WORLD ENERGY COUNCIL

World Energy Resources
Wind | 2016

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Wind

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KEY FINDINGS

1. World wind power generation capacity has reached 435 GW at the end of 2015, around 7% of total global power generation capacity. A record of 64 GW was added in 2015. The global growth rate of 17.2% was higher than in 2014 (16.4%).

2. With current policy plans, global wind capacity could rise from 435 GW in 2015 to 977 GW in 2030 (905 GW onshore and 72 GW offshore wind).

3. The global wind power leaders as at end-2015 are China, United States, Germany, India and Spain.

4. The total investments in the global wind sector reached a record level of USD 109.6 billion over the course of 2015.

5. For onshore wind, China has the lowest weighted average LCOE with a range between 50 USD/MW – 72 USD MW, while the highest weighted average LCOE are found in Africa, Oceania and Middle East with 95USD/MW, 97USD/MW and 99 USD/MW.

6. LCOE for offshore wind has continued to decrease owing to a wide range of innovations.

7. Floating foundations could be game changers in opening up significant new markets with deeper waters.

8. Direct subsidies for new wind generation are falling as the costs of wind power are today on par or below those of fossil and nuclear power generation.

9. There is ongoing research and development to modify the fundamental design of wind turbines, in order to bypass some of the limitations and environmental concerns of conventional HAWTs and VAWTs.

10. Wind deployment continues to be dominated by onshore wind, supported by continual cost reductions.

INTRODUCTION

World wind power generation capacity has reached 435 GW at the end of 2015, around 7% of total global power generation capacity. A record of 64 GW was added in 2015. The global growth rate of 17.2% was higher than in 2014 (16.4%).

China has once more underpinned its role as the global wind power leader, adding 33 GW of new capacity. This represents a market share of 51.8%. The US market saw good performance with 8.6 GW of added capacity, the strongest growth since 2012. Germany, in anticipation of changes in legislation, installed 4.9 GW. Brazil was the fourth largest market for new turbines with a market volume of 2.8 GW. India saw 2.3 GW of new installations by November 2015.

Global wind power generation amounted to 950 TWh in 2015, nearly 4% of total global power generation. Some countries have reached much higher percentages. Denmark produced 42% of its electricity from wind turbines in 2015 year, the highest figure yet recorded worldwide. In Germany wind power contributed a new record of 13% of the country's power demand in 2015.

The wind power market can be divided into large wind onshore (422 GW, around 210,000 machines), small wind onshore (less than 1 GW installed end 2015, more than 800,000 machines), and offshore (around 12 GW installed end 2015, around 4,000 machines). Large onshore and offshore wind turbines are typically arranged in a wind park. The largest wind parks exceed 1 GW in size, such as Gansu Wind Farm in China, Muppandal Wind Park in India or Alta Wind Energy Center in USA.

TABLE 1: TOP WIND POWER CAPACITY BY COUNTRY, END-2015

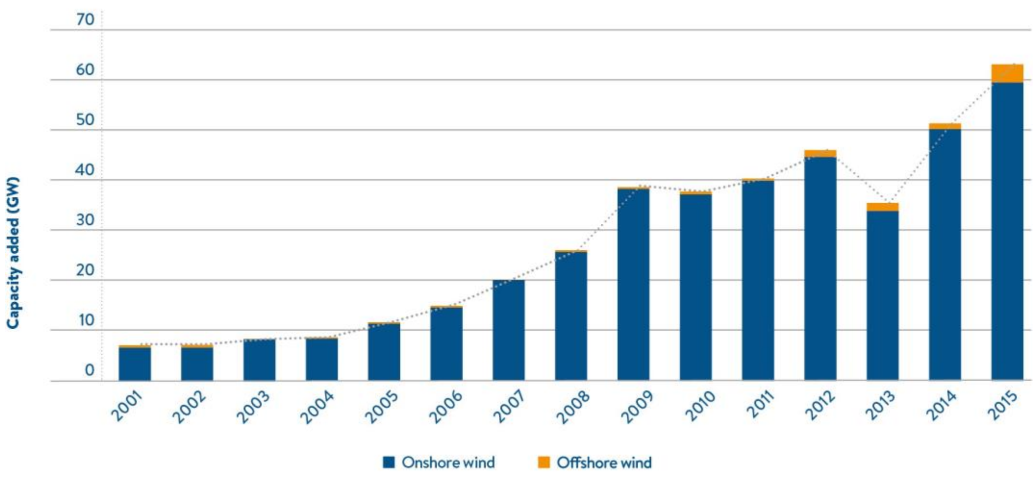
Country	Total Capacity (MW)	Added Capacity in 2015 (MW)
China	148 000	32 970
United States	74 347	8 598
Germany	45 192	4 919
India*	24 759	2 294
Spain	22 987	0

United Kingdom	13 614	1 174

* By November 2015

Source: WWEA (2016)

FIGURE 1: ANNUAL NET GLOBAL WIND CAPACITY ADDITIONS, 2001-2015



Source: IRENA, GWEC

Onshore wind is one of the cheapest renewable sources in Australia, Brazil (besides hydro), Germany, Mexico, New Zealand (besides hydro and geothermal), South Africa and Turkey. Global weighed-average installed costs of onshore wind have significantly decreased from US$4,766 per kW in 1983 to US$1,623 per kW in 2014, meaning this a decline in the costs of two-thirds[1].

The average cost per kW of onshore wind has declined by 7% and levelised cost of electricity by 12%, for each doubling of installed cumulative over the period 1983 to 2014.[2] The global weighted average LCOE of onshore wind could decline by between 20% and 30% by 2025, depending on at least two major factors: technology incremental progress and the cost of capital. Costs are considerably higher for offshore wind because of the additional cost for foundations and connection of the offshore wind parks to the grid. The weighted average cost per unit of capacity was US$4,650 per kW in 2015, with generation

[1] IRENA (2016) The Power of Change: Cost reduction potentials for solar and wind power technologies. Abu Dhabi.
[2] IRENA ibid

cost in excess of US$15 cents per kWh. However, offshore wind is still in its infancy compared to onshore wind, with total installed capacity having reached 12 GW at the end of 2015. The next generation of advanced large offshore wind turbines, reduced costs for foundations and more efficient project development practices could reduce the LCOE of offshore wind from US$19.6 cents per kWh in 2015 to roughly 12 cents per kWh in 2030.[3]

Wind power benefits from government support schemes. The type of support varies by country. Feed in tariffs, feed in renewable portfolio standards in combination with auctions, and production tax credits are among the support schemes that are deployed. Apart from the financial support wind power is usually granted preferential access and additional cost for grid management caused by wind variability are usually not borne by the wind generators. Direct subsidies for new wind generation are falling as the cost of wind power is today on par or below those of fossil and nuclear power generation.

SUBSIDY-FREE WIND ENERGY IN NEW ZEALAND

New Zealand has been one of the success stories for wind energy in recent times. Installed wind power capacity has grown nearly four-fold in the last ten years, and about 5% of total electricity generation in the country now comes from wind energy[4]. But what makes New Zealand’s wind development relatively unique is that wind and other forms of clean energy (such as geothermal and hydro) have been developed in the absence of government subsidies – therefore developers will only build a wind farm if it can produce electricity at a cost competitive with other forms of electricity generation.

The country’s rich wind resource and moderate wholesale electricity prices are the key factors for the success of the local wind industry. A 2011 report concluded that existing wind farms in the country were developed with a long-run marginal cost range of NZD 78-105 per MWh[5]. The lower end of this range compares well with other sources of electricity – forward wholesale electricity prices in the country are between (approximately) USD 53.2-60.3 (NZD 75-85) per MWh[6], with central long-run projections significantly higher[7]. In addition, thanks to New Zealand’s significant hydropower capacity capable of balancing variable supply, the associated costs of integrating further wind generation into the country’s network are likely to be lower than many other countries.

New Zealand has a pipeline worth 2500 MW of new wind power projects, and developers aim to increase wind’s contribution to annual electricity generation to 20% by 2030 (this is within the context of current renewable output at around

[3] IRENA (forthcoming), Off-shore wind technology: an innovation outlook
[4] New Zealand Wind Energy Association
[5] Deloitte (2011)
[6] ASX n.d.
[7] MBIE n.d.

80% of total generation, and the New Zealand Government's aspirational target to increase renewable penetration to 90% by 2025).

An important issue for managing power systems that integrate large amounts of wind energy is the variability of the power output. The output grows with rising wind speed and it is constant above the rated wind speed. Wind turbines do not produce during periods of low wind speed and they may also stop producing at very high wind speeds. Wind speeds can change significantly on a timescale of minutes. The output of wind turbines is therefore variable. One way to achieve a higher share of wind generation in a grid system is to operate wind turbines or wind farms using integrated transmission systems and power output prediction systems, including weather forecasting. The development of standards and certifications can help to improve the performance of small wind systems, especially in developing countries[8] .

[8] IEA-ETSAP and IRENA (2016), Wind power technology brief E07

1. TECHNOLOGIES

WIND TURBINES

A wind turbine's blades convert kinetic energy from the movement of air into rotational energy; a generator then converts this rotational energy to electricity. The wind power that is available is proportional to the dimensions of the rotor and to the cubing of the wind speed. Theoretically, when the wind speed is doubled, the wind power increases by a factor of eight (the mechanical power's formula is detailed in the section on Wind Turbine Operation).

Wind turbines have got progressively bigger, and more powerful. The size of wind turbines has continued to increase, and the average nominal rating of new grid-connected onshore turbines rose from 0.05 megawatts (MW) in 1985[9] to 2.0 MW in 2014[10]. The largest commercially available turbines to date have a nominal rating of 8.0 MW and, a rotor diameter of 164 metres.

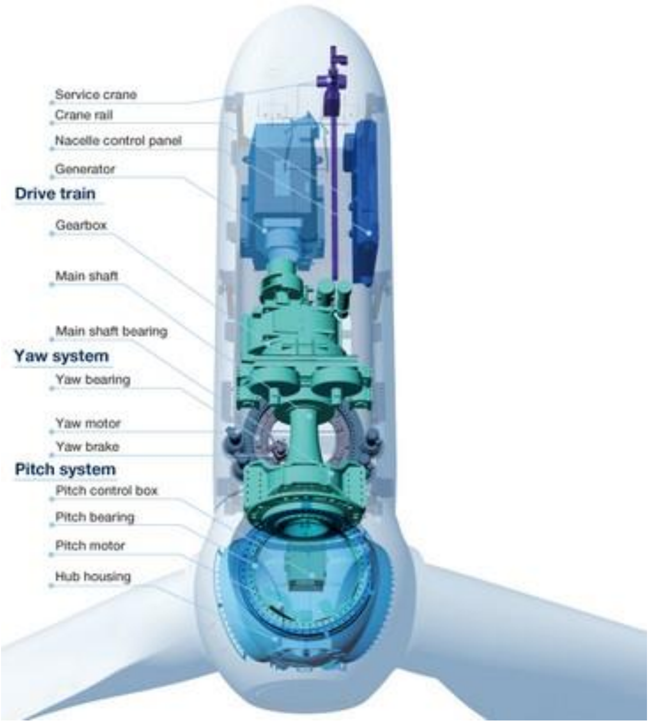
The three major elements of wind generation are the turbine type (vertical/horizontal-axis), installation characteristic (onshore/offshore) and grid connectivity (connected/stand-alone). Most large wind turbines are up-wind horizontal-axis turbines with three blades. Most small wind turbines (SWT) are also horizontal-axis. Innovative designs for vertical-axis turbines are being applied in urban environments, particularly in China. With aerodynamic energy loss of 50-60% at the blade and rotor, mechanical loss of 4% at the gear, and a further 6% electromechanical loss at the generator, overall generation efficiency is typically 30-40%. The majority of today's turbines are designed and built to commercial (i.e. utility) scale; the average turbine rated at 2-3 MW capacity.

There is a wide range of small-scale turbines from 'micro SWTs' rated at less than 1 kW, to 'midi SWTs' reaching 100 kW. SWTs are commonly used as stand-alone electricity systems and frequently applied in isolated locations where the main grid is not accessible. Hybrid wind-diesel systems can improve the stability of power supply in small and off-grid areas, while reducing the costs for fuel and fuel transport by utilising the existing diesel-based generating infrastructure. However, small wind presents lower load factors and higher capital cost per kW than bigger wind farms, as well as high planning costs per installed unit. Major challenges of small wind include the assessment of the wind resource and the reduction of turbulence's negative effects on the wind resource at the tower's height. High towers reduce the negative impacts of turbulence in the wind resource caused by obstacles in the surroundings, but they increase the costs of small wind turbines. The

[9] EWEA (2011)
[10] Broehl, Labastida and Hamilton (2015)

rapidly declining costs of competing technologies, such as solar, also poses challenges to small wind deployment. Innovation opportunities emerge with these challenges to increase the efficiency and reduce the costs of small wind technology[11].

FIGURE 2: POWERTRAIN OF A WIND TURBINE

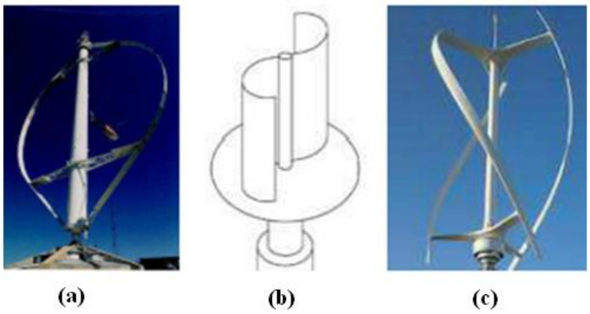


Source: Hitachi

Horizontal-axis wind turbine (HAWT) technology is the most usual kind of turbine which often has three blades, but could also have two. There are also vertical-axis wind turbines (VAWT), which can be grouped as shown in Figure 3: Darrieus (a), Savonius (b) and propeller-blade (c) turbines.

[11] IEA-ETSAP and IRENA (2016)

FIGURE 3: VERTICAL-AXIS WIND TURBINES



Types of Wind Turbines

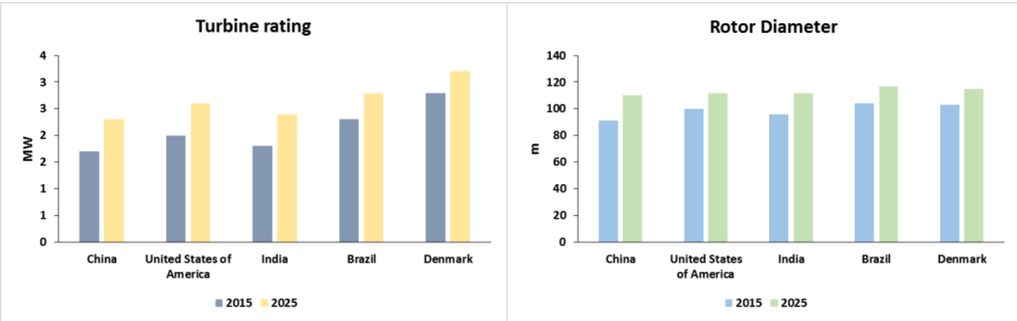
As the power available from the wind increases with the cube its wind speed, all wind turbines need to limit the power output in very high wind speeds. There are two principal means of accomplishing this, with pitch control on the blades or with fixed, stall-controlled blades. Pitch-controlled blades are rotated as wind speeds increase so as to limit the power output and, once the 'rated power' is reached; a reasonably steady output can be achieved, subject to the control system response. Stall-controlled rotors have fixed blades which gradually stall as the wind speed increases, thus limiting the power by passive means. These dispense with the necessity for a pitch control mechanism, but it is rarely possible to achieve constant power as wind speeds rise. Once peak output is reached the power tends to fall off with increasing wind speed, and so the energy capture may be less than that of a pitch-controlled machine. In the early days of the industry, the merits of the two designs were finely balanced and roughly equal numbers of each type were being built. Since the turn of the century, however, pitch-controlled machines have become much more popular. This is due to advances in pitch control, which allow larger and lighter machines compared to stall technology. Another reason is the lower efficiencies attained with stall systems when the wind speed is too high and the rotational speed is therefore decreased[12].

