

Wind Turbine Technology

Lecture 3



22

Wind Turbine Characteristics

Example

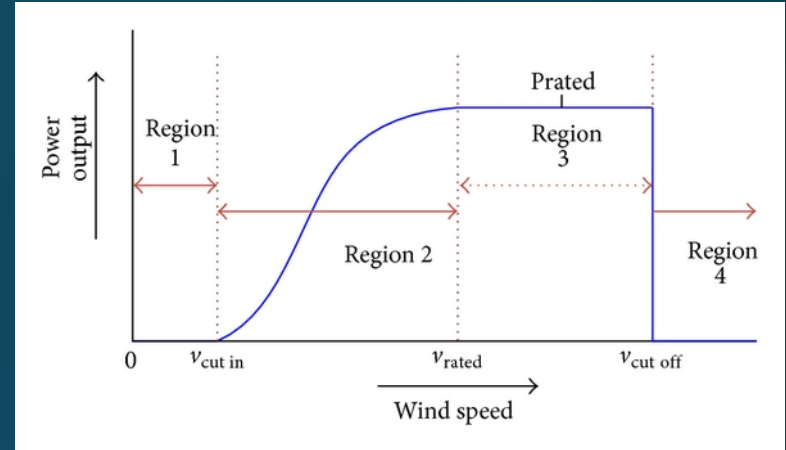
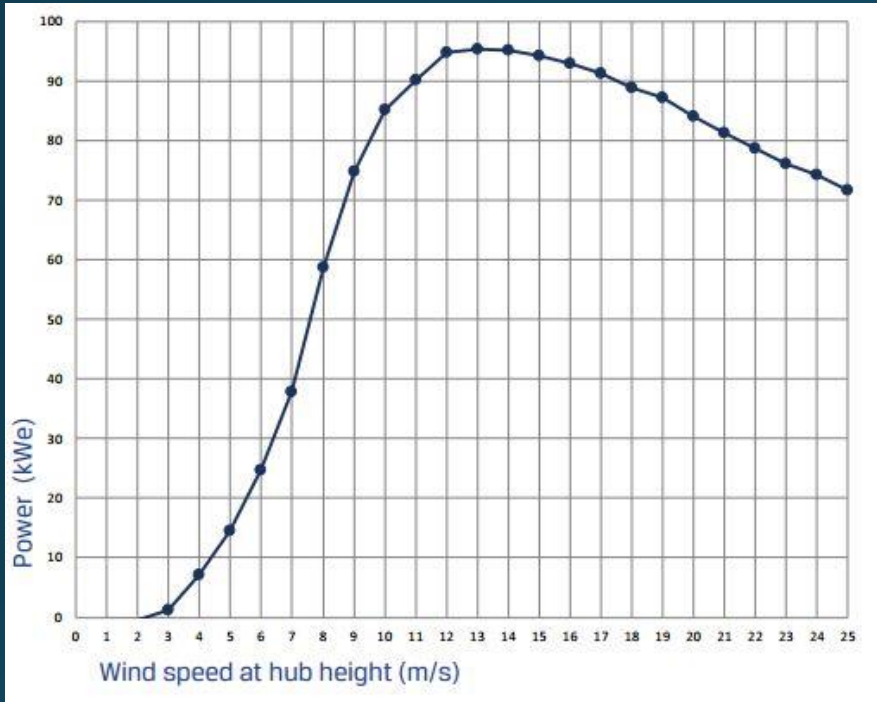
$$\text{Power (W)} = 1/2 \times \rho \times A \times v^3$$

- The standard density of air is 1.225 kg/m^3
- The turbine has a 24 m diameter, which means the radius is 12 m. Thus, the swept area (A) of the turbine is: $\pi r^2 = 3.14159(12^2) = 452.4 \text{ m}^2$
- We'll start with a 6 m/s wind.
- The power in the wind at **6 m/s** is: $1/2 \times \rho \times A \times v^3 = 0.5 \times 1.225 \text{ kg/m}^3 \times 452.4 \text{ m}^2 \times (6 \text{ m/s})^3 = 59,852 \text{ W} = \mathbf{59.85 \text{ kW}}$
- At **12 m/s**: $1/2 \times \rho \times A \times v^3 = 0.5 \times 1.225 \text{ kg/m}^3 \times 452.4 \text{ m}^2 \times (12 \text{ m/s})^3 = 478,820 \text{ W} = \mathbf{478.8 \text{ kW}}$ (8 times as large)
- At **18 m/s**: $1/2 \times \rho \times A \times v^3 = 0.5 \times 1.225 \text{ kg/m}^3 \times 452.4 \text{ m}^2 \times (18 \text{ m/s})^3 = 1,616,018 \text{ W} = 1,616 \text{ kW} = \mathbf{1.616 \text{ MW}}$ (27 times as large)

Every turbine is different. In order to determine the output of a specific turbine at a given wind velocity, you need its **power curve** (provided by the manufacturer).

Power curve of a wind turbine depicts the relationship between output power and hub height wind speed. It indicates its performance.

Power curve of the Northwind 100C, 95 kW wind turbine.



As you can see, even though this is a 95 kW turbine, it only provides (approximately) that much power at a very limited number of wind speeds - about 12 m/s through about 15 m/s.

The power output decreases if the wind speeds up past that point. For safety reasons, the turbine will stop spinning if the wind speed is higher than 25 m/s.

Wind Speed and Corresponding Power Output (kW)													
wind speed (m/s)	1	2	3	4	5	6	7	8	9	10	11	12	
power output (kW)	-0.5	-0.5	1.2	7.2	14.5	24.7	37.9	58.7	74.8	85.1	90.2	94.7	
Wind Speed and Corresponding Power Output (kW)													
wind speed (m/s)	13	14	15	16	17	18	19	20	21	22	23	24	25
power output (kW)	95.3	95.1	94.2	92.9	91.2	88.9	87.1	84.1	81.3	78.6	75.1	74.3	71.7

Assuming the turbine is operating properly, the output calculation is straightforward.

You just multiply the output at a given velocity by the number of hours the wind is blowing at that velocity. For example, let's assume that the wind hitting a “Northwind 100C” in a given day has the following velocities. (Note that in reality, the wind would likely change much more frequently than this).

The total output at 6 m/s would be: 24.7 kW (the output at 6 m/s from the power curve table) x 4 hrs = 98.8 kWh.

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power output (kW)	-0.5	-0.5	1.2	7.2	14.5	24.7	37.9	58.7	74.8	85.1	90.2	94.7

Velocity/Number of Hours/Total Output		
velocity (m/s)	number of hours at that velocity	total output (kWh)
6	4	98.8
8	8	469.6
12	5	473.5
15	4	376.8
16	3	278.7
16	3	278.7
Total	24	1,697.4

Capacity factor

Capacity factor of wind turbine is the ratio of its actual annual energy output to the theoretical maximum output.

It indicates how much energy is generated by a source relative to the maximum amount of energy it could provide. This is expressed as a percentage and is usually determined over the course of a single year [8760 hours (24 X 365)] .

(see excel file: “Wind turbine output & capacity factor calculations”)

$$\text{Capacity factor} = \frac{\textit{mean power output}}{\textit{theoretical maximum output}}$$

Modern wind turbines produce electricity 70-85% of the time, but generate different outputs dependent on wind speed.

Typically, capacity factor of modern wind farms is in the range of 20% to 50%.

Capacity Factor

Example:

So for the Northwind 100C, the theoretical maximum output is:
 $95 \text{ kW} \times 8760 \text{ hr/yr} = \mathbf{832,200 \text{ kWh/yr (or 832.2 MWh)}}$.

If the actual (mean) output over the course of a year was 250,000 kWh, (based on the operational hours), the capacity factor would be:

capacity factor = actual/maximum output = $250,000 \text{ kWh} / 832,200 \text{ kWh} = 30\%$

$$\text{Capacity factor} = \frac{\text{mean power output}}{\text{theoretical maximum output}}$$

Power Coefficient & the Betz Limit

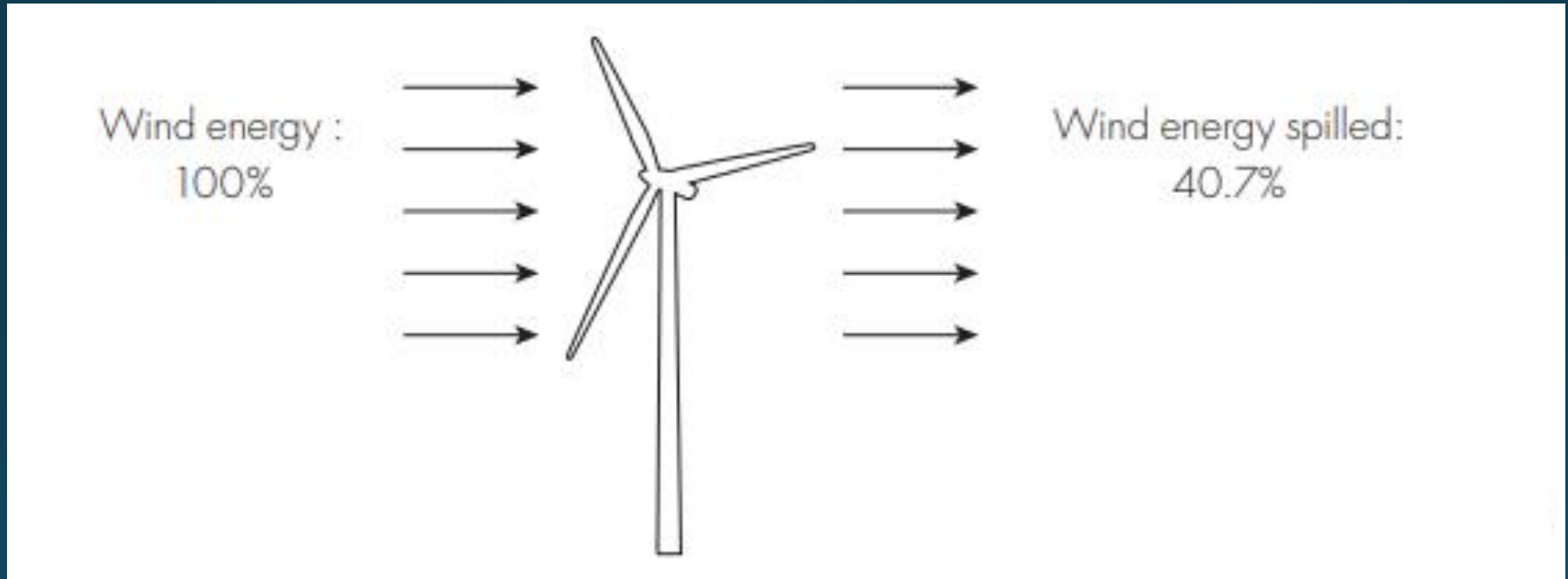
The coefficient of power (C_p) of a wind turbine is a measurement of how efficiently the wind turbine converts the wind energy into electricity.

$$C_p = \frac{\text{Electricity produced by wind turbine}}{\text{Total Energy available in the wind}}$$

Albert Betz was a German physicist who calculated that no wind turbine could convert more than 59.3% of the kinetic energy of the wind into mechanical energy turning a rotor.

This is known as the Betz Limit, and is the theoretical maximum coefficient of power for any wind turbine.

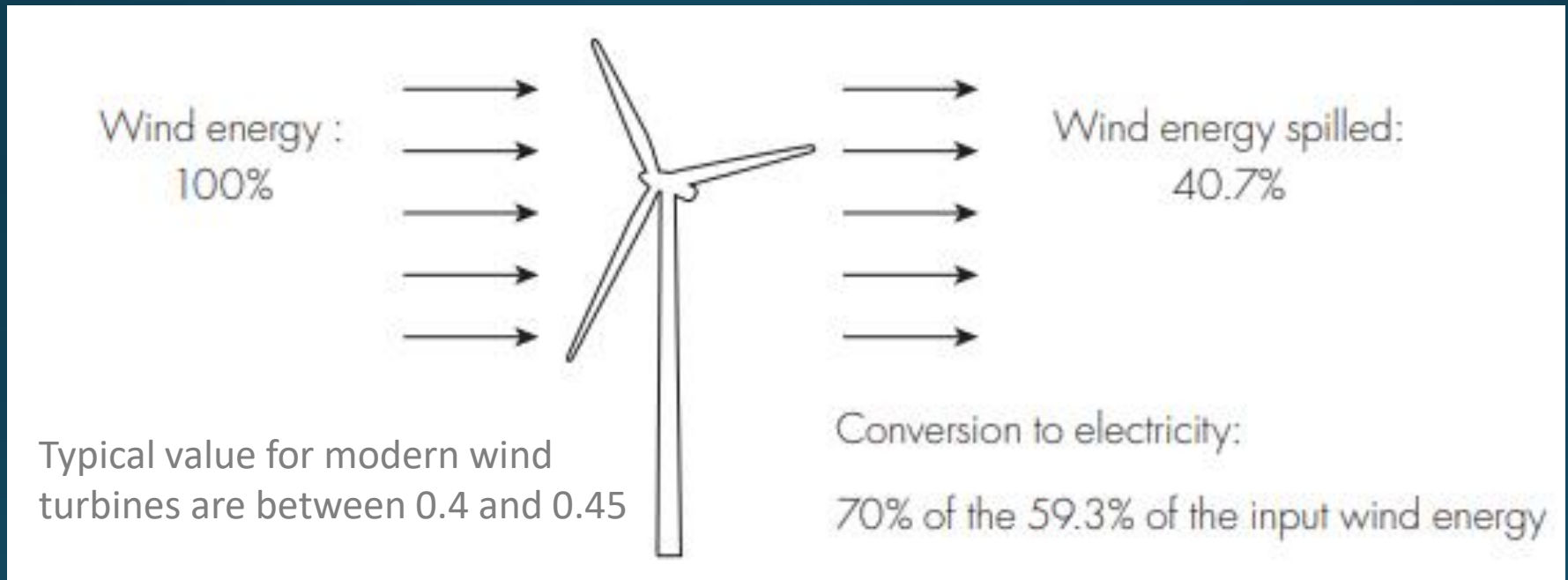
Real World Wind Turbines' Power Coefficient



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Real World Wind Turbines' Power Coefficient



In the diagram shown above, the wind turbine converts 70% of the Betz Limit into electricity. Therefore, the C_p of this wind turbine would be $0.7 \times 0.59 = 0.41$. So this wind turbine converts 41% of the available wind energy into electricity. This is actually a pretty good coefficient of power. Good wind turbines generally fall in the 35-45% range.

