Chapter

Global Prediction of Wind Energy Market Strategy for Electricity Generation

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Abstract

Global warming and increasing electricity consumption trends in many parts of the world pose a serious challenge to most countries from a climate change and energy security perspective. Wind power is the only one that offers a mature technique, as well as promising commercial prospects, and is now generally applied in large-scale electricity generation. Continued technological improvements will assist to boost the on-shore and off-shore wind farms' ability by improving micro turbine, enhancing reliability with predictive maintenance models. At the same time, as global and regional markets for wind power technologies grow, economies of scale are being reaped in manufacturing. With increased market scale, opportunities to improve the efficiency of supply chains arise. Technological improvements and cost reductions have led wind energy to become one of the most competitive options for new generation capacity. Wind energy still has significant potential for cost reduction. Indeed, by 2025, the global weighted average levelized cost of electricity (LCOE) of onshore and offshore wind could see declines of 26 and 35%, respectively. This chapter aims to provide an overview of the world wind energy market, current and forecasting development globally of wind energy, and LCOE historical growth Ffor wind energy.

Keywords: wind energy, market strategy, electricity, energy cost

1. Introduction

Sustainable development needs judicious utilization of energy sources, which are integral inputs to modern society. Renewable energy (RE) sources, such as solar, wind, biomass, etc., are of paramount importance when considering economic development.

The global renewable energy market was valued at $928.0 billion in 2017 and is expected to reach $1512.3 billion by 2025, registering a compound annual growth rate (CAGR) of 6.1% from 2018 to 2025. Renewable energy technologies convert the energy from different natural sources, such as sun, tides, wind, and others, into its usable forms such as electricity [1].

The global renewable energy market is anticipated to grow significantly during the forecast period owing to increased emissions of greenhouse gases (GHGs), particularly CO_2 due to utilization of fossil fuels for generation of energy. In addition, limited presence of fossil fuel on the earth as well its volatile prices fuels the renewable energy market. However, generation of energy from renewable sources requires huge investment. This factor is anticipated to hamper the market growth during the forecast period. Furthermore, in the Middle East, fossil fuels are majorly used to generate energy owing to its cost-effective nature as compared to other regions. This hampers the growth of the market. On the contrary, due to continuous advancement in technologies and increased government funding in renewable energy sector to offer lucrative growth opportunities during the assessment period, the renewable energy market size will be increasing because of rise in stringent government regulations regarding climate change in the developed and developing economies.

"Now that the Paris Agreement is coming into force, countries need to get serious about what they committed to last December. Meeting the Paris targets means a completely decarbonizes electricity supply well before 2050, and wind power will play the major role in getting us there," said Steve Sawyer, Global Wind Energy Councils (GWEC), Secretary General.

The increasing investment in wind energy (WE) is not only significant from the point of view of bridging the demand-supply gap but also from considering environmental issue. Currently, wind energy is one of the fastest developing RE technologies around the world including Egypt.

Wind energy dominates as an immediate viable, cost-effective option that promotes energy conservation and avoids equivalent utilization of fossil fuels and avoids millions of tons of gas emission causing ozone depletion and other environmental impacts like global warming. Wind turbines do not need any type of fuel after installation, so there are no environmental risks or degradation from the exploration, extraction, transport, shipment, processing, or disposal of fuel.

2. Electricity and energy demand

World energy demand is growing by over 50% and will continue to grow up to year 2030. **Figure 1** shows the energy consumption per person till the year 2050. Today, climate change is a major global concern. The main cause of global warming is CO2, at least 90% of it is a result of the combustion of fossil fuels for energy generation, and it is the cause for climate change, which is the main global concern [2].

By 2050, Europe will achieve an electricity system that depends on renewable energy without carbon, so it will require the replacement of much of the existing

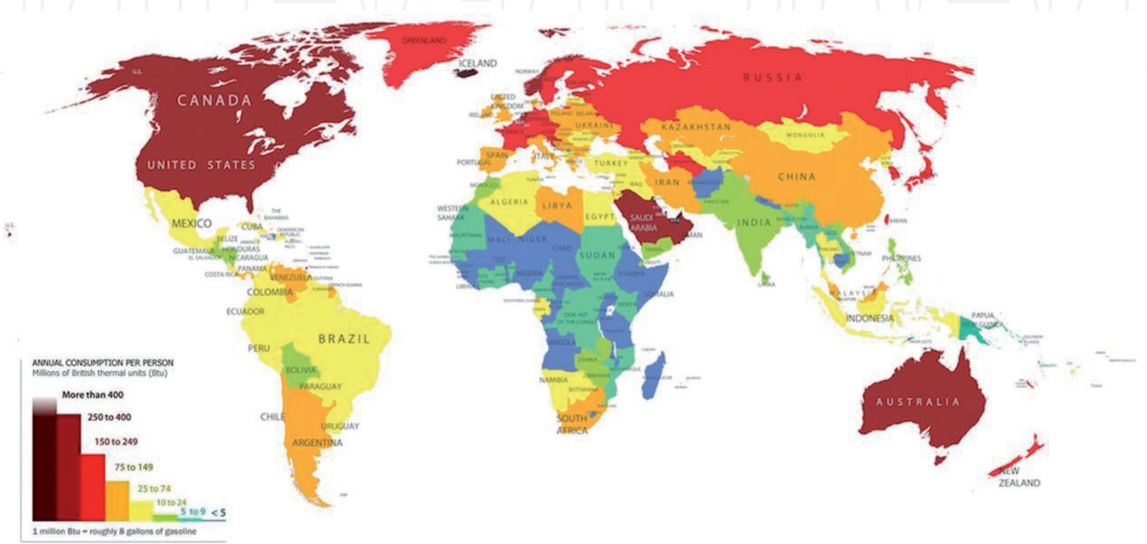

Figure 1.
Consumption of energy per person [1].

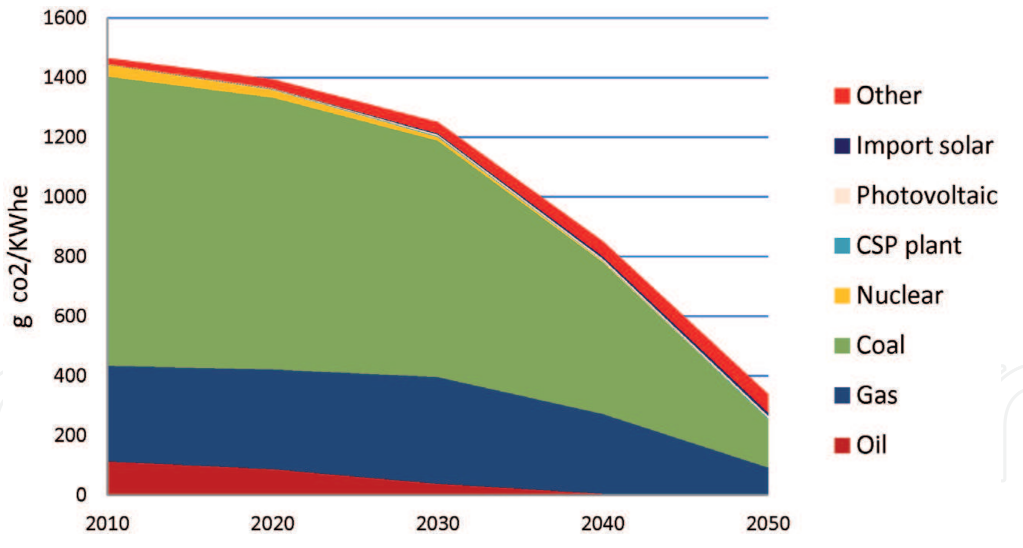

Figure 2.
CO_2 emissions from the various sources of energy [3].

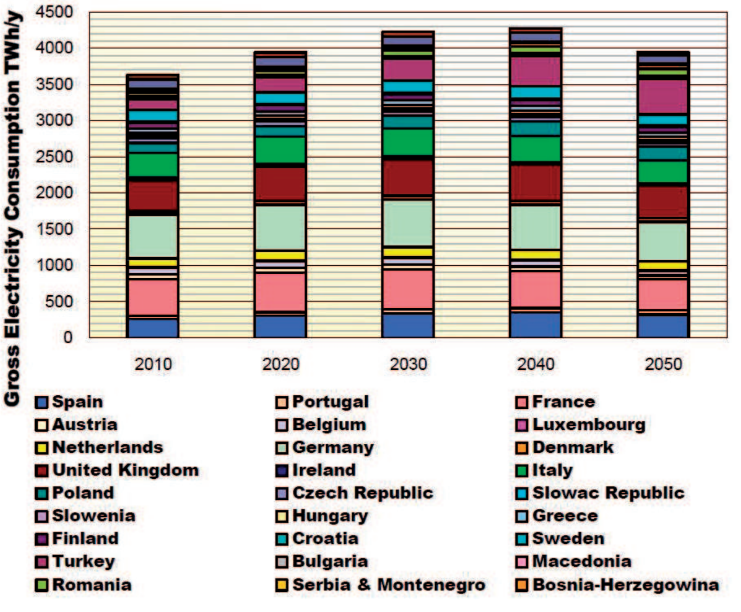

Figure 3.
Electricity consumption of the European countries analyzed between 2010 and 2050 [3].

electricity-generating capacity, and the price volatility in traditional energy has forced nearly all countries to review their energy policy (**Figure 2**). This is prompting countries that depend on imported fossil fuels to explore and evaluate alternative sources of energy to generate electricity [3].

In Europe, the thirty analyzed countries refer to the total electricity demand starting with roughly 3530 TWh/y in the year 2010 and will reach a maximum of 4300 TWh/y in 2040 [2]. **Figure 3** represents the expected future electricity demand in Europe to 2050 that is available to cover the demand with a surplus of 45% [3].

3. Wind energy market forecasting

The annual market will expect to grow in 2020, breaching the 60 GW, and continue to grow in the beginning of the new decade. And the total cumulative installations will reach 840 GW by the end of 2022 (**Figures 4** and **5**) [4].

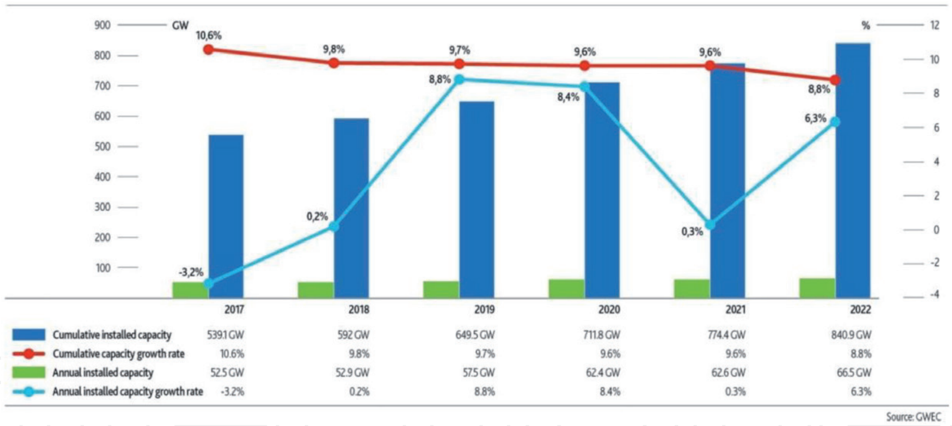

Figure 4.
Current and forecast market wind energy 2018–2022 [4].

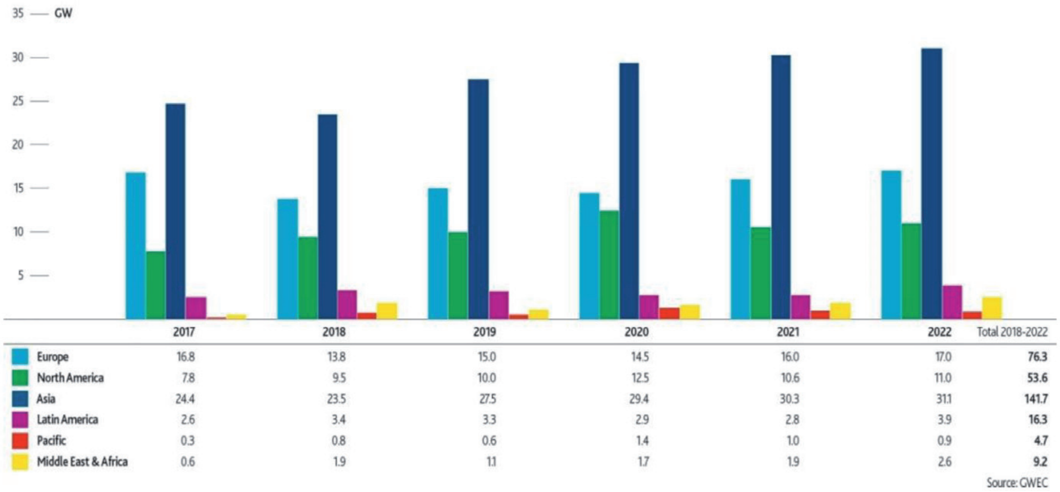

Figure 5.
Annual market forecast by region 2018–2022 (GW) [4].