Initially, conventional wind turbines operated at a fixed (rated) speed when producing power, by starting from a parked position and accelerating due to the wind until it reaches the rated speed. At this point, a connection to the electricity grid is made, and the rotor speed is maintained using either pitch or stall control. Now, variable-speed operation, where the rotor is continuously matched with wind speed, is becoming more common. This means that the rotor can operate at wind speeds below and above rated speed, hence increasing energy capture, and operation at high wind speeds relieves loading on the rotor

[12] [12] IEA-ETSAP and IRENA (2016)

blades and reduces the variability of power output. In addition, direct drive turbine systems are becoming increasingly popular, as they eliminate the requirement for a gearbox.

FIGURE 4: HISTORICAL AND PROJECTED TURBINE RATING AND ROTOR DIAMETER IN SELECTED MARKETS



Source: IRENA (forthcoming), MAKE CONSULTING (2015), and the Danish Energy Agency (2016).

Wind Turbine Operation

In 1920, the German Physician Albert Betz proved the formula for wind's mechanical power as follows:

$$P = C_p \frac{1}{2} \rho S V_0^3$$

In this formula, P is the mechanical power obtained directly from the wind. C_p is a characteristic of a wind turbine in the fact that it determines the ratio of the wind energy converted into useful electrical energy by the turbine. This coefficient is theoretically limited to 16/27 or 0.593 at the maximal value of P. ρ is the specific mass af air, depending slowly on the temperature. S is the circular surface swept by the blades and V_0 is the wind speed at that position.

Capacity Factors

Recent trends in wind power development have seen turbines grow in height and rotor diameter faster than in total power capacity, leading to a decrease in specific power output (ratio of capacity to area swept by the rotor blades) of more recent turbines. This trend has pushed up capacity factors for wind turbines generating at similar wind speeds – on average, capacity factors have improved by up to 15 percentage points from 2003 to 2013 for wind turbines generating at moderate wind speeds (8 m/s)[13]. Capacity factors are also

[13] Data from IEA (2013), Wind speeds at 50m height.

dependent on the wind resource at a specific site. In the UK, historic capacity factors stand at 26% for onshore wind and 35% for offshore wind[14]. Meanwhile, in resource-rich Denmark, aggregated lifetime capacity factor from its offshore wind farms is at 41%, and in instances can exceed 50% at certain sites[15]. The trend has also allowed for the development of rotors designed for low wind speeds (< 7 m/s), making more wind resource sites accessible for power generation.

The reliability of a wind turbine in generating power is indicated by the availability of the turbine, which is the proportion of time the turbine is ready for operation. Onshore turbines typically have availabilities of 98%, while offshore turbine availabilities are slightly lower (95-98%) but are improving due to better operation and maintenance.

WIND RESOURCE ESTIMATION AND FORECASTING

When planning the development of a wind farm at a site, it is of utmost importance to understand, as accurately as possible, the wind resource available at that site. This will inform developers in making financial decisions, such as profitability and investment requirements.

Local on-site measurement gives the most reliable estimation of the available wind resource at the site, using a meteorological mast containing measurement instruments such as a wind vane and an anemometer. The size of the proposed wind farm and the complexity of the site's terrain will determine the number of masts required to give reliable estimations of the local resource. One mast is usually sufficient for small farms. It is advisable to measure the wind speed at or close to the hub height of the proposed turbines. As taller masts are costlier to operate, measuring wind speeds at lower heights and theoretically scaling up the hub height resource is a cost-effective option, though it creates uncertainties in the resource estimate. Remote sensing using SODAR and LIDAR are also increasing in their cost effectiveness in measuring the wind at height in suitable terrain

Wind resource data from a nearby or other suitable reference station is also used to augment the on-site data, if available, hence improving data reliability. Computer models, mostly based on computational fluid dynamics (CFD), to process recorded meteorological data are widely used for resource estimation on a broader scale. Through modelling, other factors affecting wind power output can be estimated, such as wake effect, turbine performance and environmental factors.

In addition, a useful tool called WAsP Climate Analyst has been developed for wind and site data analysis. WAsP is the industry-standard software package for siting of wind turbines and wind farms. Many companies use WAsP worldwide for all steps from wind resource and energy yield assessments, to wind conditions and site suitability characterisation; from single turbines in complex terrain to large wind farms offshore. The

[14] Renewable UK, n.d.
[15] Andrew (2016)

Global Wind Atlas provides global datasets describing wind climate including the effects of high resolution topography. The data is for aggregation analysis for energy integration modelling, energy planners and policy makers. [16]

Due to the increase in wind energy penetration to the global energy mix, and the liberalised nature of many electricity markets today, there is also the growing need to accurately forecast expected wind power generation in the short term (i.e. days ahead of schedule), in order to manage the variability of wind energy. Transmission system operators require forecasting to ensure electricity supply and demand remain balanced at all times, power traders use forecasting to trade wind generation on electricity futures markets, and site operators utilise forecasting for scheduling their operations and maintenance. Table 2 shows the classification of wind forecasting timescales employed and their applications. According to the European Wind Energy Association, "to integrate wind energy successfully into an electricity system at penetration levels of more than 10%, accurate wind energy predictions are needed"[17].

TABLE 2: TIMESCALE CLASSIFICATION FOR WIND FORECASTING

Time-scale	Range	Applications
Ultra-short-term	Few minutes to 1 hour ahead	• Electricity market clearing • Real-time grid operations • Regulation actions
Short-term	1 hour to several hours ahead	• Economic load dispatch planning • Load reasonable decisions • Operational security in electricity market
Medium-term	Several hours to 1 week ahead	• Unit commitment decisions • Reserve requirement decisions • Generator online/offline decisions
Long-term	1 week to 1 year ahead (or more)	• Maintenance planning

[16] http://www.wasp.dk/DataandTools#wind-atlas__global-wind-atlas
[17] Wind energy – the facts (2010)

		• Operation management • Optimal operating cost • Feasibility study for wind farm design

Source: Chang, W.-Y. (2014)

Numerical weather prediction (NWP) models are the foundation for many wind power forecasting systems. These models are often operated by government agencies or scientific institutions, and forecast the evolution of weather systems. However, NWP methods model forecasts at a regional or global scale, and lack the resolution required for wind farm-specific forecasts. Therefore, statistical techniques, such as lag regression models and Model Output Statistics, are used to improve resolution, and correct biases and error patterns in data output. NWP-based models provide forecasts for lead times ranging from three hours to 10 days; for shorter timescales, pure statistical methods that learn from existing data on wind speed at the specific location are used[18].

The Portfolio Effect – Aggregation of Wind Farms

The intermittency and variability of the wind resource, and hence of wind turbine output, pose challenges to the integration of wind power generation to the existing electricity network. Intermittent generation will be evident at site level, but due to geographical diversity will reduce when generation is considered over larger areas (such as country or regional level). Hence, the intermittency of wind generation can be reduced significantly if the power outputs of wind farms over a specific area are aggregated together.

The 'portfolio effect' helps the accuracy of wind forecasting by reducing the mean absolute error of forecasts from singular wind farm sites. Forecasting wind generation output is commonly used for parts of Germany and Denmark, where wind generation is high and there is strong interconnectivity between farms. However, interconnection infrastructure and grid connection codes must be in place in the regions where this is done. Interconnection allows exports of wind energy, as well as other sources of variable energy, at generation peaks. In addition, larger interconnected systems are less vulnerable to frequency issues. Thus, interconnection requirements for turbines and other generation assets may be specified in international standards, such as for example IEEE 1547, Standard for Interconnecting Distributed Resources with Electric Power Systems. Grid connection codes provide requirements for connections of wind, as well as solar plants, to national electricity

[18] Kirk-Davidoff (2012)

grids. This helps to maintain stability and reliability in the system, while ensuring the operability of both, generation assets owners and grid operators[19].

TECHNOLOGICAL ADVANCEMENTS

Wind energy technology is a very mature technology – today's turbines already extract nearly 50% of the energy conveyed in the wind (theoretical maximum of under 60%), and operate at very high rates of availability. Nonetheless, wind energy remains an evolving sector as it tries to adapt to changing energy demands and market conditions.

Cost reduction is largely but not solely driven by technological development. However, there remains great potential to reduce costs significantly in onshore and offshore wind technology.[20] Other drivers for design improvements include suitability for different sites and climates, grid compatibility, noise reduction, aerodynamic performance, and visual impact. Current developments in the wind energy industry are described below:

- Turbines are continuously increasing in size, with longer rotor blades up to 80m long. This trend in design has enabled turbines to operate at higher capacity factors, and also exploit low wind speed sites. However, research has gone into devising the optimum turbine size for onshore and offshore applications, both in terms of performance and cost. Scaling up turbines to 10-20 MW and reducing mechanical stress at the tips of longer blades are targeted by R&D centres. There is major development in rotor blade design to withstand the increased stresses, from making the blades out of stronger fibreglass composite structures to curved designs of the blades.

- In addition to harvesting energy in low wind speed sites, there is also a move towards extracting energy in specific environments and climates. Cold climate areas (regions where turbines are exposed to icing and/or temperatures below operational limits) are characterised by good wind resources and low populations, and the wind energy market in these regions are growing. At least 52 GW of wind energy projects have been deployed in icy climates around the world, and an additional 30 GW of capacity is expected to come online by 2017[21]. The cost of wind energy in cold climates is higher than in moderate climates, due to higher investment costs of turbines with anti- and de-icing capabilities, steel that remains ductile in low temperatures and special foundations for permafrost, or from lower energy yields caused by icing of the rotor blades.

- Direct-drive eliminates the gearbox, and could be crucial in removing the limiting size and weight of future turbines of 10 MW and beyond. Hybrid drive systems have simpler and more reliable gearing than conventional solutions with three stages of gearing, while having a similar generator size. They contribute to a more compact

[19] IRENA (2016), Scaling up Variable Renewable Power: The Role of Grid Codes
[20] IRENA (2016), The Power of Change: Cost reduction potentials for solar and wind power technologies.
[21] Windpower Monthly, Optimising wind farms in cold climates

arrangement within the turbine’s nacelle. Hydraulic drivetrain designs also have the potential to replace the gearbox.

- Remote electronic controls are continually being incorporated into turbine design. In addition to pitch control and variable speed operation, individual turbines and whole farms may perform wind measurements remotely, using turbine-mounted technology such as lidar (LIght Detection and Ranging) and sodar (SOnic Detection and Ranging). The real-time data realised from remote sensing will optimise wind production as turbines constantly pitch themselves to the incoming wind.

FIGURE 5: VORTEX BLADELESS TURBINE AND BUOYANT AIRBORNE TURBINE

Source: Vortex Bladeless, Altaeros Energies

- There is ongoing research and development to modify the fundamental design of wind turbines, in order to bypass some of the limitations and environmental concerns of conventional HAWTs and VAWTs. A Spanish startup, Vortex Bladeless, has designed a turbine without rotor blades. It harnesses wind energy through vorticity which causes the structure to oscillate. As the design has no gears or bearings, it claims to reduce the total cost and carbon footprint of wind generation both by up to 40%[22]. However, these turbines are likely to be constrained by the amount of power they can produce

[22] http://www.vortexbladeless.com/home.php

and will struggle to operate at high altitudes where wind is more turbulent. The next generation of wind turbines may well be airborne. Different configurations have been touted, including Google's Makani Project, which is a kite-type device tethered to the ground that flies in an orbit similar to the tip of a conventional HAWT. Another concept is the Buoyant Airborne Turbine (BAT) by Altaeros Energies, which consists of a conventional HAWT suspended and held afloat in a helium filled shell. Airborne wind solutions are emerging designs yet to reach commercial viability due to challenges related to cable loading, the impact of lighting and storms and the interferences with aircrafts and radars.

OFFSHORE WIND TECHNOLOGY PROSPECTS

It is expected that the most significant technology innovations for off-shore wind applications will be the introduction of next generation turbines, with larger rotors, and a range of innovations in foundations. The largest offshore wind turbine (in terms of rotor diameter) that has been deployed on a commercial-scale wind farm before the end of 2015 was the 6 MW Siemens SWT-6.0-154 turbine, which has a 154m diameter rotor. Ongoing developments in blade and drive train technology will enable even larger turbines with higher capacity ratings. An area where there has been increased research to larger rotor diameters is in modular blade technology. This technology permits different materials to be incorporated into blade components. Modular blades may facilitate the transportation of blades and their assembly closer to the wind farm site in contrast to conventional blades. Companies such as Blade Dynamics and previously Modular Wind have taken research in modular blades to the practical demonstration stage with demonstration blades being tested with a length of 78m. Larger turbines might lower the LCOE due to higher yields from greater efficiency and reliability. It is expected that the commercialisation of 10 MW turbines may take place in the early 2020s, while 15 MW turbines might be commercialised in the 2030s.

Concerning drive train technology, several significant innovations are under development. In addition to the demonstration of direct drive and mid-speed drive trains, which have the potential to increase reliability by reducing the number of critical components, such innovations include research and development on continuously variable drive trains and superconducting generators.

Continuously variable drive trains provide a variable ratio of input to output speed between the rotor and a synchronous generator by using hydraulic or mechanical devices. This technology avoids the need for a power converter as the control of the generator speed and thus the output frequency is controlled by the variable transmission. An example of this technology is the hydraulic system developed through in-house private sector research by MHI-owned Artemis Intelligent Power which received UK government funding.

Superconducting generators uses machine conductors with zero electrical resistance when cooled below their critical temperature. Since the conductors have no losses, there is no heat to dissipate and the conductors can carry very high currents on thin sections. This reduces the size and mass of the generator, and allows a much lower top head mass. With no losses on the rotor, the machine efficiency is improved, giving a higher annual energy yield. A megawatt-scale High-Temperature Superconducting generator was made for demonstration in the UK in 2011.

Floating Foundations

Currently deployed foundations for off-shore wind turbines, as monopiles, restrain their application to water depths greater than 50 m. This constrains the access to sites with higher wind resource and, potentially, large markets as Japan and the US with limited shallow water sites. While the wind sector moves into deeper water sites, it is likely that developers may still be using a mix of known designs as piled jackets, suction buckets and gravity base foundations. However, floating foundations could offer improvements to open up new markets in deeper waters. A number of designs of floating foundations would ease the installation and reduce its costs by avoiding the use of heavy-lift vessels.

Floating foundations are buoyant structures maintained in position by mooring systems. The technologies in development at present are: i) the spar buoy, as the Hywind concept developed by Statoil, ii) the tension-leg platform, as Glosten’s PelaStar, and iii) the semi-submersible, as the one developed by Principle Power and the damped floater being developed by Ideol. Demonstration is an important ongoing stage for floating concepts and several full-scale prototype floating wind turbines have been deployed. The first was a spar buoy in Norway in 2009, followed by a semi-submersible installation in Portugal in 2011 and three installations in Japan (spar and semi-submersible) between 2011 and 2015. No tension-leg platform has been deployed for a wind application; the first, designed by Gicon is anticipated in Germany in 2016.

FIGURE 6: DIFFERENT DESIGNS OF FLOATING FOUNDATIONS FOR OFF-SHORE WIND TURBINES

Source: U.S. Department of Energy

Other innovations that have the potential to impact the industry during the next three decades include new turbine designs (e.g. airborne wind), integrated turbine installation, site layout optimisation array cables and the deployment of HVDC infrastructure and DC power take-off.

