Article 4: Current Deployment, Markets, and Incentives

Wind power has expanded across the world to the point where it is a significant source of electricity in many regions. This article looks at the growth that has occurred, considering both installed capacity and actual generation, globally and for the top countries. The geographic distribution of projects within the United States is also described. We conclude with discussions of specific projects.

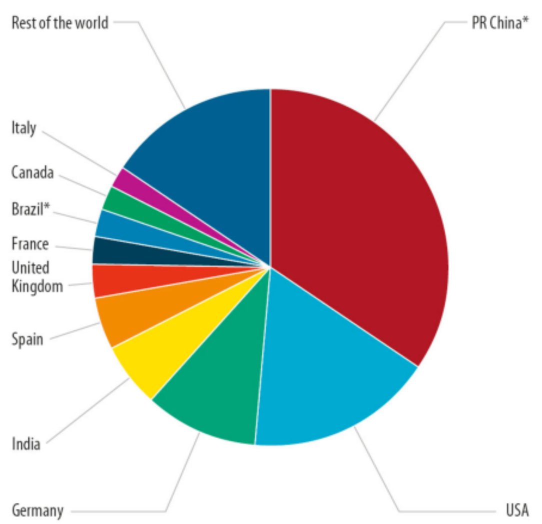
4.1 Wind Capacity and Generation

Wind Capacity, Globally and for the Leading Countries

At the end of 2017, the total global installed wind capacity was 540,000 megawatts. Its distribution across countries is seen in Figure 4.1, left panel. Additions to global capacity during 2017 are seen in Figure 4.1, right panel. Also shown are the percentages for the top ten countries ranked by total installed wind capacity.

The two pie charts in Figure 4.1 look similar. China accounts for about a third of both total and new global capacity. The U.S. and Germany are in second and third place in both cases. Spain, Canada, and Italy are

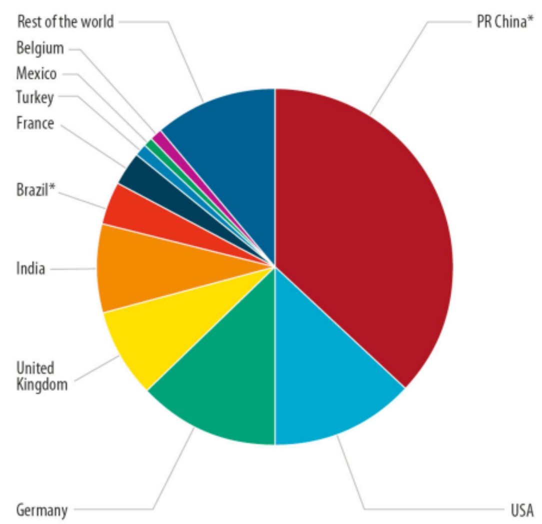
TOP 10 CUMULATIVE CAPACITY DEC 2017



Country	MW	% Share
PR China*	188,232	35
USA	89,077	17
Germany	56,132	10
India	32,848	6
Spain	23,170	4
United Kingdom	18,872	3
France	13,759	3
Brazil*	12,763	2
Canada	12,239	2
Italy	9,479	2
Rest of the world	83,008	15
Total TOP 10	**456,572**	**85**
World Total	**539,581**	**100**

Source: GWEC

TOP 10 NEW INSTALLED CAPACITY JAN-DEC 2017



Country	MW	% Share
PR China*	19,500	37
USA	7,017	13
Germany	6,581	13
United Kingdom	4,270	8
India	4,148	8
Brazil*	2,022	4
France	1,694	3
Turkey	766	1
Mexico	478	1
Belgium	467	1
Rest of the world	5,630	11
Total TOP 10	**46,943**	**89**
World Total	**52,573**	**100**

Source: GWEC

Figure 4.1: ***Left:*** **Total installed wind capacity in 2017, globally and for the ten leading countries.** ***Right:*** **New installed wind capacity in 2017, globally and for the ten leading countries. "MW" is megawatts. Source: Global Wind Energy Council, http://gwec.net/global-figures/graphs/.**