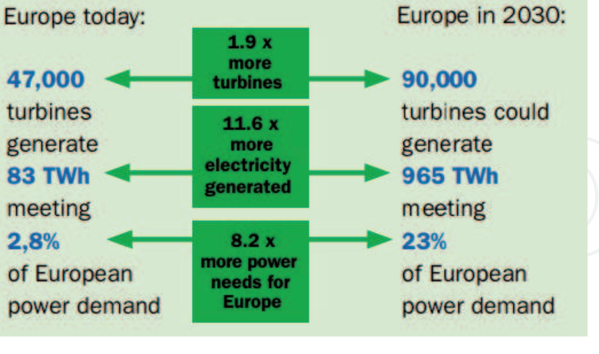

Figure 6.
More power from fewer turbines in Europe.

Europe intended to estimate installation of 47,000 wind turbines at the end of 2005. In 2004, the average size of turbines delivered to the market was about 1.3 and 2.1 MW for onshore and offshore, respectively (**Figure 6**). By 2030, the assumption of average size of a wind turbine will be 2 MW onshore and 10 MW offshore, and only 90,000 turbines (75,000 onshore and 15,000 offshore) would be needed to fulfill the 300 GW target.

By 2030, Germany expects to have 15,000 MW of offshore wind capacity. The Economy Japanese Ministry, Trade and Industry (METI) has assumed a demand of wind power at 10 GW, which is including 820 MW offshore wind power by

2030, in its future energy plan called the Energy Mix Plan, which was released in 2015. The Japan Wind Power Association (JWPA) has requested a more aggressive target for wind power, calling for 36.2 GW by 2030, including 10 GW of offshore [5].

The Dutch government has intended to install 6000 MW of onshore wind energy power by 2020 and 4500 MW of offshore wind energy power by 2023. By 2030, the Dutch Wind Energy Association (NWEA) will estimate to reach 15 and 18.5 GW of onshore and offshore wind energy, respectively [4].

Taiwan's initial offshore wind target of 3 GW by 2025 was quickly exceeded by oversubscription of projects proposed by developers, which led to an upward adjustment of the target in 2017 to 5.5 GW by 2025. The target of 520 MW by 2020 was maintained, while the target for 2030 was raised to 17 GW [3].

South Korea aims to triple the share of renewable energy in the country's power mix by 2030, which translates to adding about 47 GW of new wind and solar capacity, according to the government's latest draft policy roadmap.

New York State has become the new climate leader in the US, after California, with a series of government measures and targets being introduced to boost the clean energy industry. An offshore wind target has been set at 2.4 GW by 2030. In January 2018, New York State also released its long-awaited Offshore Wind Master Plan, encompassing 20 in-depth studies on a variety of factors that will affect the state's ability to reach its 2.4 GW offshore wind target by 2030 [6].

The Vietnamese government has set a target for wind development at 800 MW by 2020, 2000 MW by 2025, and 6000 MW by 2030 [6].

By 2030, wind power could reach 2110 GW and supply up to 20% of global electricity, creating 2.4 million new jobs and reducing CO_2 emissions by more than 3.3 billion tons per year, and attract annual investment of about €200 billion [7].

2018 is a solid year with a total installed capacity of 51.3 GW, which decreased 4.0% over the previous year and reached total installed capacity of 591 GW (9% more than 2017). In the onshore wind energy market, new plants reached 46.8 and 4.5 GW was installed in the global offshore market, bringing the global share to 8%. The Chinese onshore market installed 21.2 GW in 2018 and has been the market leader since 2008. China is the first market to exceed 200 GW of total installed capacities at the end of 2018, achieving the target of 200 GW 2 years early (based on the 5 Year Plan 2016–2020), with 206 GW of total installations [5].

The second-largest market in the US in 2018 was with 7.6 GW of new onshore installations and 96 GW total onshore installations. Future demand will be linked to RPS and increasing onshore wind power competitiveness by 2020 and 2030. In the US market, new financial models will most likely drive the volume of new installations further: Germany will be the top five wind markets with 2.4 GW in 2018, India with 2.2 GW, and Brazil with 1.9 GW in addition to the USA and China. **Figure 7** shows the top 5 wind energy markets, and **Figure 8** shows the global wind energy consumption beside renewable energy in 2017–2023 [8].

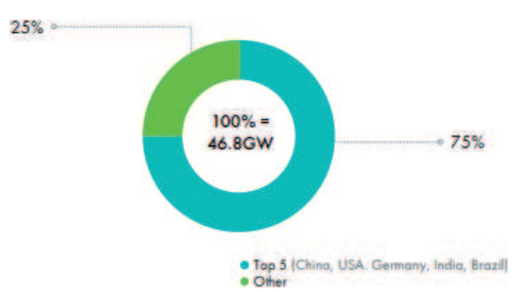

Figure 7.
New capacity in 2018 and share of top five wind energy markets [8].

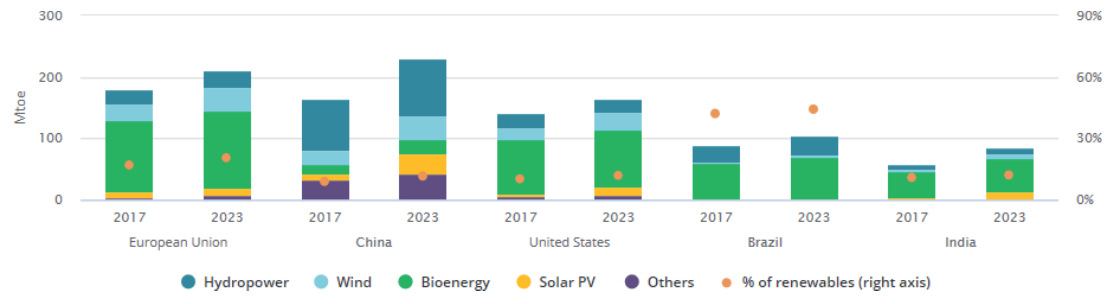

Figure 8.
Wind energy beside renewable energy consumption in major markers, 2017–2023 [8].

4. Wind power deployment globally out to 2020–2030

At the end of 2015, the globally total installed onshore wind energy capacity reached to 420 GW [9]. Cumulative installed capacity has increased to 25%/year over the last decade. At the end of 2015, China maintained the largest share of onshore wind energy capacity in the world, at 34%. This is followed by the United States, which share with 17%; Germany, 10%; India, 6%; and Spain, 5%. Onshore wind energy has set a record of 59 GW in 2015, which is twice as high as in 2014. In 2015, China accounted for 51% of global new additions, followed by the USA with 13%; Germany, 6%; Brazil 5%; and India, 4%. Strong growth in China about 30 GW and the United States about 7.7 GW accounted for around 63% of net additions in 2015 [9].

China is expected to add more than 20 GW a year from 2016 to 2020 [10]. With policy support renewed for the medium-term, the United States will add on average more than 7 GW a year up to 2020 [11]. In 2015, Brazil had a solid installation record around 2.8 GW and is set to continue installing more than 2.5 GW a year, and Germany installed more than 3.5 GW of onshore wind energy in the same year [12].

The world installed 46.8 GW of onshore wind energy turbines last year, down by 3.9% from 2017, and 4.49 GW of offshore wind farms, up by 0.5%. China led growth in both cases, installing 21.2 GW onshore and 1.8 GW offshore. For the first time, it built more offshore wind capacity than any other country. **Table 1** shows the top five onshore wind energy and offshore wind markets in 2018 [13].

The 2018 total of 51.3 GW, a decrease of 3.6% year-on-year, boosted the cumulative global wind power generation capacity to 591 GW. Energy is fundamental to any economy; wind energy can be a driver for European growth. With the right kind of investment and collaboration, electricity production from wind for European electricity consumption could raise from 83 TWh to 965 TWh from 2005 to 2030, respectively, supplying 23% of European electricity. This projection takes into account that consumption is expected to increase by half over the same

Top onshore markets in 2018	MW built	Top offshore markets in 2018	MW built
China	21,200	China	1800
USA	7588	United Kingdom	1312
Germany	2402	Germany	969
India	2191	Belgium	309
Brazil	1939	Denmark	61

Table 1.
Top five onshore wind energy and offshore wind markets in 2018 [13].

period [14]. **Figure 9** shows wind energy contribution to European electricity consumption in 2005–2030 [15].

Offshore wind has reached maturity in Europe, and costs have decreased decisively, with committed projects scheduled to start generating in the early 2020s likely to produce at a levelized cost of energy (LCOE) below €70/MWh by 2017 prices, including the cost of offshore and onshore grid connection. This has lead to increased confidence in the deployment of offshore wind around the world. By 2030, the forecasting for total installed capacity will be 120 GW, with an installation rate of over 10 GW/year being achieved before then. Much of this growth will come in Europe, building on the established capability and proven low cost. The significant capacity in China and the US will be smaller than significant volumes in Japan, Taiwan, and South Korea. By 2030, LCOEs below €60/MWh will be achieved by many newly installed offshore wind farms, which could be well below the average wholesale power price in many electricity networks, driving higher levels of deployment and the spread to currently uncharted waters.

Floating offshore wind has seen the first multiturbine demonstration project, but floating is likely to remain a niche sector throughout the 2020s. It will become cost-competitive by the end of the decade, giving it strong potential in the 2030s, especially through enabling new markets. Early deployment of floating offshore wind projects needs support mechanisms in multiple markets specifically targeted at enabling commercial-scale floating deployment. France and Japan are the most likely candidates, assuming governments are able to see clear long-term benefits. On this basis, the expectation of floating deployment will exceed 500 MW a year by 2026, increasing to over 1 GW a year by 2030 to give a total installed capacity of over 5 GW, 5% of the offshore market. In addition to France and Japan, commercial floating projects are also likely in Korea, Taiwan, the UK, and the US by 2030. If cost reductions are achieved quicker than currently expected and floating becomes cost effective much faster, the market could really 'take off' with up to 12 GW installed by the end of 2030, setting the 2030s up for substantial further global offshore wind deployment [14].

The European Commission assumes that the cost of onshore wind power will decrease to € 826/kW and €788/kW, respectively between 2020 and 2030 in its renewable energy roadmap [16].

Figure 10 shows the estimates of the European Commission on offshore and onshore cost capacity development by 2030, reflecting the capacity expenditure of wind turbine price effects in recent years. **Figure 11** shows the expected annual wind power investments from 2000 to 2030, based on the European Wind Energy Association's scenarios [17, 18] at the price of €1300 per kW onshore wind farms and offshore prices of €2300 per KW. The sharp rise in offshore wind costs reflects

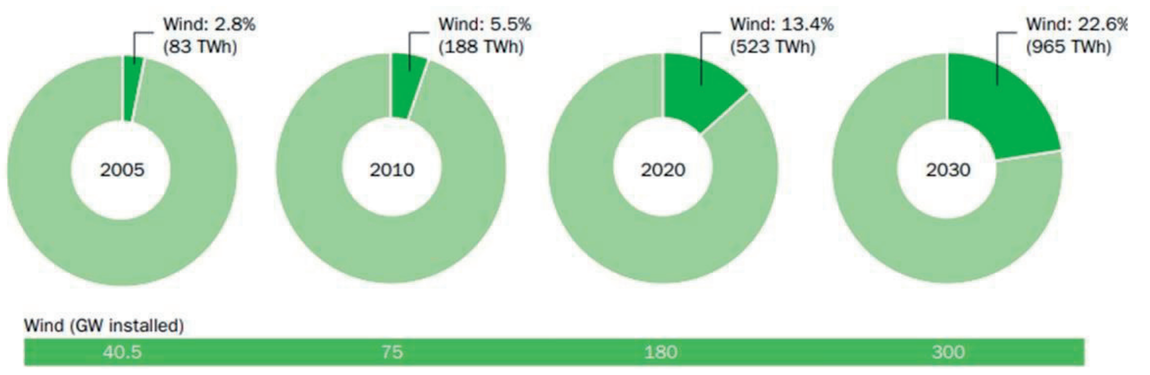

Figure 9.
Contribution of wind energy to European electricity consumption, 2005–2030 [15].