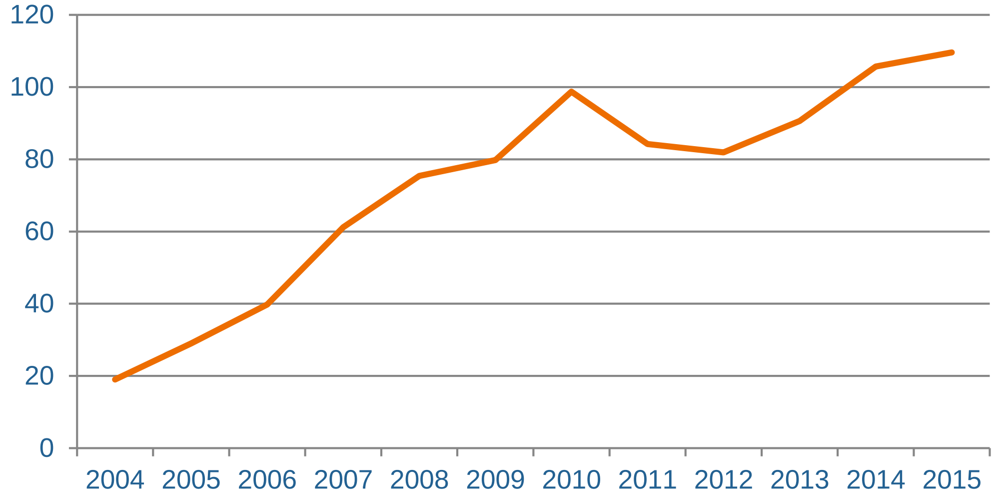
Repowering offshore wind farms may become an option to guarantee operations in a decade, when the first wind farms will reach the end of their operative lives. Repowering activities revolve around the substitution of obsolete generating assets and infrastructure, such as turbines, foundations and array cables, by more advanced units. Provided that such units may be more powerful or larger in size, repowering activities might also involve spacing the units further and adjusting the farm configuration. Repowering activities may retain transmission assets, which could reduce the cost of repowering the wind farms and thus, lead to a reduction on the levelised cost of energy[23].

[23] IRENA ibid

2. ECONOMICS & MARKETS

The total investments in the global wind sector reached a record level of US$109.6 billion over the course of 2015. From 1983 to 2014, the global stock of investments in onshore wind was in excess of US$647 billion[24]. More than 93% of these investments occurred after the year 2000. United States, China, Germany and Spain account for the bulk of these investments. During 1983 and 2000, onshore wind investment stock was estimated to be around US$40 bln. United States, Germany and Denmark accounted for the vast majority of these investments.

FIGURE 7: YEARLY NEW INVESTMENTS IN WIND ENERGY, 2004-2015 (USD BILLION)



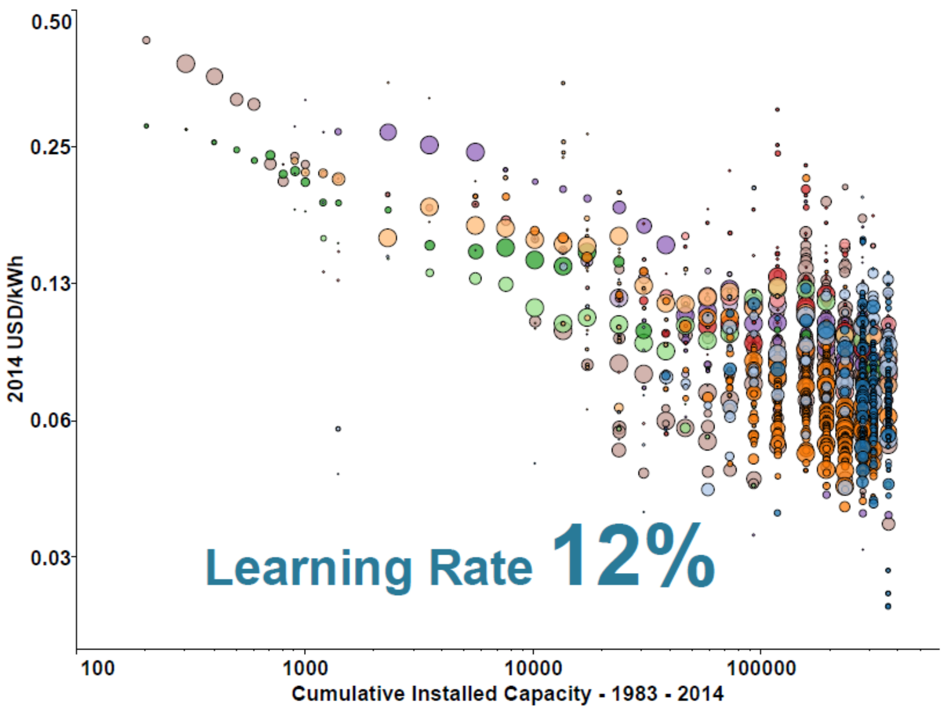
Source: Bloomberg New Energy Finance (2016)

IRENA has also updated the global learning curve for investment costs and LCOE of onshore wind. The analysis used a database of more than 3200 individual wind farms with data on costs and performance within a panel of 12 countries (Brazil, Canada, China, Denmark, France, Germany, India, Italy, Spain, Sweden, United Kingdom and United States) that accounted for 87% of onshore wind capacity at the end of 2014. The analysis covered the period 1983 to 2014 and concluded the following facts. Onshore wind power has seen a significant cost decline since its championing in early 1980s by Denmark and

[24] IRENA (2016), The Power of Change: Cost reduction potentials for solar and wind power technologies.

United States. Globally weighted average investment costs declined from 4,766 US$/kW in 1983 to 1,623 US$/kW in 2014, translating into an overall reduction of 66%. A learning rate of 6% fits the investment costs evolution. Thus, every time global cumulative installed capacity doubled, investment costs declined by 6%. The LCOE of onshore wind power experienced a higher rate of decline in comparison to investment costs to calculate the LCOE of onshore wind, so it was assumed a constant weighted average cost of capital of 7.5% for OECD countries and China, and 10% for the rest of the world. Globally, the weighted average LCOE of onshore wind declined from 0.38 US$/kWh in 1983 to 0.07 US$/kWh in 2014. Thus, the LCOE of onshore wind was 81% lower in 2014 in comparison to the estimated value in 1983. This represents a learning curve of 9%. The learning rate of LCOE is higher than the one estimated for investment costs because technological improvements allowed for lower investment costs and higher capacity factors at the same time. Additionally, lower Operation & Maintenance costs for higher rated wind turbines have helped to bring down the LCOE of onshore wind.

FIGURE 8: IRENA ONSHORE WIND LEARNING RATE



Source: IRENA Renewable Cost Database

ONSHORE WIND

Historic and Current Trends

The onshore wind sector has been characterised by a significant fall in cost of energy production, and a likewise expansion in generation capacity worldwide. 64 GW of new onshore wind capacity was added in 2015, taking total cumulative capacity to 435 GW[25]. Since 2000, installed capacity has grown at a CAGR of nearly 25%. While policy initiatives since the turn of the century have been vital to the uptake of onshore wind in key markets, much of the growth within the sector has been organic – driven by economies of scale, technology improvements and increased market competition. Interestingly, current growth in onshore wind is being led by the 'emerging' wind markets in Latin America and Africa, along with China, currently the world's largest wind market.

From a levelised cost perspective, onshore wind energy boasts some of the lowest electricity costs amongst the renewable energy sources, and in some mature markets it is now cost-competitive with conventional sources of generation if variability is not taken into account. As far as wind generation is intermittent, price of electricity is the right concept for the consumer, this price must take into account back up by other generation assets or by storage.

Drivers within the Wind Market

The following are the key drivers for general trends within the global onshore wind market:

- Technology maturity & improvement (higher capacity factors and availability, production in low wind speed sites)
- Investor familiarity
- Policy support

COST OF TECHNOLOGY

Installation Costs

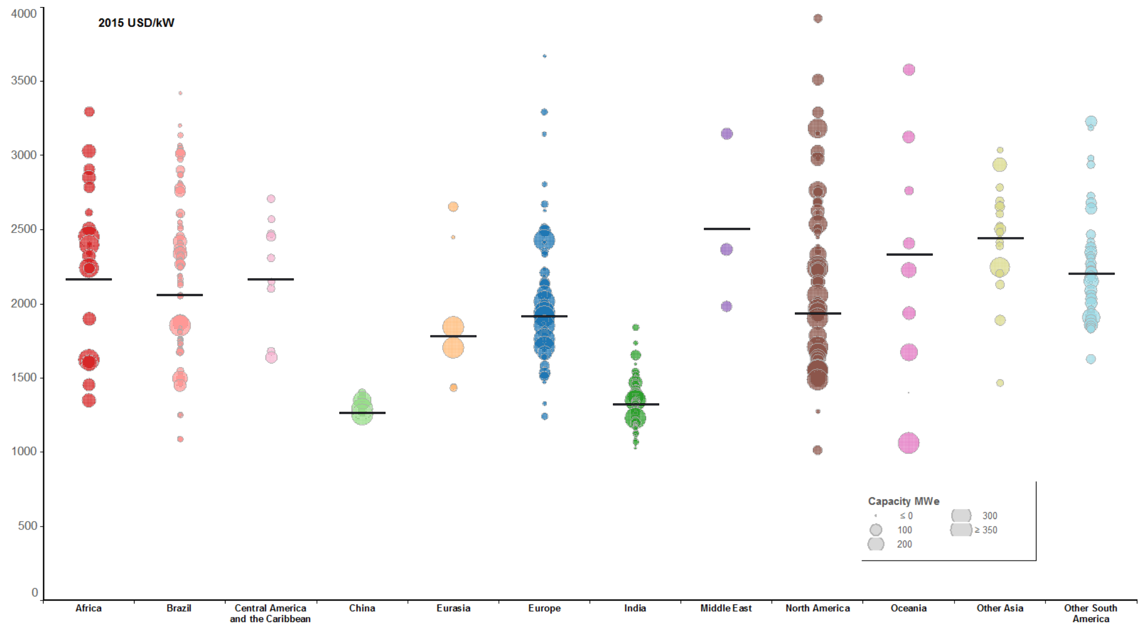
Turbines represent the single largest cost item for onshore wind energy development. Turbine cost (including electrical infrastructure and transportation) can represent a range of 64% to 84% of capital costs[26]. Shortly after the turn of the century, wind turbine average prices increased to above US$1,500/KW by 2008, although they had reached US$750/kW between 2000 and 2002 in the United States[27]. The upward trend in prices was caused by significant increases in the prices of commodities, such as copper, steel, cement and rare earth magnet material. Other factors attributed to the increase of turbine prices are the development and sale of larger (and initially more expensive turbines), a shortage in wind turbines to meet a sharp rise in global demand and inflation in the costs attributed to civil

[25] IRENA (2015)
[26] IRENA (2015), Renewable power generation costs
[27] Lawrence Berkeley National Laboratory (2015)

engineering work. Since then, turbine prices have fallen and preliminary estimations indicate that prices have reached between US$950 and US$1,240 for projects in 2016, suggesting cost reductions of 30-40%.

Chinese wind turbines fell by 37% from 2007 to 2016. A crash in commodity prices since the financial crisis, and increased competition among OEMs thanks to added manufacturing capacity in China and India have contributed to the downward trend in turbine prices. Installation costs of wind farms are dependent on project size, turbine costs, wind resource, difficulty of terrain, transport costs and local labour costs. Total installation costs mirrored the trend of turbine prices, peaking in 2009.

FIGURE 9: TOTAL INSTALLATION COSTS AND WEIGHTED AVERAGES OF COMMISSIONED AND PROPOSED WIND FARMS BY COUNTRY AND REGION, 2015



Source: IRENA Renewable Cost Database (2016)

From Figure 9 average installed costs in China and India are the lowest in the world, with weighted average installed costs between 26% and 43% lower than other regions. China and India also have the narrowest cost range for different-sized projects. Both the Chinese and Indian markets are approaching 'mature' status for onshore wind – the Chinese market saw modest reduction in costs from 2010-2014 (about 12%), while costs in India declined by 6% between 2010 to 2015. The fastest drop in costs were witnessed in South America (about 20% between 2011 and 2015), highlighting the sizeable room for growth in onshore wind in these countries.

Studies on projects completed in the United States suggest that average installation costs exhibit economies of scale, especially when moving from projects of 5 MW and below to projects within the 5-20 MW range (>30% cost reduction). The trend is less evident for larger projects, however[28].

Analysis by the IRENA Renewable Cost Database has also shown a strong correlation between installed costs and capacity factors of onshore wind farms once in operation, when examined at a global level. As capacity factor is heavily dependent on the quality of the wind resource, it appears that higher-cost projects are being installed at sites with better wind resources (and hence higher capacity factors) and vice-versa, in an effort to minimise the levelised costs of the projects.

Operation & Maintenance (O&M) Costs

Though available data from commissioned wind projects is hard to come by, it is clear that annual average O&M costs have declined significantly since 1980. Average total O&M costs for onshore wind reported by publicly traded developers in United States stood at US$24 per MWh in 2013[29], while estimated costs for European wind farms were in the range of US$11-40 per MWh in 2011[30]. In addition, projects installed in the United States since 2010, using state-of-the-art equipment, show O&M costs as low as US$9 per MWh over the period 2010-2014[31]. Caveats exist for these figures, however. Firstly, they are expressed as purely variable costs (in per unit MWh), when in actuality O&M cost has both a fixed and a variable component. Secondly, it must be stated that it is not clear whether the same boundaries to the cost structures for projects within and between the United States and Europe are applied. Recently developed projects using current generation turbines exhibit higher availability rates than older projects, hence they are out of service less frequently and have shorter downtimes, and generally lower O&M costs. The O&M market is also getting more competitive, especially in large markets such as Europe, US and China; as more turbines reach the end of their service life, O&M contractors and even turbine manufacturers hope to secure long-term service contracts.

Financing Trends

Wind projects, both onshore and offshore, are now seen as low-risk investments. The sector has a credible growth track record. It is regarded as the preferable source of grid-scale renewable electricity in many countries, hence further growth potential and deployment rates expected to increase.

A number of trends have been witnessed in the financing of wind projects in recent times. Firstly, there is increasing competition among financial institutions to provide debt to large projects. As of early 2015, banks were willing to provide over twice as much debt funding to

[28,18] Wiser and Bolinger (2015)
[29] Wiser and Bolinger (2014)
[30] IEA Wind (2011)

projects as they were only 18 months earlier. Green bonds have been issued with yields as low as 0.25%, and the majority within the 2.5-3.0% range[32]. Secondly, more players are participating in the debt market – institutional investors (e.g. pension funds or insurance companies) have joined commercial and multilateral banks and public export credit agencies in providing debt funding for wind projects. The expectation in the near future is that new projects will receive funding with lower interest rates and higher gearing (debt-to-equity) ratios (as much as 80% or more); which will contribute to increasing the internal rate of return of projects and lower the overall cost of energy.

LEVELISED COST OF ELECTRICITY[33] (LCOE)

Historical Trends in LCOE

Levelised cost of electricity for wind energy is directly affected by the combination of installation costs and energy production (i.e. capacity factor). From the 1980s to the turn of the century, significant reductions in capital costs and improvement in turbine performance combined to reduce the levelised cost of onshore wind energy, by as much as a factor of three over this period. Historical data from the United States and Denmark shows that LCOE dropped from above US$150 per MWh in 1980 to about US$55 per MWh in the early 2000s[34,35,36]. IRENA estimated that the global LCOE for onshore wind was 380 US$/MWh in 1983 and 70 US$/MWh in 2015 (in real, 2015 US$ values). From 2003 to 2008, the aforementioned increase in turbine costs and hence capital costs put upward pressure on the total LCOE. However, the increase in capital costs observed in the period up to 2009 did not have a proportional equal effect on LCOE due to the fact that the period coincides with the introduction of novel technologies with higher hub heights, rotor diameters and MW rating that offset an estimated 10-15% of CAPEX increase by increasing capacity factors.

Capital costs have since declined, but not to the lows experienced pre-2003 but accounting for the technological improvements allowing for higher energy capture, costs might be overall lower from an LCOE perspective as the estimated global weighted average LCOE in 2015 was lower than its equivalent in 2003 or any other point in time before. However, continued performance improvements mean that LCOE for onshore wind are now at record lows. This illustrates that wind project developers and OEMs are more concerned with decreasing LCOE rather than capital expenditure.