Power from the Wind

Power available from the wind is

$$P_i = \frac{1}{2} \rho A v^3$$

Where

P_i = Power in wind

ρ = density of air (kg/m^3)

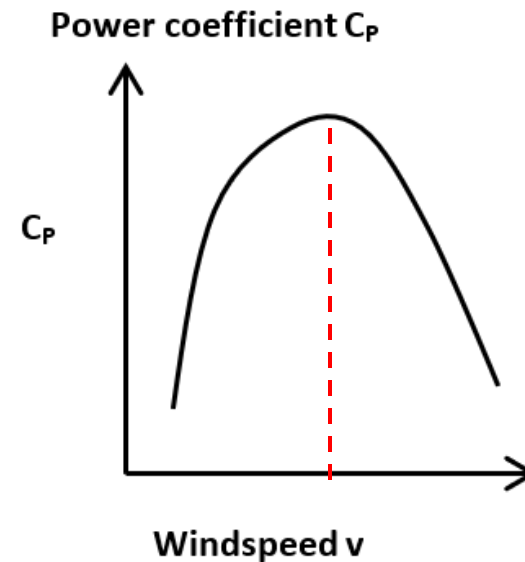
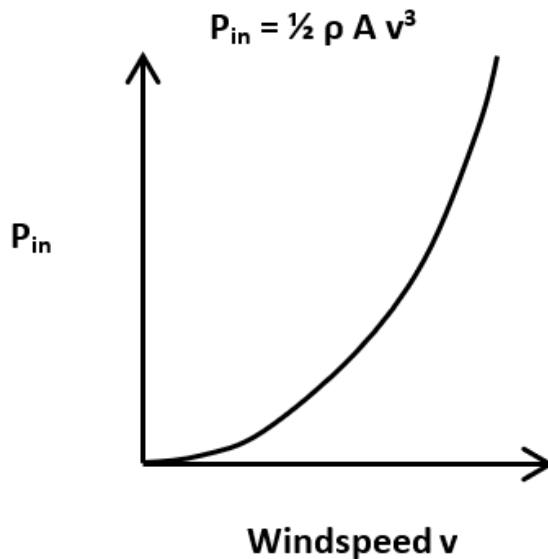
A = Swept area of rotor (m^2)

v = wind speed (free stream) (m/s)

The power captured by the wind turbine is given by:

$$P_o = \frac{1}{2} C_p \rho A v^3$$

Where C_p is power coefficient
(value given by the manufacturer)

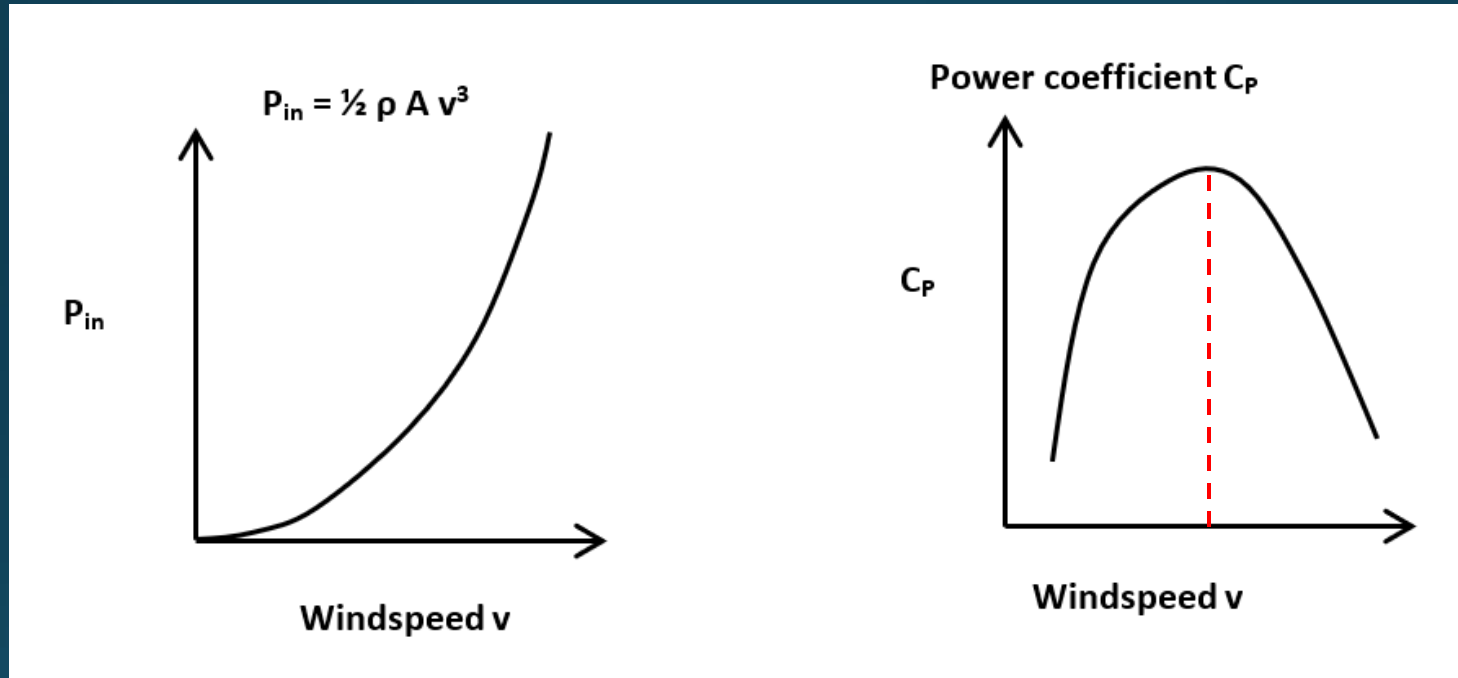


Power from the Wind

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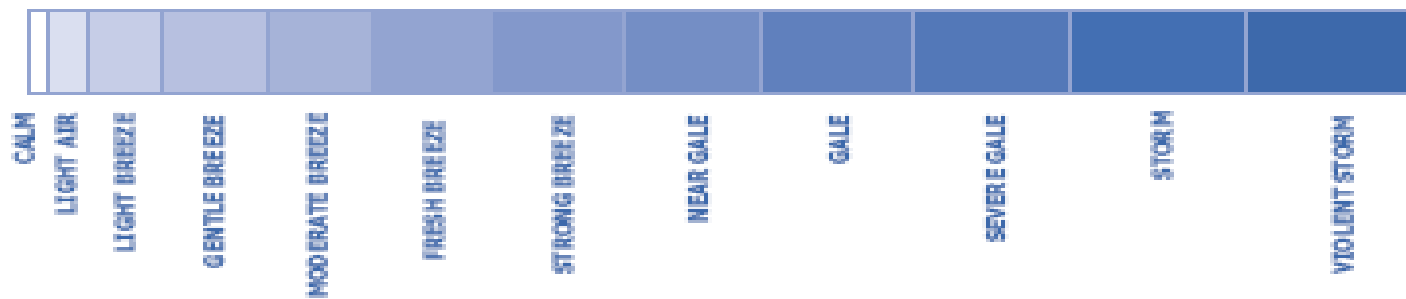
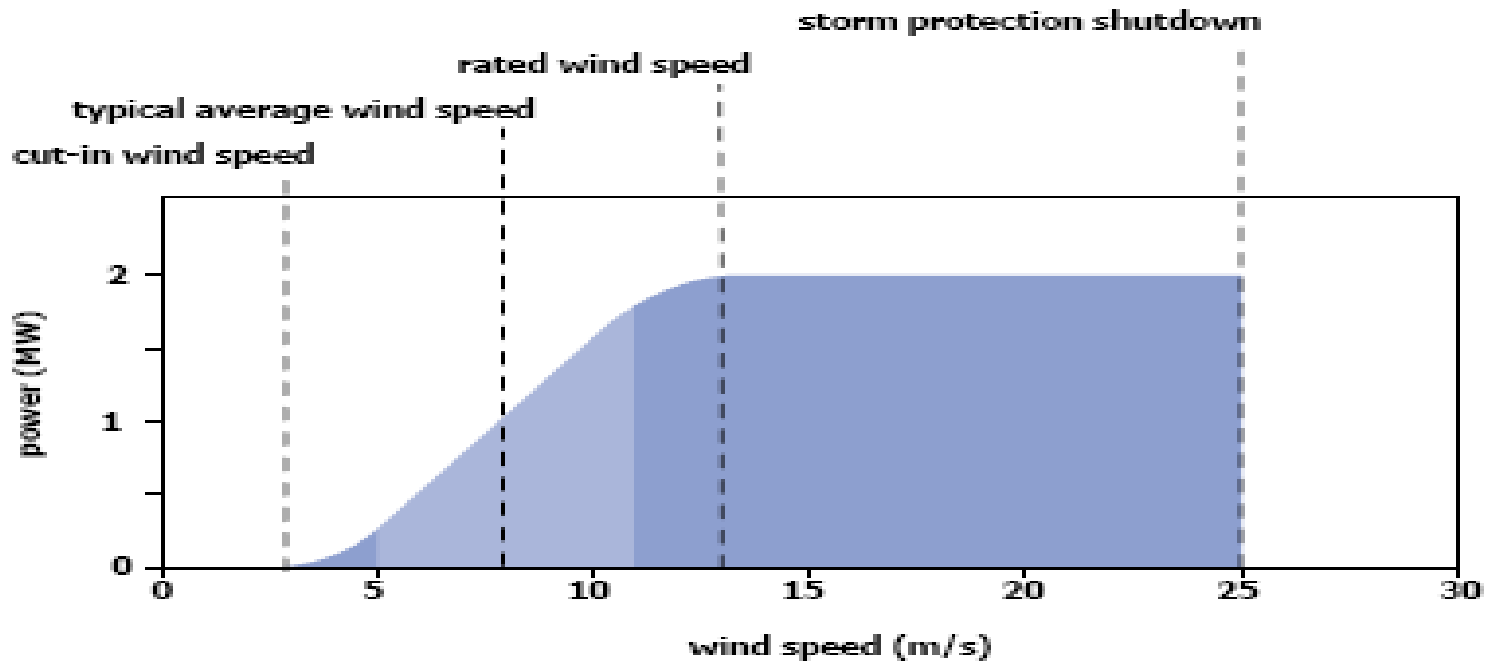
Given that the power in the wind is proportional to the cube of the wind speed, we end up with the typical power output curve for a wind turbine.

The efficiency of a wind turbine refers to the losses within the gearing and electric generator.

Generally, the power coefficient varies over the operating range of wind speeds of the turbine.

Power Curve of Wind Turbines

Typical power curve of a wind turbine



Other ideas that might increase the efficiency.....



Instead of changing the pitch angle, (wings) the "air guide" blades are rotatable to increase the efficiency

Tip-Speed Ratio (TSR)

- This is a term used to compare the rotational speed of rotors.

TSR = Speed of blade tip / Wind speed

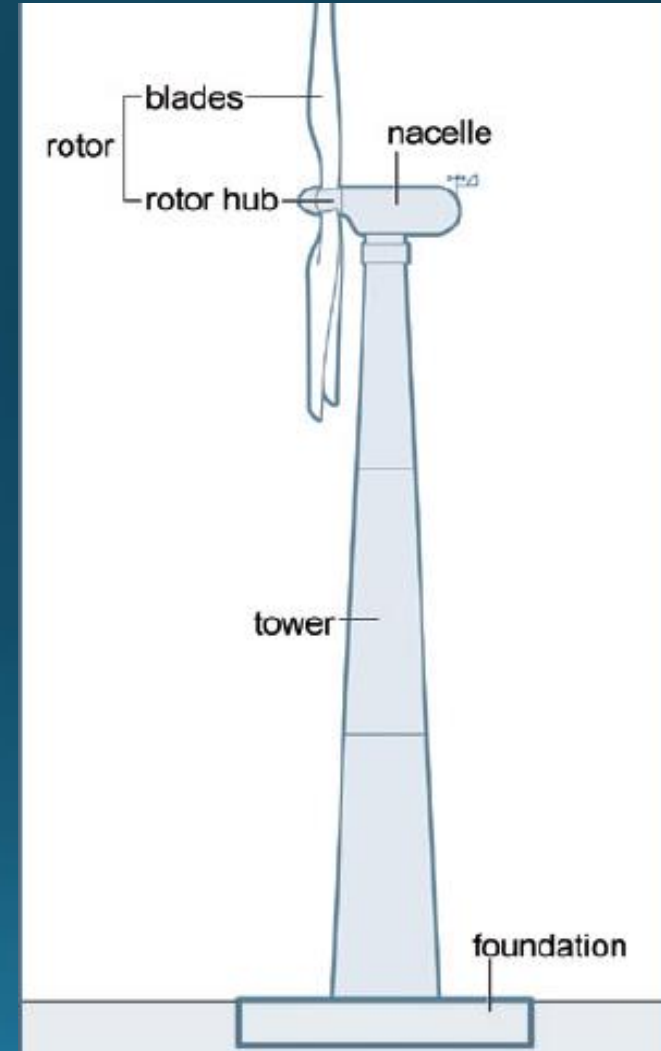
$$\text{TSR} = \omega R / V$$

ω : rotational speed of the turbine

R : radius

V : wind speed

- For maximum power extraction, the turbine should rotate at the optimum tip-speed ratio, which implies a rotational speed that varies with wind speed.
- Modern 3-bladed turbines are designed to have tip speed ratios of 6 – 7.



Tip-Speed Ratio (TSR)

Tip-speed Ratio = Tangential Speed of blade tip / Wind speed

The tip speed ratio is given by dividing the speed of the tips of the turbine blades by the speed of the wind.

- Low TSR wind simply sips through the turbine and very little energy is extracted
- High TSR turbine spins so fast that wind can barely go through the turbine
- Optimal TSR must exist at which the most power can be extracted

The Tip Speed Ratio (TSR) is used by wind turbine designers to properly match and optimise a blade set to a particular generator.