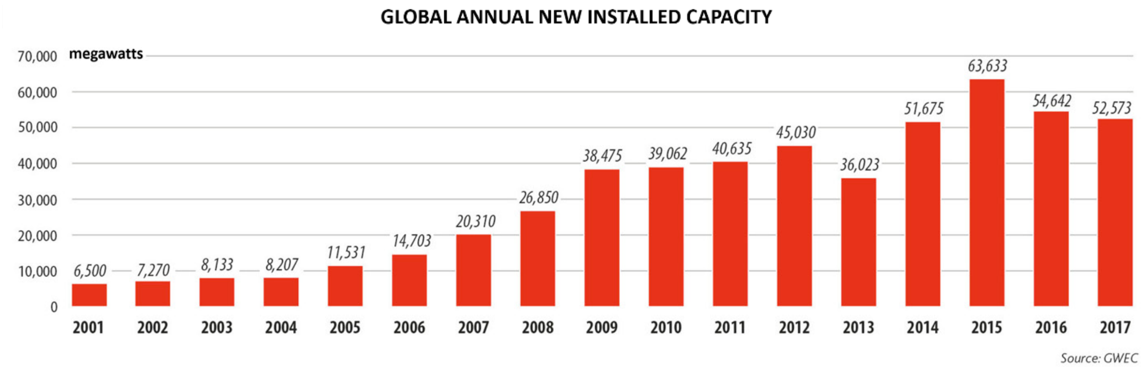


Figure 4.2: Annual additions to global installed wind power capacity, 2001-2017. By the end of 2017, the global total reached 540,000 megawatts. One megawatt is one thousand kilowatts. Source (redrawn): Global Wind Energy Council, http://gwec.net/global-figures/graphs/.

missing from the top ten in new capacity, even though they are present in the top ten for total capacity. Turkey, Mexico, and Belgium have taken their place in the rankings for new capacity.

These data are from the annual report of the Global Wind Energy Council. The same source reports that cumulatively 340,000 wind turbines were deployed as of 2016, when global installed capacity was 490,000 megawatts, from which it follows that the average capacity of these wind turbines was one and a half megawatts.[1]

Figure 4.2 shows annual incremental additions to global capacity over the preceding 17 years. Since 2009, growth has been roughly linear, rather than exponential, inasmuch as the nine additions to global installed capacity each year from 2009 to 2017, although trending upward, have all been within 30 percent of 50,000 megawatts.

An important distinction exists between onshore and offshore wind installations. As of 2017, of the 540,000 megawatts of global installed wind power, only 19,000 megawatts (3.5 percent) were installed offshore. Almost two-thirds of offshore capacity was in the United Kingdom and Germany, with China in third place. Offshore wind's share is growing: it accounted for eight percent of new wind capacity installed in 2017 (4,300 out of 53,000 megawatts).

The waters off the East Coast of the U.S. are favorable to wind power because of steady winds, ocean depths that increase slowly with distance from shore, and close proximity to large electric loads in coastal cities. Only one U.S. offshore wind farm now operates, near Block Island, Rhode Island, with five six-megawatt turbines. However, a burst of new construction may lie immediately ahead in the northeastern U.S., as the wind industry responds to lower costs in combination with mandates from several states for specific amounts of offshore wind by specific dates. With such mandates, these states are competing for new, large wind farms off their coasts.

Wind Electricity Production, Globally and for the Leading Countries

The wind industry's primary sources provide data for installed capacity but do not estimate actual electricity production. However, the U.S. Department of Energy's Energy Information Agency, in its International Energy Outlook 2017, has such estimates for wind electricity production in 2015 for the world and for specific countries. Total global wind electricity production was 890 billion kilowatt-hours in 2015. China and the U.S. produced essentially the same amount of wind electricity that year, 240 billion kilowatt-hours each – or just over a quarter of the world's wind electricity in each country. Figure 4.3, from the Energy Information Agency, shows how global wind power production evolved from 1992 to 2015. It also disaggregates global production to show China, the U.S., and Germany separately. Offshore wind is also growing, from 2.6 percent of overall wind generation in 2011 to 4.4 percent in 2015.

The world is now producing about five percent of its electricity from wind. For Denmark, famously, wind accounts for 48 percent of its overall in-country electricity generation.[2] The corresponding values for Germany, the U.S., and China recently are 12 percent, 4 percent, and 3 percent, respectively.

