RES4Africa Foundation Knowledge Platform

Wind technologies

Siemens Gamesa

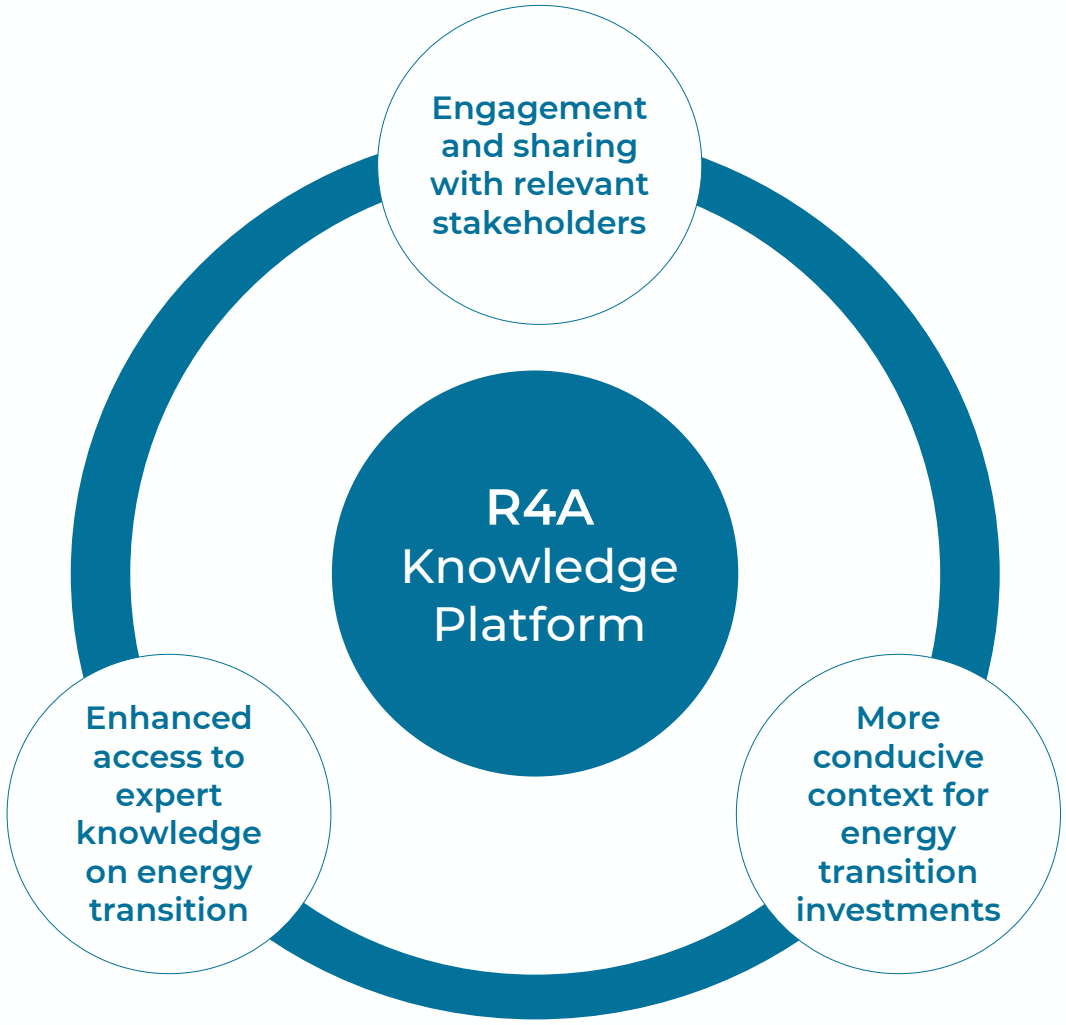
RES4AFRICA FOUNDATION

The RES4Africa Knowledge Platform offers a set of content-driven, technical-functional training