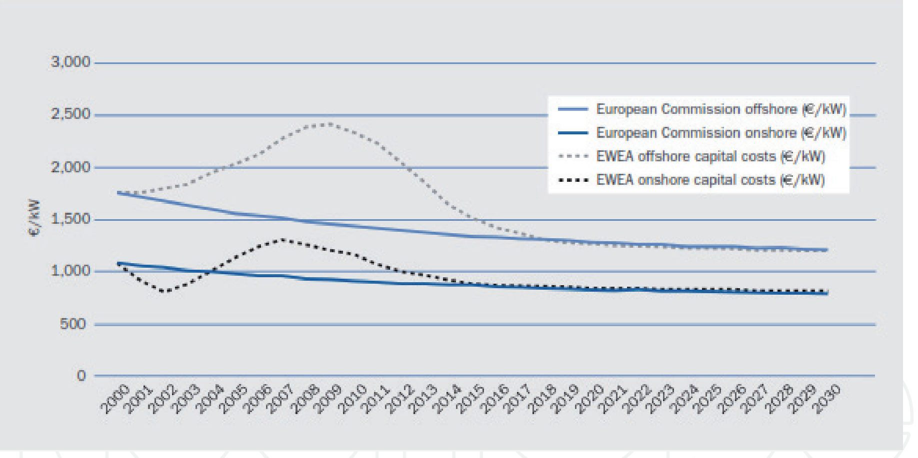

Figure 10.
Cost of onshore and offshore wind (€/kW) European Commission/EWEA assumptions [17, 18].

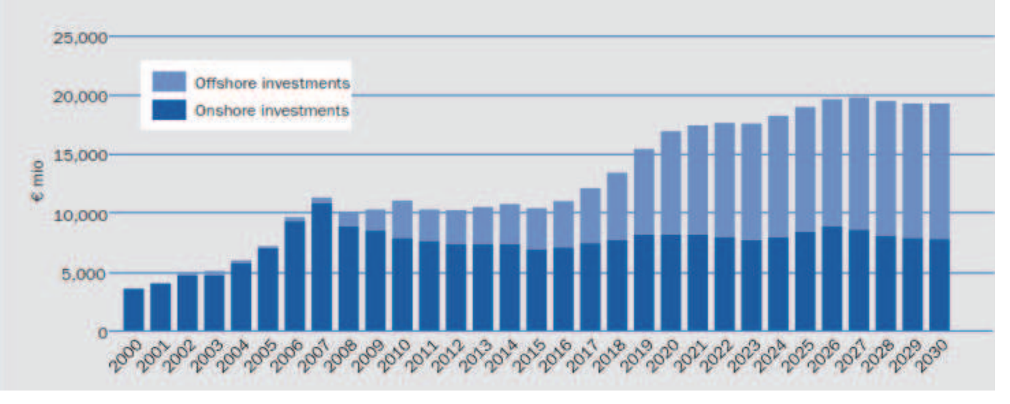

Figure 11.
Wind energy investments, 2000–2030 (€mio.) [17, 18].

the few producers in the overseas market, the lack of economies of scale as a result of low market deployment, and supply chain bottlenecks [14].

By 2020, the annual wind energy market will have increased to €17 billion per year. About half of the investments go offshore. Annual wind energy investment in the EU-27 will reach €20 billion by 2030, with 60% of offshore wind energy investments [11].

GWEC said it expects stable capacity additions from mature regions in Europe and the US in the next few years. Significant growth is also forecast to come from developing markets in South East Asia and the global offshore market.

Globally, offshore wind deployment is to reach up to 7–8 GW during 2022 and 2023 [19], and offshore wind energy installations in Asia could surpass 5 GW per year if governments remain committed and projects and investments continue. The US offshore wind market is seen to hit 1 GW by 2022–2023 [20].

5. Wind energy economics

One of the main economic advantages of wind power is that it reduces economic volatility of fuel prices. **Table 2** shows cost structure of a typical 2 MW wind turbine installed in Europe (2006) [16].

The rapid European and global development of wind power capacity has had a strong influence on the cost of wind power over the last 20 years. To illustrate the trend toward lower production costs of wind-generated power, a case in **Figure 12**

	INVESTMENT (€1,000/MW)	SHARE OF TOTAL COST %
Turbine (ex works)	928	75.6
Grid connection	109	8.9
Foundation	80	6.5
Land rent	48	3.9
Electric installation	18	1.5
Consultancy	15	1.2
Financial costs	15	1.2
Road construction	11	0.9
Control systems	4	0.3
TOTAL	1,227	100

Table 2.
Cost structure of a typical 2 MW wind turbine installed in Europe (2006) [16].

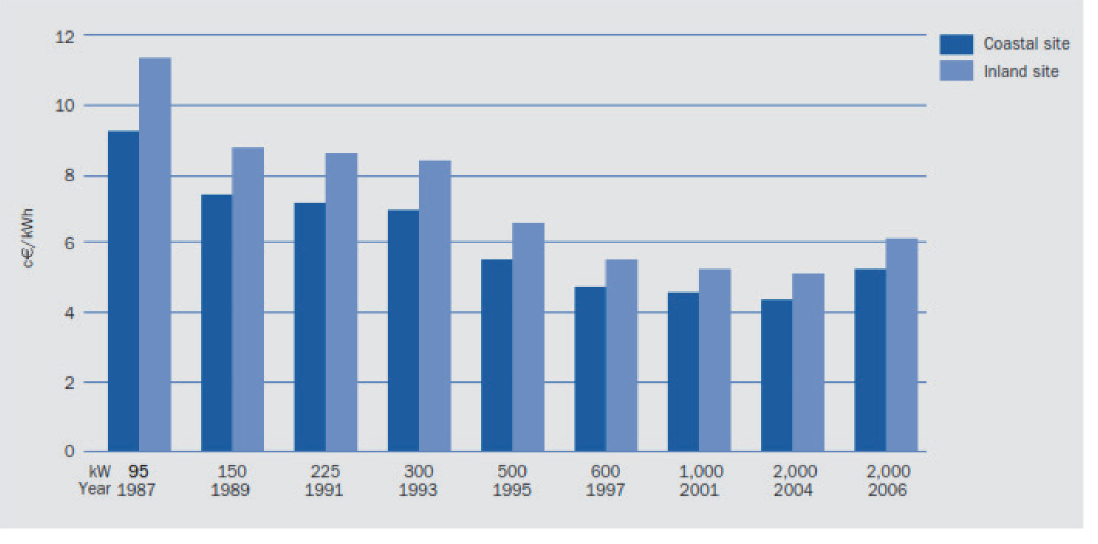

Figure 12.
Total wind energy costs per unit of electricity produced, by turbine size (c€/kWh, constant € prices), and assuming a 7.5% discount rate [21].

that shows the production costs for different sizes and models of turbines is presented, which are constructed for Denmark [21].

The economic consequences of the trend toward larger turbines and improved cost-effectiveness are clear. For a coastal site, for example, the average cost of the turbine (mainly installed in the mid-1980s) has dropped from around 9.2 c€/kWh to approximately 5.3 c€/kWh for a relatively fresh 2.000 kW, an improvement of more than 40% in 2006 [21].

The estimated progress ratios range from 0.83 to 0.91, which corresponds with the learning rates of 0.17 to 0.09 based on special energy expenses (expenses per kWh generated). This means that if the total wind power installed doubles, the cost per kWh produced for new turbines decreases by 9 to 17% [22].

The total installed wind turbines worldwide account for a small amount of offshore wind: about 1%. In the northern European countries of the North sea and the Baltic Sea, there have primarily been developments in offshore winds, with approximately 20 projects implemented. The capability was located offshore at the end of 2008 at 1471 MW [23].

Offshore wind capacity is still approximately 50% higher than onshore wind. However, with higher wind speeds and a lower visual impact on large turbines expected to benefit, several countries-mainly in the Member States of the European Union-have ambitious off shore wind goals.

While investments in offshore energy farms are significantly higher than those in the onshore wind farms, the overall electrical output from turbines is partially offset, given the high offshore wind speeds. The energy production indicator normally amounts to approximately 2000 to 2500 full charge hours annually for onshore operations, while the figure for a typical offshore facility reaches up to four thousand full charge hours per year, according to location [24].

The market remained stable with an estimated €10 billion per year until 2015, and investment in the offshore market gradually increased. By 2020, the wind power annual market will have grown to €17 billion per year, with roughly half of the offshore investment. By 2030, annual EU investments in wind energy are expected to reach nearly €20 billion with 60% of offshore investment [25].

5.1 Wind energy investments and total avoided lifetime cost for the fuel and emission of CO_2

In the reference price equivalent of $118/barrel in 2010 for natural gas, the price of coal is expected to double, and the price of CO_2 is expected to increase by 50% and by 35€/t in 2008 to 60€ /t [26]. **Figure 13** shows sensitivity analysis of costs of generated power comparing conventional plants to wind power, assuming increasing fossil fuel and CO_2 [15, 27].

To determine the amount of CO_2 and fuel costs avoided from wind turbine investments over the entire life of a given year, it is important to remember that in a given year, investment in wind energy capacity will continue to avoid fuel cost and carbon costs over the 20 to 25 years of life of wind turbines. Wind farms installed throughout 2030 will continue, for example, to avoid costs until and after 2050. **Figure 14** shows the total costs of CO_2 and fuel avoided during the lifetime of the installed wind turbine capacitance of 2008–2030, taking into consideration the technical life of onshore wind power turbines of 20 years and offshore wind turbines of 25 years in accordance with EWEA reference scenarios [22]. It is also presumed that the average price of a CO_2 allowance for wind energy is €25/t CO_2, and €42 million in fuel is prevented for every TWh of wind power, which is the

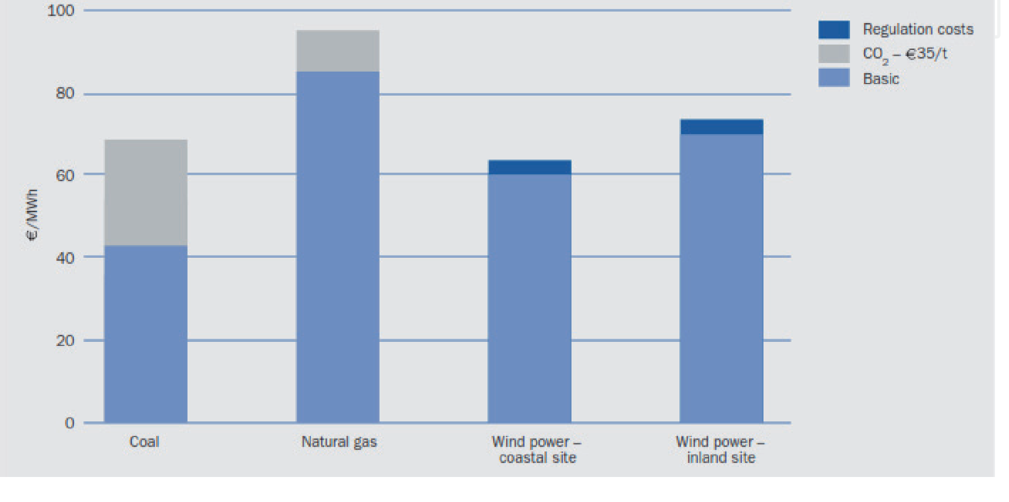

Figure 13.
Sensitivity analysis of costs of generated power comparing conventional plants to wind power, assuming increasing fossil fuel and CO_2 [15, 27].

equivalent of €90 per barrel of oil during the period. The average cost of the allowance for CO_2 is €42 million. For example, the 8554 MW of wind energy installed in the EU in 2007 had an investment value of €11,3 billion and will avoid €6,6 billion of CO_2 emissions over the whole lifetime and €16 billion in the cost of fuel, assuming an average CO_2 cost of €25 per ton and an average price of fuel for gas, coal, and oil based on $90/barrel of oil. Likewise, between 2008 and 2020, the €152 billion investment in wind power will avoid CO_2 cost of €135 billion and fuel costs of €328 billion in the same way. Wind energy expenditure of €339 billion is avoiding €322 billion of CO_2 and €783 billion of fuel for the period up to 2030.

As price reductions on wind, solar, and other renewables drop dramatically in recent years, energy decarburization is not only technically feasible but also economically competitive. African, Asian, and Latin American markets are quickly evolving, providing clean energy to promote sustainable development.