[1]These must be only the large wind turbines. Another source (https://www.worldenergy.org/data/resources/resource/wind/) reports that there were 800,000 "small" turbines installed as of 2015, and that their combined capacity was less than 1,000 megawatts (only two tenths of a percent of total installed capacity). The average capacity of these small turbines, therefore, was roughly one kilowatt, more than one thousand times smaller than the average "large" turbine. Small wind turbines evidently play a negligible role in grid-scale electricity.

[2]In 2015, Denmark had net imports of 17.5 percent of its electricity supply, since it trades on the Nordpool market with countries like Germany, Norway, and Sweden [1]. In terms of consumption, wind met 42 percent of electricity demand.

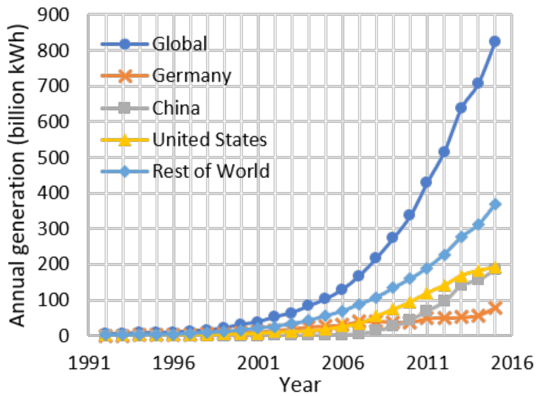


Figure 4.3: Annual global wind energy generation, and a disaggregation into four regions, 1992-2015. Data source: U.S. Energy Information Administration, https://www.eia.gov/beta/international/data/browser/.

As for wind generation per capita, the leading countries are all European: Denmark, Sweden, Ireland, Portugal, Spain, and then Germany. The U.S. ranks ninth and China twentieth.

We can combine the insights in Figures 4.1 and 4.3 using the concept of the capacity factor, which is a measure of onsite turbine performance. The capacity factor is the energy actually produced over a period of time divided by energy that would have been produced during that time if the turbine had produced electricity at its rated capacity.[3] The average capacity factor for the world's wind turbines was 22 percent in 2015. Because China produced roughly the same amount of electricity as the U.S., but from approximately twice as much installed capacity, the capacity factor for China's wind turbines was only half that for the U.S.: roughly 15 percent for China and 32 percent for the U.S. in 2015. The capacity factor for Chinese wind power is increasing as China better utilizes its generation capacity [2]. In fact, preliminary data shows the capacity factor has jumped above 21 percent in 2017.

Capacity factors are high where winds are steady, and turbines are sized to match the wind. Because offshore winds are generally steadier than onshore winds, offshore sites usually have higher capacity factors than onshore sites. As an example of how high a capacity factor can be with steady winds and good grid integration, the twelve offshore wind farms operating in Denmark in 2017 had an average capacity factor of 46 percent [3]. Winds are also less uneven further above the surface, so taller turbines lead to higher capacity factors as well.

Deployment by U.S. State

Figure 4.4 shows a breakdown of the installed wind capacity in the U.S. by state in 2016. Texas was responsible for nearly one quarter of installed capacity, followed by Iowa, Oklahoma, California, and Kansas. Not shown in Figure 4.4, leading in the percentage of in-state electricity generation coming from wind were Iowa, South Dakota, Kansas, and Oklahoma, all of which produced more than 25 percent from wind power. Texas ranked 11th, with 13 percent of its electricity generation coming from wind.

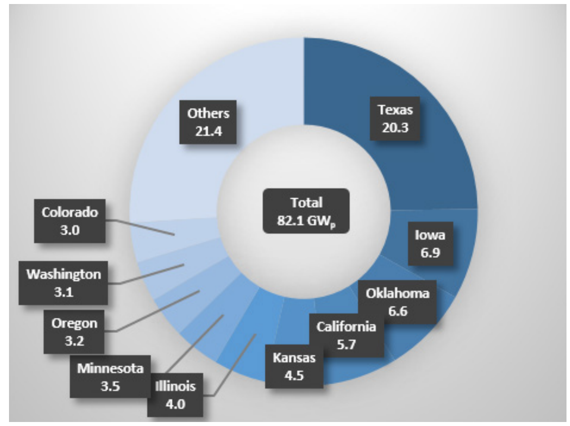


Figure 4.4: Cumulative installed wind capacity at the end of 2016 by U.S. state, in gigawatts of peak capacity (GWp). 1 gigawatt = 1,000 megawatts = 1,000,000 kilowatts. Data source: Department of Energy [4].