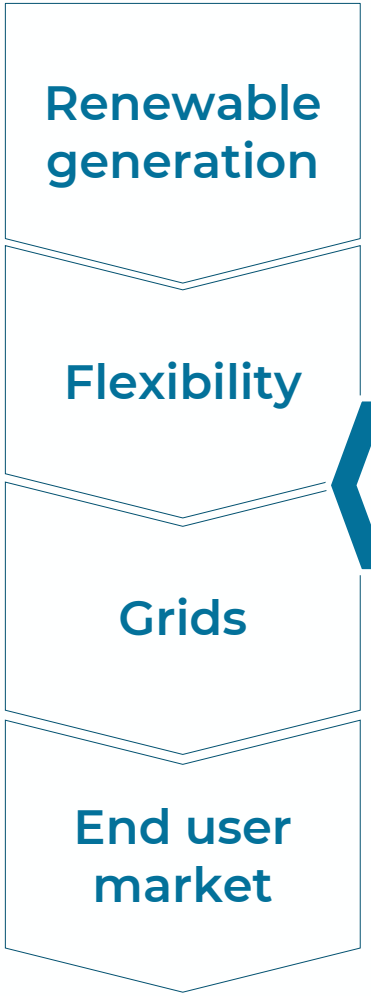
The aim of the RES4Africa Knowledge Platform is to establish a public platform of technical training content, usable by third parties in accordance with the Foundation's core principles of a think tank and open hub for knowledge sharing.

The purpose of the Platform is to offer a set of technical-functional content, organized in sharp modules covering renewable energy and more in general the key topics part of the energy transition.

The modules will be also delivered to on-request professionals of the energy sector (e.g., Energy Ministries, Regulatory Authority, vertically integrated incumbents, Associations, other relevant parties).



The Platform covers all the key areas of energy transition, with a comprehensive perspective across the value chain



The Platform covers the following thematic areas:

Technologies: a comprehensive understanding of different technological options and features / potential is a pre-requisite for a successful planning and implementation of fully functioning energy systems

Policies and regulations: must go hand in hand with measures ensuring that industrial and other economic capabilities are aligned with sustainable development and climate priorities

Access to market: Successful deployment of RES and flexibility technologies depends on how effectively MWh produced can be sold on the market and to what extent risk is properly hedged

Permitting: one of the key hurdles that developers face, especially for utility-scale RES projects. Key common issues can be identified, and proper management principles can be set up

Financing: bankability is one of the highest impact factors to ensure that utility-scale RES projects are successfully deployed. Compliance with requirements from international funding entities is fundamental

Operation: considering the level of maturity reached by RES technologies, a significant share of the value that can be extracted by RES projects stems from an advanced asset management approach

Sustainability: is progressively becoming a top priority for investors and energy industry stakeholders in assessing investment opportunities. A more comprehensive evaluation approach must be adopted

Wind power can to play a decisive role for Africa's energy transition

The Platform covers the following thematic areas:

Technologies

Policies and regulations

Access to market

Permitting

Financing

Operation

Sustainability

Wind technologies are crucial enablers for sustainable growth

What is the context: wind power stands out as an exceptionally clean and abundant source of renewable energy. Together with other renewables like solar power, it has the advantage of producing no harmful emissions or greenhouse gases. Additionally, wind technologies are highly effective in generating reliable and green electricity

Why is this relevant: By evaluating the latest advancements and enhancements in wind energy technologies and systems, we can gauge the substantial advantages it offers and forecast its future direction

What are the key questions:

— What are the basics of wind power?

— What have been the major developments and improvements?

— What are their implications?

— How can they support Africa's green transition?