The IEA has amended its assumptions, both fuel prices and building costs, in its 2008 edition of World Energy Outlook. It therefore increased its new building cost estimates. It was also assumed for the EU that a $30 carbon price per ton of CO_2 would add $30/MWh to coal production and that it could generate $15/MWh to combined cycle gas turbines (CCGT)-generated plants. **Figure 15** shows the assumption of the IEA that in 2015 and 2030 new coal, gas, and wind power will

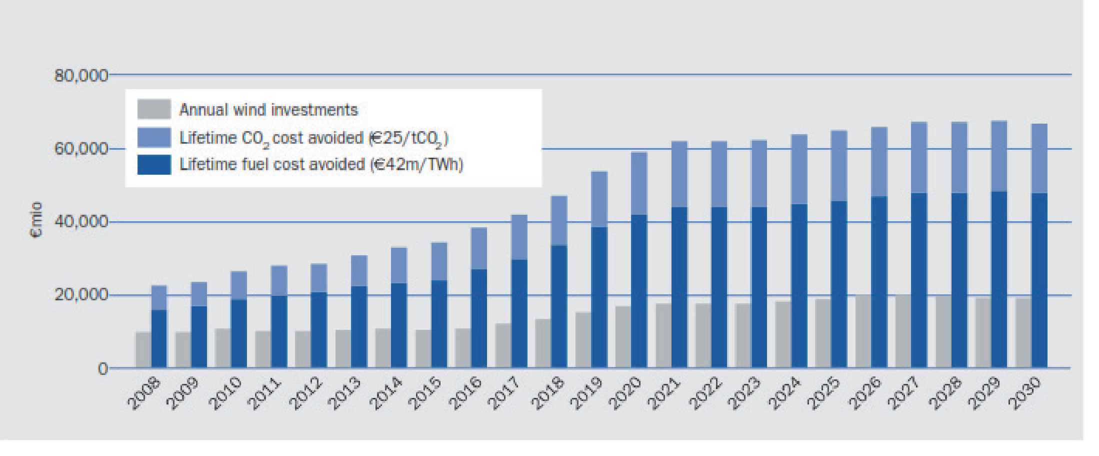

Figure 14.
Wind investments compared with lifetime avoided fuel and CO_2.

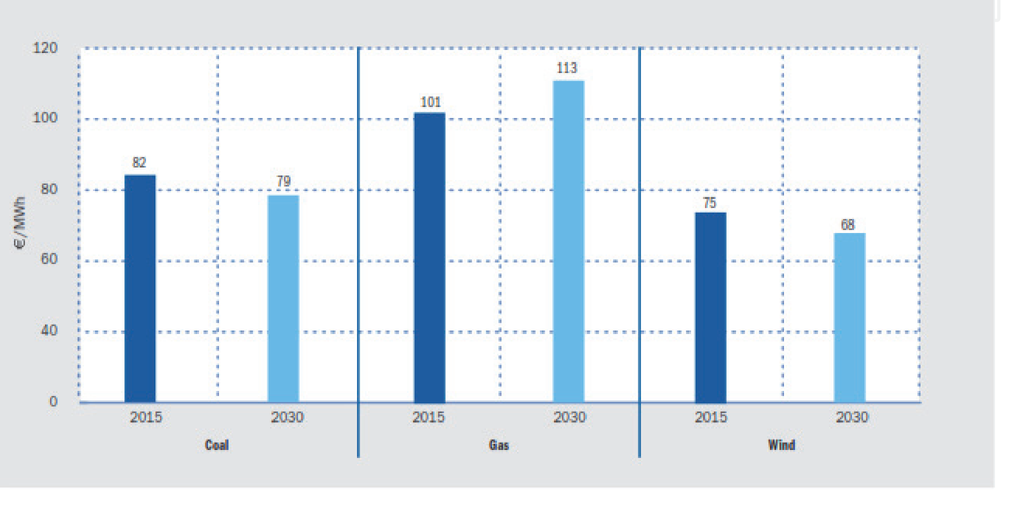

Figure 15.
Costs of electricity generating in the EU, 2015 to 2030.

generate future costs in the EU. It shows that the IEA expects new wind capacity in 2015 and 2030 to be cheaper than coal and gas [28, 29].

5.2 Wind power cost for electricity production

Conventional electricity production general cost is determined by four components:

1. Fuel cost

2. CO_2 emissions cost

3. Cost of O&M

4. Investment costs, planning, and construction work

The capital costs of wind energy projects are dominated by the cost of the wind turbine itself. **Figure 16** shows the typical cost structure for wind energy [22].

The share of the turbine costs is around 76%, while the grid link accounts for around 9% and the base for around 7%. The costs of obtaining a turbine site differ greatly from one project to the next, so the information provided in **Table 3** is an instance. Other cost elements, such as land and control systems, represent only a small proportion of total expenses.

The total cost per kW of installed wind power varies greatly from country to country and the costs per kW were the lowest in Denmark and somewhat higher in Greece and the Netherlands, as shown in **Figure 17** [31]. Typically, the cost per kW varies between €1000/kW and €1350/kW. It should, however, be noted that **Figure 17** is based on limited data so the findings for the countries mentioned may not be fully representative. In addition, there are significant variances among nations in "other expenses," such as foundation and grid connection, which vary from approximately 32% of total turbine expenses in Portugal, about 24% in Germany, about 21% in Italy, and only about 16% in Denmark. Cost varies however

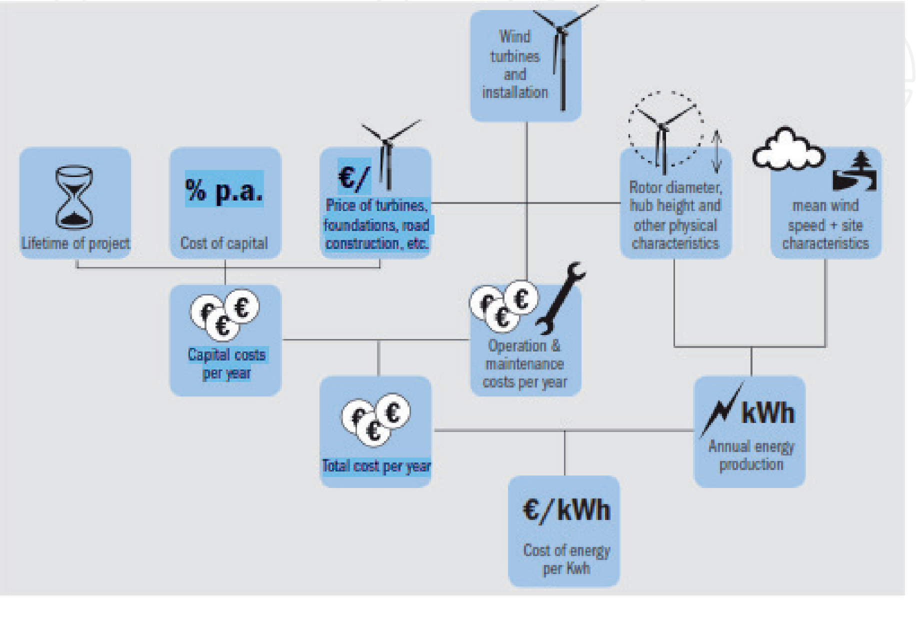

Figure 16.
Cost of wind energy.

	SHARE OF TOTAL COST (%)	TYPICAL SHARE OF OTHER COST (%)
Turbine (ex works)	68-84	-
Grid connection	2-10	35-45
Foundation	1-9	20-25
Electric installation	1-9	10-15
Land	1-5	5-10
Financial costs	1-5	5-10
Road construction	1-5	5-10
Consultancy	1-3	5-10

Table 3.
Medium-sized wind turbine cost structure [30].

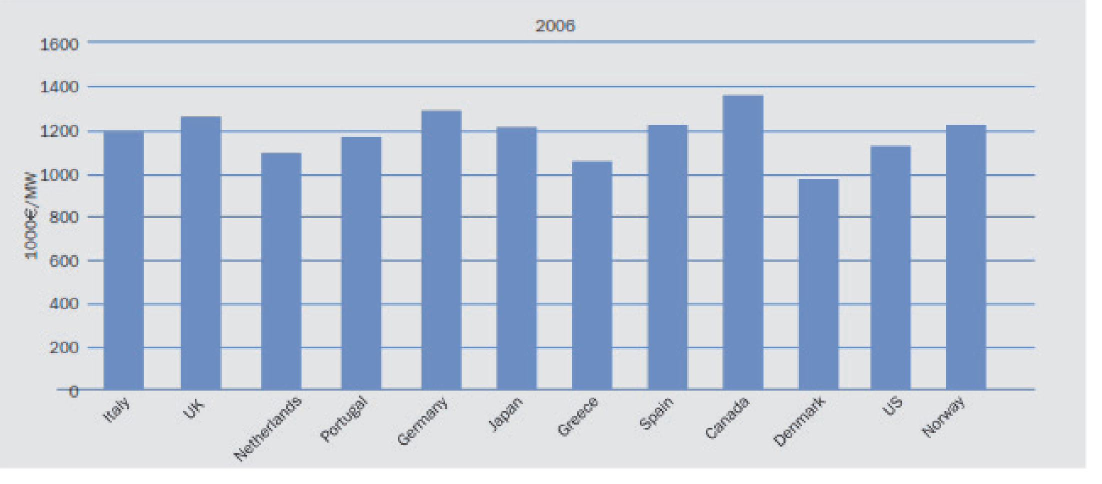

Figure 17.
Total investment cost, including turbine, foundation, and grid connection, shown for different turbine sizes and countries of installation [31].

depending on the size of the turbine and the nation of installation, grid distance, property ownership, and soil nature [31].

The typical ranges of these other cost components as a share of the total additional costs are shown in **Table 3** [30]. The only major extra aspect in terms of variation is the cost of the grid connection, which in certain instances can account for almost half of the auxiliary expenses, followed by typically lower shares of the basic and electrical installation expenses. These subsidiary costs can therefore add up to the overall turbine costs to significant amounts. Cost elements, such as consultancy and land, usually account for only a small share of extra costs.

5.3 Levelized cost of energy

5.3.1 Estimation of the LCOE

The **LCOE** energy cost, also known as the levelized electricity cost, is an economic evaluation of the average overall cost of building and operating an energy generation system over its lifetime divided by overall system power over this lifetime [1]. LCOE is the definition of the price that will be equivalent to the total life-cycle cost (LCC), if it is allocated to each unit of energy generated by the device during the analysis period [32].

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad (1)$$

where LCOE is the average lifetime levelized cost of electricity generation, It is the year t investment expenditures, Mt. is the year t (O&M) expenditures, Ft is the year t fuel expenditures, Et is the year t electricity generation, r is the discount rate, and n is the system lifetime.

The LCOE of a wind power project is determined by total capital costs:

- Wind resource quality
- Wind turbines' technical characteristics
- O&M costs
- Economic life of the project and the cost of capital

As with today's range of installed costs, the LCOE also varies by country and region. **Figure 18** presents cost metrics contributing to the calculation of the LCOE [32].

5.4 LCOE historical growth for wind energy

By depending on one of the most significant steps within the power sector, levelized cost of electricity (LCOE), the wind sector can demonstrate its growing maturity, price competitiveness, and effectiveness.

For several years, LCOE has been the common measure to define wind and other power sources' price. Industry stakeholders and politicians use LCOE to evaluate objectives and levels of support.

LCOE's important role will not change and will continue to show the progress of wind power. With the aid of LCOE, wind energy is one of the cheapest sources of energy. As the energy industry is changing, the scope is expanding and wind energy is now also offering maximum system value. This enhanced emphasis on value comprises the knowledge of an energy source's effectiveness, how to integrate an

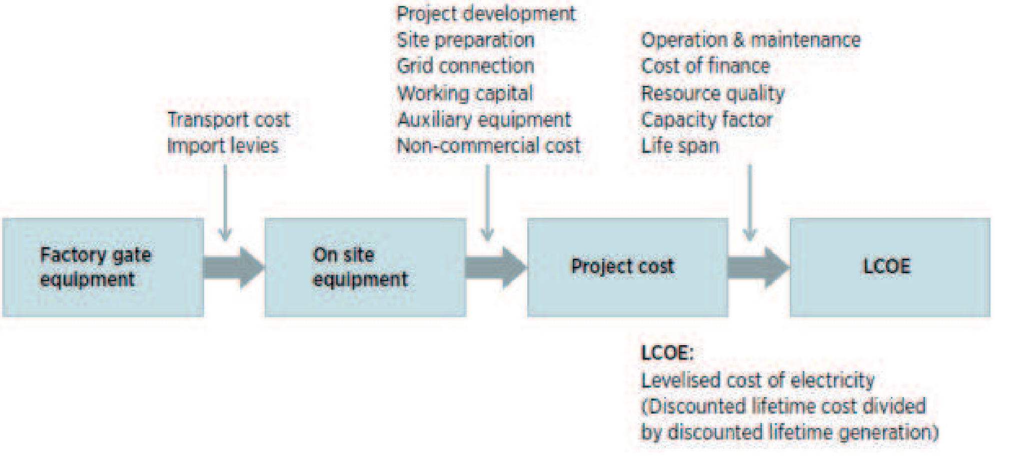

Figure 18.
Cost metrics contributing to the calculation of the LCOE [32].