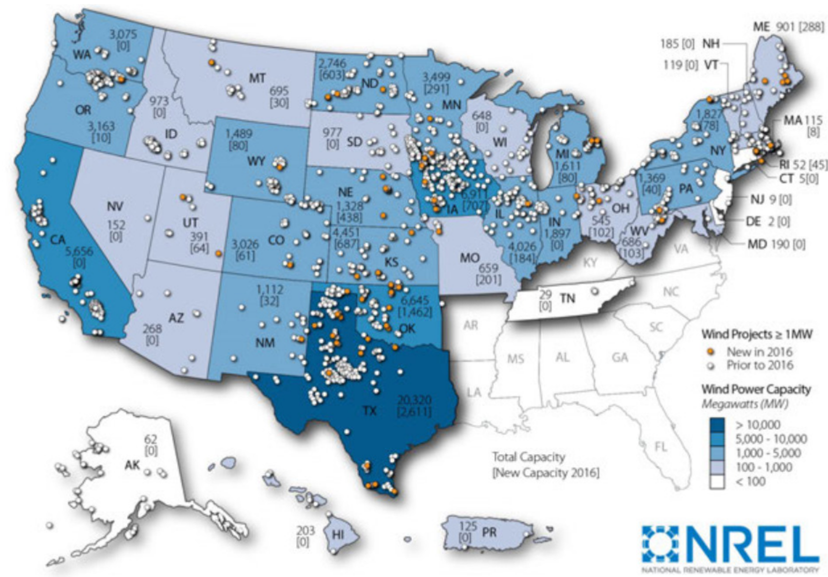
Figure 4.5 shows the geographical distribution of all U.S. wind projects larger than one megawatt operating by the end of 2016, and it specifically identifies those projects added in 2016. Comparing Figure 4.5 to the U.S. wind map in Figure 3.2 reveals, not surprisingly, that wind farms are concentrated where the wind resource is most abundant. The concentration of projects in western Texas, western Oklahoma, and Iowa is evident, as well as the absence of wind projects in the southeastern states. In 2015, there were almost 700 working wind farms in the U.S., with a combined capacity of 62,000 megawatts, making the average capacity of a U.S. wind farm 90 megawatts. The average capacity of the farms that were added in 2015 was 150 megawatts, an indication that farms are getting larger. As a historical footnote, in 1975 there was only one wind farm in the U.S., located in southern California.

4.2 Wind Energy Projects

When wind turbines are deployed whose rated capacity exceeds one megawatt, they rarely stand alone. Rather, many turbines are clustered, forming a wind farm.

A typical wind farm is planned, financed, and permitted as a single entity, and generally it hosts a single type of turbine. But some farms have a more complex history: the San Gorgonio Pass farm in California, for example,

[3] A turbine's rated capacity and its rated speed are design features that do not depend on where the turbine is sited. The rated speed is the speed above which the turbine is designed to produce roughly constant power, and the rated capacity is the power production at the rated speed. The rated speed and rated capacity are chosen by the wind power developer to maximize economic performance at a site.



Note: Numbers within states represent cumulative installed wind capacity and, in brackets, annual additions in 2016.

Figure 4.5: Wind farms in the U.S., including those built in 2016 (orange) and before 2016 (white). The individual states are colored by their total wind capacity. Source: Department of Energy [4].

had a total capacity of almost 200 megawatts in 1985, spread over almost 3,000 turbines built by multiple developers [5]. Turbines at that time had an average capacity of only 60 kilowatts. By 2008, development had continued and the farm collectively evolved to a capacity of 615 megawatts from 40 individual projects, still with only around 3,000 turbines [6]. While wind farms today are usually independent entities, the Gansu Wind Farm "megaproject" in Gansu Province, China, partially completed, is a concentration of wind farms that is intended to reach a total rated capacity of nearly 20,000 megawatts.