Regional Differences in LCOE

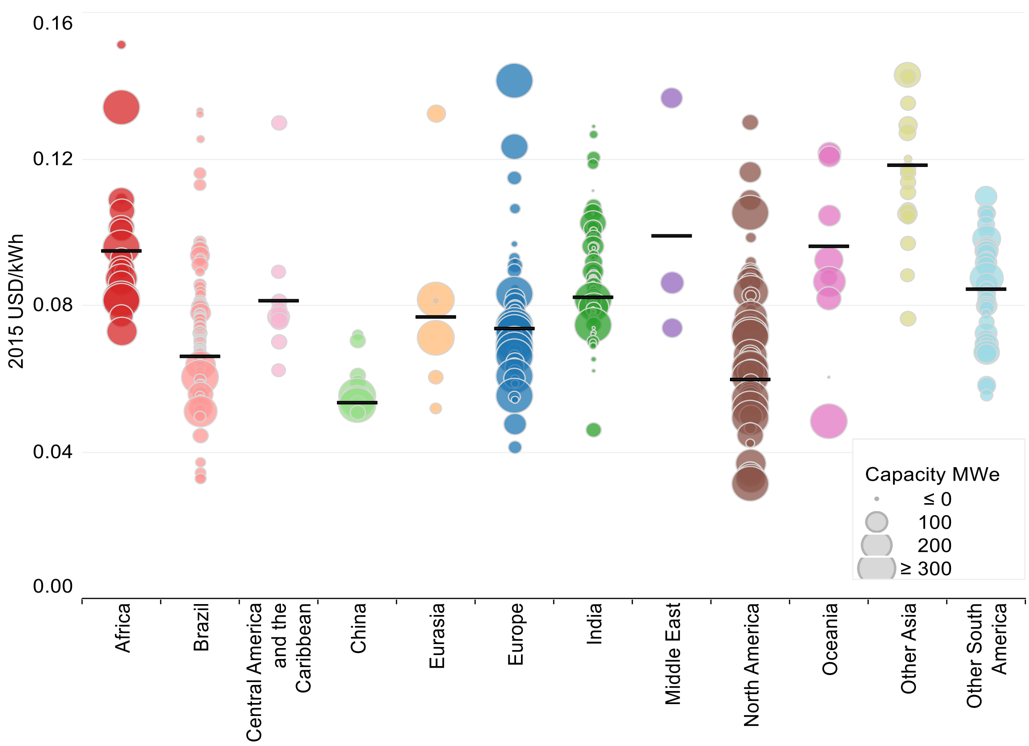
From Figure 10, China has the lowest weighted average LCOE for onshore wind projects, 52 US$/MWh, with a very narrow range, between 50 US$/MWh and 72 US$/MWh. India exhibits a relatively low weighted average LCOE, at 82 US$/MWh with a wider range,

[32] Arántegui and González (2015)
[33] LCOE is the average revenue required per unit of electricity generated to make a market rate of return over the total lifetime investment in a project.
[34] Wiser and Bolinger (2011)
[35] Lemming *et al* (2009)
[36] Danish Energy Agency (1999)

between 46US$/ MWh and 129 US$/kWh. Overall, in Asia, the most expensive projects cost more than 142 US$/MWh.

The LCOE of onshore wind has a very competitive weighted average in North America and Brazil with 60 US$/MWh and 66 US$/MWh respectively and virtually the same ranges of 31 US$/MWh to 130 US$/MWh. The highest weighted average LCOE are to be found in Africa, Oceania and Middle East with 95 US$/MWh, 97 US$/MWh and 99 US$/MWh respectively.

FIGURE 10: LCOE AND WEIGHTED AVERAGES OF COMMISSIONED AND PROPOSED WIND FARMS BY COUNTRY AND REGION, 2015



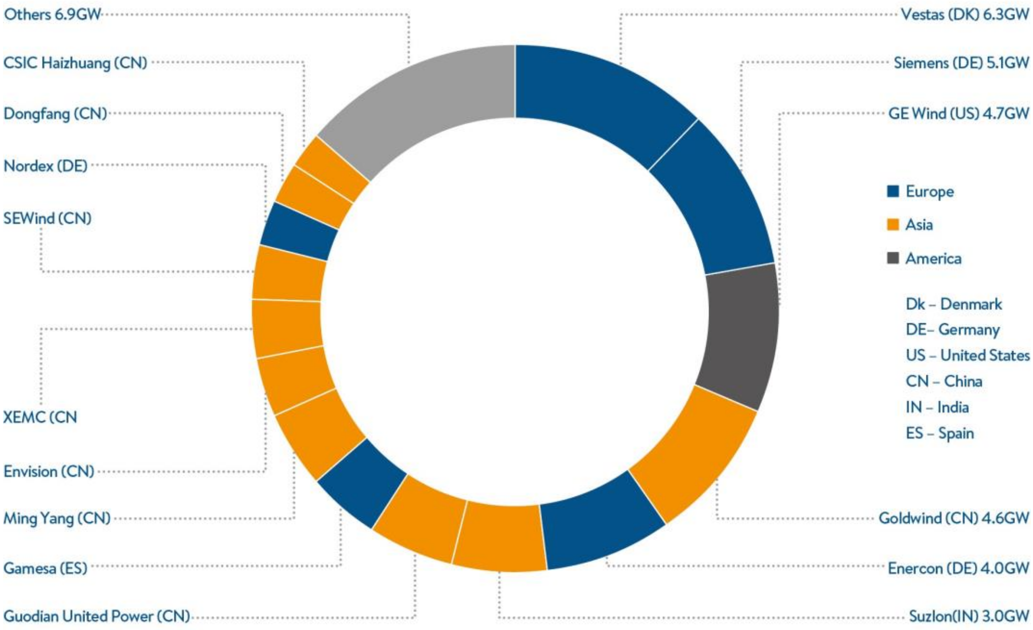
Source: IRENA Renewable Cost Database

INDUSTRY TRENDS

Turbine Manufacturers

Figure 11 gives a breakdown of the global wind market in 2014 (by capacity additions), according to turbine manufacturer. Vestas (Denmark, 12.3% of global market) was the top supplier of wind turbines globally in 2014, followed by Siemens (Germany, 9.9%), GE (United States, 9.1%) and Goldwind (China, 9.0%)[37].

FIGURE 11: SHARE OF THE GLOBAL TURBINE MANUFACTURER MARKET, WITH RESPECTIVE CAPACITY ADDITIONS, IN 2014



Source: BTM Navigant (2015)

Trends within the supplier industry in recent years show strong consolidation of the major companies and the shift in the global wind market eastwards to China and India. In 2003, only one Chinese manufacturer (Goldwind, 0.5% share) made any substantial contribution to the global wind market. Nine Asian companies, eight of which from China, made up the global top 15 turbine manufacturers - compared to five from Europe - in 2014, each with at least with a 2% share of the global market. Since 2009, China has contributed 35-50% of annual wind installations. The Indian manufacturer Suzlon has nearly 6% global market share. It should be noted however that the growth of the Chinese manufacturers thus far has been largely restricted to the domestic market. On the other hand, the European manufacturers commanded a 78% share of the global non-Chinese market in 2014 (Vestas and Siemens had virtually no home market in that period). GE, the only major manufacturer

[37] BTM Navigant (2015)

from the United States, had over 60% of its supplied capacity installed domestically in 2014.

The financial health of turbine manufacturers has rebounded after the witnessed dip in earnings in 2011-12. Strong competition between manufacturers and production overcapacity were adjudged to be the main reasons for the dip in this period, but now the market presents a much healthier financial situation.

RISKS TO INVESTMENT

Policy Uncertainty

With the dramatic fall in costs for onshore wind, governments are re-considering their policy support structures for the technology. Policy uncertainty in Europe and the United States in 2013 was largely responsible for the fall in net capacity additions in both markets for that year. However, it has been commented that high levels of incentives are no longer necessary for onshore wind, though their economic attractiveness still depends on adequate regulatory frameworks and market design[38].

Longevity of Assets

Wind projects are developed with an assumed operational lifetime of 20-25 years. As more operational turbine fleet approach retirement, there is the realisation that the performance of some projects may have been over-estimated during the planning phase of the project. In addition, long-term O&M profiles of projects are variable and not yet fully understood and this could have led to underestimate costs attributed to maintenance and, eventually, decommissioning.

PIONEER HYBRID ELECTRICITY SYSTEM IN SPAIN: WIND AND HYDRO-PUMP ENERGY STORAGE IN ISLANDS

In July 2014, the Gorona del Viento wind-hydro plant was inaugurated in the Spanish island of El Hierro. Thanks to this project, El Hierro relies mostly on wind its electricity supply. The pumped hydro plant stores the excess energy from the five wind turbines by pumping water to an artificial reservoir located further up on a hill. When the wind resource is not sufficient to meet the electricity demand, the water in the reservoir is released and channelled through turbines to produce electricity[39]. Through this system, the electricity demand of the 10,000 locals of El Hierro has been met by 100% renewables for extended periods of time, beyond 40 hours at times[40].

[38] IEA (2015)
[39] Kenning (2015)
[40] REE (2016), https://demanda.ree.es/visionaCan/VisionaHierro.html#app=2547&9127-selectedIndex=0

The case of El Hierro presents a number of innovative aspects. Unlike most of the existing pumped storage systems, which use a river or a conventional dam as reservoir, Gorona del Viento's artificial reservoir was created specifically for storage purposes. By doing this in an island, El Hierro became a pioneer island to rely on such hybrid electricity system. Still, opportunities for innovation exist. For example, smart grids that enable electricity consumption mostly at generation peaks and postpone non-critical uses of the electricity when the wind resource is insufficient pose opportunities to increase the duration of storage.

It is estimated that this US$91 million project, has contributed to save more than 3,200 tonnes of fuel and thus, prevented 10,800 tonnes of CO_2 to be released to the atmosphere in less than a year[41]. Systems like Gorona del Viento can contribute to diminish the reliance on fossil fuels in islands, where diesel is generally imported at a particularly high price due to transportation. In addition, the combination of wind and pumped hydro energy storage mitigates the variability intrinsic to wind power generation[42].

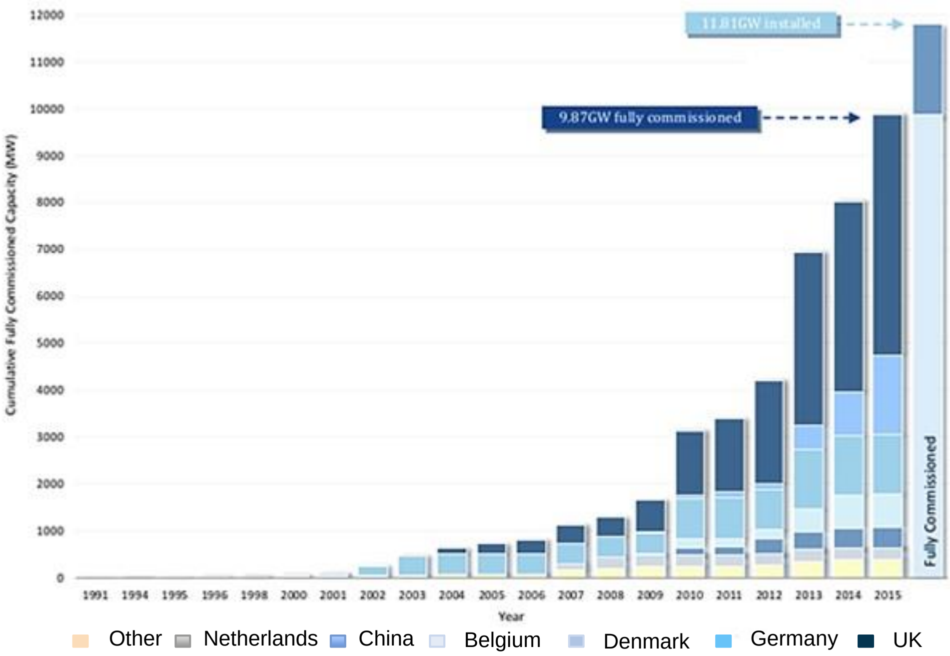
OFFSHORE WIND

In 1991 Elkraft (now DONG Energy) installed the first offshore wind farm in Vindeby, Denmark. It comprised eleven Siemens (formerly Bonus) 450 kW, 35 m rotor diameter machines with a total capacity of 4.95 MW. The project was 2 km from shore in 2 to 4 m water depth and the project is still operational. The industry has developed significantly in the 24 years since then and a single 5 MW turbine can now produce the energy produced by all 11 turbines.

Global installed capacity of offshore wind capacity reached around 12,107 MW end-2015, with 2,739 turbines across 73 offshore wind farms in 15 countries. Currently, more than 92% (10,936 MW) of all offshore wind installations are in European waters but governments outside of Europe have set ambitious targets for offshore wind and development is starting to take off in China, Japan, South Korea, Taiwan and the US. This will be extremely beneficial for the technology, reducing market risk, increasing the supply base and allowing innovations to emerge.

[41] Gorona del Viento, n.d,.
[42] Fillon (2016)

FIGURE 12: PLANNING CAPACITY BREAKDOWN BY COUNTRY



Source: 4C Offshore Wind Overview Report (2016)

Although Denmark was the first mover in the industry, the UK is now the leader with 5,144 MW of installed capacity, over 40% of the total and more than all other countries in the world combined (see Figure 12). The 5 GW threshold was crossed when Gwynt y Mor wind farm, off the coast of North Wales, was officially inaugurated on 18 June 2015. Following the UK in Europe is Germany (3,137 MW), Denmark (1,271 MW), Belgium (712 MW) and the Netherlands (376 MW). Outside of Europe, offshore wind projects can be found in Asia with China as the leader with 718.9 MW of installed capacity; Japan, 52 MW; and South Korea, five MW as of October 2015[43].

Looking forward, globally, it is expected that there will be 41 GW of installed capacity by 2020[44] and 84.2 GW by 2024[45]

[43] Environmental and Energy Study Institute (2016)
[44] Bloomberg New Energy Finance (2015), Global Wind Market Outlook,
[45] Bloomberg New Energy Finance (2015), Q3/2015 Global Wind Power Market Outlook Update

MAIN MARKET REGIONS

Europe

The UK will remain a key market and is expected to double the capacity installed to around 10 GW by 2020. Germany however, is developing its market rapidly. In the first six months of 2015, 1.77 GW of new offshore wind was connected to the grid in German waters. An additional roughly 2.1 GW is in the pipeline bringing the total to around 5.4 GW in the next few years[46]. The Netherlands will also grow rapidly with a target of 4,450 MW by 2023. Belgium is targeting 2 GW by 2020 and has limited capacity to 8 GW due to space for offshore wind. France has not defined a specific target but has held two tender rounds with combined capacity of 2,924 MW for installation by 2025.

Asia

China has ambitious plans with a target of 10 GW by 2020 and 30 GW by 2030. With only around 718.9 MW installed so far, it is questionable if these targets are achievable. In Japan, an estimated 900 MW of fixed-foundation offshore capacity is under development at 11 locations[47]. The anticipated start of construction on SoftBank's 100MW wind farm at Kashima — the country's first commercial-scale offshore project — and the recent announcement that a consortium led by Hitachi Zosen Corp. will invest around ¥100b (US$850m) in a 220 MW wind farm off the northwest coast, should also help build momentum[48]. The government in Taiwan has turned its attention to offshore as onshore wind is not expected to grow beyond 1.2 GW of installed capacity because of land restrictions and the west coast of the country is considered to be one of the best global locations for offshore wind. There are currently 36 pre-identified zones for construction and the government has targeted 4 GW of offshore wind capacity by 2030. South Korea installed its first offshore wind turbines in 2012, following a 2011 announcement that the government would provide nearly US$8 billion to fund the phased development of a 2,500 MW offshore project, with operations beginning in 2019. Although development appears to be lagging, as a result of concerns raised by the fishing industry, approximately 500 MW of projects are advancing through the Korean pipeline[49]. There is currently no offshore wind in India but The Indian Ministry of New and Renewable Energy has introduced an offshore wind policy targeting 1 GW by 2020 and Suzlon Energy is working on 600 MW offshore wind farm off coast of Gujarat[50].