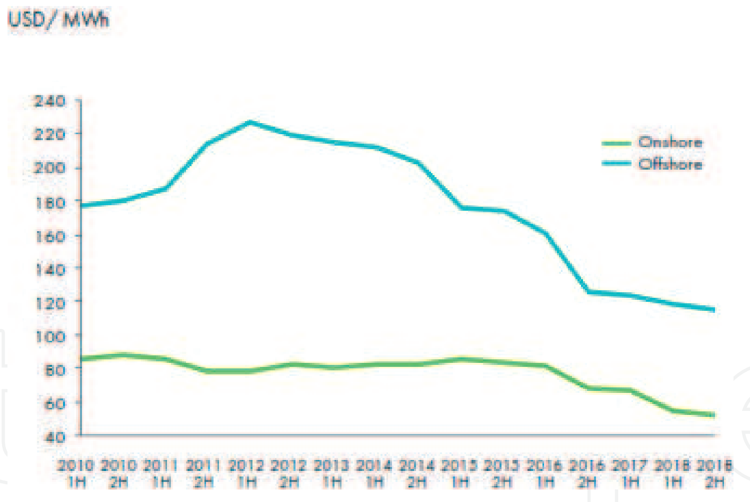

Figure 19.
LCOE-historical development [34].

energy source, and the time frame for supply and demand [33]. **Figure 19** depicts LCOE-onshore and offshore wind power historical growth.

The weighted average LCOE for onshore by country or region ranged from \$0.053/kWh in China to \$0.12/kWh in Asia. North America had the second lowest LCOE after China, with \$0.06/kWh. Eurasia (\$0.08/kWh), Europe (\$0.07/kWh), and India (\$0.08/kWh) had slightly higher average LCOEs than China and North America. Onshore wind energy is a highly competitive source of renewable energy generation capacity, with low and medium wind speeds becoming economically competitive [35].

The potential improvement in capacity factors by 2025 could result in reducing the global weighted average LCOE of onshore wind energy by around \$0.01/kWh, or 49% of the total projected reduction in onshore wind LCOE of \$0.018/kWh as the global weighted average LCOE falls to \$0.053/kWh by 2025 [35].

Reductions in total installed costs, driven mostly by cost reductions for towers, turbines, and wind farm development, contribute around \$0.006/kWh or 34% of the total reduction in the LCOE. Improvements in turbine reliability, improved predictive maintenance schedules, and the more widespread application of best practice (O&M) strategies reduce the LCOE by around \$0.003/kWh by 2025, or 17% of the total reduction [35].

6. Current and predicted LCOE for wind power

In 2018, the global weighted-average LCOE commissioned onshore wind energy projects, at \$0.056/kWh, was 13% below 2017's level and 35% below 2010, when it was at \$0.085/kWh. The onshore wind electricity expenses are now at the lesser end of the price range of fossil fuel [36].

The continuous reduction of total installed expenses and the improvement of the average capacity factor led to electricity expenses to lower onshore wind energy in 2018, as in **Figure 20**. Continuous improvements in turbine design and production, competitive worldwide supply chains, and a growing variety of turbines intended to minimize LCOE in a range of working circumstances are key drivers of this trend, with rises of 18.5 and 6.8 GW, respectively; China and the United States accounted for the largest development in onshore wind power. GW or greater capacity additions have endorsed deployment in Brazil, around 2.1 GW; France 1.6 GW; Germany about 2.7 GW; and India, 2.4 GW, respectively [37].

The LCOE's worldwide weighted average of 13% decrease in 2018 relative to 2017 represents a culmination of a large number of countries' experiences. The weighted average LCOE in 2018 in China and the United States for newly commissioned wind farms was 4% lower than in 2017, as **Figure 21**. However, both India and Brazil faced slight increases in the weighted average LCOE for 2018 projects, partly due to currency weaknesses in the last several years. Such rises are also motivated by an estimated average slightly reduced weighted lifetime factor for projects started in 2018 [36].

Onshore wind farms operated in China and the USA in 2018 had the same weighted average LCOE of $0.048/kWh. While China has lower capacities than the USA, lower installed costs offset this. In 2018, the average LCOE weighted onshore wind farms commissioned in Brazil was $0.061/kWh; in France, it was $0.076/kWh; in Germany, it was $0.075%; in India, it was $0.062/kWh; and in the UK, it was $0.063/kWh [38].

The number of LCOE projects that have been commissioned with a volume from $0.03 to $.04/kWh has increased since 2014. The combinations of competitive installed costs in regions with excellent wind resources are becoming an increasing proportion of new installations in some markets. The projects are much cheaper than even the cheapest fossil fuel-fired options for new energy production, and the variable operating costs of certain existing generators of fossil fuel are undercut.

The global weighted average total installed cost for onshore wind farms decreased by 6% year-on-year from $1600/kW in 2017 to $1500/kW in 2018, when price rates for wind turbines continued to drop. The reduction in total installation costs still depends on reductions in wind turbine prices. **Figure 22** shows wind turbine price indices and price trends, 1997–2018, which decreased by around 10 to 20% between 2017 and 2018 and also on reductions in the project cost balance. Improved technical and process technologies, regional infrastructure, and competitive supply chains all contribute to keeping turbine pricing under pressure [39, 40].

The average turbine prices of 2018, China and India excluded, varied between $790 and $900 per kW and decreased between $910 and 1050/kW in 2017, respectively. In 2018 for the onshore wind farms installed in China, there was approximately $1170/kW, approximately $1200/kW in India, around $1660/kW in the United States, $1820/kW in Brazil, approximately $1830/kW in Germany, and around $2030/kW in Europe that shows in **Figure 23**. Australia added 940 MW and installed costs were a competitive 1640$/kW [39, 40].

The worldwide weighted average capacity factor of onshore wind energy farms commissioned in 2018 grew to 34% of 32% in 2017, due to the trend toward greater turbine hub heights, bigger sweeping regions, and greater capabilities and harvesting more electricity from the same wind resource. While the final data for 2018 cannot be accessible, between 2010 and 2017, both turbine diameter and turbine size were significantly increased, and this is expected to continue until 2018. Higher hub heights allow access to higher wind speeds, while larger swept areas can increase output across the range of operating wind speeds.

There is a slightly greater cost for longer blades and taller towers, but with the correct optimization, a total decrease in LCOE can be accomplished. Ireland's continuous trend toward larger turbines with larger swept areas is distinguishing, but for both these metrics, Denmark is still absolutely behind the market leader [39, 40].

Between 2010 and 2017, Ireland improved its average plate capabilities by 95%, with its rotor diameter by 76%. Denmark had an average 118 m rotor diameter and a turbine capability of 3.5 MW for projects launched in 2017. Brazil, Canada, France,

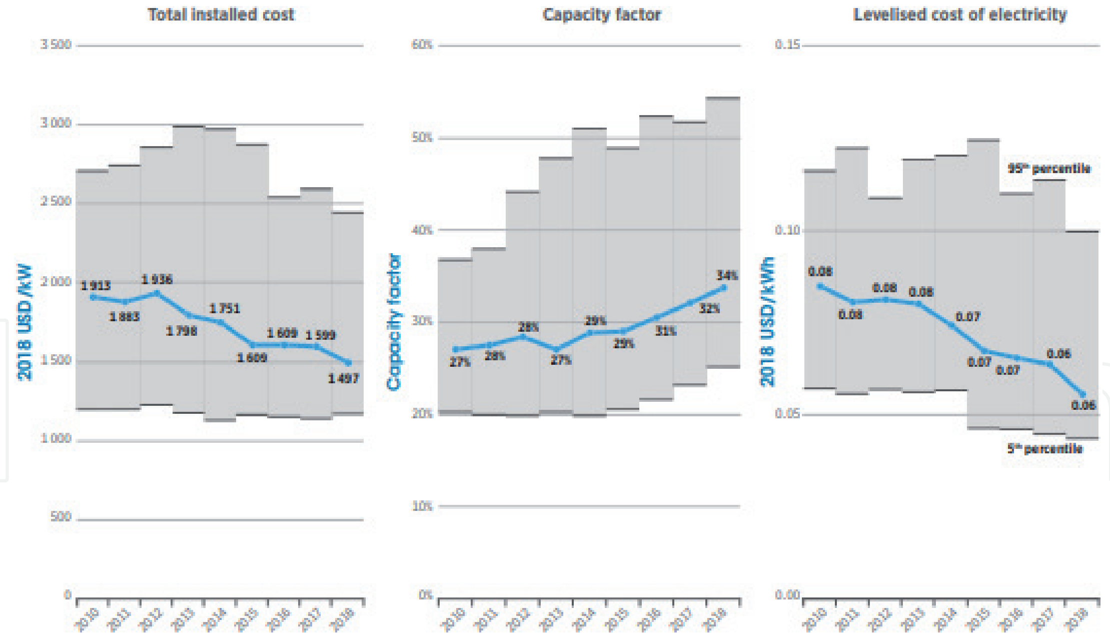

Figure 20.
Global average total installed costs, capacity factors, and LCOE for onshore wind, 2010–2018 [36].

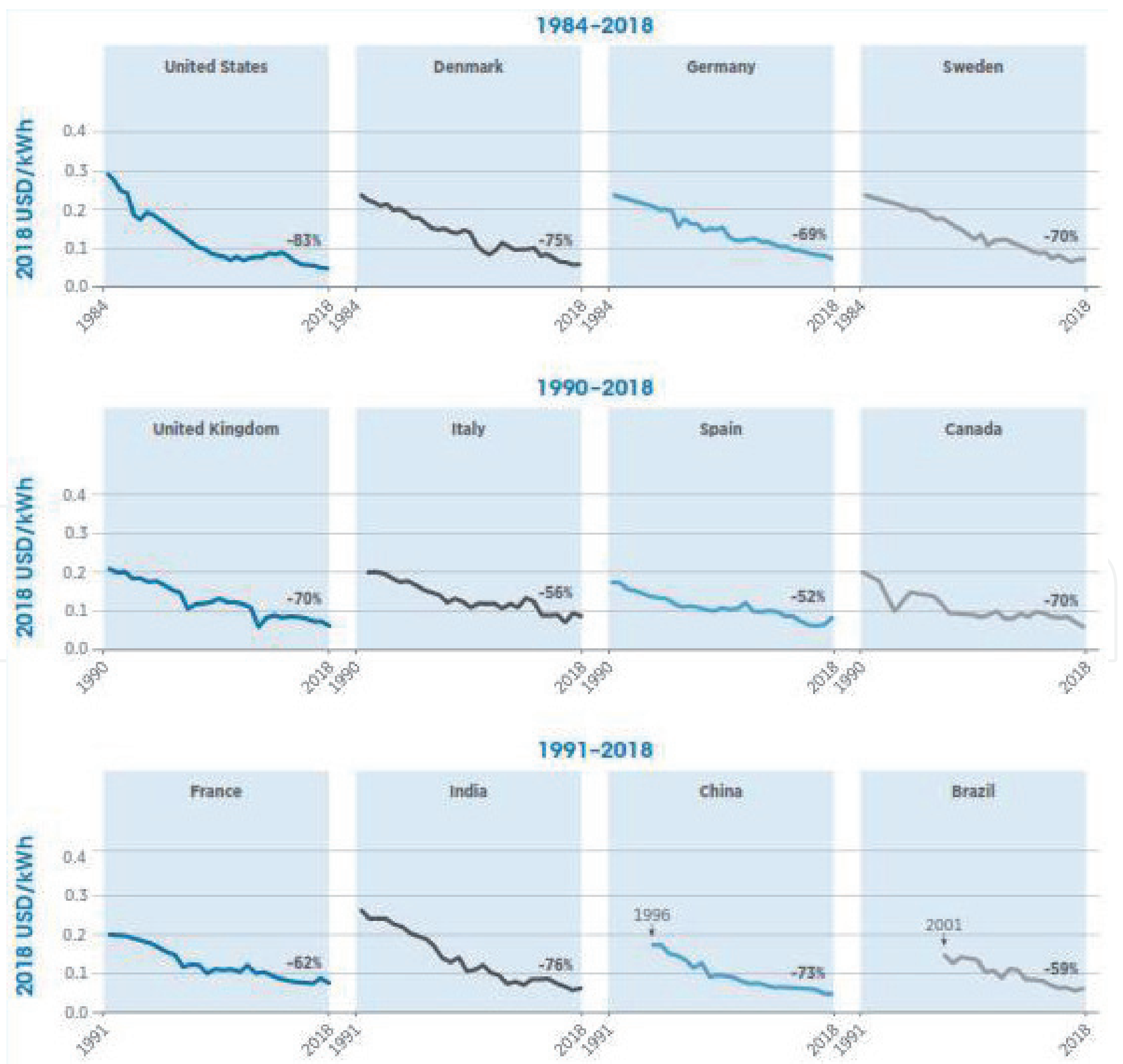

Figure 21.
Weight average LCOE of commissioned onshore wind energy projects in 12 countries, 1984–2018 [36].