Trends in Deployed Turbines

Figure 4.6 shows trends in three key turbine parameters for new turbines installed in the U.S. from 1998 to 2016: rated capacity, height of the tower (approximately, "hub height"), and rotor diameter (approximately, twice the blade length). Nearly all rotor diameters in 2016 were between 100 and 120 meters in diameter, while in 2009 none exceeded 100 meters. Meanwhile, the height of the tower has hardly grown since 2006, when on average it was 80 meters. Having a longer blade on a similar tower contributes to the falling cost of wind power, inasmuch as the tower is expensive and a larger blade enables greater harvesting of the energy in the oncoming wind.

The data underlying Figure 4.6 also show that, since 2009, new turbines smaller than one and a half megawatts have been rare and the majority of turbines in 2016 had a capacity between two and three megawatts. These trends in rated capacity are generally comparable to those in other countries.[4] The average rated capacity in the EU in 2016 was 2.64 megawatts, compared to 2.15 megawatts in the U.S. Unlike the U.S., Europe has a strong presence in offshore wind: in 2016, the average new European offshore turbine had a capacity of 4.8 megawatts, a rotor diameter of 128 meters, and a height of 93 meters.[5]

Investment Costs

The capital cost of a large wind project is dominated by the wind turbines themselves. Currently, GE Energy (U.S.), Vestas (Denmark), and Siemens (Germany) have supplied 88 percent of U.S. installations [7]. Globally, the same three companies are the three leading manufacturers of turbines, when accounting for the recent merger of Siemens and Gamesa (Spain). Goldwind (China) and Enercon (Germany) are also major players [8].

Figure 4.7 shows trends in turbine price per unit of capacity, 1997-2017, as analyzed by the National Renewable Energy Laboratory (NREL). From 1997-2017, there was a significant variation in the turbine cost, but not an overall trend. The price increase from 2001 to 2008, NREL found, was associated with a weak U.S. dollar relative to foreign currencies and increases in material costs, particularly for steel. Moreover, labor

[4]For data on wind power in European countries, see https://community.ieawind.org/task26/dataviewer.

[5]See http://windmonitor.iee.fraunhofer.de/windmonitor_en/4_Offshore/2_technik/3_Anlagengroesse/ and https://windeurope.org/about-wind/statistics/offshore/european-offshore-wind-industry-key-trends-statistics-2017/.

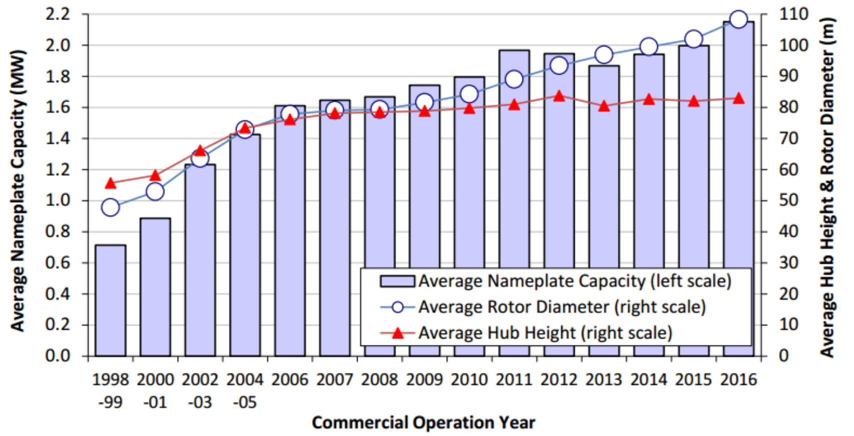


Figure 4.6: U.S. turbine capacity (blue bars), hub height (red triangles), and rotor diameter (white circles) by year installed. The "nameplate capacity" is the rated capacity; the rotor diameter is roughly twice the blade length, and the hub height is almost as large as the tower height. Source: Department of Energy [4].