United States of America

A project has yet to be commissioned in the US and there is no official target for offshore wind. However, in 2015 the 30 MW Block Wind offshore wind farm became the first offshore wind farm to reach financial close and from a report released by the Department of

[46] Morris (2015)
[47] Anticipated
[48] EY (2015)
[49] NREL (2015), 2014-2015 Offshore Wind Technologies Market Report
[50] GWEC (2014)

Energy in September 2015, there are 21 offshore wind projects in development in the US, for a total of 15,650 MW of potential capacity[51].

LCOE AND COST REDUCTION[52]

Advancements in wind power technologies continue to move forward towards cost reduction as well as the expansion into new markets. With onshore wind power reaching cost competitiveness against conventional power generation technologies, more attention is now paid to technology developments for offshore applications. The offshore wind market may represent an increase of the additional installed wind power capacity of up to 100 GW by 2030 and 400 GW by 2045 globally.

Progress in offshore wind has been observed since the beginning of the century. The LCOE from offshore wind was about 260 US$/MWh in 2001 and it decreased to approximately 196 US$/MWh by the end of 2015. While finance, OMS and turbines are the elements contributing more significantly to the LCOE, decommissioning would represent the less significant expenditure of around 0.7% of the LCOE[53]. Currently, the global operating offshore wind power capacity at present is 12.7 GW, located mainly in northern Europe. This has been enabled by a wide range of innovations, including offshore-specific turbine designs, bespoke offshore wind installation vessels and advanced offshore electrical interconnection equipment. From 2001 to 2015, the rated capacity of commercially deployed offshore wind turbines has also grown from 2 MW to more than 6 MW. This progress not only improved the efficiency of the turbines but also resulted in cost economies across the rest of the wind farm. Nonetheless, the offshore wind sector has to continue and reinforce its efforts to reduce cost and ease its integration into the grid to become a competitive energy supply technology.

Industrialisation and Maturation of the Supply Chain

The offshore wind supply chain has matured over the past five years, stepping out of the shadow of other sectors. For instance, offshore wind specific turbines are now built in offshore wind specific factories and installed from offshore wind specific installation vessels. This is in part due to companies (such as DONG Energy, Siemens Wind & Bladt) having offshore wind as a core part of their business, generating revenue and profit in the process. This creates a strong incentive for these companies to innovate to ensure a sustainable business in the long term. Risk management has also improved with experience, with installation times per turbine decreasing. Finally, chronic supply shortages in certain areas (e.g. installation vessels in 2010/11) have eased, with reasonable levels of competition across the value chain.

Collaboration between suppliers and developers is also important. If a design of a substation for example, can be standardised across a number of windfarms, this helps

[51] Environmental and Energy Study Institute ibid
[52] IRENA (forthcoming) – Off-shore wind technology: an innovation outlook
[53] IRENA ibid

suppliers to efficiently utilise their manufacturing capabilities as well as giving visibility of project's pipeline to justify investment in manufacturing facilities. DONG Energy for example, commissioned Atkins to design eight substations across four of their windfarms (Burbo Bank Extension, Race Bank, Walney Extension and Hornsea) with the key aim of reducing costs.

Finance Cost Reductions

Offshore wind is very capital intensive with financing costs at around a third of the LCOE. Improvements in financing therefore have a large impact on the cost base.

Traditionally, offshore wind was financed off the balance sheet of utilities yet there is an increasing trend towards project finance. At the same time, the offshore wind sector has seen a huge increase in appetite from investors to finance projects. The size and scale of offshore wind, combined with the secure, long term, inflation linked returns have been particularly attractive for investors, with significant competition between parties to invest in good projects. As a result, the cost of debt and equity has fallen, while debt-to-equity ratios have improved. There is evidence in the market of projects achieving up to 70% gearing as with the case of the Green Investment Bank (GIB) and Marubeni who in August 2014 raised £370m debt to refinance their 50% share in DONG Energy's Westermost Rough project, bought in May for £500m[54]. The sector is also developing a strong project finance record - as an example, see Case Study on Gemini Offshore Wind Farm.

Another approach that is producing competitive debt and new participants to the market is bond financing which helps to access a larger pool of investors. In September 2015, DONG Energy signed an agreement to divest 50% of the 330 MW German offshore wind construction project, Gode Wind 1, to Global Infrastructure Partners (GIP), a leading global, independent private equity infrastructure investment fund. The total sales price amounts to approximately €780 million (DKK 5.8 billion) which will be paid in the period 2015 to 2016. As a part of the transaction, GIP will issue a rated project bond to a consortium of renowned German insurance companies with Talanx, one of the largest German insurance groups, as cornerstone lender. This transaction marks the issuance of the first non-recourse, investment grade, certified green bond dedicated to part-finance an offshore wind farm asset under construction.

One of the key challenges for the industry has been finding an investment partner willing to take on construction risk. Thankfully, the participation of state banks, multilateral banks and export credit agencies such as GIB and the European Investment Bank (EIB) are helping to bridge this investment gap.

[54] https://ore.catapult.org.uk/documents/10619/110659/CRMF+Qualitative+Summary+report/dc37fb9c-e41e-429c-862e-747f8db091c0

FINANCING GEMINI OFFSHORE WIND PROJECT

A big financing success came in May 2014 when the 600 MW Gemini project[55], 85km of the coast of the Netherlands became the largest-ever project financed offshore wind farm raising €2.8 billion. More than 22 parties, including 12 commercial creditors, 4 public financial institutions, together with one pension fund and Northland as subordinated debt lenders, and the four members of the equity consortium were involved in the signing of the financing contracts. €2.2 billion of the financing was debt equivalent to 70% of the total project cost[56].

FIGURE 13: GEMINI PROJECT'S CAPITAL STRUCTURE

Financing type	Financing volume	Percentage of total investment requirement	Investors
Senior debt	€2,000 million	70%	12 commercial banks, 3 ECAs (Eksport Kredit Fonden, Euler Hermes & Delcredere/Ducroire) & the European Investment Bank
Sponsor equity	€400 million	15%	Northland Power, Siemens Financial Services, Van Oord & HVC Group
Subordinated debt	€200 million	7.5%	Northland Power and Danish pension fund PKA
Pre-completion revenues	€200 million	7.5%	
Total	**€2,800 million**	**100%**	

Other Drivers

Substantial cost levers for cost of electricity can be found in site selection considering wind speed, distance to shore, water depth, ground conditions and project size. These factors do not always move in the same direction. For example, a site further offshore will have higher

[55] Gemini is owned by a consortium consisting of Northland Power (60%), Siemens Financial Services (SFS - 20%), Van Oord Dredging and Marine Contractors BV (Van Oord - 10%) and N.V. HVC (HVC - 10%).
[56] BNEF (2014), Gemini Offshore Wind

O&M costs and CAPEX costs related to the transmission system but these costs should be offset by the higher wind speeds.

Design life assumption is also an important driver for LCOE and this has improved with the market moving towards a 25-year design life up from a previous baseline of 20 years. Siemens' direct drive SWT -6.0- 154 turbine has been certified for a 25 lifetime, which is an additional five years compared with the previous turbine lifetime Siemens has designed towards[57].

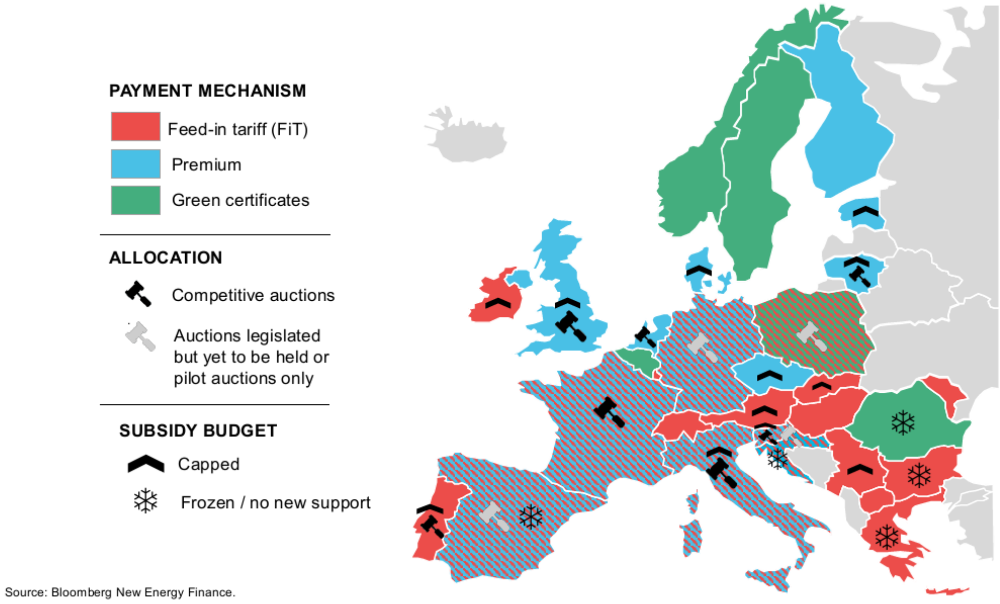
COMPETITIVE AUCTIONS

The major policy trend is the continued move towards competitive tendering of financial support in auctions. This is not specific to offshore wind; most renewables technologies have been subject to the same pressures, driven by governments' targets to reduce support to renewable technologies and to push developers to deliver cost reductions in order to eventually be subsidy free.

The results for cost reductions are promising. For instance, in the UK, East Anglia 1 will deliver 719 MW at £119.89/MWh, while Neart na Gaoithe will deliver at £114.39/MWh[58]. This is a strong result for the first competitive bidding process for the new support regime – Contracts for Difference – delivering 38% reductions when compared to support under the previous support scheme – Renewables Obligations[59]. The results from the Danish auction for Horns Rev 3 also delivered cost savings with a winning bid from Vattenfall at €10.31 kWh, 32% cheaper than the last offshore wind farm constructed in Denmark, Anholt offshore wind farm[60]. The Netherlands is also pushing for lower costs through competitive allocation with maximum prices for the upcoming auction rounds in the Netherlands.

[57] Smith (2014)
[58] DECC (2015)
[59] This is comparing 2 ROCs at £45 fir 20 years to a CfD for 15 years at a strike price of £120/MWh, assuming a wholesale price of £45/MWh, http://offshorewind.works/offshore-wind-vision/
[60] Danish Ministry of Energy, Utilities and Climate (2015)

FIGURE 14: SUPPORT SCHEMES FOR LARGE SCALE RENEWABLE ENERGY PROJECTS IN THE EU



Source: BNEF

The move towards auctions radically changes the development process and risk profile of the individual projects. Developers and suppliers are still coming to terms with this change.

The sector has rapidly cut costs, yet the sector remains an expensive energy generating technology. Further reductions are therefore needed to allow the sector to be viable, independent of government support and in turn secure a sustainable industry. There is huge potential to cut costs further. Yet to do this will need partnership between government and industry, with government setting the right policy environment with long term certainty to allow industry the confidence to invest and innovate further reductions.

3. SOCIO-ECONOMICS

GLOBAL RENEWABLE ENERGY BENEFITS

There is growing evidence that renewable energy can ensure both economic growth and decarbonisation across the globe and the conventional consideration of trade-offs between the two is outdated. IRENA analysis shows that renewables deployment not only contributes to a climate safe future, but also fuels economic growth, creates new jobs, develops new industries and enhances human welfare.

IRENA's report Renewable Energy Benefits: Measuring the Economics provides the first global estimation of the macroeconomic impact of accelerated deployment of renewable energy. It finds that doubling the share of renewables in the global energy mix by 2030 would increase global GDP in 2030 up to 1.1%, or US$1.3 trillion, versus the business-as-usual case. This is equivalent to adding the combined economies of Chile, South Africa and Switzerland today. The increased economic activity is mainly a result of the larger investment in renewable energy deployment, which triggers ripple effects throughout the economy[61]

Renewable energy benefits go beyond the traditional (and limited) measurements of economic performance, improving human welfare in a much broader manner. Welfare improvements would go beyond GDP gains, since doubling the share of renewables by 2030 would increase global welfare by around 3%. The largest contributor to welfare improvement is the reduction of greenhouse gas emissions and associated climate change impacts, followed by improved health and education.

Doubling the share of renewables would also affect international trade, increasing trade in renewables equipment and other investment goods and services such as engineering services, steel or cables. This brings new export opportunities, including for today's fossil fuel exporters.

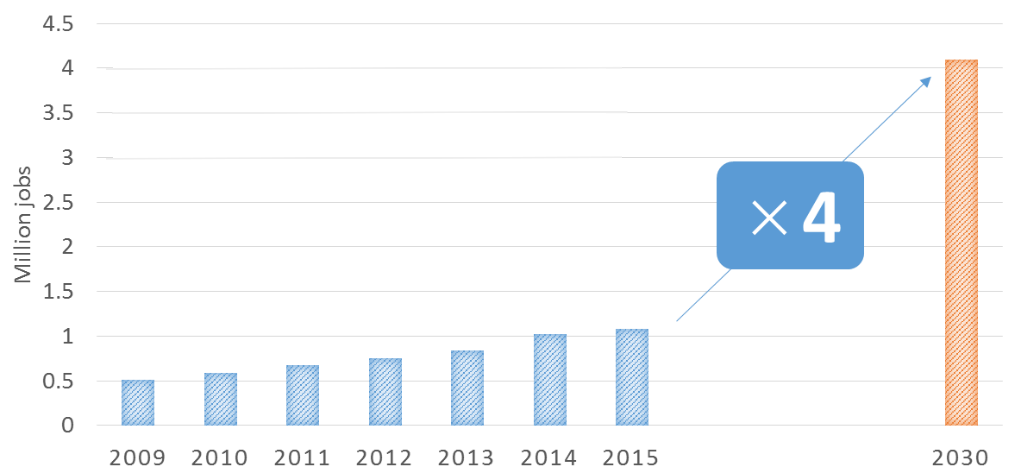
Lastly, IRENA estimates that doubling the share of renewables could increase global employment in the renewable energy sector to beyond 24 million people by 2030, up from the 9.4 million employed today in all technologies including large hydropower.

[61] IRENA (2016a)

JOBS IN THE WIND INDUSTRY

Wind power alone could support more than 4 million jobs in 2030, four times more than the level today. This represents a rapid increase in wind energy employment, which has been growing at a steady pace of 13% over the last five years (Figure 15).

FIGURE 15: TRENDS IN WIND ENERGY EMPLOYMENT



Source: IRENA (2016b)

Currently employment in the sector stands at 1.1 million jobs, more than half of which are concentrated in Asia. In fact, the share of Asia in global wind energy employment has increased from 48% in 2013 to 53% in 2015, primarily due to increased deployment, but also due to a rise in manufacturing. While Asia is the leading the job growth in the technology, the European Union, North America and Latin America have also benefitted from jobs gains (up 4%, 18% and 20% respectively) according to the last available estimates.

China is the leading wind energy employer with more than 0.5 million jobs. Germany and the United States are also top players, followed by Brazil and India.

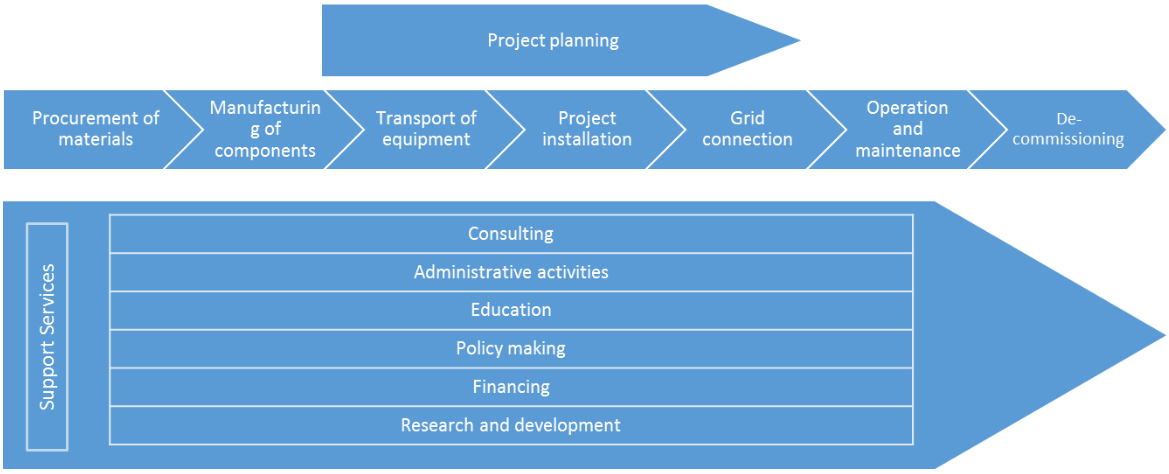
China's position as a leading wind energy employer is rooted in the rise of strong installations and manufacturing companies. Goldwind, for example, now ranks as the world's largest wind energy company in terms of new capacity commissioned. Five out of the top 10 wind companies in terms of new commissioned capacity in 2015 are Chinese[62].