Company profile – Siemens Gamesa in Africa

670 MW
Under construction

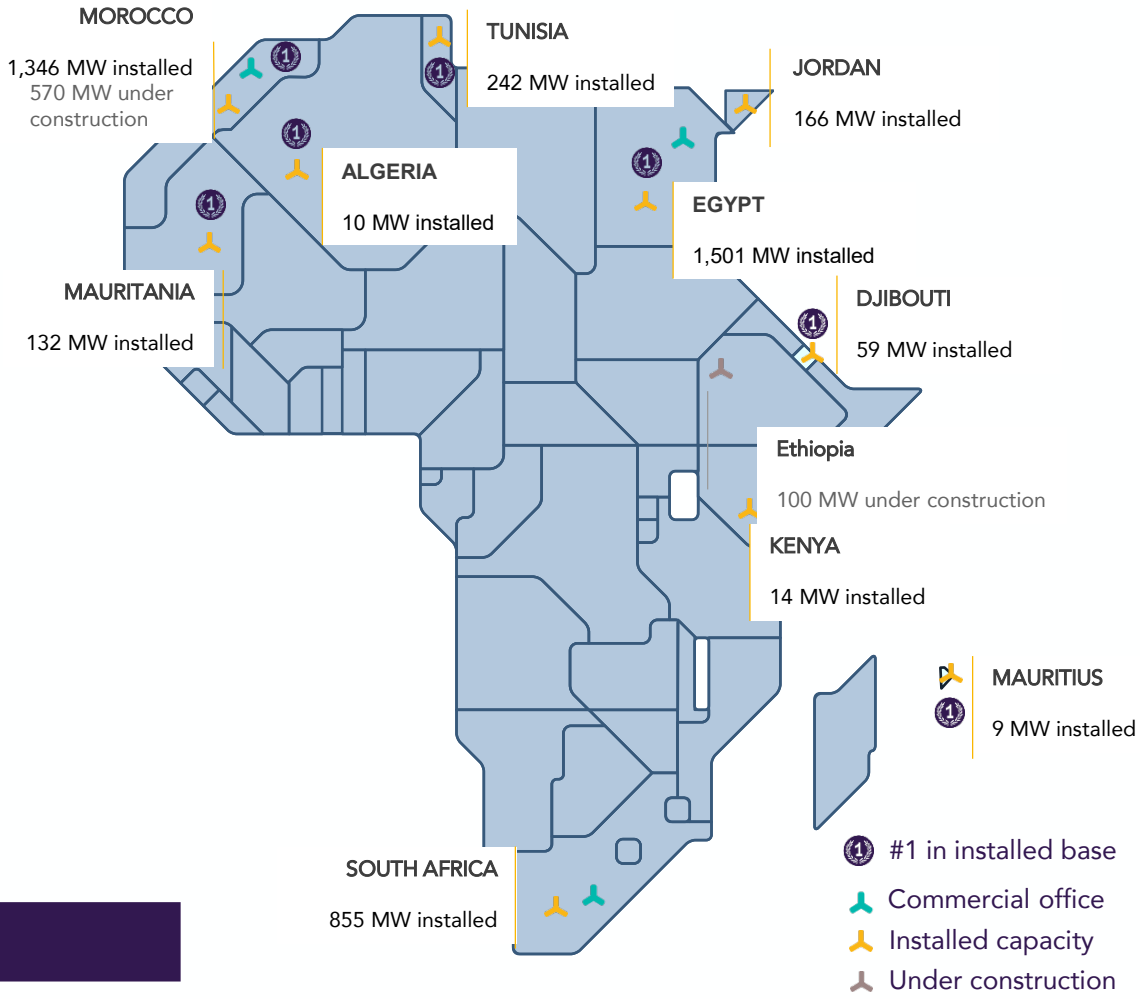
3,102 MW
under maintenance

4,334 MW
of installed power

46.9%
market share

Figures as of CY2Q2022.