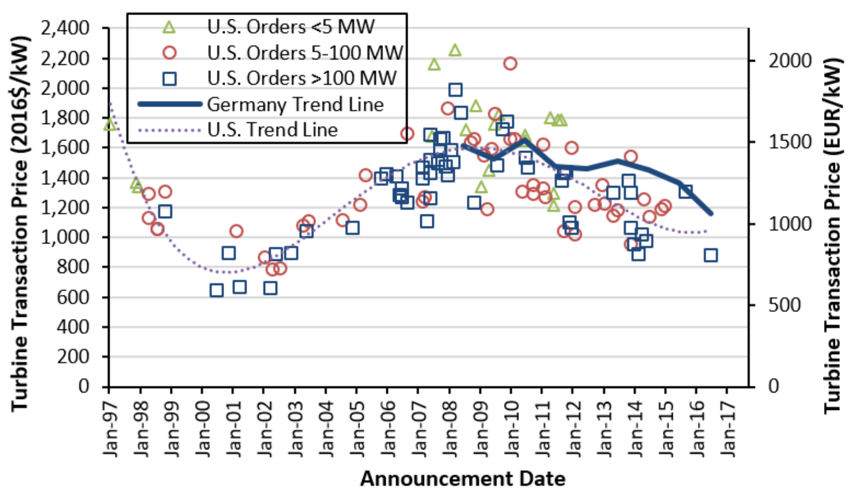


Figure 4.7: Wind turbine cost trends from 1997 to 2017, showing a rapid decrease in the late 1990s, increase until about 2009, and a decrease continuing until present. U.S. orders are broken into three size groups and also compared to trends for prices in Germany. "kW" is kilowatts. Source: Department of Energy (2017) [4] (modified for clarity) and International Energy Agency Wind, https://community.ieawind.org/task26/dataviewer.

costs, warranty costs, and profit margins rose over that period. From 2008 to 2015, the trends in foreign exchange rates and material costs reversed, driving overall prices back down. Figure 4.7 also shows that U.S. turbine prices were lower when purchases are bundled for larger wind farms, and that overall U.S. prices have been similar to other countries, such as Germany.

Figure 4.8 disaggregates the capital costs associated with the construction of typical onshore and offshore wind farms, considering all capital costs (more inclusive than just considering turbine costs as was presented in Figure 4.7). A reference 2.0 megawatt onshore turbine and a 4.1 megawatt offshore turbine are analyzed. For such an onshore project, the turbine cost accounts for 71 percent of total cost. The balance of system accounts for 20 percent, defined here to include all physical equipment on the farm other than the turbines, including electrical connections and turbine foundations, as well as construction and development costs. Financial expenses make up the remaining nine percent; these include "contingency," which allows for unexpected constructions costs.

For offshore wind projects, the total cost per kilowatt of capacity is much higher: $4,600 dollars per kilowatt, compared to $1,700 per kilowatt for onshore. The turbine cost (32 percent of the total capital cost) is less than the cost of the balance of system (47 percent). Siting fees, tower foundations, and assembly fees are all more costly offshore.

Since wind power costs are dominated by capital costs, the cost of capital is a critical variable, affected by access to credit, interest rates, and foreign exchange rates. In turn, access to capital is affected by funders' judgments about market structure, competitors, and risks. The financial viability of a wind power project improves when the turbine achieves a higher capacity factor, meaning that the same turbine now produces more kilowatt-hours of electricity over the same time period. To be sure, there are costs other than costs at the front end of the project: there are operating costs, such as the costs of maintaining and repairing the turbines, which, in turn, are related to turbine lifespan. And there are incentives and disincentives throughout the system resulting from government policies.

4.3 Some Features of the Wind Power Market

Producers of wind power sell their output through either "merchant" contracts or "power purchase agreements." These two arrangements differ in who bears the risks