Germany was the leading employer in the European Union with 149,000 jobs in 2014, well ahead of the next 6 largest countries put together[63]. Wind employment in the United States increased by 20% in 2015 to reach 88,000 jobs, as new capacity additions grew by two-thirds over 2014[64]. In Brazil, wind energy auctions and financing rules that encourage local content have resulted in a 14% growth in jobs in 2015 to reach 41,000 wind jobs. Indian wind energy industry currently employs 48,000 people, and can add more than 180,000 jobs by 2022 if the 60 GW wind target is realised.

Creating Local Value

The potential for job creation and income generation in a country deploying wind energy depends on the extent to which the value chain is localised and existing industries are leveraged. Figure 16 illustrates the different segments of the value chain where value-creating activities take place.

FIGURE 16: WIND ENERGY VALUE CHAIN



Source: IRENA (2016c)

Some activities require specific expertise and knowledge in the wind sector that are not necessarily available locally at the initial stages of development of the sector. Initial activities in the project planning phase related to site selection, technical and financial

[62] BNEF (2016)
[63] The next largest wind employers are Denmark, the United Kingdom, Portugal, France, Italy and Spain. The employment data for the European Union is only available until 2014.
[64] AWEA (2016)

feasibility studies and engineering design, for example, require wind sector-specific expertise that might need to be imported. The project development activity in this phase, however, can solely rely on local labour with knowledge of the domestic markets, be it legal, administrative, regulatory, etc.

Table 3 shows the human resources (human-days) needed for planning a 50 MW wind farm, where local knowledge represents a fair share of the total human requirements.

TABLE 3: HUMAN RESOURCES NEEDED FOR PROJECT PLANNING ACTIVITIES (HUMAN-DAYS/50 MW)

Professions needed	Human resources needed for project planning activities (human-days/50 MW)			
	Site selection	Feasibility analyses	Engineering design	Project development
Environmentalists	50	30	-	-
Geotechnical experts	50		-	-
Electrical/civil/mechanical/energy engineers	50	90	150	-
Lawyers, experts in energy regulation, experts in real estate, land property and taxation	140	60	100	720
Financial analysts	-	30	-	700
Safety experts	-	-	50	-
Experts in logistics	-	-	-	360
Total for activities	**290**	**210**	**300**	**1,780**
Total for project planning	**2,580**			

Source: IRENA (2016c)

Other activities are less reliant on wind-specific knowledge, offering large potential for local value creation, such as manufacturing. The cost of a wind turbine constitutes between 65% and 85% of the total cost of the project, offering considerable potential for employment, and most of the jobs created can be fulfilled by the local workforce. Indeed, Table 4 shows that a large share of human resources required are factory workers with little or no wind-specific skills. It should be noted, however, that this phase is very capital-intensive, and its long-term value relies heavily on the existence of a market for the products, and on the implementation of specifications and standards that ensure good quality and timely delivery of products at competitive costs with international markets.

TABLE 4: HUMAN RESOURCES NEEDED FOR MANUFACTURING MAIN COMPONENTS (HUMAN-DAYS/50 MW)

Professions needed	Human resources to manufacture main components (human-days/50 MW)			
	Nacelle	Blades	Tower	Monitor and control system
Management	185	110	90	-
Industrial engineers	480	277	232	15
Factory workers	5,890	3,400	2,850	300
Experts in logistics	620	125	300	15
Experts in quality control	620	125	300	15
Marketing and commercial professionals	480	290	230	45
Administrative and accountant personnel	480	113	230	45
Safety experts	620	125	300	30
Telecommunication engineers	-	-	-	15
Experts in regulation and standardization	-	-	-	15
Total for main components	**9,375**	**4,565**	**4,532**	**495**

Total for manufacturing	**18,967**

Source: IRENA (2016c)

An important factor that would maximise the benefits of manufacturing components locally is the availability of existing industries that produce the raw materials needed. Countries that have a domestic steel industry, for example, can benefit more from producing some of the components locally. Table 5 shows that there are required between 64 and 87 tonnes of steel to manufacture the subcomponents of a nacelle for a 3 MW wind turbine.

TABLE 5: RAW MATERIALS FOR A NACELLE OF A 3 MW TURBINE (TON/TURBINE)

Components	Raw materials to manufacture and assemble a nacelle of a 3 MW turbine (ton/turbine)			
	Steel (grey cast iron)	Aluminium	Copper	Glass Reinforced plastic
Hub	12.8 - 17.3	-	-	-
Gearbox	19.2 - 25.9	0.2 - 0.3	0.2 - 0.3	-
Generator	4.7 - 6.4		2.5 - 3.4	-
Frame, machinery and shell	27.5 - 37.2	2.9 - 4.0	1.3 - 1.8	1.0 - 1.3
Total	**64.2 - 86.8**	**3.1 - 4.3**	**4.0 - 5.5**	**1.0 - 1.3**

Source: IRENA (2016c)

Another factor that facilitates the decision to manufacture wind equipment locally is the logistical requirements associated with importing bulky parts, such as 53 meters long blades, especially when destined to remote areas with abundant wind resources. In some cases, setting up a manufacturing facility close to the location of the wind farm is more economic.

In the absence of manufacturing experience, some components can be transported, but at high cost. The estimated cost of transport of the components of a 50 MW wind farm by truck over a distance of 300 miles can reach up to US$750,000. The human resources needed are summarised in Table 6, with a majority that can be sourced locally. Special equipment is needed for this activity, including high capacity trucks and specific trailers. Trains can be used if the land is flat and if tunnels, bridges and sharp curves can be avoided. Moreover, vessels can be used if the transport is carried out by sea, with cranes needed to lift the equipment in the lorry or the boat.

TABLE 6: HUMAN RESOURCES FOR TRANSPORTING PARTS BY TRUCK (HUMAN-DAYS/50 MW)

Human resources for transport by truck over 300 miles (human-days/50 MW)	
Truck drivers	500
Crane operators	125
Administrative personnel	125
Logistic experts	50
Experts in regulation	50
Technicians to supervise the loading and unloading	25
Total	**875**

Source: IRENA (2016c)

Parallel to the transport of equipment, installation of the project can start. This phase, lasting between 12 to 20 months, offers considerable opportunities for value creation, in particular, in construction and grid connection, where existing resources (equipment, labour, and expertise) can be leveraged. Table 7 shows the considerable number of job opportunities for construction workers and technicians in a 50 MW wind farm for installation and grid-connection.

TABLE 7: HUMAN RESOURCES NEEDED FOR PROJECT INSTALLATION AND GRID CONNECTION ACTIVITIES (HUMAN-DAYS/50 MW)

Professions needed	Human resources needed for project installation and grid connection (human-days/50 MW)				
	Site preparation	Civil works	Assembling equipment	Grid connection	Commissioning
Engineers/construction foremen	320	1,000	600	-	-
Electrical/mechanical engineers	-	-	-	180	200
Construction workers and technicians	1,600	12,000	6,000	6,000	1,000
Logistic experts	120	120	-	-	-
Environmentalists	120	600	-	-	-
Safety experts	120	600	600	100	100
Quality control experts	-	-	-	100	-
Professionals managing cranes, trucks, etc.	-	-	3,000	-	-
Total for each activity	**2,280**	**14,320**	**10,200**	**6,380**	**1,300**
Total	**34,480**				

Source: IRENA (2016c)

O&M of a wind farm ensures more long-term activities (up to 25 years). Modern wind farms are automated and controlled by a supervisory control and data acquisition system (SCADA), and their operation is normally undertaken by remote operators that reset the systems after line or grid outages. As for the maintenance, it involves preventive and corrective maintenance and constitutes almost 50% of the total O&M costs (Table 8). However, the maintenance is usually undertaken by the original turbine manufacturer and/or subcontracted to engineering companies and is not necessarily localised. However, there is a considerable percentage of total O&M cost that is always spent domestically, such as insurance and land rental that can benefit local industries.

TABLE 8: OPERATION AND MAINTENANCE COST BREAKDOWN OF WIND ENERGY PROJECT

Onshore wind energy operation and maintenance cost breakdown		
Cost	**US$/MW**	**%**
Wind turbine maintenance	20,100 - 24,500	47.6% - 49.3%
Electrical installation maintenance	1,100 - 1,300	2.6% - 2.6%
Insurances	7,500 - 9,800	18.9% - 18.4%
Land rental	4,000 - 6,000	11.7%-9.8%
Management and administration	8,100 - 9,900	19.2%-19.9%
Total	**40,800 - 51,500**	**100%**

Source: IRENA (2016c)

Finally, the decommissioning of the wind farm consists of planning the activity, dismantling the farm, recycling and disposing of equipment and clearing the site. These can be localised with little import requirements, as skills and equipment are usually available domestically.

The human resources for the decommissioning of a 50 MW wind farm are summarised in Table 9, with the majority required as technicians and civil works.

TABLE 9: HUMAN RESOURCES NEEDED FOR PROJECT DECOMMISSIONING ACTIVITIES (HUMAN-DAYS/50 MW)

Professions needed	Human resources needed for decommissioning (human-days/50 MW)			
	Planning the activity	Dismantling the project	Disposing of equipment	Clearing the site
Industrial/mechanical/electrical engineers	30	360	-	40

Environmentalists	25	180	40	90
Logistic experts	25	180	20	-
Technicians and civil workers	-	3,700	800	1,000
Lorry drivers and crane operators	-	1,800	-	-
Safety experts	-	-	40	90
Total for main activities	**80**	**6,220**	**900**	**1,220**
Total for decommissioning	**8,420**			

Source: IRENA (2016c)

In order to support local value creation from the deployment of wind project, when feasible, a broad range of cross-cutting policy instruments need to be implemented. Tailored to the specific country conditions and the level of maturity of the sector, the mix of policies should focus on building institutional and human capacity, promoting research and development, strengthening the domestic industry and creating an investment-friendly environment.

4. ENVIRONMENTAL IMPACTS

Wind energy is continually hailed as one of most the environmentally friendly energy resources; particularly that it is a low-carbon source. In addition to this, turbines have no water requirement during operation, and its effective land footprint can be minimised by ‘sharing’ the land with other activities. Wind power does have some substantial environmental impacts, not least determined by the perception within the local population of the severity of the impacts.

LAND USE

The land use requirement for wind energy is dependent on the size of the wind turbines and the terrain of the site used. Installations in hilly terrain may take advantage of the ridgelines for positioning the turbines. Meanwhile, installations on flat terrain are positioned more uniformly, and have a larger footprint. Research by NREL showed the total land footprint for wind farms in the United States averaged at 82 acres (333,000 m^2) per MW[65].

As a general rule, the distance between turbines in the prevailing wind direction should be equivalent to 5-12 times the turbines’ rotor diameter, while the spacing between turbines in a row perpendicular to the wind direction is 3-5 times the rotor diameter[66] (depending on various factors such as the wind direction distribution, ground roughness, vegetation or wind speed). While the spacing requirements of turbines averages for a very large land footprint, only a fraction (3-5%) of the land required is actually disturbed by the wind energy infrastructure (including roads, transmission lines and maintenance equipment); and the remainder of the land could be utilised for agriculture and transport links.

As offshore turbines are not situated on land, there is virtually no direct land footprint from offshore wind energy; however, their presence may have an effect on sea-based activities such as fishing, sea travel, and oil & gas extraction. Over the past years, the European research community has increased its interest on application of offshore aquaculture within offshore wind farms to combine sustainable uses of the ocean space[67].

LIFE-CYCLE EMISSIONS

Wind energy has some of the lowest life-cycle emissions of all the energy resources. Greenhouse gas emissions from wind energy are in the magnitude of 10-20 gCO_2e/kWh, up to 80% less than that from solar photovoltaics. About 86% of total GHG emissions occur

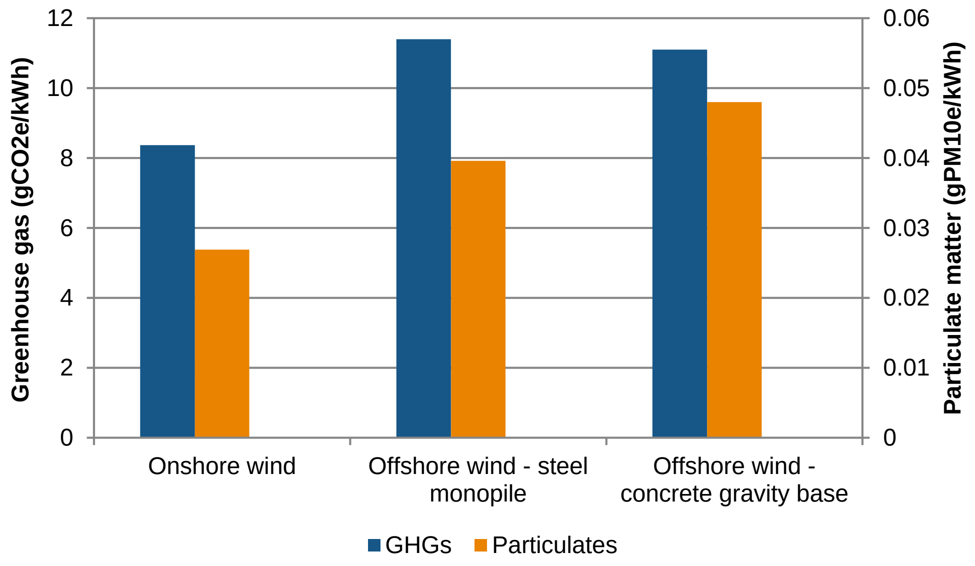
[65] NREL (2012)
[66] Langreder n.d.
[67] Wever, Krause and Buck (2015)

in upstream processes[68], while up to half of emissions for offshore wind come from the extraction of the raw materials required for construction[69].

Operational wind power, however, will have an additional 'carbon cost', associated with the need to balance the grid in the face of wind intermittency. Fossil fuel generation required to back-up wind power operate at lower efficiencies, however the emissions savings obtained from wind power are still significant. For instance, the marginal displacement of wind power in the UK in 2012 was estimated at 550gCO_2/kWh, with 20% higher than the reported average emissions from electricity[70].

Figure 17 shows greenhouse gas, particulate matter and eco-toxicity emissions from wind energy.

FIGURE 17: LIFE-CYCLE EMISSIONS FROM WIND ENERGY, BY TECHNOLOGY



Source: Hertwich *et al.* (2014)

ECOLOGICAL IMPACTS

Concerns remain with the impacts of wind energy development on wildlife, in particular on bird species and bats. Bird and bat populations are directly affected through deaths from colliding with wind turbines. Wildlife may also deliberately avoid areas with turbines due to

[68] NREL (2013)
[69] Weisser, IEA
[70] Thomson and Harrison (2015a)

habitat fragmentation and degradation. Offshore wind farms may have effects on fish and marine life, particularly during the installation phase due to noise impact of piling operations on migratory fish. However, studies have continuously shown that these effects, in relative terms, are minimal; so long concerted efforts are made in the planning phase to ensure wind farms are not installed in areas where there will be a high risk of conflict with wildlife (e.g. bird migration routes).