Understanding Tip-Speed Ratio (TSR)

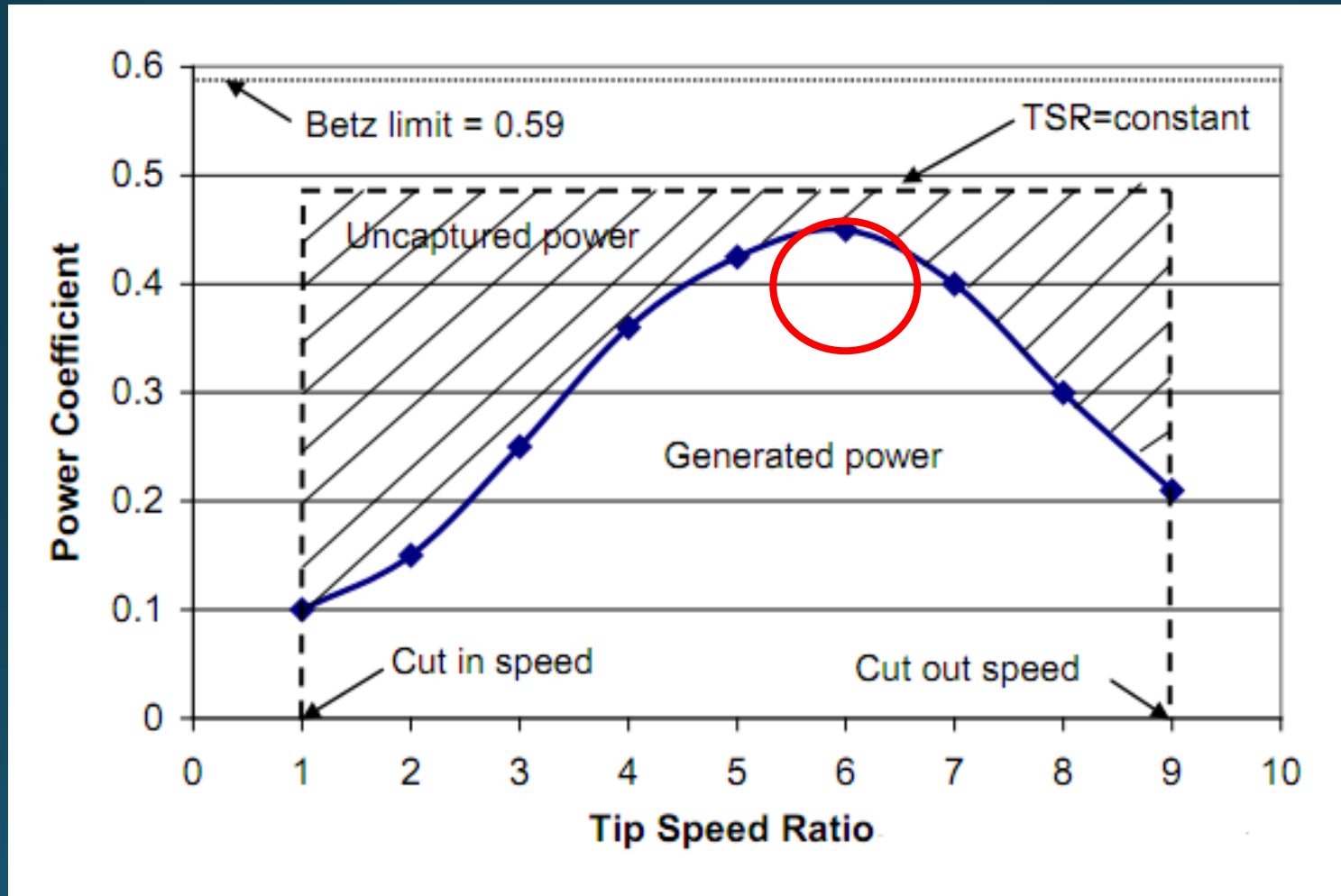
Why is this important?

For a particular generator, if the blade set spins too slowly then most of the wind will pass by the rotor without being captured by the blades. If the blades spin too fast, then the blades will always be traveling through used/turbulent wind.

It is important that enough time lapses between two blades traveling through the same location so that new/unused wind can enter this location. Thus, the next blade that passes through this location will be able to harness fresh/unused wind.

In short, if the blades are too slow they are not capturing all the wind they could and if they are too fast, then the blades are spinning through used/turbulent wind. For this reason, TSR's are employed when designing wind turbines so that the maximum amount of energy can be extracted from the wind using a particular generator.

Power Coefficient as a function of TSR

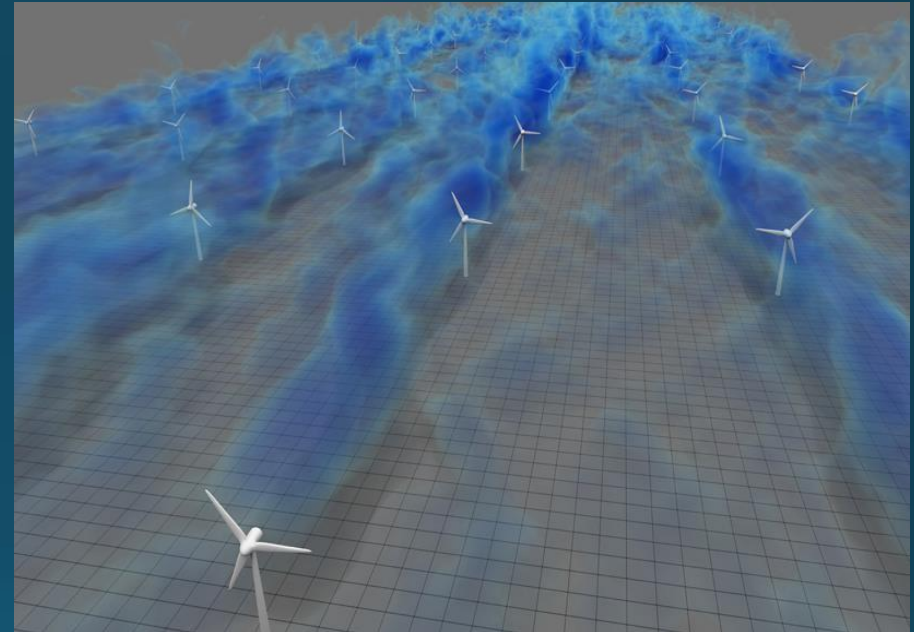


Speed of blade has to be adjusted according to the wind speed

Wake Effect

Wake effect is an important parameter to be considered when planning the turbine placement in a wind farm since it affects the overall energy production of the wind farm.

Wake is the long trail of wind behind the turbine which is quite turbulent and slowed down when compared with the wind arriving in front of the turbine.



Source: <http://xn--drmstrre-64ad.dk/wp-content/wind/miller/windpower%20web/en/tour/wres/wake.htm>

Energy output from a Wind Turbine

Annual output (kWh) = Rated output (kW) x load factor x 8760 (hrs/yr)

Another empirical relationship is given by Boyle (2012):

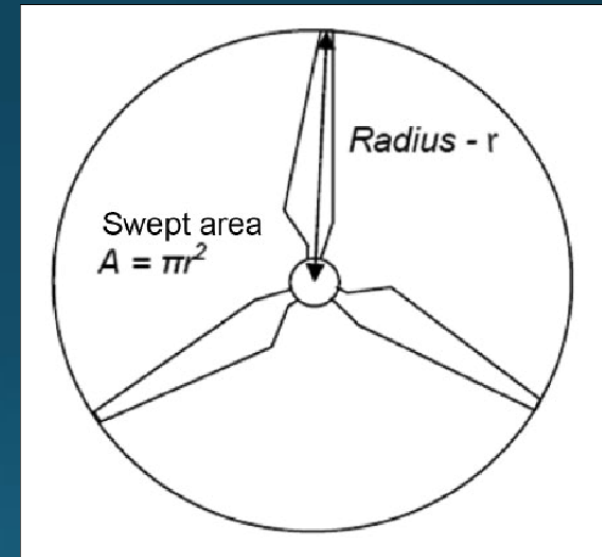
$$E_{an} : K A v_{mean}^3$$

Where E_{an} : Annual energy output (kWh)

K is an empirical constant (2.6 or 3.2), based on typical turbine performance characteristics.

A is the swept area of rotor (m^2).

v_{mean} is the mean wind speed on the site.



Example – Annual Energy Production

Calculate the Power output in kWh from a 4 blade wind turbine with a **rotor diameter** of 100m.
The mean wind speed on the site is 6.9 m/s.

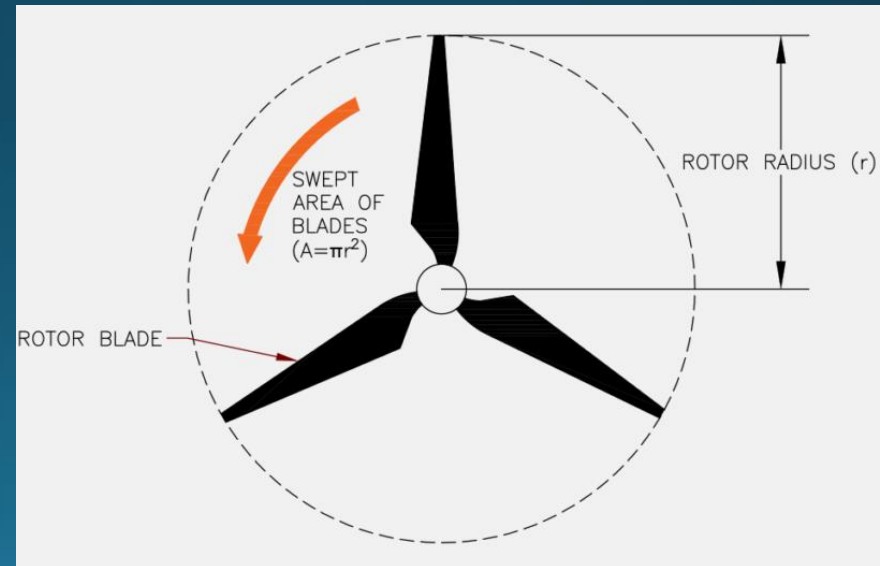
(rotor diameter means the cross sectional dimension of the circle swept by the number of rotating blades of a wind-powered energy generator.)

$$\begin{aligned} \text{Annual Energy output (E}_{an}) &= K * A * v_{\text{mean}}^3 = 3.2 * (3.14 * 100^2 / 4) * 6.9^3 = \\ &= 3.2 * (3.14 * 2500) * 6.9^3 = 8.252 \times 10^6 \text{ kWh} \end{aligned}$$

E_{an} : Annual energy output (kWh)

K: empirical constant (2.6 or 3.2),
based on typical turbine performance
characteristics

A: is the swept area of rotor (m^2)



Micro-Wind Turbines

Micro Wind Turbines

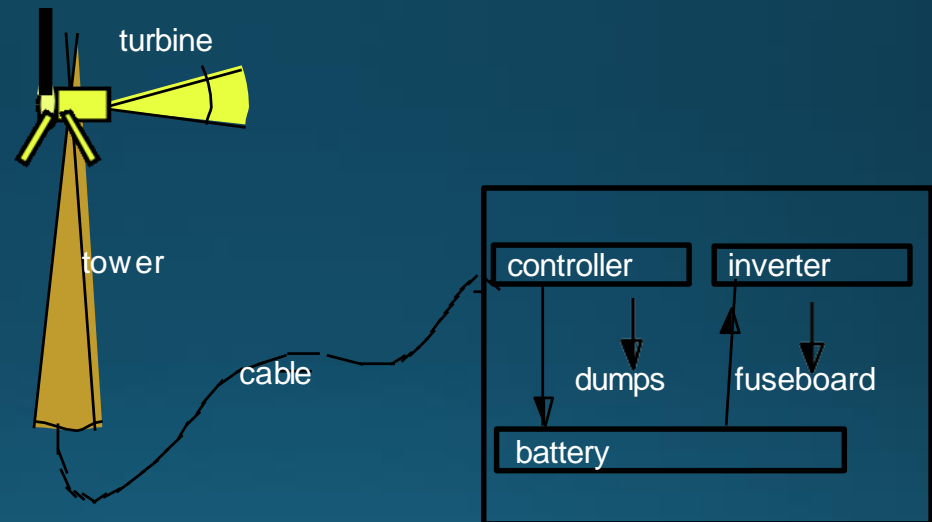
- ❑ Micro wind turbines can range from less than 100 W to several kW.
- ❑ Normally used in domestic applications.
- ❑ Can be used as stand-alone or grid connected systems.
- ❑ Should to be positioned carefully in order to attract desired level of wind speed.



Stand Alone Micro Wind Turbines

- ❑ There are many components to the system. Cost is high therefore high maintenance burden.
- ❑ Batteries are a particular ongoing cost
- ❑ Mains power is not available, so the alternative is usually costly and unpleasant generator power.
- ❑ Much of the cost is in the battery and inverter which provides 24 hour power to the user, regardless of the primary energy source.