Figure 22.
Wind turbine price indices and price trends, 1997–2018 [39, 40].

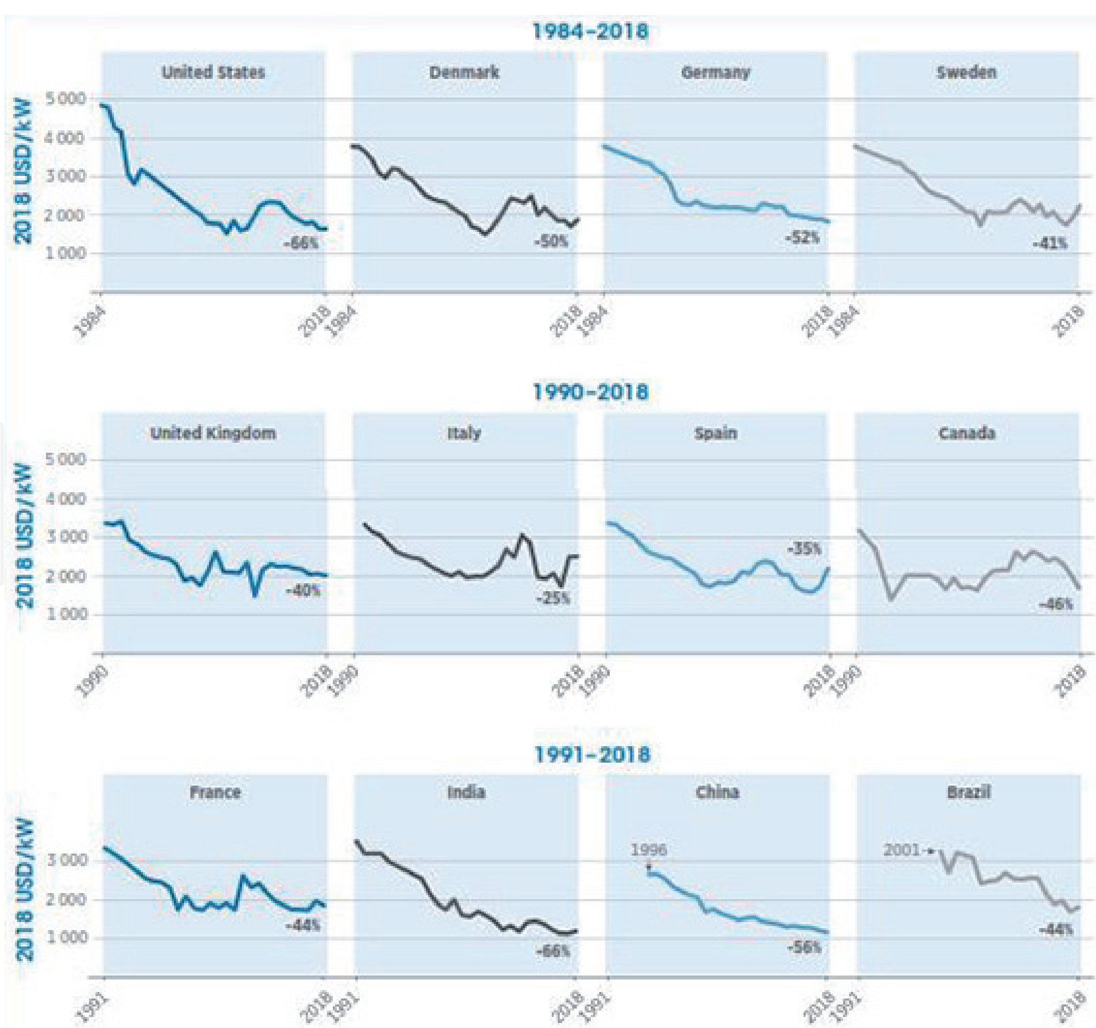

Figure 23.
Onshore wind energy weighted average installed costs in 12 countries, 1984–2018 [39, 40].

and the United States are interesting examples of markets that have increased the rotor diameter faster than the nameplate capacity. The newly commissioned rotor diameter has risen 42% in Brazil, 64% in Canada, 25% in France, and 34% in the United States between 2010 and 2017, while the growth in nameplate capability is 31%, 41%, 16%, and 29%, respectively [39, 40].

The average rotor diameters in 2017, in Brazil, Denmark, Germany, India, Sweden, Turkey, and the United States, were over 110 m compared to 2010 when the range was from 77 m in India to 96 m in Denmark. In 2018, onshore wind farms commissioned 46% in Brazil, 44% in the United States, 40% in Britain, 37% in Australia, and 29% in China; France and Germany had a weighted average capacity factor of 46% (**Figures 24** and **25**). In 2018, the country's particular weighted average capacity factor decreased slightly from 48 to 46% in Brazil, year-on-year. In 2018, there was an increase in most other significant markets.

The worldwide weighted average LCOE for offshore wind power projects started to slightly decrease by 1% relative to 2017 (**Figures 26** and **27**). This leads to an increase from $0,159/kWh to $0,127/kWh in LCOE offshore winds from 2010 to 2018 to 20%. In 2018, the full construction expenses for offshore wind projects built were 5% smaller than those in 2010. Innovative wind turbine technology, installations, and logistics have led to the reduction in the cost of electricity from offshore wind energy; economies of scale in O&M (from large turbines and offshore wind power clustering); and improved capacity factors from higher hub heights, better wind resources (despite increasing cost in deeper waters offshore wind energy), and larger rotor diameters (**Figures 28–30**).

In 2018, a total of 4.5% GW of global offshore wind power plants is mostly in Europe and China. Global average weighted LCOE offshore wind energy was 0.127 $per kWh, which was 1% below 2017 and 20% below the 2010 average. A further 4.5 GW of new offshore power was concentrated in China by 40% in 2018, with an important share of the UK capacity growth of approximately 29% and Germany of approximately 22%. The market is therefore limited to a small number of major players. In the coming years, projects will be implemented in North America and Oceania [39, 40].

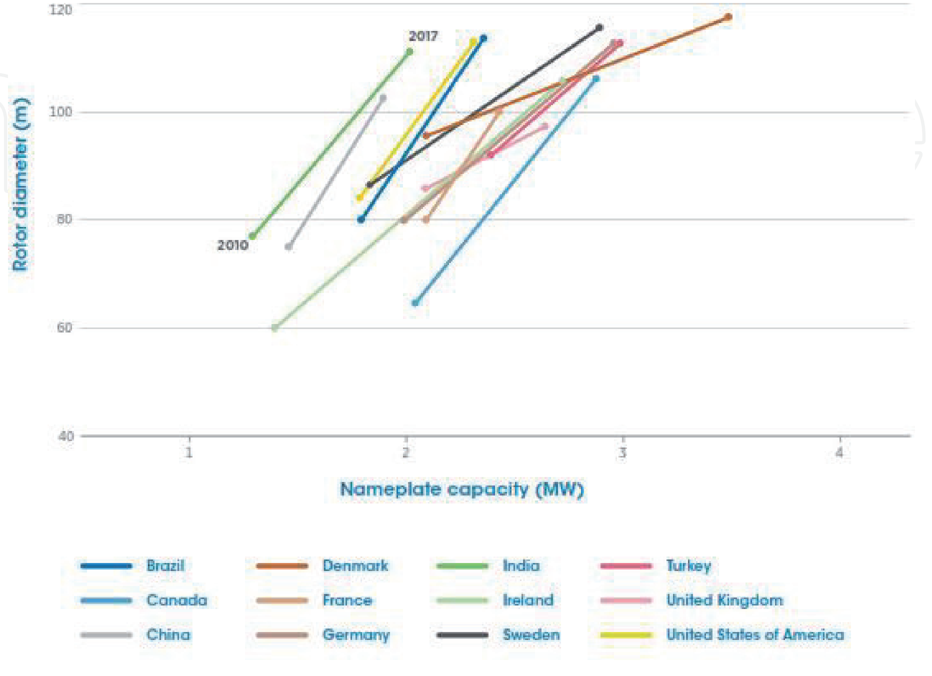

Figure 24.
Weighted average rotor diameter and nameplate capacity evolution, 2010–2018 [39, 40].

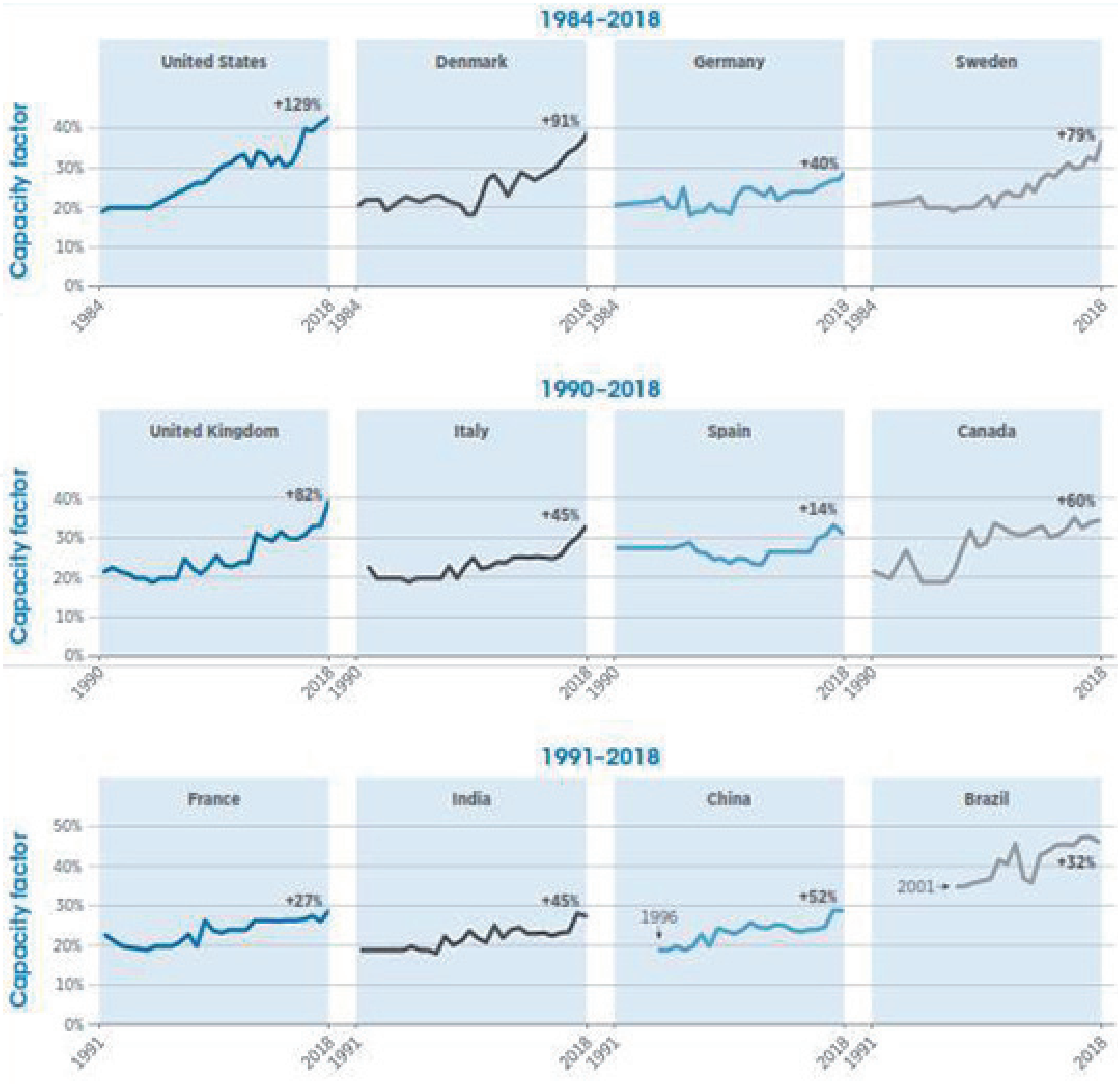

Figure 25.
Historical onshore wind energy weighted average capacity factors in a sample of 12 countries by year of commissioning, 1984–2018 [39, 40].