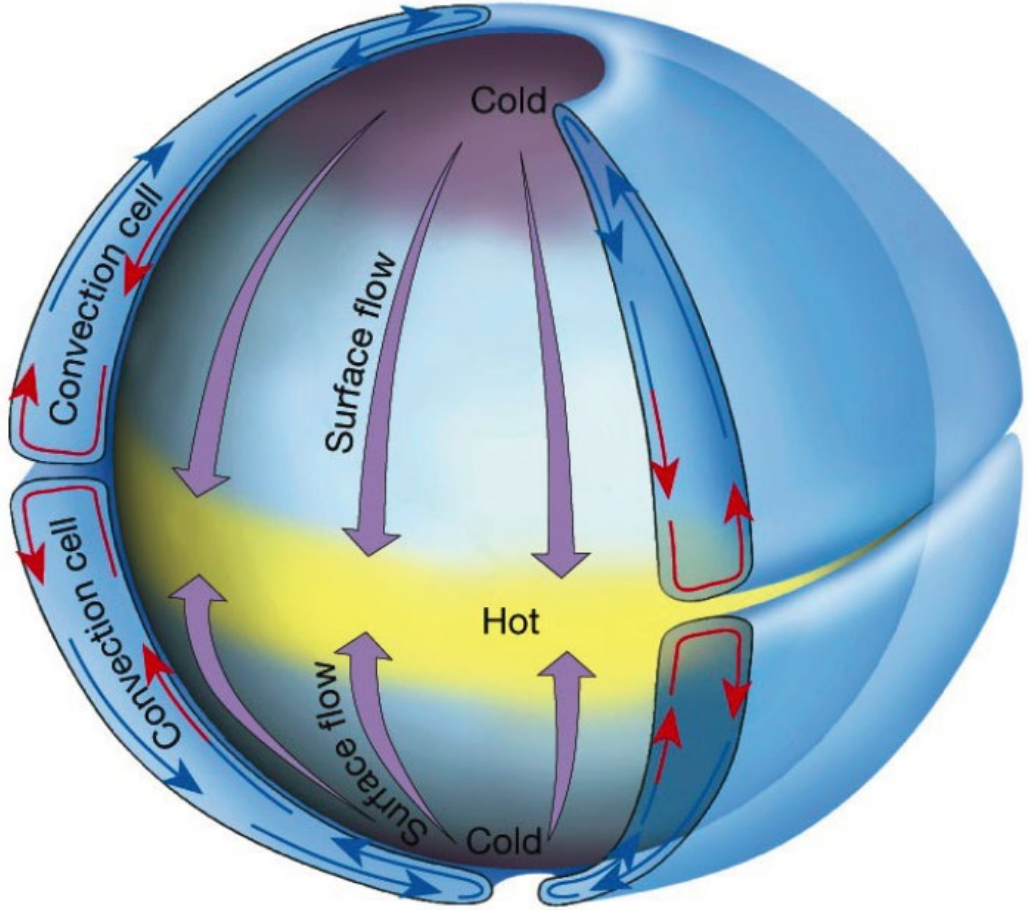
Leaders in the continent with 4.3 GW installed



Introduction to energy basics: wind and meteorology

Source of the wind

- The wind is mainly due to the **uneven solar radiation on the Earth surface**. An air flow is generated by the temperature gradient between the cold poles and the hot equatorial area.
- At the equator, the air is heated at the ground level and rises until it is not buoyant. At this point it is forced to go poleward by the air below continuously rising.
- As it goes towards the poles, the air cools down and starts sinking towards the ground.
- Around 1-2% of solar radiation is converted into wind. The mean power density of solar radiation is approximately 1.4 kW/m^2.
- Therefore, the cross-section of Earth receiving solar radiation is around 10^{14} m^2. The **wind power around Earth is huge** ! (1,4* 10^8 GW)