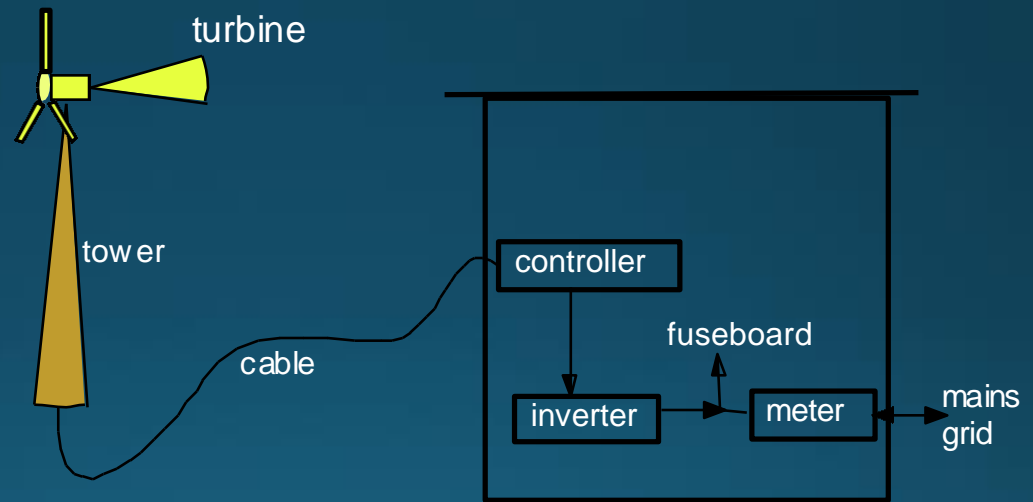
Cost: £4.000 to £ 5.000 depending on the kW size



Grid Connected Micro Wind Turbines (MWT)

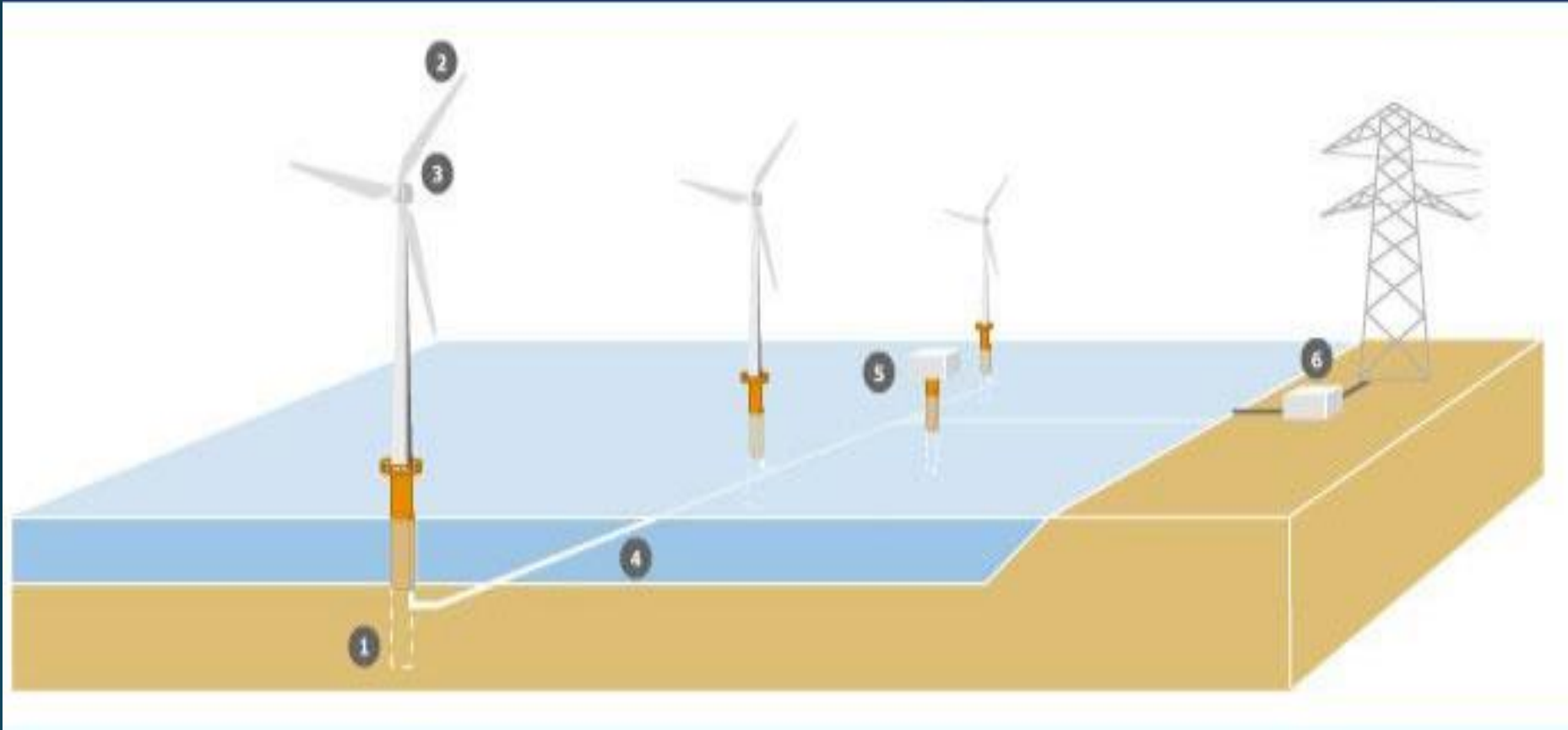
❑ These systems do not involve batteries and therefore less cost compared to stand alone system.

❑ The grid is always available as a backup source, so reliability of supply is not an issue.



A grid-connected MWT and take advantage of the applicable incentives, which may make use of small turbines as a financial benefit.

Offshore Wind



There are higher wind speeds offshore than on land, so offshore farms generate more electricity per amount of capacity installed. Offshore wind farms are also less controversial than those on land, as they have less impact on people and the landscape.

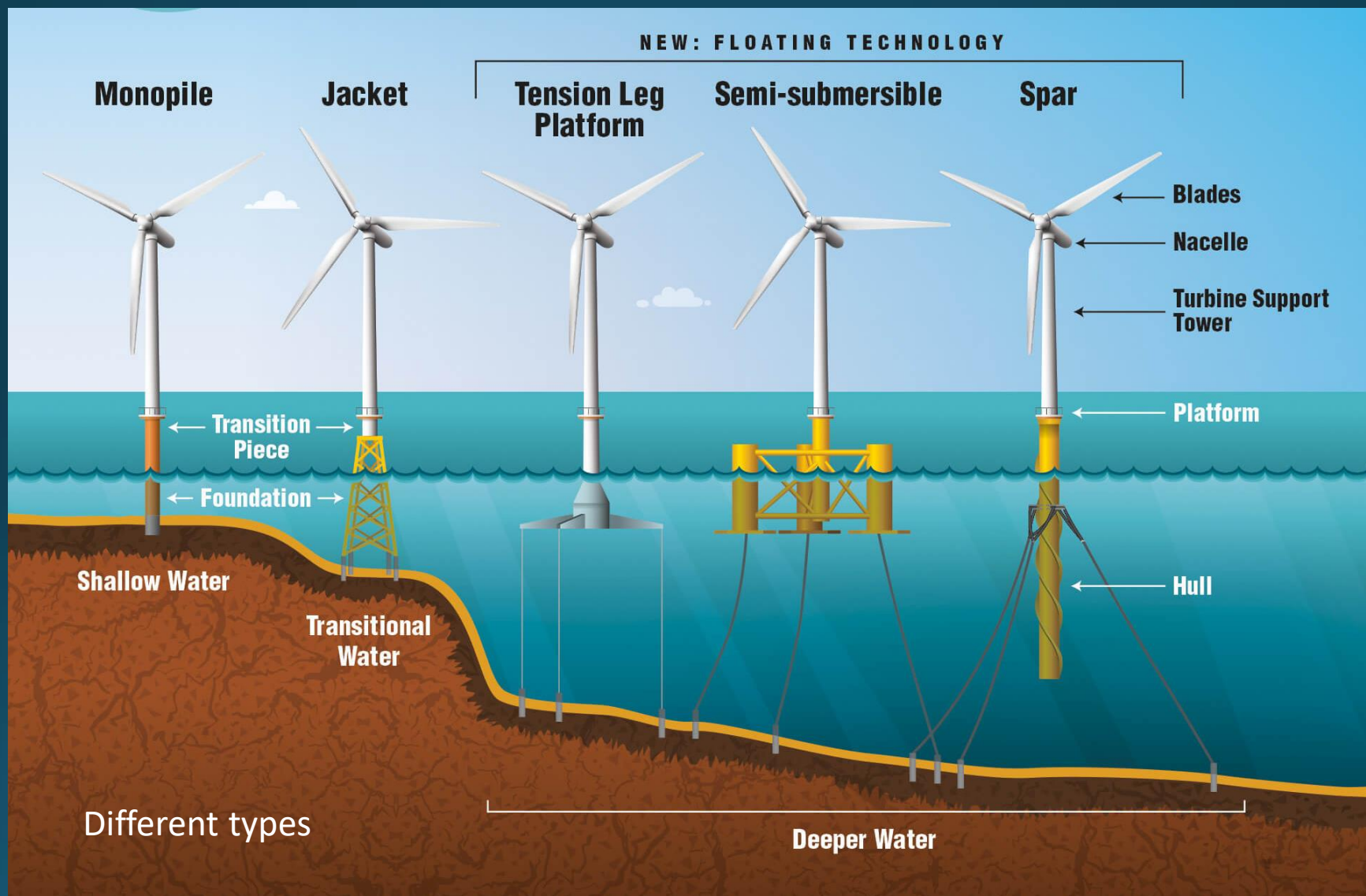
Offshore Wind

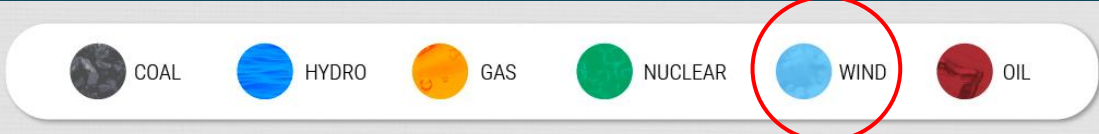


The cost of offshore has historically been higher than that of onshore. Offshore wind power in Europe became price-competitive with conventional power sources in 2017.

Offshore wind generation grew at over 50% since 2010. As of 2020, offshore wind power had become a significant part of northern Europe power generation, though it remained less than 1 percent of overall world electricity generation.

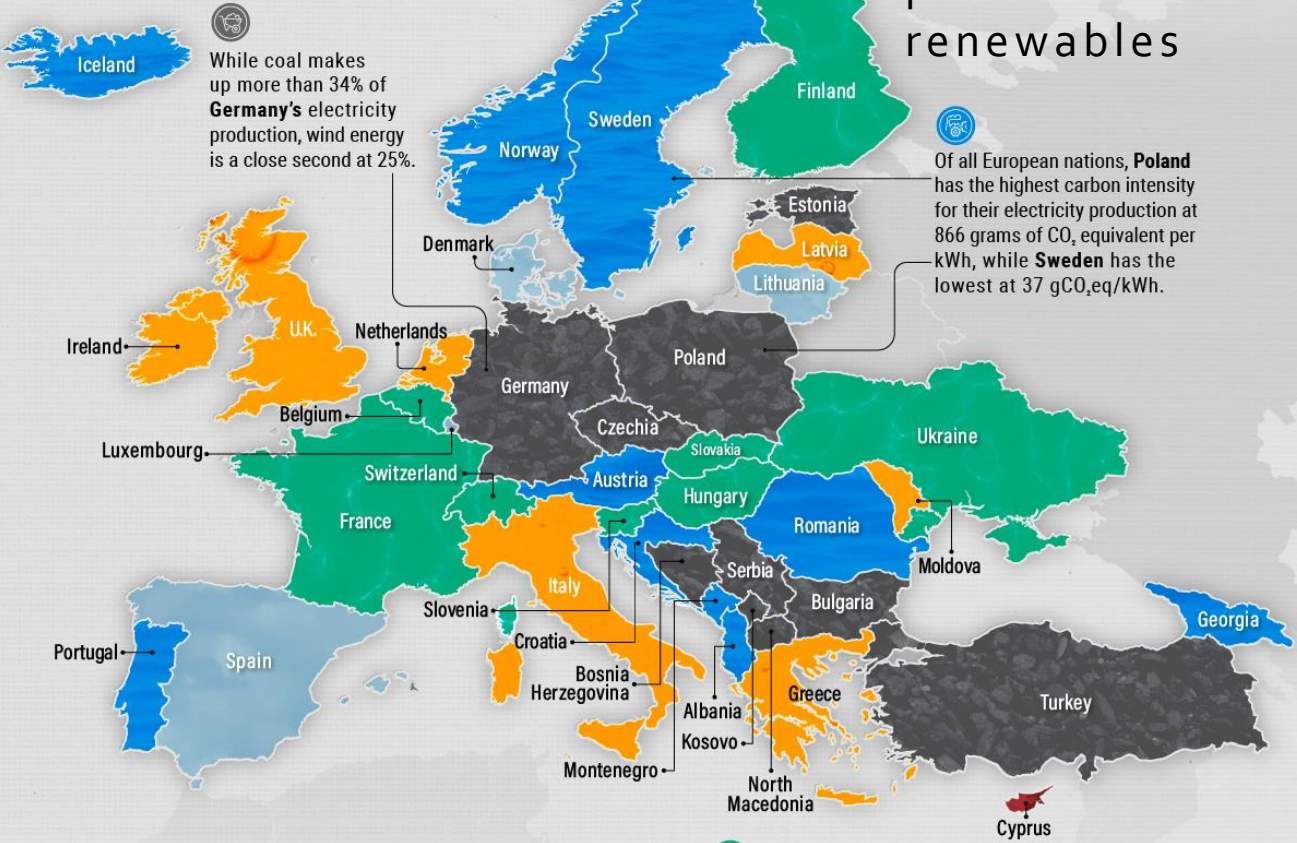
Offshore Wind





Current situation

electricity production from renewables



While coal makes up more than 34% of **Germany's** electricity production, wind energy is a close second at 25%.

Of all European nations, **Poland** has the highest carbon intensity for their electricity production at 866 grams of CO₂ equivalent per kWh, while **Sweden** has the lowest at 37 gCO₂,eq/kWh.

EU Electricity Generation by Source 2021



A decade ago, more than a quarter of Europe's electricity was produced using **coal**. Since then, **solar and wind** generation have doubled to replace declining coal use.

New Technological Advancements

Floating Wind Turbines (3rd Generation)

- ❑ Hywind Scotland: First commercial scale offshore floating wind farm.
- ❑ The flotation element stretches 100 metres below the sea surface.
- ❑ Floating wind turbines are anchored to the seabed with multiple mooring lines and anchors
- ❑ It can be anchored in waters up to 700 meters deep.
- ❑ Emerging industry reports suggest that 5 MW floating wind turbines are technically and economically viable.



Air Floating Wind Turbines

- ❑ The Air floating wind turbines also termed as inflatable wind turbine or Buoyant Airborne Turbine (BAT), can float over 350 meters above in the air with the help of helium inflated chassis.
- ❑ The BAT are designed to be mainly used for small scale off-grid applications. Due to experiencing up to 5-8 times stronger and consistent wind speed and reduced installation cost results into around 65% lower energy cost compared to fixed wind turbines.



