects will be connected to. Then developers compete for sites through an auction process that takes place every year. Winning bidders are awarded a subsidy contract for 15 years and all necessary permits to progress with wind farm construction. RVO is executing both the offshore wind energy subsidy and permit tenders on behalf of the Ministry of Economic Affairs and Climate Policy. (RVO 2015). The government’s financial support for offshore wind farms is based on a subsidy mechanism called Subsidieregeling Duurzame Energie+ (SDE+) with a guaranteed price lowered by the electricity market price (market premium). This price is capped by a minimum electricity price and is yearly corrected by an imbalance and profile factor for offshore wind projects (PWC 2017). The annual allocation of at least 700 MW of projects up to 2030 provides good visibility for developers and has allowed the Dutch TSO to standardise offshore substations reducing transmission costs.

13.5 Current Installations

Offshore wind reached a global installed capacity of 23 GW in 2018 of which 18 GW were installed in Europe, 5 GW in Asia and 30 MW in the US. A summary of recent offshore wind installations in Europe is provided in Fig. 13.3 with 3.6 GW installed in 2019. Figure 13.4 provides an overview of the global cumulative offshore wind capacity in 2018, as presented in a recent report by the Global Wind Energy Council.

The global installed capacity in 2019 reached 29 GW, with Europe and Asia installing 6.1 GW additional capacity.
Fig. 13.3 Annual offshore wind installations (left axis) by country and cumulative capacity (right axis) (Source WindEurope 2020a)

Fig. 13.4 Global cumulative offshore wind capacity in 2017 and 2018 (Source GWEC 2019a)
13.6 Conclusions on the Status and Future Challenges of Offshore Wind

Beyond 2020 the forecast of offshore windfarm capacity installations for the coming decades varies depending on scenarios considered. Several governments have already outlined commitments and targets for offshore wind deployment, while others have indicated aspirations to enter the sector. In addition to the current leading markets of UK, Germany, China, Netherlands, Belgium and Denmark, new emerging markets are expected to increase their activity in the offshore wind sector, both within Europe and in countries such as India, Vietnam, Japan, Taiwan, South Korea and the USA. In Europe, the UK, Germany and the Netherlands are expected to dominate the market with approximately 60 GW of installations to come online by 2030. France that has been developing wind farms for over a decade has not seen projects being realised yet, however, strong growth is expected till 2030 with at least 5 GW of new installations. Ireland has just passed a marine development plan that could pave the way for installations of at least 3.5 GW by 2030. Other Baltic states that will see offshore wind growth include Denmark with additional 2.4 GW agreed in June 2019, Estonia, Finland, Latvia, Lithuania, Poland and Sweden. Romania has also announced plans for developing offshore wind in the Black Sea. Outside Europe, US projects start building momentum with the allocation of seabed leasing rounds by the US Bureau of Ocean Energy Management (BOEM) which are expected to be constructed in the coming years. US capacity is set to grow from 30 MW today to 2 GW by 2025, and with a development pipeline of 25 GW, the total capacity could reach 10 GW by 2030 (GWEC 2019b). In Asia, China had an installed capacity of 4.6 GW by the end of 2018, making it the third-largest country in the world in offshore installed capacity. However, this is expected to change in the coming years with annual installations exceeding 5 GW per year, making China the strongest player by 2030. Taiwan is currently a hot market in offshore wind and is expected to witness up to 5.5 GW of new installations by 2025 and 10 GW by 2030. South Korea, Japan and Vietnam could also see significant growth during that period. The emergence of floating wind technology could also unlock new sites for
offshore wind in deeper waters in the North part of the North Sea, the Atlantic coast and the Mediterranean Sea. France is taking a leading role in floating wind developments with the announcement of tender programmes of a 250 MW floating wind project in Brittany in 2021, followed by two of the same size in the Mediterranean in the following years. The UK, Norway and Portugal should follow a similar example moving from demonstration projects to large-scale floating projects in ongoing dedicated tenders. Floating wind installations worldwide could exceed 5 GW by 2030. Other countries that are looking into tapping into floating wind include the USA, Taiwan, Japan, South Korea and Saudi Arabia.