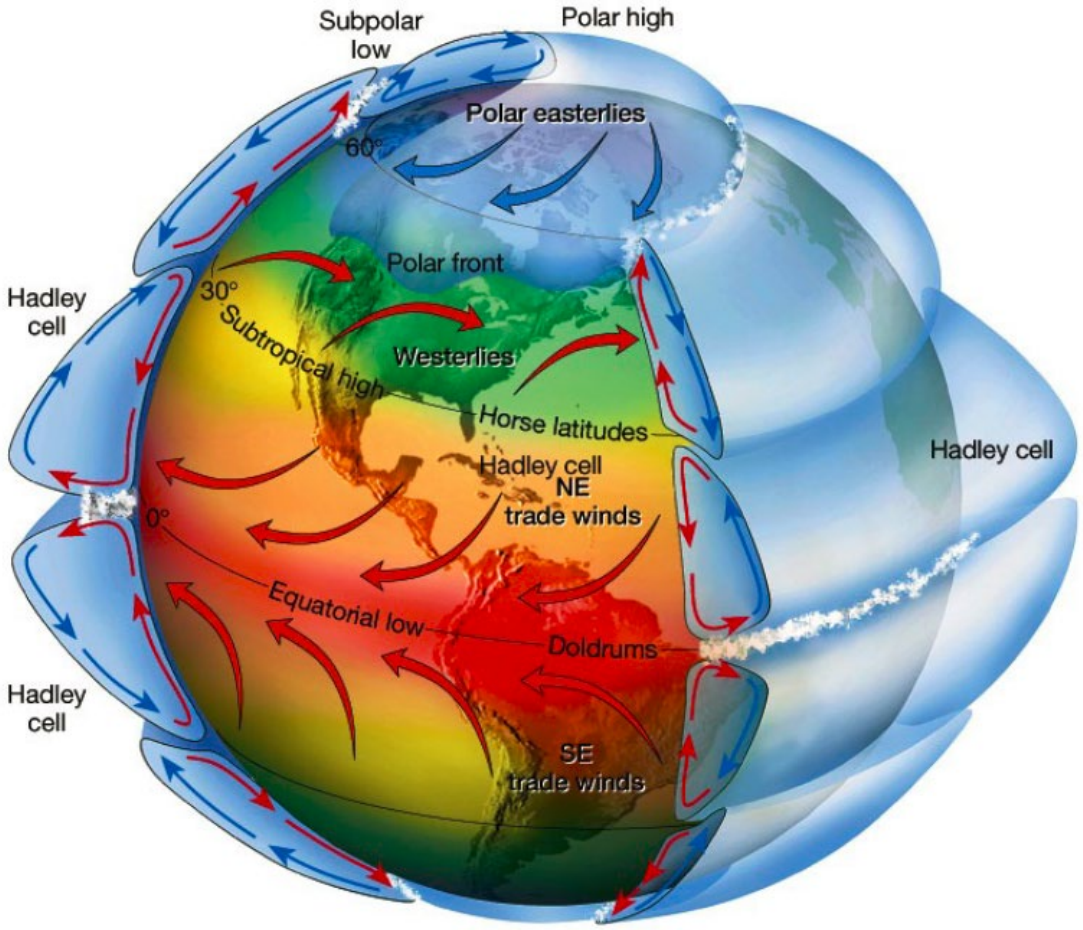


Source : *The Atmosphere, 8th edition*, Lutgens and Tarbuck, 8th edition, 2001

Introduction to energy basics: wind and meteorology

Source of the wind

- The **Coriolis force** due to Earth rotation also creates a force on the air around the Earth. The **geostrophic** wind is the flow created by the equilibrium between the Coriolis force and the force due to the temperature gradient.
- Cells are created by a mechanism involving both the effect of the temperature gradient and the Coriolis force.
- This mechanism creates prevailing winds, i.e in a given region, winds will in average blow in a dominant direction.