3-D Printing Sky-High Wind Turbine Towers With Additive Manufacturing

Massive tower components to their installation sites is logistically challenging and costly, but GE Renewable Energy has a solution: 3-D printing the base of the concrete tower on site, making tall wind turbines easier to build, more efficient, and with lower transportation costs.

GE research facility in Bergen, NY



Source: <https://cleantechnica.com/2022/04/22/3-d-printing-sky-high-wind-turbine-towers-with-additive-manufacturing-video/>

Environmental Impacts

Environmental Impacts

Visual impact

- ❑ One of the most common criticisms on wind turbines is their tendency to alter the natural scenery.
- ❑ The visual perception of wind turbines is determined by a variety of factors. These include physical parameters such as the size and design of turbines, the number of turbines in a wind farm, the layout of the wind farm and the extent to which moving rotor blades attract attention.

Disturbance of habitats

- ❑ Wind turbines can also cause disturbances for birds. The main concern in this respect is that of potential fatal collisions between flying birds and the rotating blades.

Disturbance to communication system

- ❑ Wind turbines can sometimes reflect electromagnetic waves that can interfere with radio and TV communications. These electromagnetic waves can also disrupt aviation radars.

Environmental Impacts

Noise

- ❑ Wind turbines do have acoustic issues that can be classified into two types:
- ❑ Aerodynamic noise is produced as the rotor blades cut through the airstreams. The level of this noise tends to increase with the speed of the rotor.
- ❑ Mechanical noise is associated with electrical and mechanical components such as generator and gearbox. Technical advancements over the last couple of decades have significantly arrested the issue of mechanical noise.

Accidents

- ❑ Wind turbines consist of a large number of stationary as well as moving components. Owing to the wide ranging stresses resulting from these components, wind turbines are prone to structural and fire related accidents.

Structural Collapse

Wind turbines have to withstand massive amounts of strain — especially during storms — which can lead to structural failures as shown in figures.



Fire Accidents

Short circuits, friction or lightning strikes can cause wind turbines to go up in flames — like this one in Nissan factory in Sunderland in December 2005.



Wind Turbine Economics

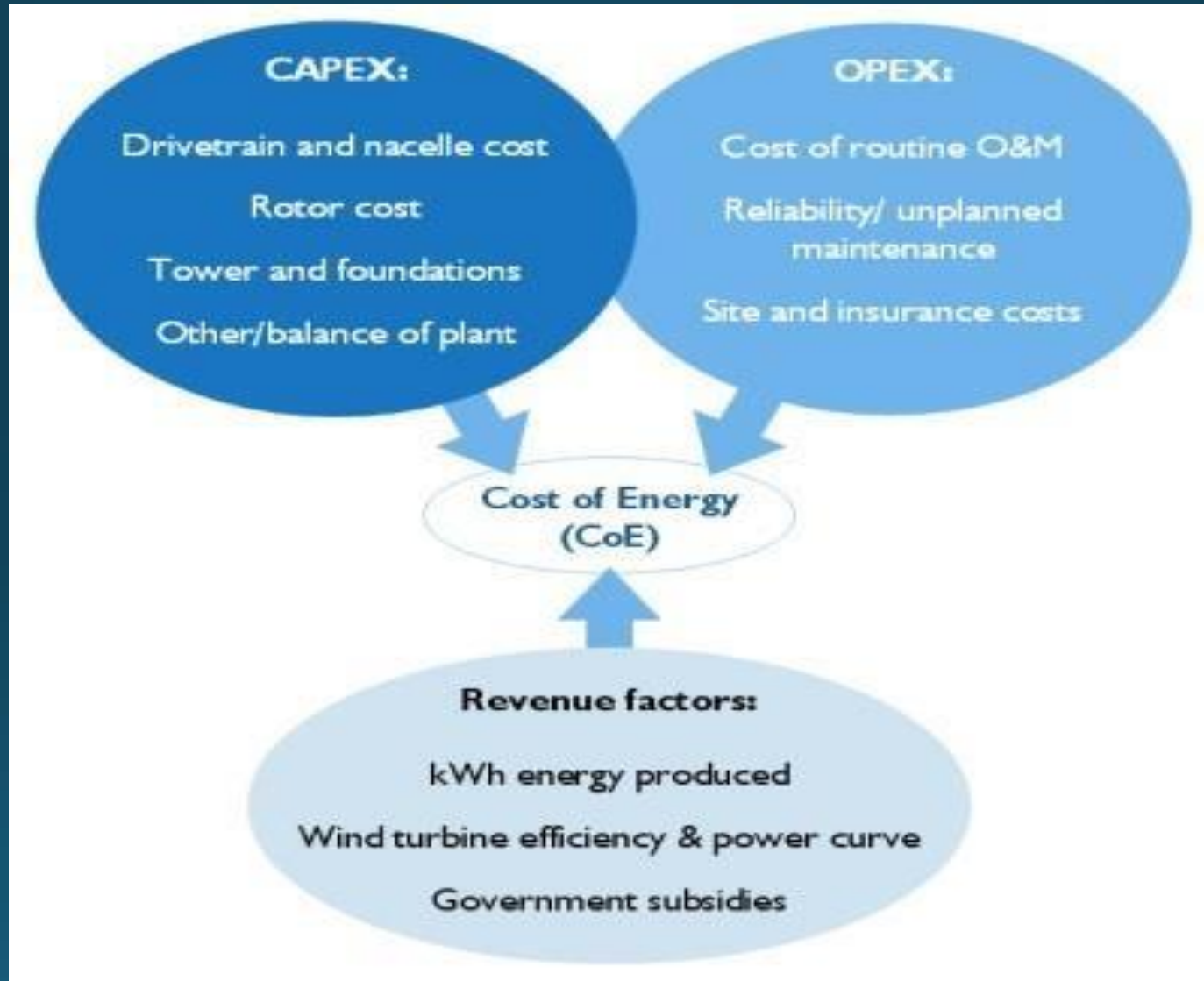
Some key abbreviations

CapEx: Capital expenditures, are funds used by a company to acquire, upgrade, and maintain physical assets such as property, plants, buildings, technology, or equipment.

OpEx: Operating expenses (are the day-to-day expenses a company incurs to keep its business operational.

LCOE: The levelised cost of energy, or levelised cost of electricity, is a measure of the average net present cost of electricity generation for a generating plant over its lifetime. It accounts for all lifetime costs of the system including operation, maintenance, construction, taxes, insurance, and other financial obligations of the project.

Economics of Wind Turbines



Economics of Wind Turbines

levelised cost of energy

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

Where:

LCOE = the average lifetime levelised cost of electricity generation;

I_t = investment expenditures in the year t ;

M_t = operations and maintenance expenditures in the year t ;

F_t = fuel expenditures in the year t ;

E_t = electricity generation in the year t ;

r = discount rate; and

n = economic life of the system.

Economics of Wind Turbines

LCOE (levelised cost of energy)

To understand the LCOE concepts, consider a simple example of a 100 MW wind farm with the following parameters:

Total Capital Cost = £1,400/KW
Fixed O&M Cost = £45/KW-year
Capacity Factor = 40%
Useful Life = 30 years
Discount Rate = 6%

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

Using the calculations below, we can calculate the Total Capital Cost and Fixed O&M Cost as follows:

Total Capital Cost (I_t) = £1,400/KW × 100 MW × 1,000 KW/MW = £140 million

Fixed O&M Cost (M_t) = £ 45/KW-year × 100 MW × 1,000 kW/MW = £4.5 million/year

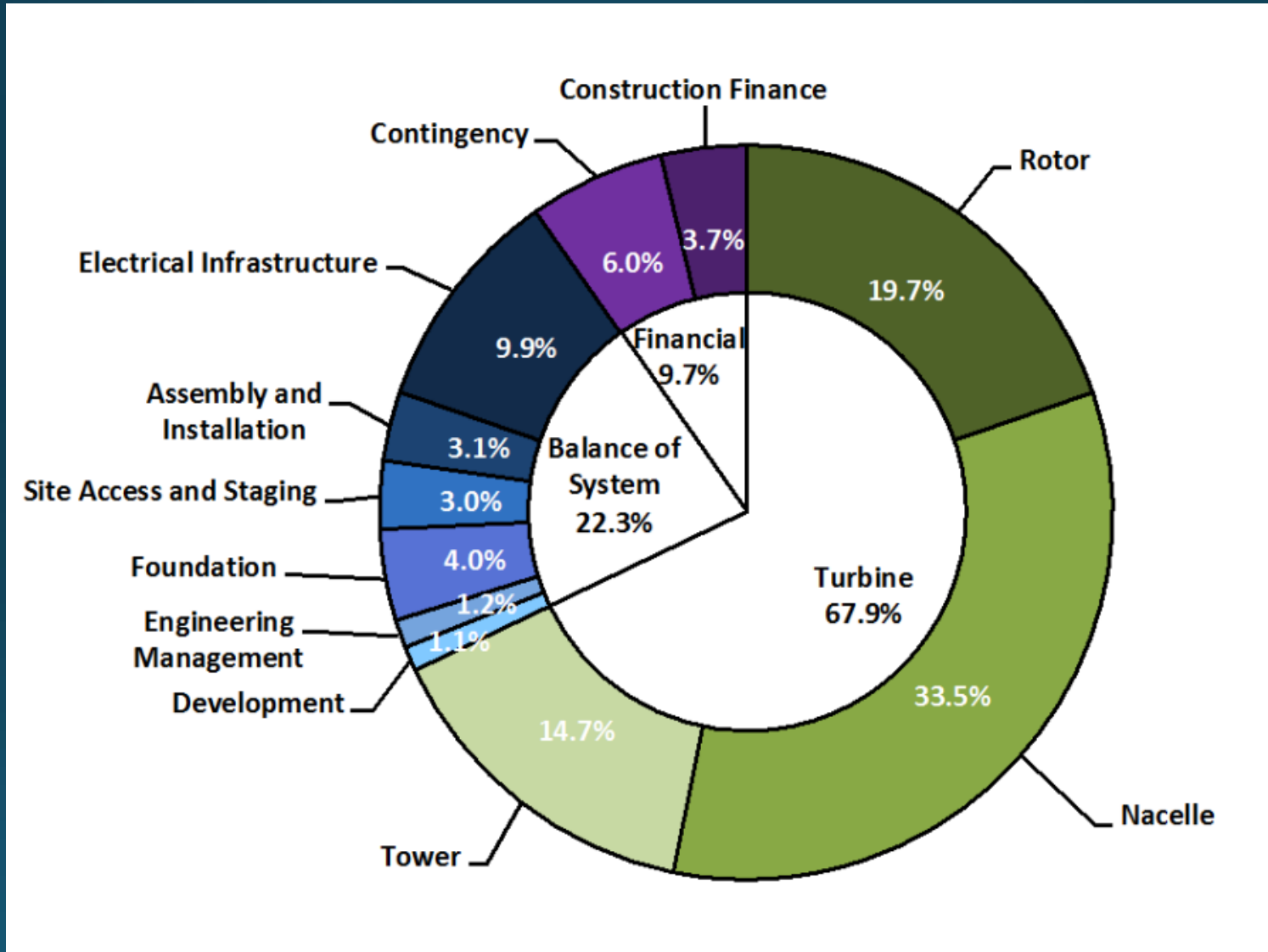
The wind farm's annual electric generation can be calculated as follows:

Annual electricity generation (E) = 100 MW × 8,760 h/year × 40% = 350,400 MWh

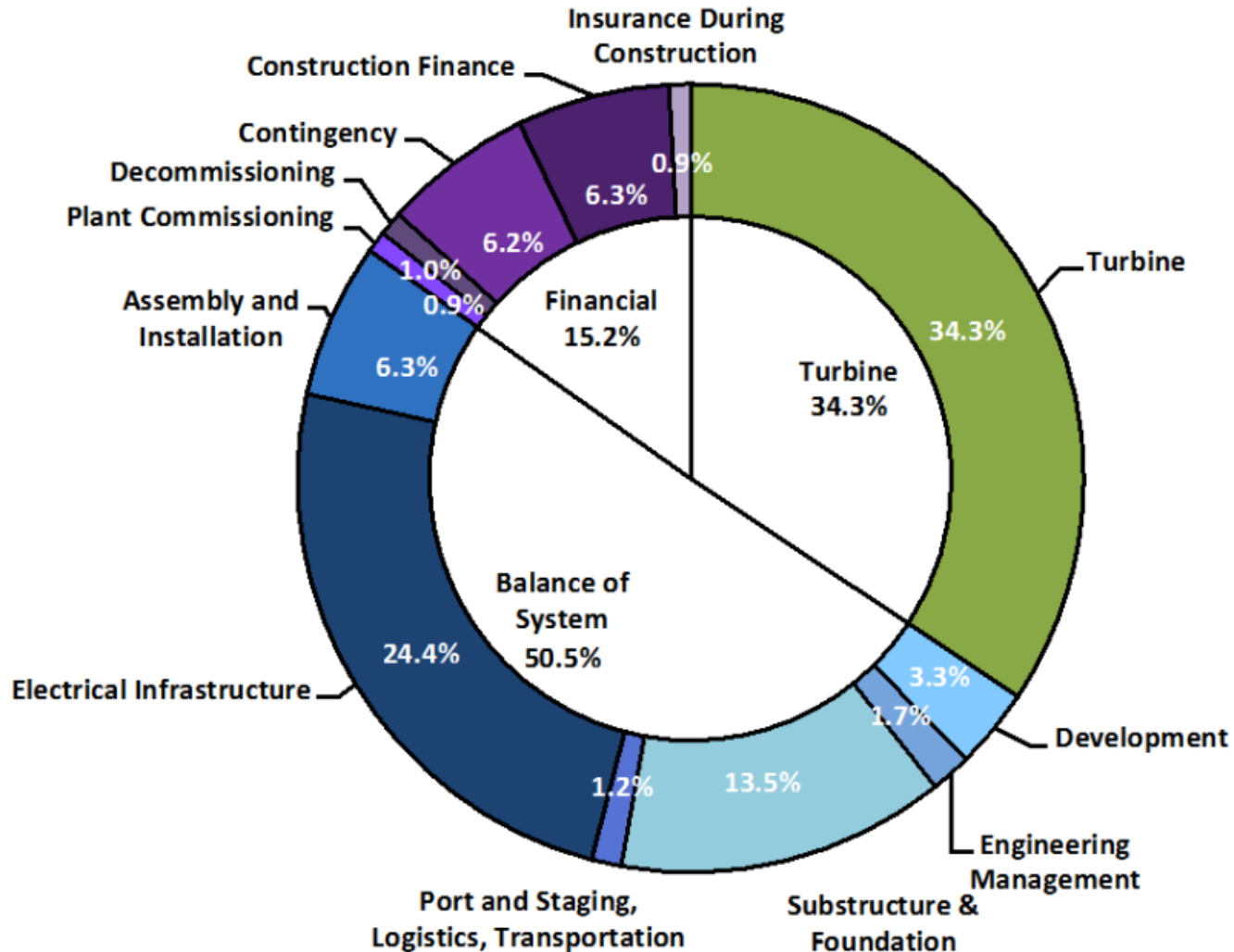
Incorporating the inputs from 100 MW wind farm example:

LCOE = £ 140MM + 13.76 × £ 4.5MM / 350,400MWh × 13.76 = £ 1.87/MWh

Wind Power Project Cost Breakdown

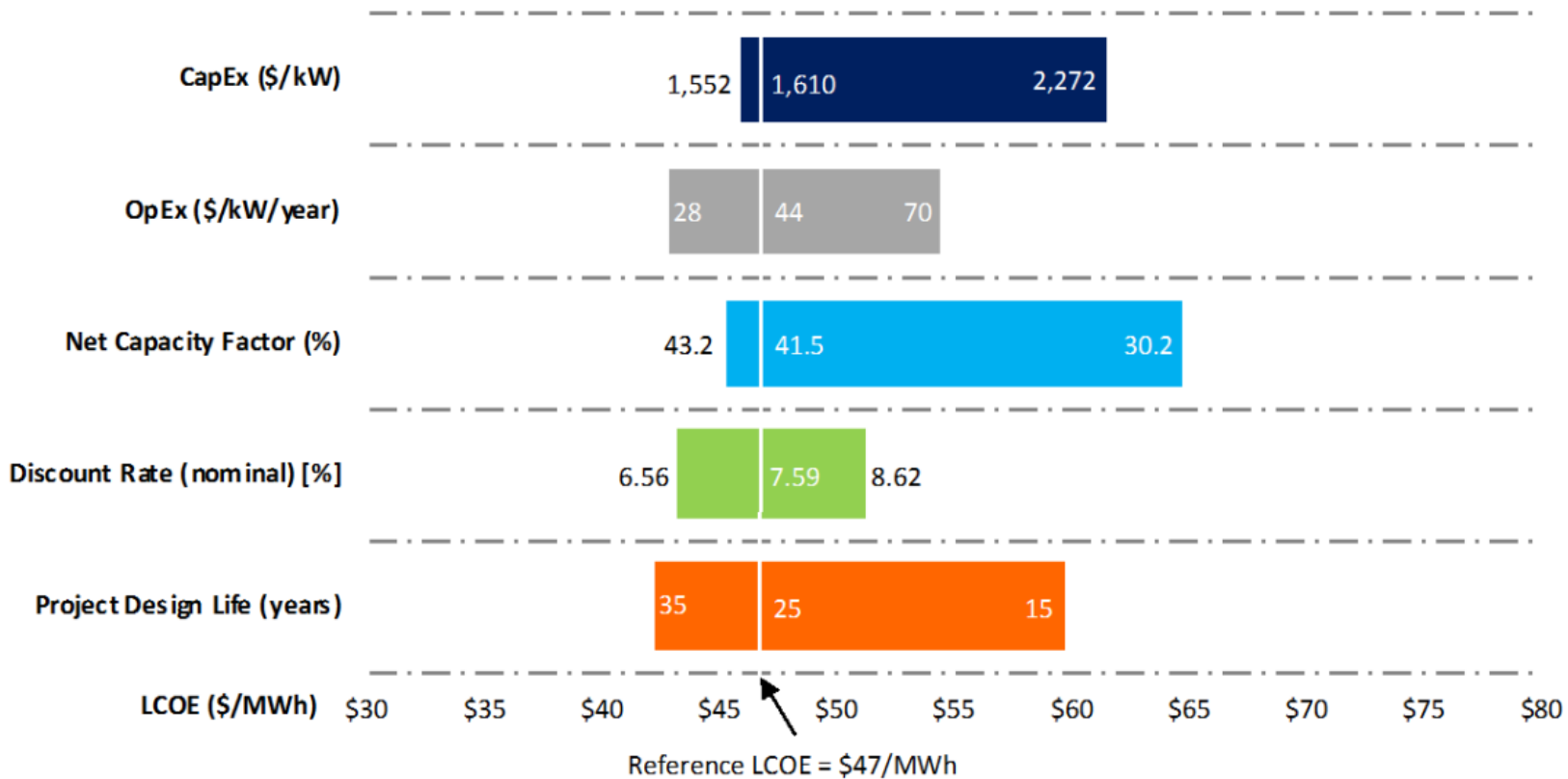


Wind Power Project Cost Breakdown



Wind Power Project LCOE

Key Parameters for LCOE Sensitivity Analysis

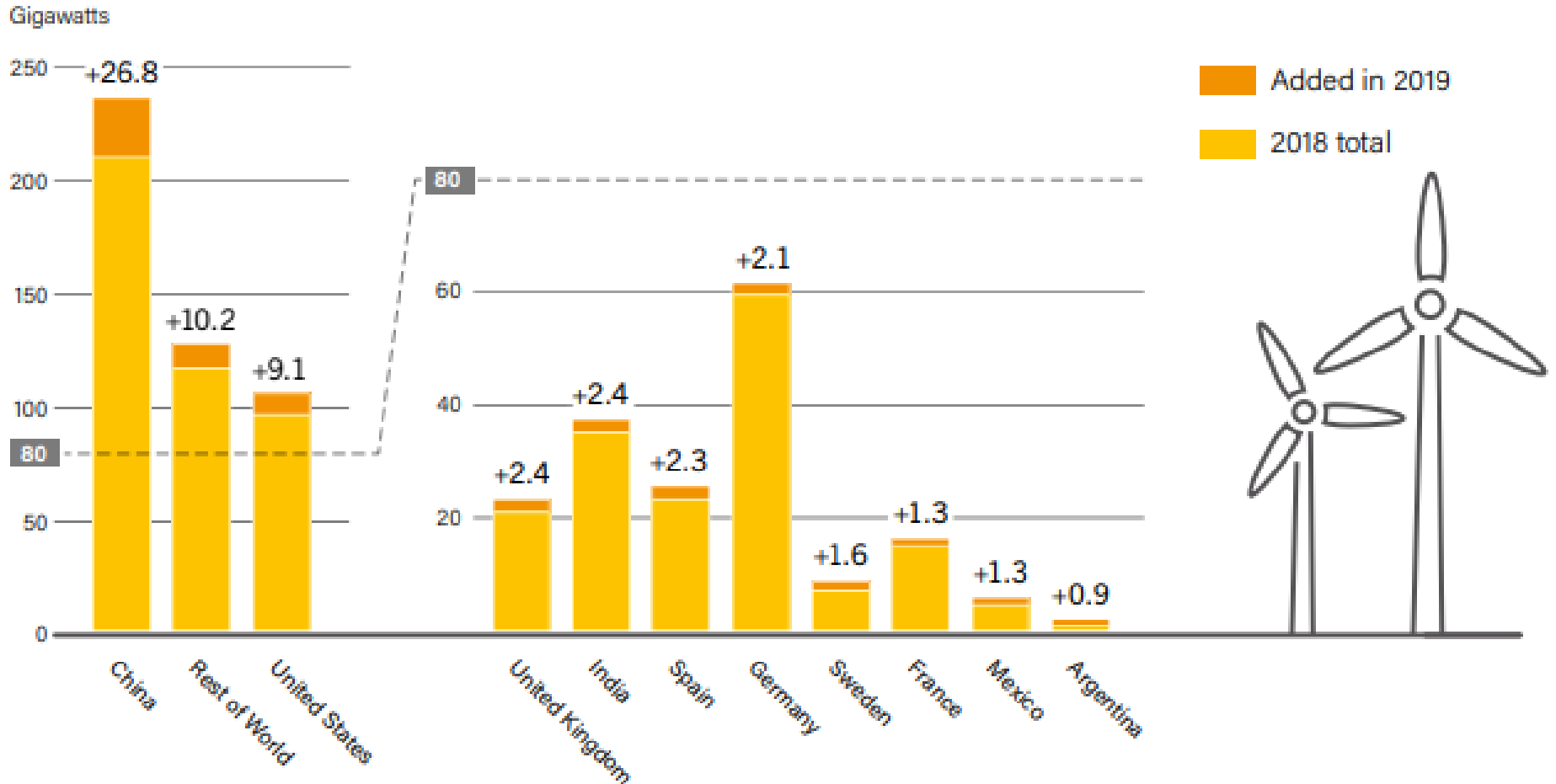


Source: NREL Onshore Wind project

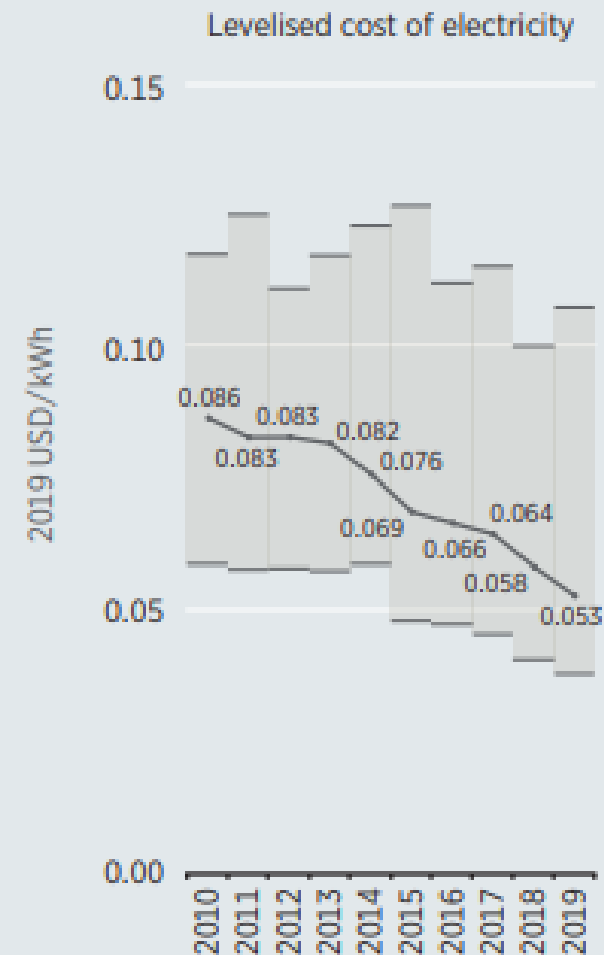
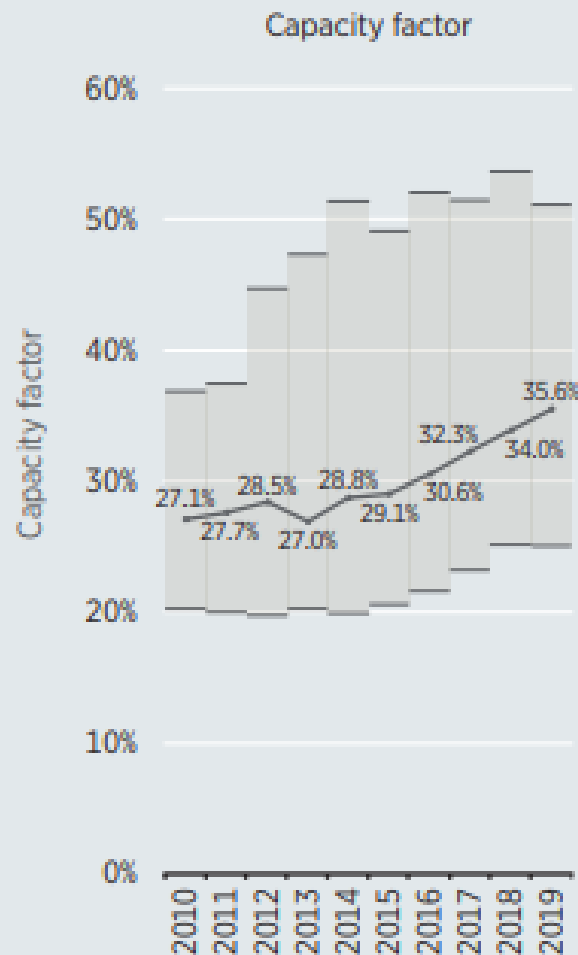
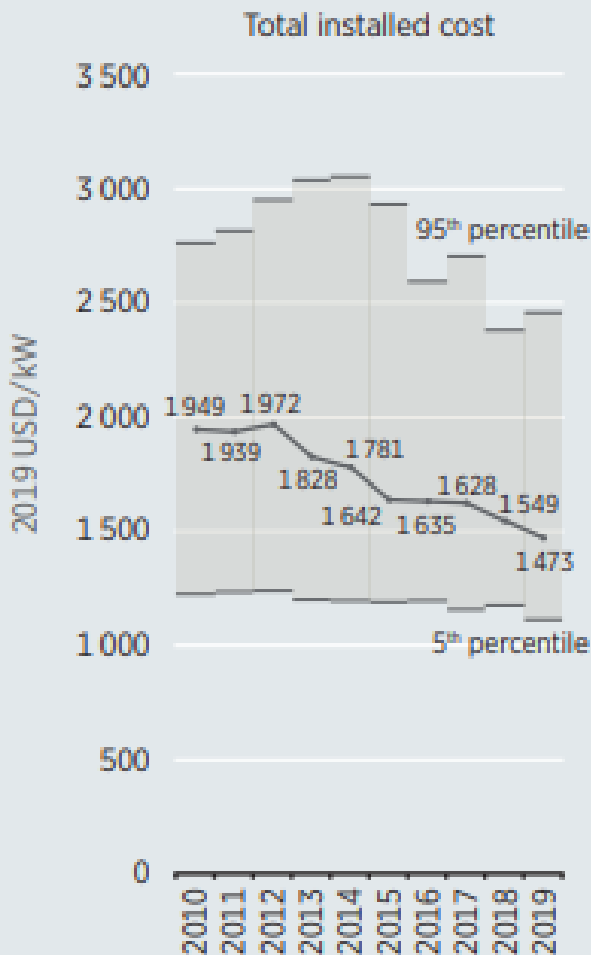
Changes in LCOE for a single variable can be understood by moving to the left or right along a specific variable. Values on the x-axis indicate how the LCOE will change as a given variable is altered, assuming that all others are constant. For example, as capacity factor decreases toward 30%, the LCOE shown on the x-axis will increase accordingly to approximately \$65/MWh. Or, as the operational life for the reference project moves toward 35 years, the period in which a project achieves the requisite cash flow it needs to recover its initial CapEx and meet investors' internal rate of return threshold is assumed to be 35 years; therefore, the resulting LCOE decreases to nearly \$42/MWh.