PUBLIC HEALTH

Concerns with wind turbines on public health are mostly related to the sound and visual impacts of turbines. The sound emitted by turbines is predominantly of two types – aerodynamic noise from the movement of turbine blades through the air, and mechanical noise from the gearbox, generator etc. Newer turbine models generate significantly less mechanical noise. A general acceptable noise threshold for a wind farm is 35-45 db(A)[71], about the same level of a quiet urban dwelling at night.

Visual impacts are more subjective, and depend on the opinion of the viewer. Anti-wind farm campaigners claim that wind turbines and associated infrastructure are an eyesore to the (especially rural) landscape. Shadow flicker is another potential problem with wind turbines, hence lighting conditions at a potential site are also taken into consideration during planning. Turbine towers and their moving blades may also interfere with electromagnetic signals, and may also affect radar systems. In the United States, measures are taken to eliminate any potential impacts from turbines on air travel. As with all structures 200 feet high and above, some turbines within a wind farm must have lighting to alert nearby aircraft.

[71] Stevenson (2009)

5. OUTLOOK

PROSPECTS FOR DEPLOYMENT: GROWTH IN EMERGING AND NEW MARKETS

Market growth in the emerging markets of China, India, South America and Eastern Europe are expected to be maintained in the short-to-medium term. With the possible exception of Northern and Central Europe and Japan, overall onshore wind is expected to be further deployed, supported by continual cost reductions. For example, the highly competitive auction system implemented in Brazil will see installation costs drop sharply, from an average of US$1,840 per kW in 2015 to around US$1,600 by 2017[72].

Offshore wind energy market is expected to continue growing in Europe and Asia, but also opportunities for new markets might emerge. The 30 MW offshore wind project under construction at Block Island, as well as increased activities to secured site control and conduct environmental surveys suggests that the next few years could see an expansion of offshore wind in North America[73].

GLOBAL FUTURE OUTLOOK

IRENA Remap analysis suggests that with current policy plans account for a global wind capacity rise from 435 GW in 2015 to 977 GW in 2030.[74] This includes 905 GW onshore and 72 GW offshore wind capacity. These projections significantly underestimate the wind sector dynamics. Even stabilisation at the annual capacity addition rate of 2015 would yield 1400 GW capacity in 2030. A technical and economic potential exists to accelerate deployment and reach 1879-2318 GW in 2030. This would imply a doubling of onshore wind and a quadrupling of offshore wind growth, compared to the reference case in 2030. It would imply more than a fourfold increase of the installed capacity from 2015 levels. The share of wind power could increase to more than 12% of total global power generation.

SCOPE FOR COST REDUCTION

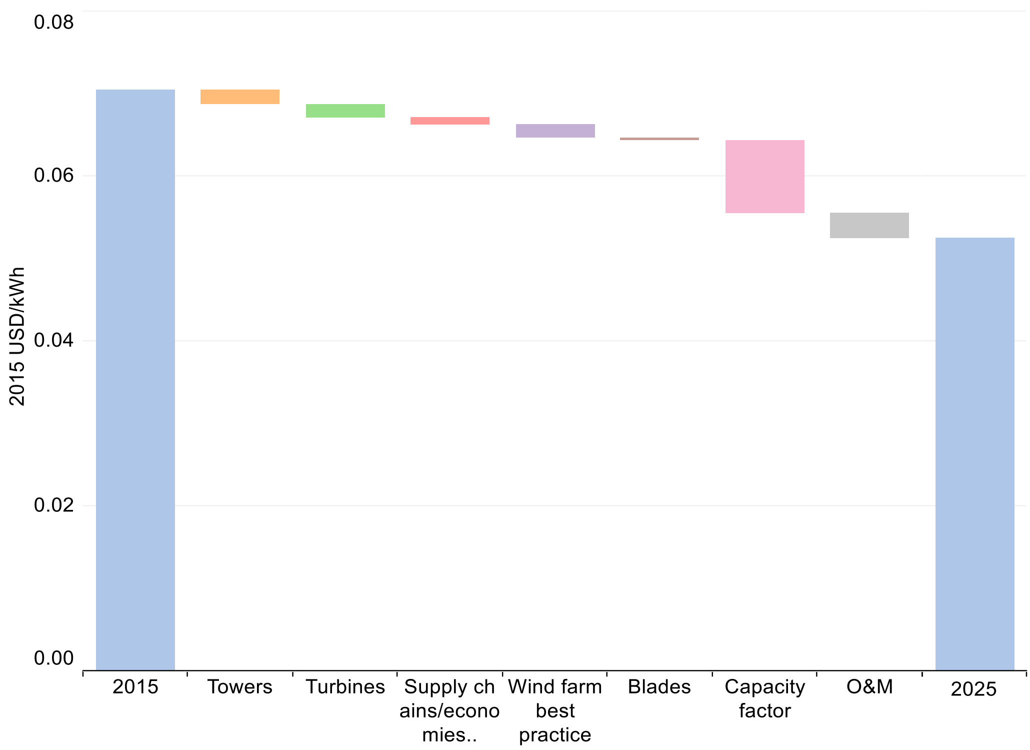
Opportunities for cost reduction remain in the onshore wind sector. A study by KIC InnoEnergy suggests that thorough improvements in technology and operational processes could lower the average LCOE of onshore wind in Europe by 5.5% when comparing costs at final investment decision for 2014 and 2025[75]. As shown in Figure 18, the biggest opportunities for reduction in LCOE come from improvements to the wind turbine rotor. Also, in some instances, improvements actually contribute to increase capital or O&M costs; indeed, CAPEX is predicted to rise by 3% during this period. However, these are

[72] IRENA (2014) Renewable Cost Database
[73] IRENA (forthcoming), Off-shore wind technology: an innovation outlook
[74] IRENA (2016), REmap: A roadmap for a renewable energy future.
[75] KIC InnoEnergy (2014), Future renewable energy costs: Onshore wind

more than offset by increases in energy production – hence reiterating the desire of the industry to lower LCOE despite a possible increase in installation costs.

IRENA estimates that the global LCOE of onshore wind is likely to decrease to 26% in the period to 2025 mainly due to lower installed costs, higher capacity factors and declining O&M costs. Higher hub heights, rotor diameters and turbine rating will account for most of the decline in the LCOE of onshore wind.

FIGURE 18: ONSHORE COST REDUCTION POTENTIAL FROM 2015 TO 2025



Source: IRENA (2016)

TABLE 10: IMPACT OF INNOVATIONS IN ONSHORE WIND SECTOR BETWEEN 2014 AND 2025 ON COSTS FOR A WIND FARM AT A HIGH WIND SITE*

	Innovations	Impact on CAPEX	Impact on OPEX	Impact on AEP**	Impact on LCOE
Wind farm development	• Improvements in resource measurement • Improvements in resource modelling • Improved complex terrain and forest modelling	0%	0%	0.4%	-0.4%
Turbine nacelle	• Improvements in mechanical geared high-speed drivetrains • Introduction of mid-speed drivetrains • Improvements in workshop verification testing • Improvements in AC power take-off system design	-0.4%	-2.8%	0.3%	-1.1%
Turbine rotor	• Optimisation of rotor size with improved materials • Improvements in blade aerodynamics • Improvements in blade design standards and process • Improvements in blade pitch control • Introduction of inflow wind measurement • Introduction of active aero control on blades • Improvements in hub assembly components	3.4%	-0.3%	5.9%	-3.0%
Balance of plant	• Introduction of concrete hybrid towers • Introduction of space frame steel towers	0%	0.2%	0.4%	-0.4%
Construction and commissioning	• Improvement of transport vehicle design for site access • Introduction of multi-part blades	0%	0%	0%	0%

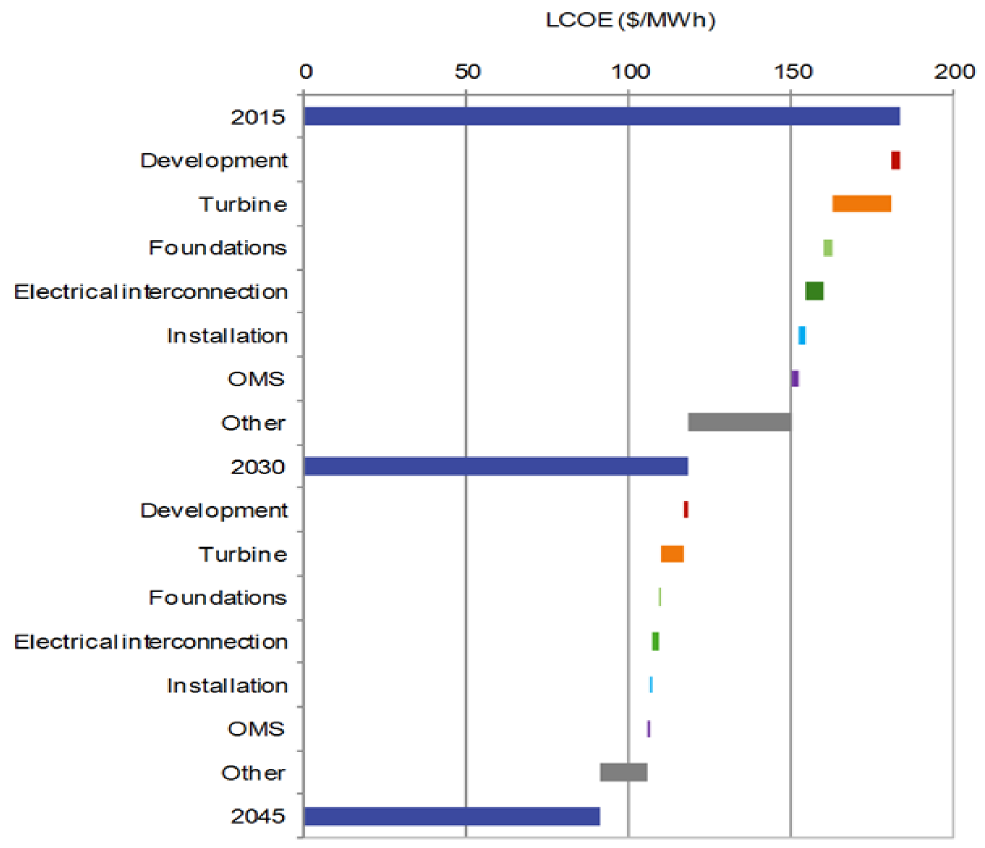
Operation maintenance and service	• Improvements in weather forecasting • Improvements in inventory management • Optimisation of blade inspection and repair • Introduction of turbine condition-based maintenance • Introduction of wind farm wide control strategies • Improvements to wind farm condition monitoring • Introduction of holistic asset management strategies	0.2%	-3.0%	0.5%	-0.9%
Total		**3.2%**	**-5.8%**	**7.5%**	**-5.5%**

**Negative values indicate a reduction in the item and positive values indicate an increase in the item. All OPEX figures are per year, beginning from year six of the wind farm's operation*

***AEP = annual energy production*

Source: KIC InnoEnergy (2015)

FIGURE 19: IMPACT OF INNOVATION IN EACH ELEMENT ON COST OF ENERGY FOR OFFSHORE WIND PROJECTS COMMISSIONED IN 2015 THROUGH 2045



Source: IRENA (forthcoming)

IRENA analysis[76] indicates that together technology innovations, added to a range of other non-technology factors, such as the characteristics of available sites, market scale and competition and, importantly, decreasing financing risk, may result in a decrease in the LCOE for off-shore wind farms up to 121 US$/MWh by 2030 and 91 US$/MWh by 2045. The cumulative impact of innovation in each element of the wind farm is shown in Figure 19.

[76] IRENA (forthcoming), Off-shore wind technology: an innovation outlook.

6. GLOBAL TABLE

TABLE 11: WIND POWER GLOBAL TABLE

Country	Total Wind Installed Capacity (MW) in 2015 IRENA (2016)	Onshore Wind (MW) in 2015 IRENA (2016)	Offshore Wind (MW) in 2015 IRENA (2016)	Wind Energy Consumption In 2015 Gigawatt-hours (GWh)[77] BP (2016)	Total Wind Energy Generation in 2014 (GWh) IRENA (2016)	Share of Wind in Total Installed Capacity in 2015 (%)[79] BP (2016)
Algeria	10	10	-	-	1	-
Argentina	279	279	-	706	619	0.1%
Armenia	4	4	-	-	4	-
Aruba	30	30	-	-	158	-
Australia	4 187	4 187	-	10 692	10 252	1.0%
Austria	2 411	2 411	-	5 119	3 846	0.6%
Azerbaijan	66	66	-	-	2	-
Bahrain	1	1	-	-	1	-
Bangladesh	2	2	-	-	4	-
Belarus	3	3	-	-	11	-
Belgium	2 229	1 517	712	5 564	4 614	0.5%

[77] Data from BP Statistical Review of World Energy (2016)

[79] Ibid

Country	Total Wind Installed Capacity (MW) in 2015 IRENA (2016)	Onshore Wind (MW) in 2015 IRENA (2016)	Offshore Wind (MW) in 2015 IRENA (2016)	Wind Energy Consumption In 2015 Gigawatt-hours (GWh)[77] BP (2016)	Total Wind Energy Generation in 2014 (GWh) IRENA (2016)	Share of Wind in Total Installed Capacity in 2015 (%)[79] BP (2016)
BES Islands	11	11	-	-	41	-
Bolivia	3	3	-	-	8	-
Brazil	8 715	8 715	-	21 737	12 210	2.0%
Bulgaria	700	700	-	1 450	1 331	0.2%
Cabo Verde	24	24	-	-	100	-
Cambodia	1	1	-	-	1	-
Canada	11 200	11 200	-	24 589	22 538	2.6%
Chile	904	904	-	2,125	1 443	
China	145 104	144 086	1 018	185 100	158 271	33.4%
Chinese Taipei	647	647	-	1 525	1 501	0.1%
Colombia	18	18	-	68	70	-
Costa Rica	268	268	-	-	753	0.1%
Croatia	423	423	-	-	730	-
Cuba	12	12	-	-	19	-
Curacao	30	30	-	-	200	-
Cyprus	158	158	-	-	182	-

Country	Total Wind Installed Capacity (MW) in 2015 IRENA (2016)	Onshore Wind (MW) in 2015 IRENA (2016)	Offshore Wind (MW) in 2015 IRENA (2016)	Wind Energy Consumption In 2015 Gigawatt-hours (GWh)[77] BP (2016)	Total Wind Energy Generation in 2014 (GWh) IRENA (2016)	Share of Wind in Total Installed Capacity in 2015 (%)[79] BP (2016)
Czech Republic	281	281	-	572	477	1.3%
Denmark	5 063	3 792	1 271	14 275	14 453	1.1%
Dominica	7	7	-	-	1	-
Dominican Republic	80	80	-	-	247	-
Ecuador	21	21	-	98	80	-
Egypt	610	610	-	1 505	1 332	0.2%
Eritrea	1	1	-	-	2	-
Estonia	341	341	-	-	604	-
Ethiopia	324	324	-	-	526	0.1%
Falklands Malv	2	2	-	-	5	-
Faroe Islands	20	20	-	-	35	-
Fiji	10	10	-	-	4	-
Finland	1 027	1 001	26	2 334	1 107	0.2%
France	10 358	10 358	-	20 166	17 249	2.4%
Germany	44 947	41 652	3 295	87 975	57 357	10.4%

Country	Total Wind Installed Capacity (MW) in 2015 IRENA (2016)	Onshore Wind (MW) in 2015 IRENA (2016)	Offshore Wind (MW) in 2015 IRENA (2016)	Wind Energy Consumption In 2015 Gigawatt-hours (GWh)[77] BP (2016)	Total Wind Energy Generation in 2014 (GWh) IRENA (2016)	Share of Wind in Total Installed Capacity in 2015 (%)[79] BP (2016)
Greece	2 152	2 152	-	4 631	3 689	0.5%
Grenada	1	1	-	4.6	-	-
Guadeloupe	23	23	-	-	54	-
Guatemala	50	50	-	-	-	-
Honduras	176	176	-	-	397	-
Hungary	329	329	-	696	657	0.1%
Iceland	3	3	-	-	8	-
India	25 088	25 088	-	41 404	33 455	5.8%
Indonesia	1	1	-	-	1	-
Iran	117	117	-	245	256	-
Ireland	2 486	2 461	25	6 570	5 140	0.6%
Israel	6	6	-	-	9	-
Italy	9 126	9 126	-	14 675	15 178	2.1%
Jamaica	42	42	-	-	119	-
Japan	3 035	2 985	50	5 398	2 196	0.7%
Jordan	119	119	-	-	2	-
Kazakhstan	68	68	-	-	13	-