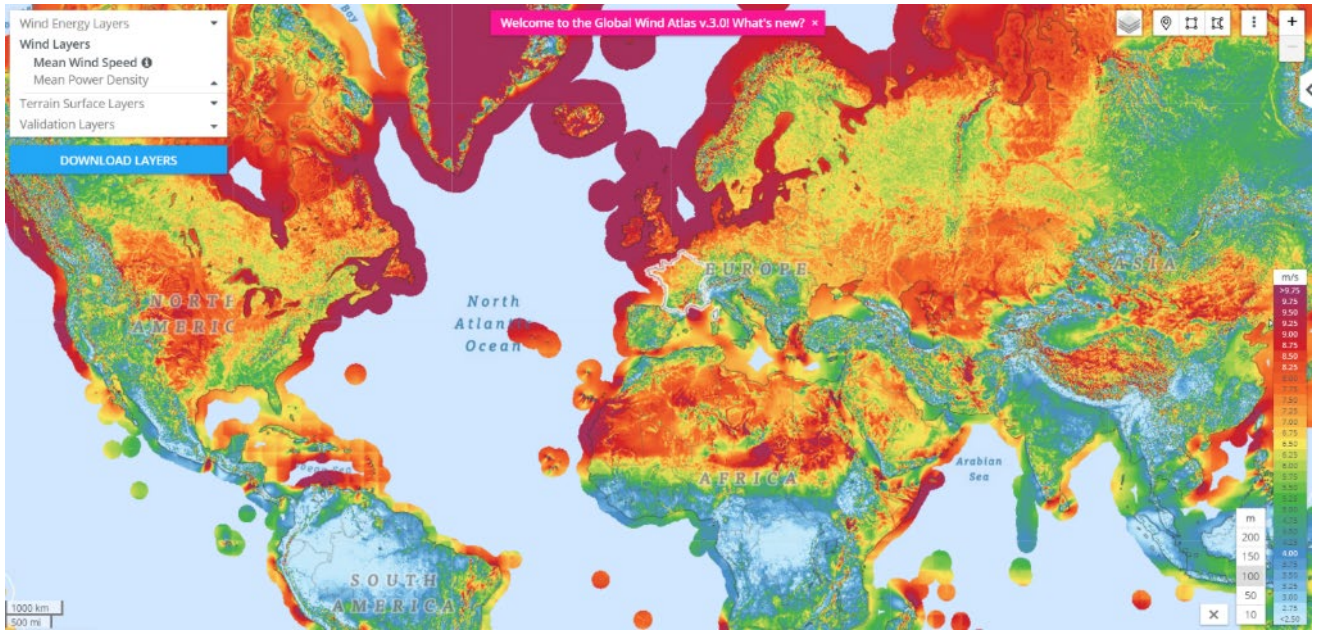


Source : *The Atmosphere, 8th edition*, Lutgens and Tarbuck, 8th edition, 2001

Introduction to energy basics: wind and meteorology

Wind resource

- The local **wind resource** can be evaluated in terms of wind power density or mean wind speed.
- The **Global Wind Atlas database** provides a map of the onshore wind resource.
- It is based to a downscaling process. It starts with large-scale climate data and uses physical models to calculate the wind speed on a finer mesh, taking into account variables like the terrain topology.
- This figure shows the mean wind speed at a height of 100m.
- More information and data can be found at



Source : https://globalwindatlas.info/

Does Africa have a good wind resource? 1/3

IFC engaged Everoze & Vortex to answer this question:

1. Assessment of technical potential for entire continent using basic constraints

2. Identify short-list of countries for detailed assessment

3. Detailed analysis of target countries using deeper constraints

Everoze assumptions:

- Use high resolution wind data:
- Global Wind Atlas: 250m x 250m resolution
- Modern turbines matched to site conditions:
- Hub height = 125 meters
- Rotors = 120-to-158-meter diameter
- Rated power = 4.3 to 5.3 MW
- Apply basic constraints for technical and E&S:
- Wind speed, elevation, slope, urban areas
- High population density, protected areas
- More detailed constraints will come later