Global Market and Trends

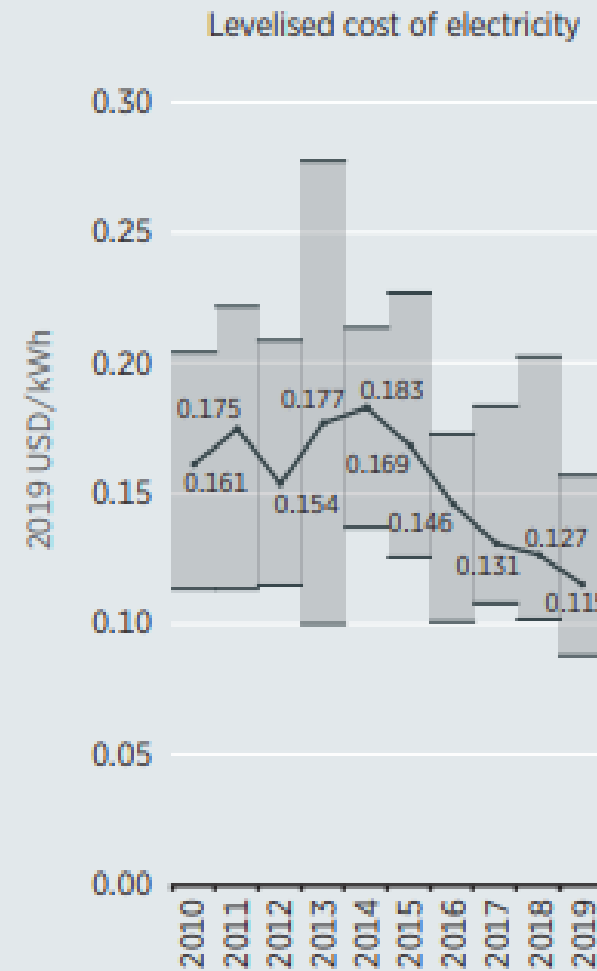
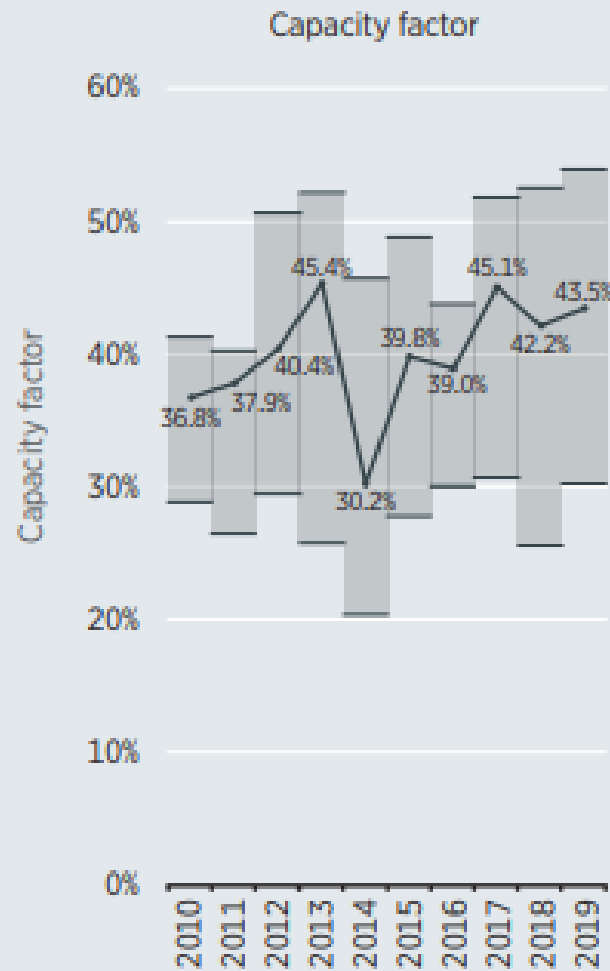
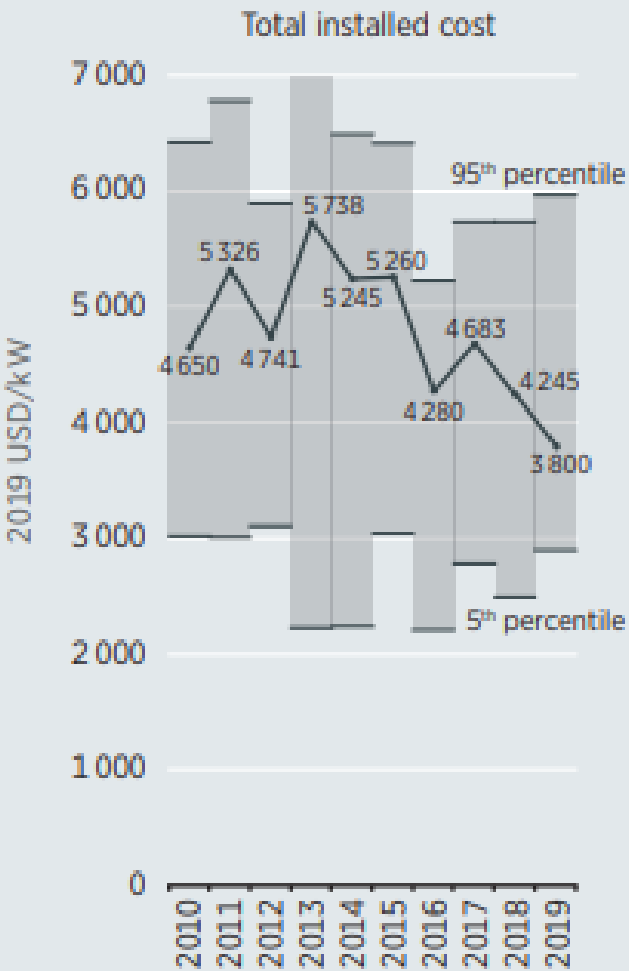
Wind Power Capacity- Top 10 Countries



Global Trend of Installed Cost, LCOE, Onshore Wind



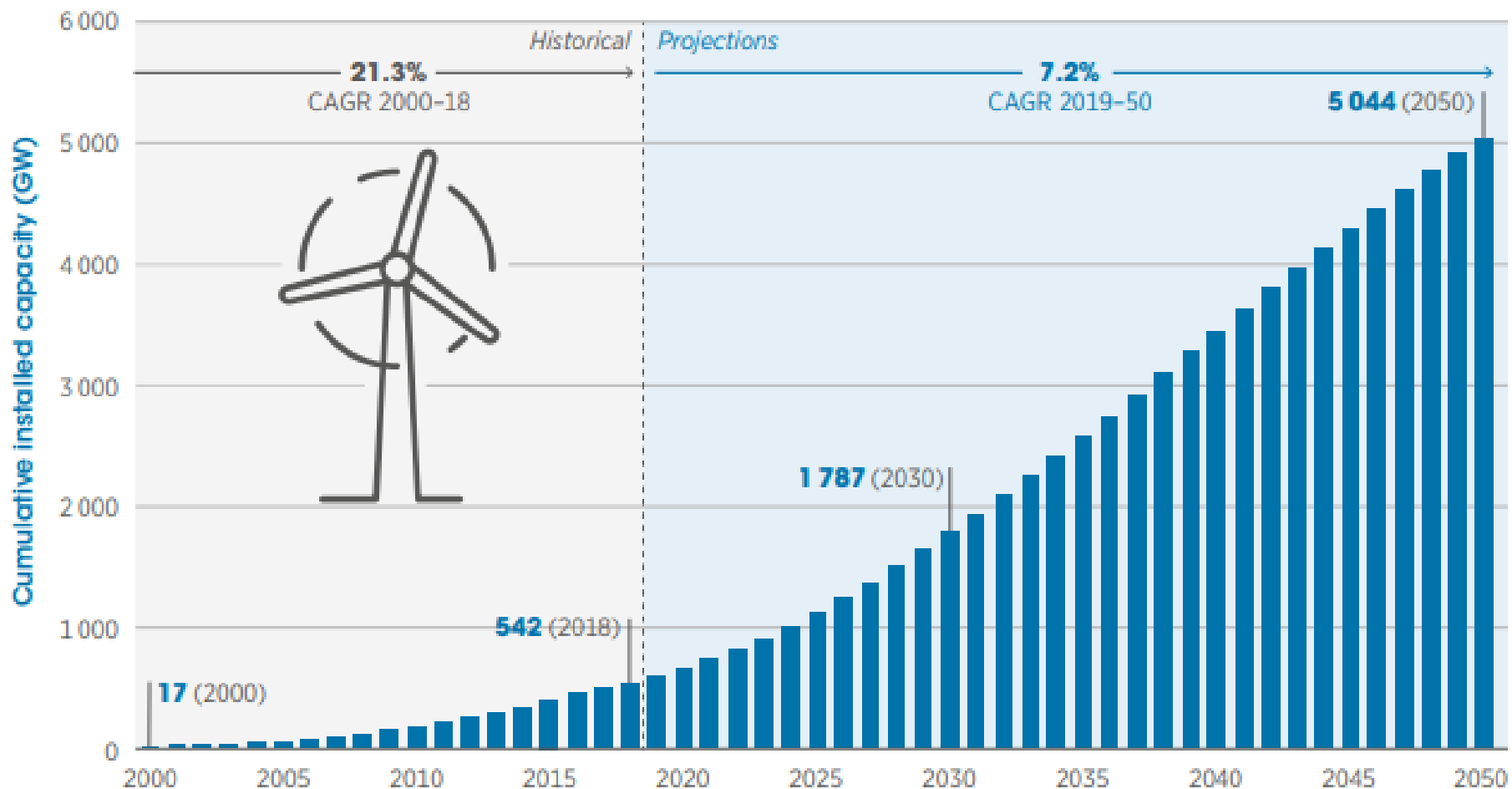
Global Trend of Installed Cost, CF & LCOE, Offshore Wind



Future of Wind

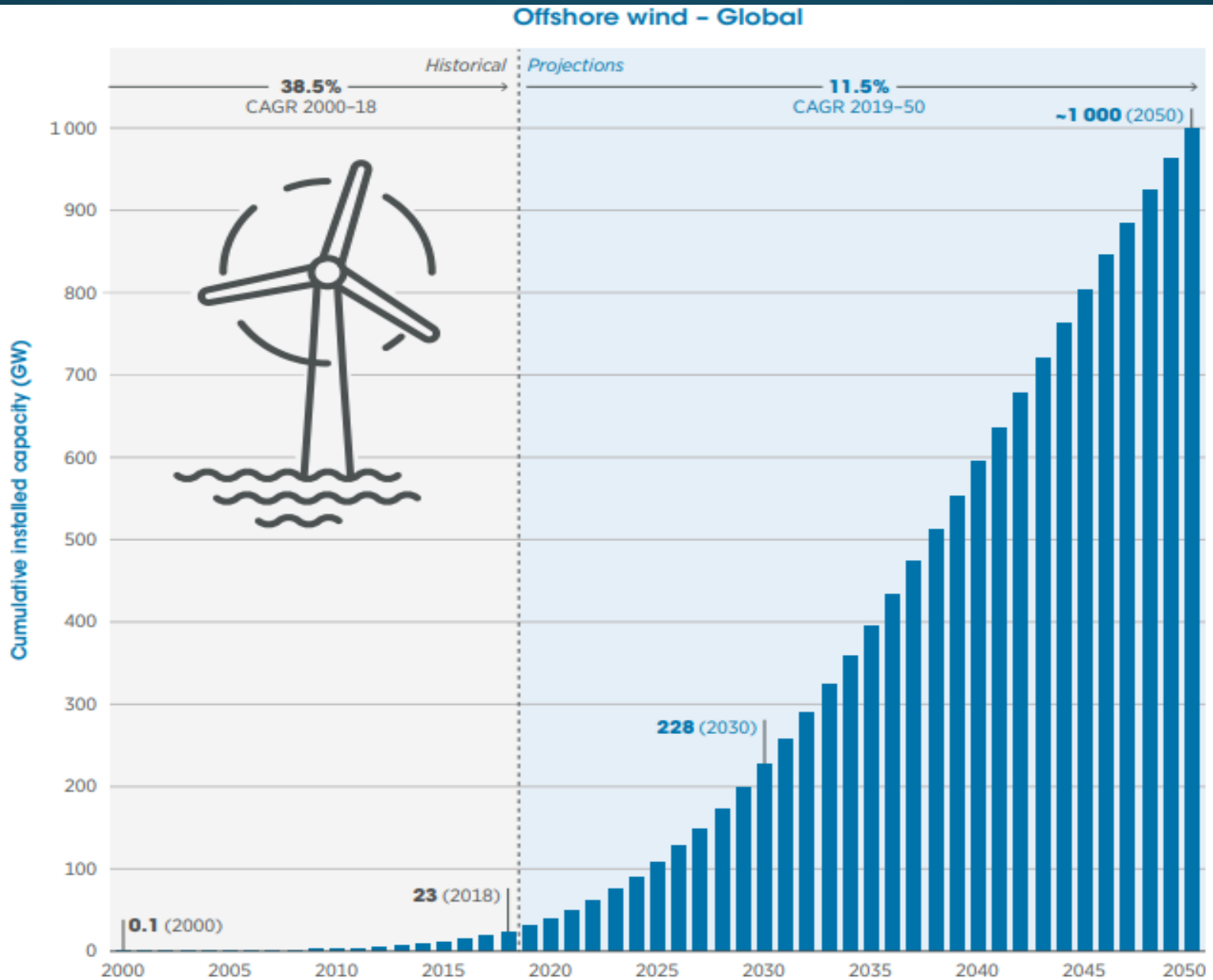
Onshore Wind Future Outlook

Onshore wind - Global



Source: Historical values based on IRENA's renewable capacity statistics (IRENA, 2019d) and future projections based on IRENA analysis (IRENA, 2019a).