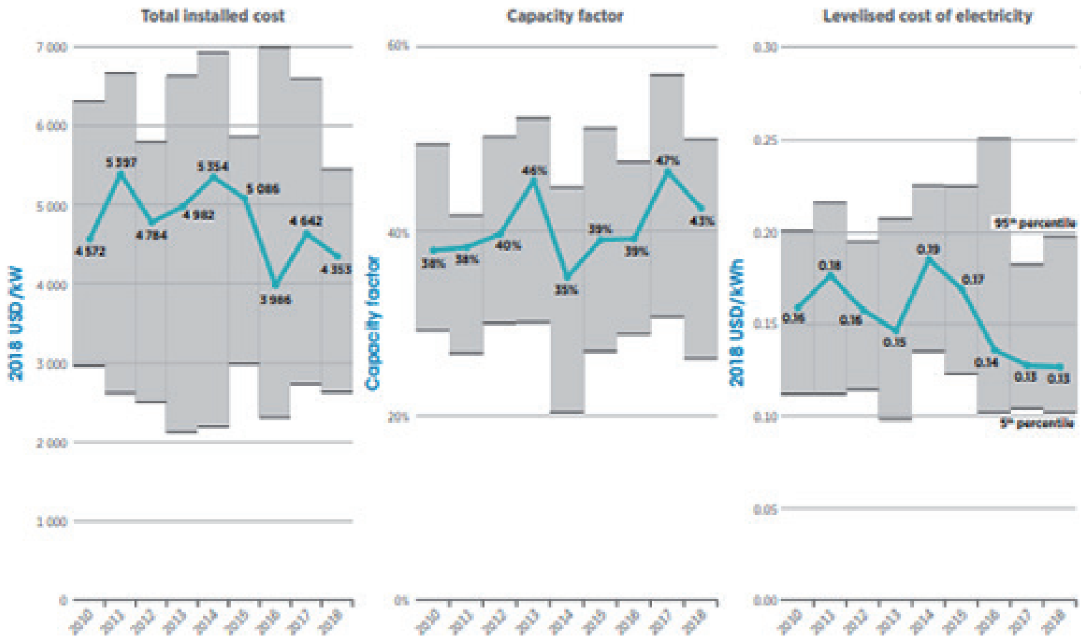

Figure 26.
Global weighted average total installed costs, offshore wind capacity factors, and LCOE, 2010–2018 [39, 40].

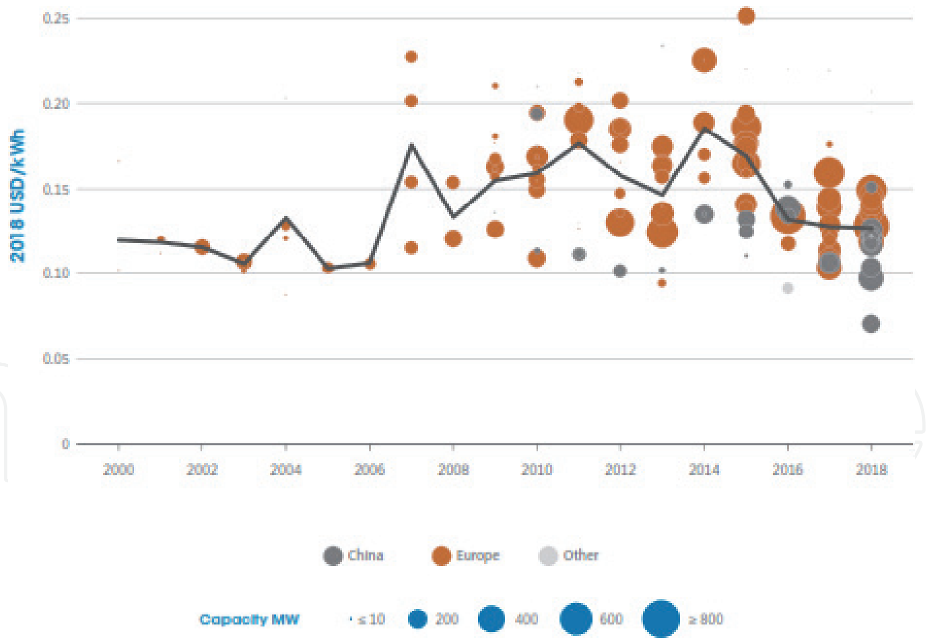

Figure 27.
LCOE for commissioned offshore wind energy projects and global weighted average, 2000–2018 [39, 40].

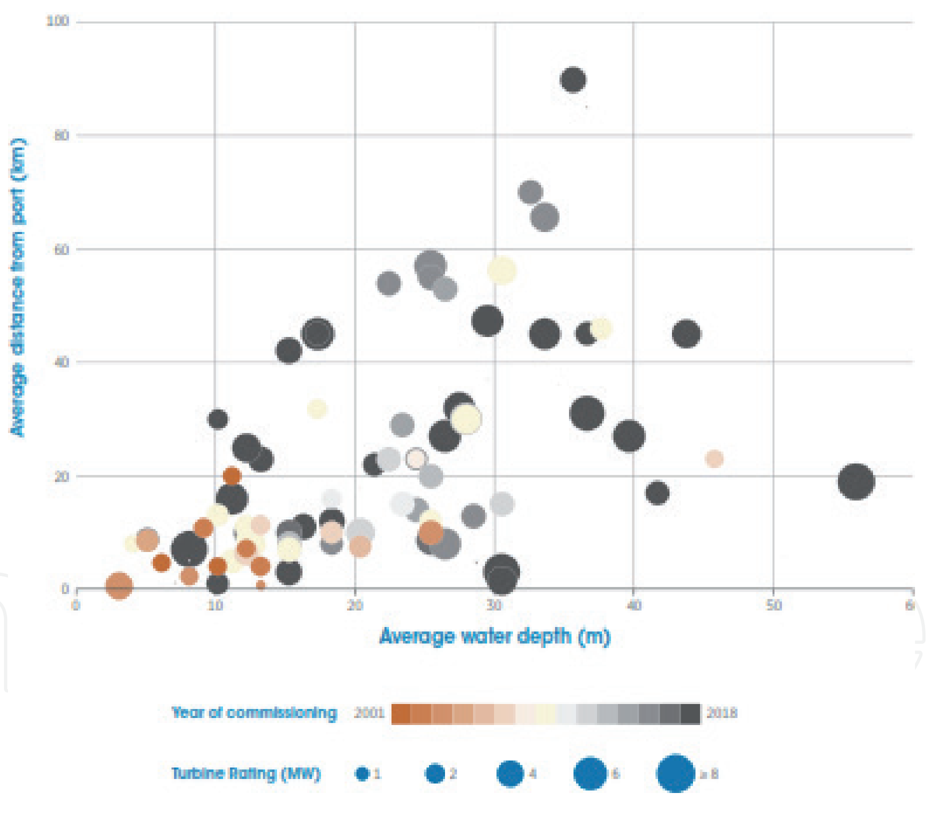

Figure 28.
Average distance from port and water depth for commissioned offshore WE projects, 2001–2018 [39, 40].

The trend to larger turbines, which increases wind farm capacity and/or reduces the number of turbines required for a given capacity, has contributed to lower installation and project development costs. But the change to offshore wind farms in deeper waters away from ports has compensated for this decrease, to a higher or lesser extent-but often with a more stable and better wind regime. This has contributed to the rise of offshore wind farms and the global weighted average offshore wind turbines increased from 38 to 43% in 2010 to 43% in 2018. Meanwhile, the cost of O&M has been reduced with the optimization of the O&M strategies; preventive

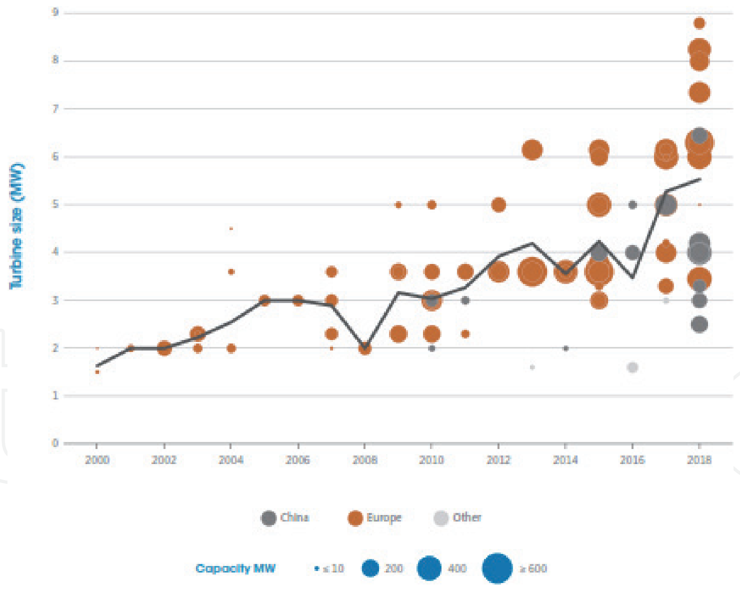

Figure 29.
Turbine sizes for commissioned offshore WE projects and global weighted average, 2000–2018 [39, 40].

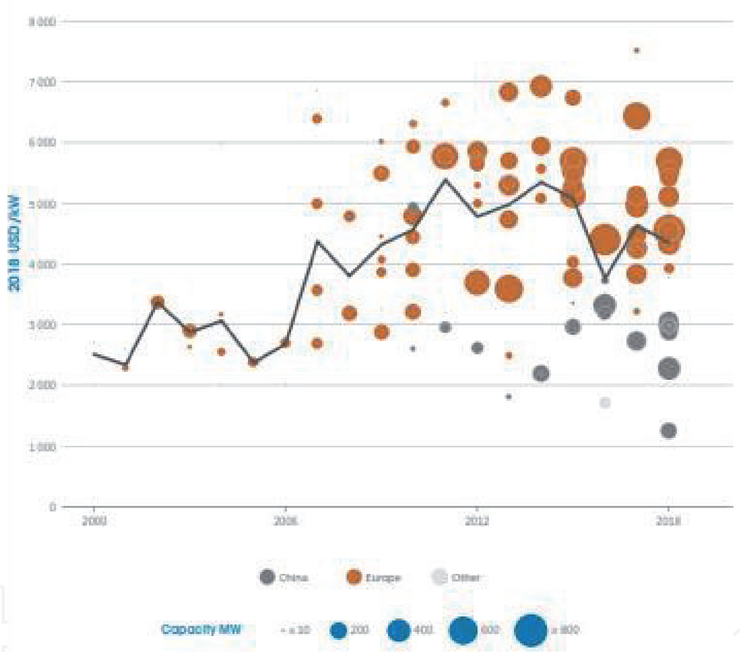

Figure 30.
Total installed costs for commissioned offshore WE and global weighted average, 2000–2018 [39, 40].

maintenance programs based on predictive failure rates analysis; and economies of scale in offshore wind energy service rather than in individual wind farms.

The offshore wind power sector remains relatively thin and LCOE declines have varied widely since 2010. LCOE fell by 14% from $0.156/kWh to $0.134/kWh in Europe, the biggest offshore wind energy deployment between 2010 and 2018 projects. Between 2010 and 2018, the largest drop was in Belgium, with LCOE falling from $0.195/kWh to $0.141/kWh. Between 2010 and 2018, there were 24% and 14% drops, with LCOE in Germany and the UK drop-offs of $0.125/kWh and $0.139/kWh in 2018, respectively. The LCOE decrease from $0.178/kWh to $0.106/kWh was 40% in Asia between 2010 and 2018. This was pushed by China, which has more than 95% of Asia's offshore wind power systems. The LCOE in Japan has an estimated $0.20/kWh in contrast to China, as projects to date are low and may be better classified as demonstration projects.

Since 2010, total costs installed on offshore wind farms have decreased modestly. In view of the relatively low yearly capacity adds over a few years, a significant level of volatility exists in the total cost installed of the newly commissioned offshore wind farms. Between 2010 and 2018, the average global weighted installed cost for offshore wind power decreased by 5%, from $0.4572/kW to $0.4353/kW.

The general evolution in cost installations is based on a complex range of variables, with some causing costs to fall and others causing them to increase. Europe's initial small-scale and logistical capacity and challenges as well as the shift to more offshore and more deepwater deployment have, in some cases, increased the cost of installation, foundation, and grid connection costs. In latest years, however, the sector has increased and some of these stresses have been reduced. At the same moment, turbine innovation, higher turbine ratings, more project development experience, and cost savings have contributed equally to the reduction of expenses.

7. Prediction of Potential reductions in LCOE by 2025

Overall reductions could be around 12% in 2015 to 2025, taking into account the trend for larger turbines with higher hub heights and greater swing spaces, for the global average cost installed for onshore wind farms. This estimate falls within the range of 7% for the total installed costs, as identified by the updated onshore wind power curve and the IRENA Remap projections for 2030.