Country	Total Wind Installed Capacity (MW) in 2015 IRENA (2016)	Onshore Wind (MW) in 2015 IRENA (2016)	Offshore Wind (MW) in 2015 IRENA (2016)	Wind Energy Consumption In 2015 Gigawatt-hours (GWh)[77] BP (2016)	Total Wind Energy Generation in 2014 (GWh) IRENA (2016)	Share of Wind in Total Installed Capacity in 2015 (%)[79] BP (2016)
Kenya	19	19	-	-	18	-
Korea Republic	869	859	11	1 605	1 077	0.2%
Latvia	69	69	-	-	141	-
Lebanon	1	1	-	-	1	-
Lithuania	424	424	-	808	639	
Luxembour g	58	58	-	-	80	-
Macedonia	37	37	-	-	71	-
Madagasca r	1	1	-	-	-	-
Martinique	1	1	-	-	2	-
Mauritania	35	35	-	-	10	-
Mauritius	1	1	-	-	3	-
Mexico	3 073	3 073	-	7 947	6 426	0.7%
Moldova	1	1	-	-	1	-
Mongolia	51	51	-	-	125	-
Morocco	787	787	-	-	1 924	0.2%

Country	Total Wind Installed Capacity (MW) in 2015 IRENA (2016)	Onshore Wind (MW) in 2015 IRENA (2016)	Offshore Wind (MW) in 2015 IRENA (2016)	Wind Energy Consumption In 2015 Gigawatt-hours (GWh)[77] BP (2016)	Total Wind Energy Generation in 2014 (GWh) IRENA (2016)	Share of Wind in Total Installed Capacity in 2015 (%)[79] BP (2016)
Netherlands	3 431	3 004	427	7 491	5 797	0.8%
New Caledonia	38	38	-	-	57	-
New Zealand	623	623	-	2 357	2 214	0.2%
Nicaragua	186	186	-	-	846	-
Nigeria	2	2	-	-	2	-
Norway	863	861	2	2 515	2 216	0.2%
Pakistan	256	256	-	639	459	0.1%
Panama	270	270	-	-	116	-
Peru	143	143	-	602	258	-
Philippines	387	387	-	641	152	-
Poland	5 100	5 100	-	10 800	7 676	1.2%
Portugal	5 034	5 032	2	11 593	12 111	25%
Puerto Rico	125	125	-	-	218	-
Reunion	15	15	-	-	16	-
Romania	3 244	3 244	-	7 044	6 201	0.7%

Country	Total Wind Installed Capacity (MW) in 2015 IRENA (2016)	Onshore Wind (MW) in 2015 IRENA (2016)	Offshore Wind (MW) in 2015 IRENA (2016)	Wind Energy Consumption In 2015 Gigawatt-hours (GWh)[77] BP (2016)	Total Wind Energy Generation in 2014 (GWh) IRENA (2016)	Share of Wind in Total Installed Capacity in 2015 (%)[79] BP (2016)
Russian Federation	103	103	-	-	5	-
Samoa	1	1	-	-	2	-
Serbia	10	10	-	0.42	-	0.14%
Seychelles	6	6	-	-	7	-
Slovakia	3	3	-	-	6	-
Slovenia	4	4	-	-	4	-
Somalia	2	2	-	-	6	-
South Africa	1 053	1 053	-	2 135	600	0.2%
Sri Lanka	76	76	-	-	147	-
Spain	23 008	23 003	5	49 289	52 013	5.3%
St Kitts Nevis	2	2	-	-	8	-
St Pierre Mq	1	1	-	-	2	-
Sweden	6 025	5 813	212	16 617	11 234	1.4%
Switzerland	60	60	-	101	101	-
Syria	1	1	-	-	1	-

Country	Total Wind Installed Capacity (MW) in 2015 IRENA (2016)	Onshore Wind (MW) in 2015 IRENA (2016)	Offshore Wind (MW) in 2015 IRENA (2016)	Wind Energy Consumption In 2015 Gigawatt-hours (GWh)[77] BP (2016)	Total Wind Energy Generation in 2014 (GWh) IRENA (2016)	Share of Wind in Total Installed Capacity in 2015 (%)[79] BP (2016)
Thailand	223	223	-	427	305	0.1%
Tunisia	245	245	-	-	507	0.1%
Turkey	4 694	4 694	-	11 552	8 520	1.0%
Ukraine	426	426	-	1 025	1 172	
United Arab Emirates	1	1	-	-	1	-
United Kingdom	13 855	8 750	5 105	40 442	32 016	3.3%
United States of America (USA)	72 578	72 578	-	192 855	183 892	17.2%
Uruguay	845	845	-	-	733	-
Vanuatu	3	3	-	-	5	-
Venezuela	50	50	-	-	88	-
Vietnam	135	135	-	204	68	-
World Total	**431 948**	**419 787**	**623**	**841 231**	**713 846**	**100%**

Source: International Renewable Energy Agency IRENA (2016); BP Statistical Review of World Energy 2016 Workbook

Note: Numbers are approximated, with for instance figures between 1 and 1.5 shown as 1, and between 1.5 and 2, shown as 2.

Note: With regards to the Wind Generating Capacity (first column in the table above) the data per country exhibited above from IRENA, 2016 is slightly different than the data presented in BP Statistical Review of World Energy 2016. The former data source refers to the Installed Generating Capacity, while the latter refers to Cummulative Installed Wind Turbine Capacity. In this context, we included only the data from IRENA because it is more detailed in terms of countries reported and onshore/offshore division; in contrast with BP Statistical Review 2016, which was used for completing the last two columns.

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REFERENCES

American Wind Energy Association AWEA (2016) *U.S. Wind Industry Annual Market Report Year Ending 2015*, Washington DC.

American Wind Energy Association AWEA (2016) *U.S. Wind power jobs hit record, up 20 percent in 2016*, April 12, http://www.awea.org/MediaCenter/pressrelease.aspx?ItemNumber=8736

Andrew (2016) 'Capacity factors at Danish offshore wind farms', *Energy Numbers*, May 19, http://energynumbers.info/capacity-factors-at-danish-offshore-wind-farms

Arántegui, R. L. and González, J. S. (2015), *JRC wind status report. Technology, market and economic aspects of wind energy in Europe*, https://setis.ec.europa.eu/system/files/2014JRCwindstatusreport_EN_N.pdf

ASX n.d. *New Zealand electricity*, http://www.asx.com.au/products/energy-derivatives/new-zealand-electricity.htm

Bloomberg New Energy Finance, UNEP (2016) Global trends in renewable energy investments, http://fs-unep-centre.org/sites/default/files/publications/globaltrendsinrenewableenergyinvestment2016lowres_0.pdf

Bloomberg New Energy Finance (2016) *In a first, Chinese firm tops annual rankings of wind turbine makers*, http://about.bnef.com/press-releases/in-a-first-chinese-firm-tops-annual-ranking-of-wind-turbine-makers/content/uploads/sites/4/2016/02/2015-Wind-Market-Share.pdf

Bloomberg New Energy Finance (2015) *Q3 2015 Global Wind Market Outlook*.

Bloomberg New Energy Finance (2015) *Q3/2015 Global Wind Power Market Outlook Update*, MAKE

Bloomberg New Energy Finance BNEF (2015) *How Extending the Investment Tax Credit Would Affect US Solar Build*, 15 September.

Bloomberg New Energy Finance BNEF (2014) *Gemini Offshore Wind*

Broehl, J., R.R. Labastida and Hamilton, B. (2015) *World Wind Energy Market Update 2015*. Navigant Consulting. Boulder, Colorado. http://www.navigantresearch.com/research/world-wind-energy-market-update-2015.

BTM Navigant (2015) *World Wind Energy Market Update 2015*, http://www.provedor.nuca.ie.ufrj.br/estudos/navigant1.pdf

Danish Ministry of Energy, Utilities and Climate (2015) *Denmark gets cheaper power from offshore wind turbines*, February 27, http://www.efkm.dk/en/news/denmark-gets-cheaper-power-from-offshore-wind-turbines

Deloitte for the New Zealand Wind Energy Association (2011) *Economics of wind development in New Zealand*.

Department of Energy & Climate Change DECC (2015) *CFD auction allocation round one – a breakdown of the outcome by technology, year and clearing price*, https://www.gov.uk/government/statistics/cfd-auction-allocation-round-one-a-breakdown-of-the-outcome-by-technology-year-and-clearing-price

Environmental and Energy Study Institute (2016) *Fact Sheet: Offshore Wind - Can the United States Catch up with Europe?*, January 4, http://www.eesi.org/papers/view/factsheet-offshore-wind-2016

EY (2015) *Renewable Energy Country Attractiveness*, Issue 43, http://www.ey.com/Publication/vwLUAssets/Renewable_Energy_Country_Attractiveness_Index_43/$FILE/RECAI%2043_March%202015.pdf

Fillon, L. (2016) ‘El Hierro, the Spanish island vying for 100% clean energy’, in *Phys*, April 20, http://phys.org/news/2016-04-el-hierro-spanish-island-vying.html

Global Wind Energy Council GWEC (2014) *Global Wind Report – Annual market update*, http://www.gwec.net/wp-content/uploads/2015/03/GWEC_Global_Wind_2014_Report_LR.pdf

Gorona del Viento, n.d. http://www.goronadelviento.es/index.php?accion=articulo&IdArticulo=170&IdSeccion=89

International Energy Agency IEA (2013) *Technology Roadmap Wind Energy*, https://www.iea.org/publications/freepublications/publication/Wind_2013_Roadmap.pdf

International Energy Agency Wind IEA (2011) *2011 Annual Report*, http://www.ieawind.org/annual_reports_PDF/2011/2011%20IEA%20Wind%20AR_1_small.pdf

International Energy Agency-Energy Technology Systems Analysis Program and IRENA (2016) *Wind power technology brief E07*. Abu Dhabi.

International Renewable Energy Agency IRENA (2016) *Renewable Energy Capacity Statistics*, http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Capacity_Statistics_2016.pdf

International Renewable Energy Agency IRENA (2016) *Remap: A roadmap for a renewable energy future*. Abu Dhabi.

International Renewable Energy Agency IRENA (2016) *Quality Infrastructure for Renewable Energy Technologies: Small Wind Turbines*, Abu Dhabi.

International Renewable Energy Agency IRENA (2016) *Scaling up Variable Renewable Power: The Role of Grid Codes*. Abu Dhabi.

IRENA (2016a) *Renewable Energy Benefits: Measuring the Economics*, Abu Dhabi.

IRENA (2016b) *Renewable Energy and Jobs: Annual Review 2016*, Abu Dhabi.

IRENA (2016c) *Renewable Energy Benefits: Leveraging Local Industries*, Abu Dhabi.

IRENA (2016) *Renewable energy statistics 2016*.

IRENA (2015) *Renewable power generation costs.*

IRENA (2016) *The Power of Change: Cost reduction potentials for solar and wind power technologies*. Abu Dhabi.

IRENA (forthcoming), *Off-shore wind technology: an innovation outlook*. Abu Dhabi.

IRENA, *Renewable Cost Database*

Kenning, T. (2015) 'Spanish island's run of four hours on 100% renewables 'very significant', says IRENA expert', in *Energy Storage News*, august 26, http://www.energy-storage.news/news/only-renewables-plus-energy-storage-power-spanish-island-for-four-hours

KIC InnoEnergy (2014) *Future renewable energy costs: Onshore wind*

Kirk-Davidoff, D.B. (2012) 'Wind Power Forecasting', *Wind Systems*,

http://windsystemsmag.com/article/detail/355/wind-power-forecasting

Langreder n.d. *Siting of Wind Farms: Basic Aspects*, http://www.wwindea.org/technology/ch02/en/2_4_1.html

Lawrence Berkeley National Laboratory (2015) *2014 Wind technologies Market Report.* CA: LBNL.

Lemming JK, Morthorst PE, Clausen NE, Hjuler Jensen P. (2009) *Contribution to the Chapter on Wind Power in Energy Technology Perspectives 2008*, IEA. Roskilde, Denmark: Risø National Laboratory.

Ministry of Business, Innovation & Employment MBIE n.d. *Electricity demand and generation scenarios*, http://www.mbie.govt.nz/info-services/sectors-industries/energy/energy-data-modelling/modelling/electricity-demand-and-generation-scenarios/

Morris, C. (2015) *German offshore wind progress*, August 17, http://energytransition.de/2015/08/german-offshore-wind-progress/

National Renewable Energy Laboratory NREL (2015) *2014-2015 Offshore Wind Technologies Market Report,* http://www.nrel.gov/docs/fy15osti/64283.pdf

National Renewable Energy Laboratory NREL (2013) *Wind LCA Harmonization*, http://www.nrel.gov/docs/fy13osti/57131.pdf

National Renewable Energy Laboratory NREL (2012) *Renewable electricity futures study*

New Zealand Wind Energy Association n.d. *A kiwi success story*, http://www.windenergy.org.nz

Rapin, M. and Noël, J. M. (2010) *Energie Eolienne, Principe et Etudes de cas*. Dunod, Paris

REE, Red Electrica de España (2016) https://demanda.ree.es/visionaCan/VisionaHierro.html#app=2547&9127-selectedIndex=0

Renewable UK, n.d. *UKWED Figures explained*, http://www.renewableuk.com/en/renewable-energy/wind-energy/uk-wind-energy-database/figures-explained.cfm

Smith, P. (2014) *Question of the week: Are offshore projects built to last?*, November 3, http://www.windpowermonthly.com/article/1320109/question-week-offshore-projects-built-last

Stevenson, R. (2009) *Environmental Impact Assessment for Wind Farms*

Thomson, R. C. and Harrison, G. P. (2015a) *Life cycle costs and carbon emissions of offshore wind power: Main report*. Edinburgh, Scotland: ClimateXChange.

WAsP n. d. *Toolbox for wind and site data analysis*, http://www.wasp.dk/DataandTools#wind-atlas__global-wind-atlas

Wever, L., Krause, G. and Buck, B. H., (2015) 'Lessons from stakeholder dialogues on marine aquaculture in offshore wind farms: Perceived potentials, constraints and research gaps', *Marine Policy*, 51, pp. 251–259

Wind Energy (2010) *The facts*, http://www.wind-energy-the-facts.org/

Windpower Monthly, *Optimising wind farms in cold climates,* http://www.windpowermonthly.com/

Wiser, R. and Bolinger, M. (2015) *2014 Wind Technologies Market Report*, U.S. Department of Energy, http://energy.gov/sites/prod/files/2015/08/f25/2014-Wind-Technologies-Market-Report-8.7.pdf

Weisser, International Energy Agencvy n.d. *A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies*, https://www.iaea.org/OurWork/ST/NE/Pess/assets/GHG_manuscript_pre-print_versionDanielWeisser.pdf

Wiser, R. and Bolinger, M. (2014) *2013 Wind Technologies Market Report*, U.S. Department of Energy, https://emp.lbl.gov/sites/all/files/2013_Wind_Technologies_Market_Report_Final3.pdf

World Wind Energy Association (2016) *The World sets New Wind Installations Record: 63,7 GW New Capacity in 2015*, http://www.wwindea.org/

World Wind Energy Association WWEA (2015) *Small wind world report, 2015 summary*. Bonn.

4C Offshore (2016) *Offshore Wind Farm Subscription, Market Overview Report Sample*. Available at: http://www.4coffshore.com/windfarms/downloads/samples/20160404_OverviewReportSample.pdf

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