Offshore Wind Future Outlook



How sustainable is wind power?



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Source: <https://www.dw.com/en/how-sustainable-is-wind-power/a-60268971>

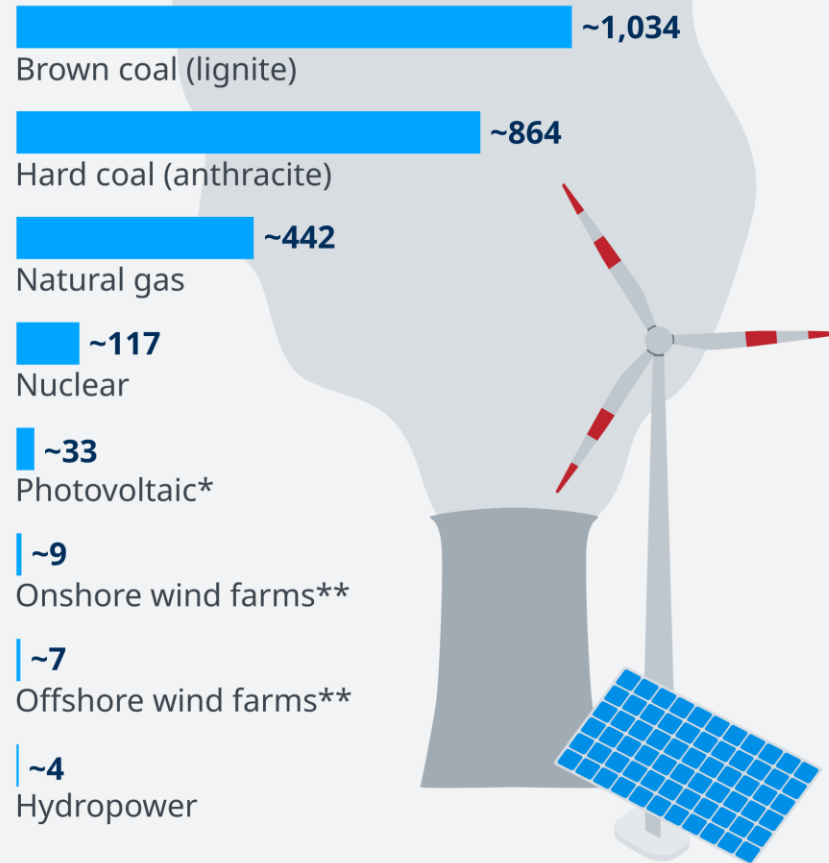
How sustainable is wind power?

But what about the negatives? How much of a wind turbine can be recycled? And what about the impact on species, and especially bird life? What is the lifetime carbon footprint of wind power?

According to the German Environment Agency (Umweltbundesamt, UBA), wind power plants take between 2 1/2 to 11 months to generate the amount of energy that was needed for their construction.

How does electricity affect the environment?

CO₂ equivalent (gram per kilowatt-hour)*



* *complete life cycle*

** *solar panels using silicon*

*** *most recent generation of wind turbines*

What can be recycled?

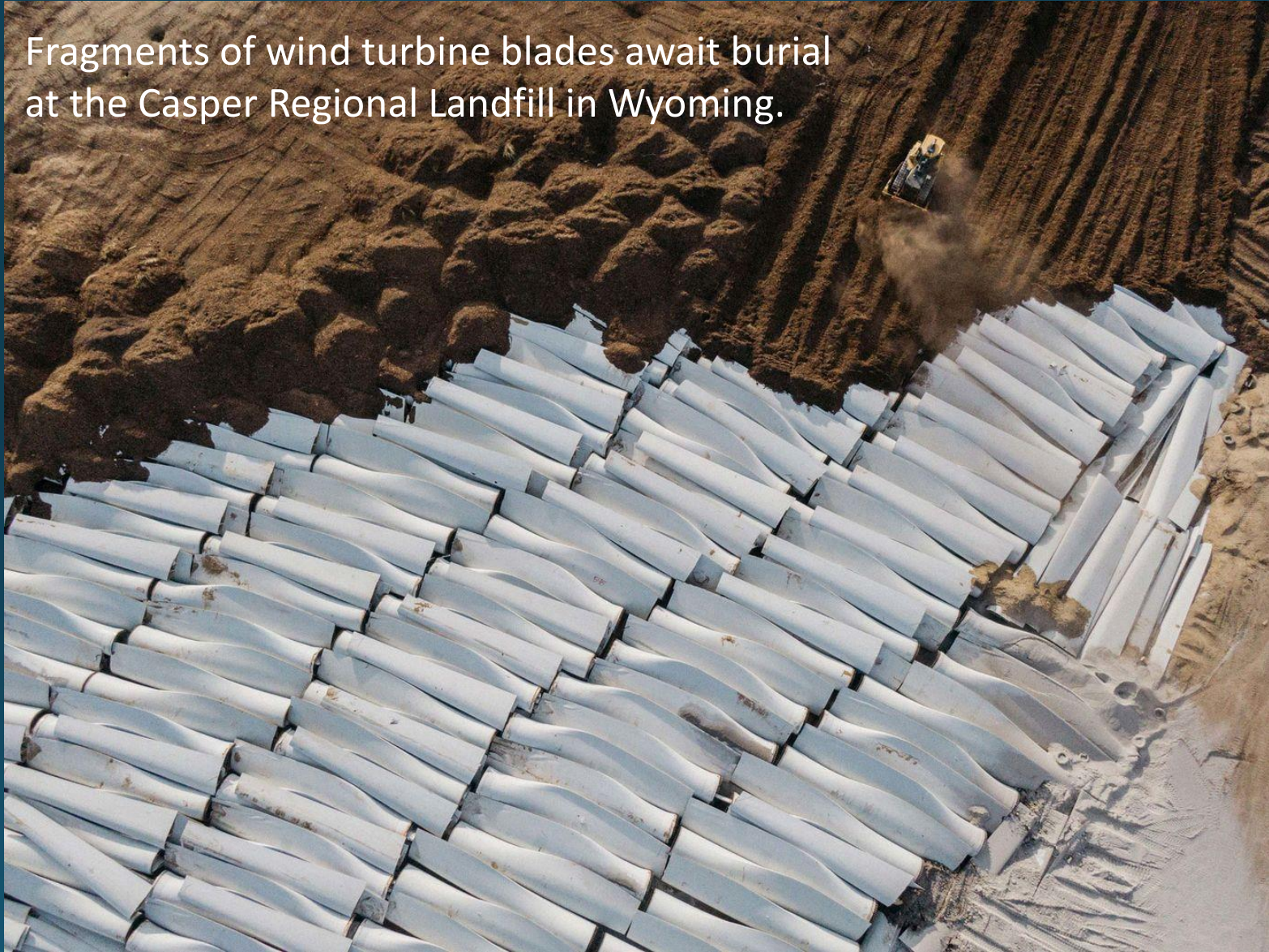
Due to their long lifetime, only a few old plants have so far been decommissioned. But by 2050, up to 50,000 wind farms will need to be shut down and replaced by newer and much more efficient wind power technology.

This will require the disposal of much of the concrete found in the foundation, steel in the tower and the gear box and a compound of plastic with glass or carbon fibre used in the rotor blades.

The concrete can be crushed and used in roadworks, and the precious steel can be recycled into new steel. Other valuable metals such as copper and aluminum can be reused.

What can be recycled?

Fragments of wind turbine blades await burial at the Casper Regional Landfill in Wyoming.



<https://www.bloomberg.com/news/features/2020-02-05/wind-turbine-blades-can-t-be-recycled-so-they-re-piling-up-in-landfills>

Photographer: Benjamin Rasmussen for Bloomberg Green

What can be recycled?

Engineers been working diligently over the past five years to push for the development of a new resin system used in wind turbine blades. Following a step-by-step process, the collaboration has successfully materialized into commercial production of the RecyclableBlade - the world's first recyclable wind turbine blade.

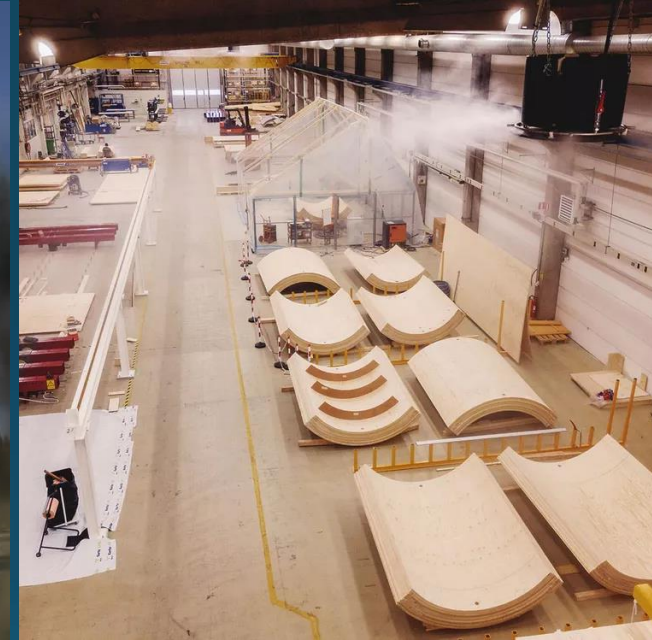


Source: <https://www.siemensgamesa.com/en-int/explore/journal/2021/11/recyclable-blade>

By 2030, the plant constructor Siemens Gamesa plans to only sell recyclable rotor blades: from 2040 the production of the company's wind power plants is expected to be completely carbon neutral.

What can be recycled?

Modvion completed a 30-meter prototype in 2020 and is now working on a 100-meter tower for Varberg Energi. It is now turning out giant curved slabs of LVL that will be glued together into tubular sections on site. This is a major advantage over steel towers, which are usually giant cylinders that are hard to transport and don't fit under bridges.



Source: <https://www.treehugger.com/wood-wind-turbine-tower-low-carbon-footprint-5324270>

The Scandinavian spruce is certified under FSC (Forest Stewardship Council) or PEFC (Programme for the Endorsement of Forest Certification) standards. The carbon emission savings are significant: Modvion states the life cycle emissions of a 360-foot steel tower are about 1,250 metric tons of carbon dioxide (CO₂) while a wood tower has 90% fewer emissions.

Does wind power help with species protection?

Whales, seals and fish have also been disturbed by noisy construction works on the seabed when the foundations for offshore wind plants are built.

From a technical point of view, this problem has largely been solved via a ring of tiny air bubbles used during constructions activities that dampens noise by around 90%.

Offshore wind plants can even have a positive effect on sea animals since the respective area can no longer be used for trawl fishery, allowing fish stocks to recover. Moreover, the plants' foundations become colonized by sea creatures such as mussels.

The future of Wind Power



About 1.3 million people work in the wind industry worldwide. About 550,000 of them are in China, 110,000 in the USA, 90,000 in Germany, 45,000 in India and 40,000 in Brazil. Installing and operating wind turbines is more costly than coal-fired power, so the expansion of wind power is creating more and more jobs.

The future of Wind Power



Wind power has been used for centuries. It pumps water, grinds grain, saws wood and brings sailing ships to their destination. In Europe, there were hundreds of thousands of wind turbines in the 19th century. The Dutch mainly used them to drain marshes. Today, wind power generates clean electricity and is central to meeting climate targets.

The future of Wind Power



Wind turbines often generate the cheapest energy. Electricity from a new coal or nuclear power plant costs two to three times more today. Wind power generated on land is particularly cheap. According to forecasts, the cost of wind power will drop even further, to €0.03 per kilowatt hour (kWh) by 2030 in good wind locations.

The future of Wind Power



A large wind turbine installed near Wilhelmshaven in northern Germany generates 6,000 kilowatts of power and covers the household electricity needs of 10,000 people there. Older models dating back 25 years, only achieved 500 kilowatts — enough for about 500 people. Modern turbines now stretch up to 180 meters into the sky. The taller they are, the more wind they catch.

The future of Wind Power



At sea, the wind is reliable and strong. About 5% of the world's wind power comes from offshore parks like this one off the Dutch coast. Turbines such as these have an output of up to 10,000 kilowatts. From 2025 their capacity is expected to rise to as much as 15,000 kilowatts and provide electricity for more than 40,000 people.

The future of Wind Power



Half of all new wind turbines worldwide are currently installed in China. In 2020 alone, the country built new turbines with a capacity of 52 gigawatts of wind power. That is equivalent to the output of 50 nuclear power plants. The pioneers in wind expansion are Denmark and Germany. Denmark already covers about 50% of its electricity needs with wind power, while Germany achieves 25%.

The future of Wind Power



In the past, sailing ships carried freight all over the world, but then diesel engines took over. Now, modern sails are coming back into play. With additional wind propulsion, the energy consumption of freighters can be reduced by up to 30%. In addition, ships will be able to use green hydrogen as fuel in the future.

The future of Wind Power



There is enough space in the sea for wind power. But in many places the water is too deep for a foundation in the seabed. Floating turbines on buoys are an alternative. They are fixed to the seabed with long chains. Floating wind farms already exist in Europe and Japan, and remain stable even during storms.

The future of Wind Power



The 147-meter-high Strata SE1 skyscraper in London is an eye-catcher with futuristic wind turbines. But such rooftop installations are usually not economical, because the wind in cities is generally too weak. Photovoltaic systems on roofs are almost always the more efficient alternative.

The future of Wind Power



Within 3 to 11 months, wind turbines generate the energy required to build them. No CO₂ is produced in the electricity generation process but they do alter the landscape. Still, compared to other energy sources, they come off best in the environmental balance sheet. According to Germany's Federal Environment Agency, their environmental cost is 70 times lower than that of coal-fired power.

Questions