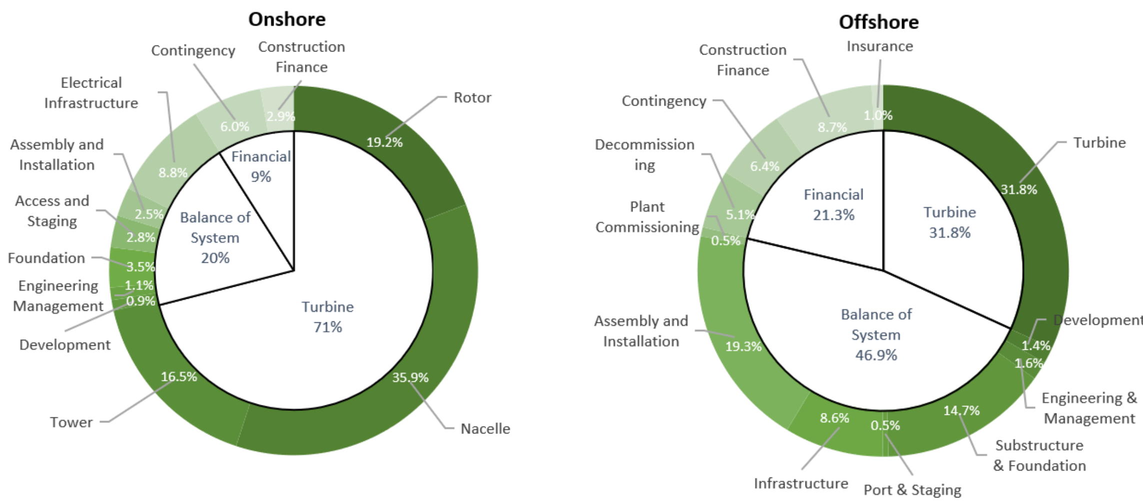


Figure 4.8: Breakdown of capital costs for typical onshore *(left)* and fixed-platform offshore *(right)* wind farms in the U.S. in 2015. Source: Mone et al. [7] (remade for clarity).

associated with uncertain future prices. Merchant wind power operators bear the risks themselves: they sell power on the real-time spot market or make only short-term contracts. Wind developers who have entered into a power purchase agreement have off-loaded the price risk to a buyer who agrees to pay a fixed price for a fixed number of years; the certainty of future revenue is often the key to securing project financing.

For wind farms the payout time for power purchase agreements is often 20 years (the nominal lifetime of a wind farm), but it ranges from less than 10 to as long as 30 years. The buyer is either a utility or (where an electricity market is deregulated) another credit-worthy customer, such as a large company that wants to increase its renewable energy consumption. Google and Amazon, among many others, have used this mechanism to acquire wind power in the last several years to reduce the carbon dioxide emissions associated with their operations [9].

The most important effect of wind power on electricity markets is to lower prices, at least where electricity markets have marginal-cost pricing (where the price at a given time is the cost of producing the last required kilowatt-hour at that time). When wind power is available, it is usually less expensive than the two energy sources that currently dominate most electricity markets — coal and natural gas. The extra cost of running a wind turbine on a given hour, versus not running it, is considerably less than the extra cost of running a plant burning coal or natural gas. The fossil fuel plant needs to pay for the cost of the extra fuel it burns, but a wind farm needs only to pay the salaries of the plant's operators and the costs associated with a slight shortening of the lifetime of its turbines by this extra use. As a result, when electricity demand exceeds wind supply, all the wind power available is usually sold. Less coal and gas power is sold as they become less profitable, and what is sold gets a lower price.

As wind power drives down the price of electricity, it necessarily affects the profitability of wind power itself. Figure 4.9 illustrates this phenomenon by showing how the electricity price is suppressed when renewable energy is abundant. Using weekly data for the German electricity grid in 2013, the grid's electricity price is plotted against the fraction of total grid electricity provided by wind and solar power. The average price during weeks when solar and wind power accounted for 15 percent of total electricity was one-third less than when they accounted for only 5 percent. Several proposals are being considered to address this form of self-limiting economics [10].

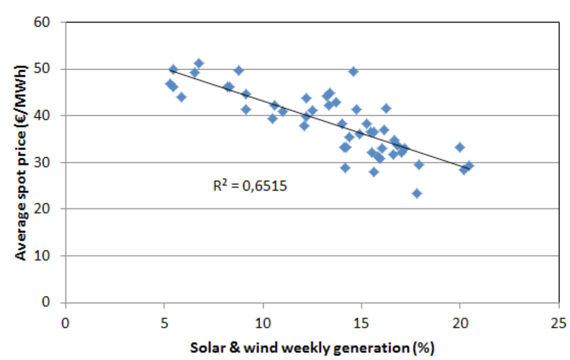


Figure 4.9: The relationship between weekly electricity prices in Germany in 2013 and the percent of that week's total electricity production provided by solar and wind power. On the vertical scale, the € is a euro, slightly more than a U.S. dollar. Source: The Energy Collective, http://www.theenergycollective.com/schalk-cloete/324836/effect-intermittent-renewables-electricity-prices-germany.

4.4 Policy Incentives for Wind Power

Federal Incentives in the U.S.

Incentives at all levels of government promote every type of energy generation. Each incentive lowers the costs of one source of supply relative to those sources with which it competes. In the case of wind, government policy has been crucial in creating a self-sufficient industry capable of competitive power generation.