Figure 31 shows total installed cost reductions for onshore wind energy farms, 2015–2025. These account for 27% and 29%, respectively, of the total reduction in the global weighted average installed cost of onshore wind energy farms. Yet, the increased application of best practices in wind farm development by project developers and regulators could yield around one quarter of the total cost reduction. Overall, the global weighted average total installed cost for onshore wind energy could fall from around $1560/kW in 2015 to $1370/kW in 2025 [41].

The combination of the technological and process innovations in the development and operation of offshore wind energy farms could potentially see the average cost of electricity from these fall by around 35% from around $0.17/kWh in 2015 to $0.11/kWh in 2025 (**Figure 32**). This represents a central estimate of the cost reduction potential [43].

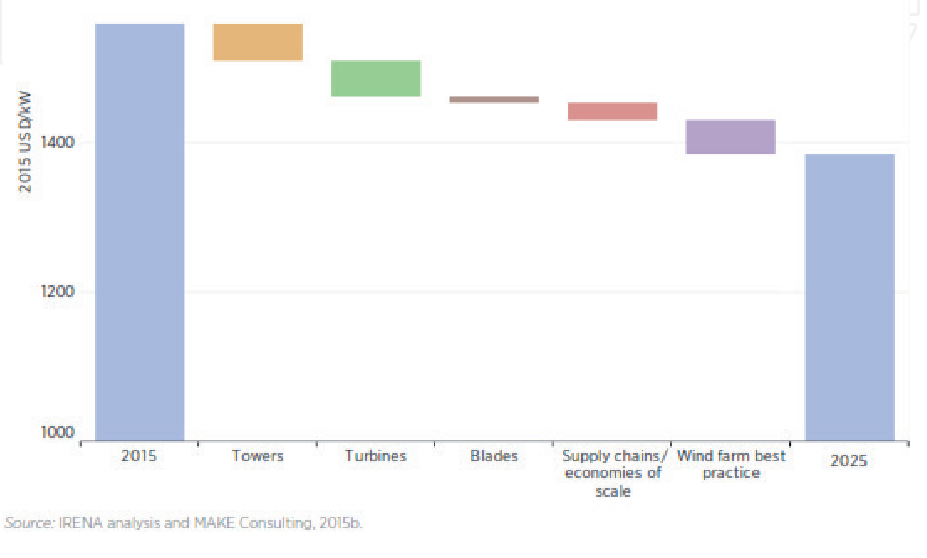

Figure 31.
Total installed cost reductions for onshore wind energy farms, 2015–2025 [41].

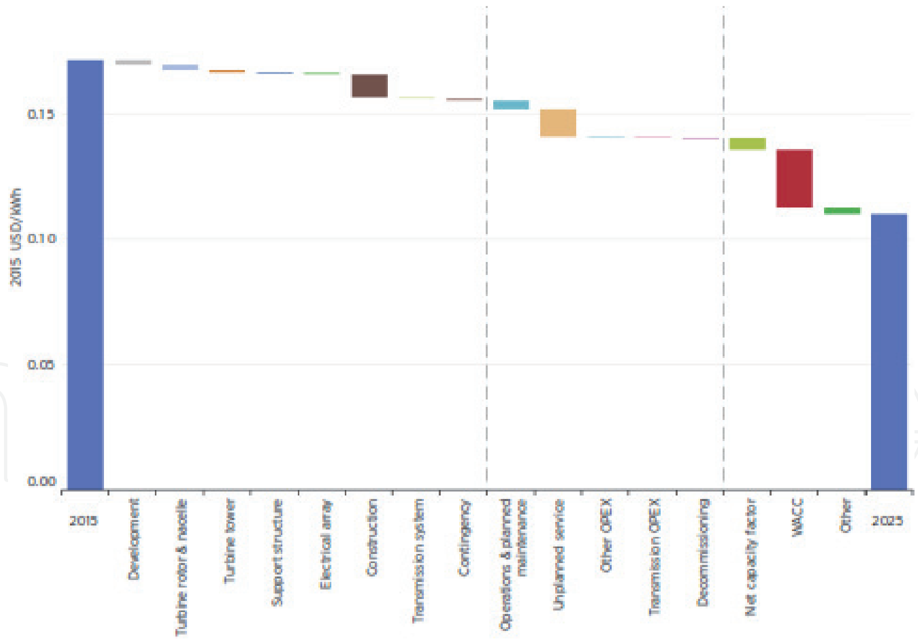

Figure 32.
Offshore wind energy levelized cost of electricity reduction potential, 2015–2025 [42].

By the year 2025, the LCOE of offshore wind farms could drop by 35% due to the deployment of advanced large offshore wind turbines. Future wind farms are going to have higher capacity factors while financial institutions are developing in a larger industry. The decrease in LCOE will also result from lower installation and building costs and more efficient project development practices [39, 40].

Reductions of total installed costs for offshore wind farms account for about 24% of LCOE's overall reduction potential and a 57% decrease in construction and installation costs. Innovations regarding turbine reliability, O&M strategies, and prevention should significantly improve the LCOE as unplanned installation needs have been reduced. The reduction in unplanned service could account for about 17% of the total cost-cutting potential for LCOE between 2015 and 2025 [43].

The reduction in planned operations and maintenance expenditures will account for 6% of the total cost reduction potential. In total, the O&M $0.018/kWh decrease will bring down the total share of LCOE from 30% today to 23% by 2025. The capacity factors of offshore wind farms will be enhanced by technological developments in turbine design and manufacturing, as well as control strategies and enhanced efficiency. This is roughly 8% of the complete decrease in LCOE [44].

Combination of current technological trends, increased availability due to enhanced reliability and innovation in turbine control, improved efficiency of blades, and enhanced growth of micrositting and the growth of wind farms could result in a worldwide average weighted capacity factor rising from 27% in 2015 to 32% by 2025 [42].

At a global level, the average contribution of increased capacity factors would be to reduce the global weighted average LCOE by around $0.01/kWh. There are, however, a variety of variables that may lead to a higher or lower real weighted average capacity factor value in 2022 (represented in **Figure 33**). This is due to uncertainty about the pace of growth of hub heights and rotor diameters in main markets, such as India and China, which significantly influence the globally weighted average adoption rate for bigger machinery. The trends for the quality of the resources for wind farms up to 2025 may remain as the biggest uncertainty [35].

Onshore wind energy is now a highly competitive source of new power generation capacity, with medium- and even low-wind speed sites now available economically. The potential improvement in capacity factors by 2025 could result in reducing the global weighted average LCOE of onshore wind by around $0.01/kWh, or 49% of the total projected reduction in onshore wind LCOE of $0.018/

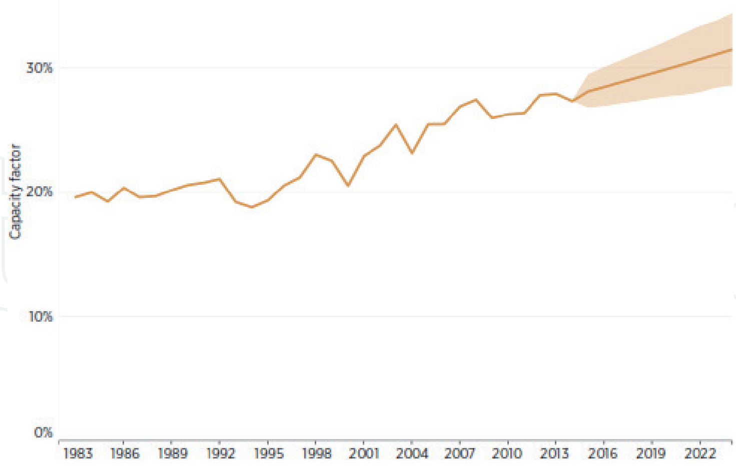

Figure 33.
Global weighted average onshore wind energy farm, 1983–2022 [35].

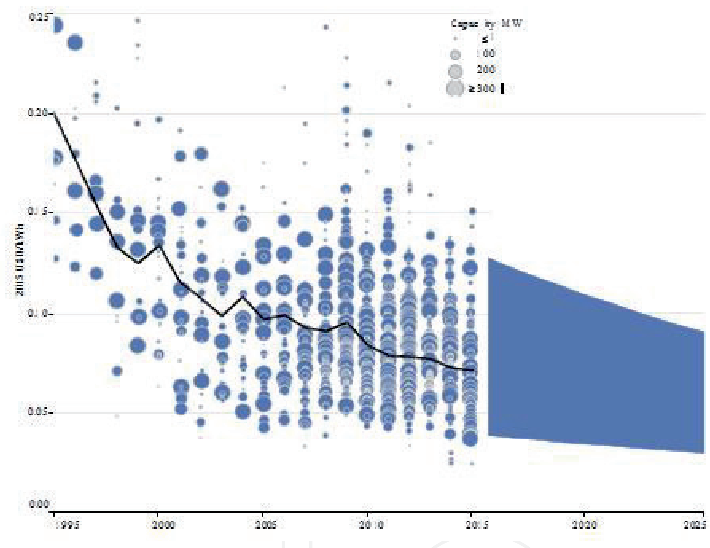

Figure 34.
Levelized cost of electricity of onshore wind, 1995–2025 [35, 45].

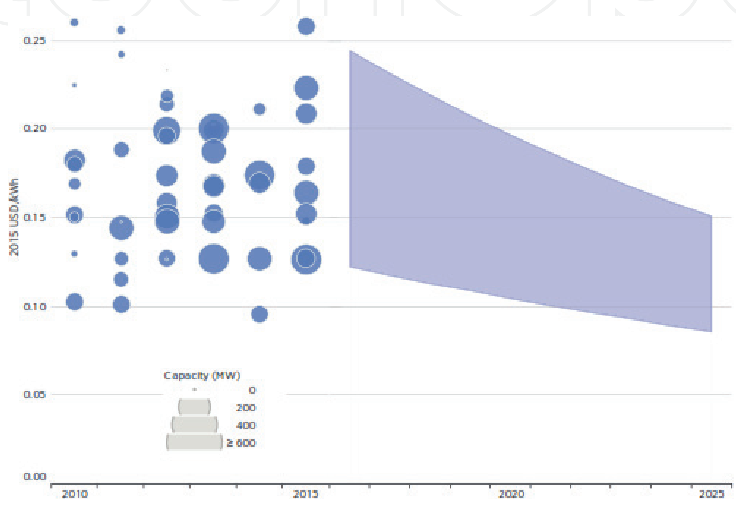

Figure 35.
Historical offshore wind energy cost by projections to 2025 [35].

kWh as the global weighted average LCOE falls to $0.053/kWh by 2025. **Figure 34** shows levelized cost of electricity of onshore wind, 1995–2025 [35, 45].

Reductions in total installed costs, driven mostly by cost reductions for towers, turbines, and wind farm development, contribute around $0.006/kWh, which means 34% of the total reduction in the LCOE. Improvements in turbine reliability, improved predictive maintenance schedules, and the more widespread application of best practice O&M strategies reduce the LCOE by around $0.003/kWh by 2025, or 17% of the total reduction [28].

Reducing the weighted average capital cost of offshore wind energy project from the current 8–10% to an average of around 7.5% will account for around 43% of the total potential reduction in the LCOE of offshore wind energy by 2025. **Figure 35** presents the LCOE historical evolution of offshore wind in 2010 to 2015 for the data available in the IRENA Renewable Cost Database. It also shows offshore wind LCOE projection evolution to 2025. Offshore wind energy projects in tidal or near-shore locations could see costs fall to as little as $0.08/kWh by 2025 [17, 46, 47].

8. Conclusions

Wind energy market is set to grow subject to effective economic feasibility across remote areas when compared with grid-connected networks. Government incentives toward rural electrification coupled with growing adoption of microgrid networks will further boost the business landscape.

Low installation costs along with government incentives including net metering and feed in tariff will positively impact the on-grid wind energy market share. Rapid expansion of utility-based electricity networks to cater growing energy demand across suburban areas will further complement the industry's growth.

Growing demand for renewable energy coupled with rising awareness toward environmental conservation will stimulate the global market size. National targets for clean energy along with ongoing depletion of fossil fuel reserves will further propel the industry's growth. In 2016, France set its target of renewable energy capacity to 70 GW by 2023 including 23 GW from onshore wind.

Declining project development cost subject to fall in component prices favored by government incentives will stimulate the market share. In addition, utility scale installations tend to bear lower operational costs when compared to auxiliary generation technologies. Rapid technological enhancements in line with the integration of smart monitoring and sensing units across turbines have reduced overall system losses. Therefore, economical cost structure in addition to improved efficiencies will positively influence the industry landscape.

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