Although the future of offshore wind in Europe may seem bright, it is not a bed of roses. With more offshore wind coming online, new offshore wind allocated marine areas are needed to support the EU’s long-term targets. However, offshore areas can get quite crowded and congested considering marine habitats and other users such as oil and gas, shipping, fisheries, aquaculture, coastal tourism, aviation and military among others. To address these future challenges, an integrated marine spatial planning in national and EU level is ongoing with cross-border and cross-industry collaboration to address stakeholder interests for allocation of dedicated offshore wind spatial areas. Such collaborations should consider efficient seabed management synergies and potential future multi-uses such as large-scale mussel farming together with offshore wind. The EU deadline for the establishment of national maritime spatial plans is set in 2021. Another big technical challenge is the ability to absorb large amounts of offshore wind and to meet the respective energy demand at any time considering the intermittency of wind energy. Denmark is the country with the largest share of wind energy in its electricity demand of 48% in 2019 (WindEurope 2020c). Denmark achieves this through strong interconnection links with its neighbouring countries. To achieve this in European level, interconnections are an important tool to deliver security of supply, market integration and the large-scale uptake of renewables. In this respect, the EU has set an electricity interconnection target of at least 10% of its installed capacity by 2020 and 15% by 2030. Projects of common interest play a pivotal role in this process, including the North Seas offshore grid with the aim
to transmit offshore wind electricity between neighbouring countries. However, there are also technical limitations in the transmission capacity and with increased renewable penetration negative electricity prices that may lead to curtailment will be more common. This is where hydrogen is coming to play a role as storage fuel for offshore wind generation. Recently, since H1 2020, major oil and gas players have been looking at demonstrator projects producing hydrogen from offshore wind and the German government is expected to produce a strategy in offshore wind hydrogen later this summer (Recharge 2020). This could be a game changer in future use of offshore wind. The last challenge is access to finance and investor confidence in unprecedented challenging times for the energy sector following the coronavirus pandemic. The resilience of renewable energy during the oil price shock caused by the COVID-19 crisis shows that renewables are here to stay with more than 3 GW of offshore wind reaching financial close in the first week of June 2020 in Europe. The green recovery package set by the EU commission on 27 May 2020 sets the tone by pouring money to energy efficiency, green heating, renewable energy, hydrogen and clean cars and trains.

Based on the Global Wind Energy Council report (GWEC 2019b) 190 GW of offshore wind capacity could be installed worldwide by 2030. The majority of installations is expected in Asia (100 GW) followed by Europe (80 GW) and USA (10 GW). In this transition period, where the Chinese market is expected to become the world leader in offshore installations, Europe should ensure it keeps up with the competition for the years to come, considering also remaining resilient. How can EU countries achieve this? The answer lies in coordinated policy measures at European level. The European Commission set a European Green deal in December 2019, targeting to make Europe the first climate-neutral continent by 2050. Following the coronavirus pandemic, the Commission has set the European Green Deal as key to the EU’s recovery strategy. Offshore wind will play an important part in this energy transition, which must go hand in hand with Europe’s new industrial strategy to benefit its society. Under this new industrial strategy focus should be given to supporting skills and innovation, accessing cheap finance for capital-intensive investments and maximising supply chain efficiencies. With EU members setting binding renewable
energy targets for 2030, offshore wind developments should be expanded in new territories including the Mediterranean Sea. An important part in this expansion is an EU maritime spatial plan. Interconnections will also play an important role in a future integrated EU electricity market via projects of common interest. Research funding support should be targeted to allow technology and supply chain providers to further reduce costs and improve technology offerings to the EU and the global market for existing and new products such as renewable hydrogen. The European Commission has also set ambitious goals for 2050: between 230 and 450 GW (WindEurope 2019). These strategies will allow Europe to stay in competitive edge beyond 2030. The offshore wind market will be a trillion-dollar industry by 2040, with hundreds of GW installed in the coming decades (IEA 2019). According to a report published by the International Renewable Energy Agency (IRENA 2016), global offshore wind capacity could reach 400 GW by 2045. As a comparison to the offshore case, the onshore wind had a global capacity of 13 GW in 1999 and took until 2016 to grow to 475 GW.

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