The most widely used incentive for utility-scale wind projects in the U.S. has been the federal government's Production Tax Credit. The Production Tax Credit gives owners of wind farms a tax credit for every kilowatt-hour of electricity that the farm generates, for the first ten years of a farm's operation. In 2016 the Production Tax Credit was 2.4 cents per kilowatt-hour, but it is being phased out. It was reduced by 20 percent and 40 percent for projects that began in 2017 and 2018, respectively (and then corrected for inflation). The tax credit is scheduled to drop by 60 percent in 2019 and to disappear entirely beginning in 2020 [11].

The rules for the Production Tax Credit include a provision that encourages existing wind farms to repower. If at least 80 percent of the farm's capital cost is replaced with new equipment, then the farm can be eligible for another 10 years of benefits [12]. This can take the form of replacing older turbines with more modern equipment, while re-using existing sites and towers. The rules also contain a safe harbor clause, which assures that projects are considered "in construction" as soon as five percent of the replacement cost has been spent. Aware that the value of the Production Tax Credit would fall in 2017, several wind farm owners invested the necessary five percent by the end of 2016 to get the full 2016 credit; they now have the option to invest in the replacement, as long as they complete the replacement by 2020.

Two other federal incentives currently foster renewable energy in the U.S.: favorable depreciation deductions and the Investment Tax Credit. The federal government's tax depreciation rules for wind projects allow wind energy assets to be depreciated over five years, a much shorter period than the full project lifetime. Wind has also been eligible for special bonus depreciation, writing off 50 percent of the asset value within one year of project completion. The benefit from the Production Tax Credit and from accelerated depreciation rules can be significant, provided that there is a partner involved with sufficient tax liability [13, 14].

The Investment Tax Credit has not proved important to the wind industry. The Investment Tax Credit allows developers to deduct a portion of the cost of their investment from their tax liability, but it has been used mostly for small wind projects (projects with a total capacity of less than 100 kilowatts). It cannot be claimed if the Production Tax Credit is claimed, and the Production Tax Credit is usually more advantageous for a large wind project. As a general rule the Production Tax Credit is used for wind projects and the Investment Tax Credit for solar projects.

State Incentives in the U. S.

The principal state-level incentive for wind power in the U.S. is the Renewable Portfolio Standard, which mandates that retail electricity providers include a specified minimum fraction of their total electricity from renewable electricity; otherwise, they face penalties. More than half of the U.S. states currently have such targets [15]. In New Jersey, for example, each provider of electricity is required to supply 24.5 percent of its electricity from renewable sources in 2020. This requirement is implemented flexibly, through a market in Renewable Energy Certificates. Massachusetts has announced that it intends to procure up to 1,600 megawatts of offshore wind by 2027, and several other northeastern U.S. states are making similar decisions. Some states have already established a competitive bidding process, where the state will choose those developers offering to provide the requisite wind power at the lowest cost.

National Incentives Outside the U.S.

Many countries in the European Union, as well as China, promote wind power using an incentive called the feed-in tariff [16, 17, 18], where the government pays the producer of wind energy a specified amount for each kilowatt-hour of electricity produced. The feed-in tariff is similar to the Production Tax Credit in the U.S., but one important difference is that the ratepayers (electricity customers) pay the feed-in-tariff, while the taxpayer pays the Production Tax Credit.

Sometimes, the price of the feed-in tariff is established by a reverse auction in which governments award a project to the developer willing to accept the lowest payment. In Denmark, the Horns Rev 3 Project was won in 2016 by a developer who accepted a payment of approximately 11 U.S. cents per kilowatt-hour. This price was 32 percent lower than the previous auction's price for production from an offshore wind farm – but far higher than the prices in new contracts for wind power in the U.S. (as low as 3 cents per kilowatt hour).

Governments incentivize wind power indirectly when they create a price on carbon dioxide emissions to the atmosphere that applies to electricity production – either a tax or a cap-and-trade market. The objective of carbon pricing is to reduce the rate of onset of climate change and its associated societal costs. The incentive for wind power is relative to power from fossil fuels, because fossil fuels emit carbon dioxide when they are burned, but wind power has almost no associated emissions. The incentive has little effect on the competitiveness of wind power relative to solar power, hydropower, or nuclear power, because they all have similarly low carbon dioxide emissions.

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