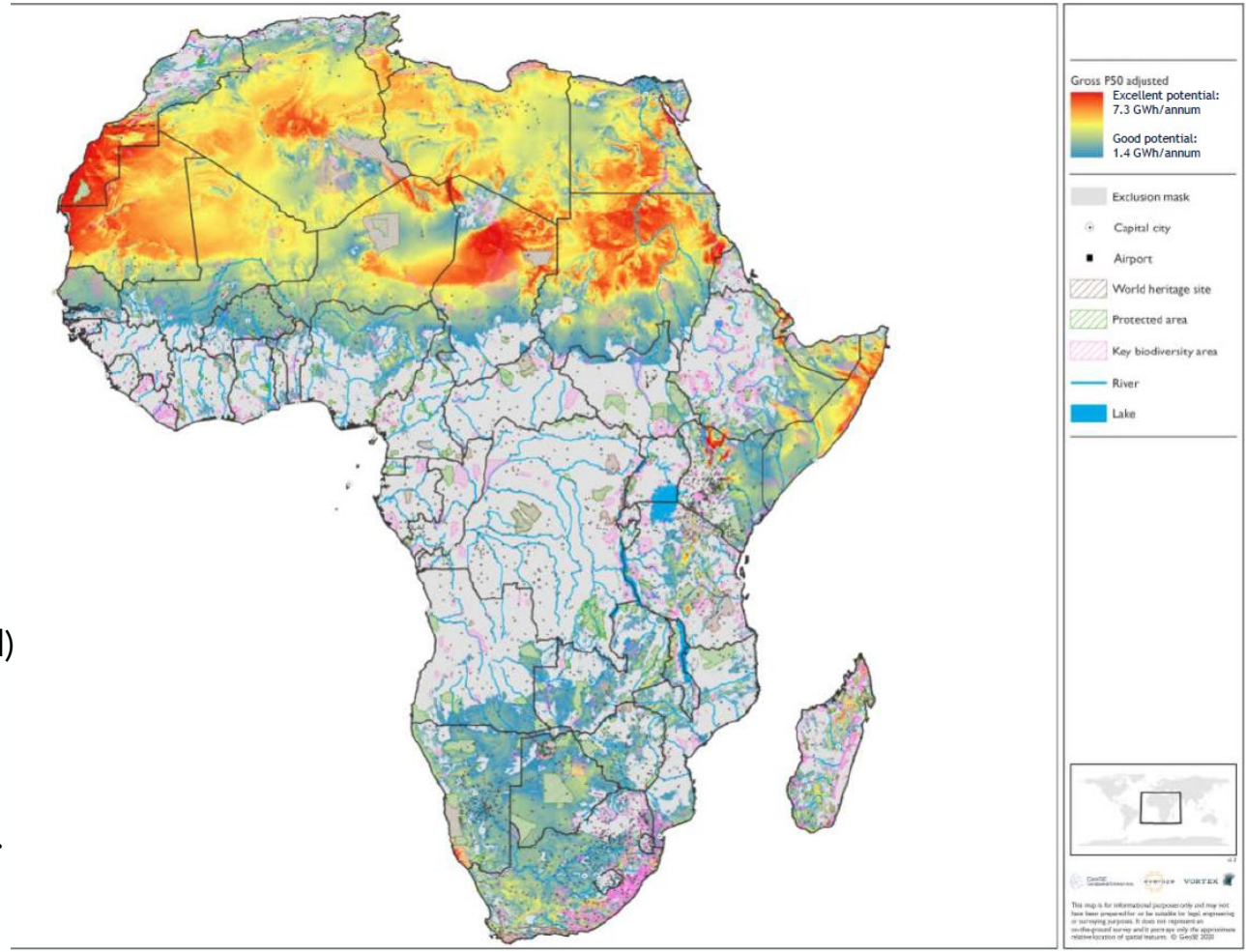
Constraints	Exclusions
Wind resource quality	Exclude if wind speed < 6.0m/s at 150m Exclude if wind speed > 16.0m/s at 150m
Elevation	Exclude if elevation > 2,000m
Slopes	Exclude if slopes > 20%
Land use cover	Exclude urban areas and airports (2km)
Population density	Exclude if population density > 200 people/km^2
Water bodies	Exclude
Protected areas	Exclude if UNESCO World Heritage site Exclude if IUCN Protected Area Management codes Ia, Ib and II.

Source : Exploring Africa's untapped wind potential
Sean Whittaker, Principal Industry Specialist, IFC, October 5, 2020

Does Africa have a good wind resource? 2/3

Africa has great wind resources!

- Total wind potential = 180,000 TWh/yr = 250x current continental demand
- Two-third are locations with wind > 7.5 m/s
- One-third is in locations with wind > 8.5 m/s, yielding very high productivity
- 27 countries on their own could satisfy the entire continental electricity demand (17 of these have average capacity factors over 30%)
- Many countries with no projects have great potential:
  - Algeria: 24,980 TWh (34% in high wind)
  - Tanzania: 1,564 TWh potential (12% in high wind)
  - Malawi: 322 TWh potential (7% in high wind)
  - Namibia: 4,399 TWh (3% in high wind)
  - Nigeria, Cameroon, Mozambique, Ivory Coast …



Source : Exploring Africa's untapped wind potential
Sean Whittaker, Principal Industry Specialist, IFC, October 5, 2020

Does Africa have a good wind resource? 3/3

- Technical potential: Only locations with wind > 8.5 m/s
- Total potential for high-wind only = 16,600 GW ➔ 64,700TWh/year

Rank	Country	P50 [TWh/annum]	Capacity [GW]	CF [%]
1	Sudan	11,705.8	3,294.4	40.5%
2	Mauritania	11,515.5	3,307.1	39.7%
3	Algeria	8,591.8	2,602.2	37.7%
4	Chad	7,470.8	1,994.7	42.7%
5	Libya	5,373.6	1,659.9	36.9%
6	Egypt	4,021.2	1,164.4	39.4%
7	Mali	3,654.0	1,173.6	35.5%
8	Niger	3,174.1	940.8	38.5%
9	Somalia	1,652.3	477.1	39.5%
10	Kenya	533.2	139.6	43.6%
11	Morocco	519.1	143.0	41.4%
12	Tunisia	503.0	150.8	38.1%
13	Ethiopia	355.2	107.4	37.7%
14	Somaliland	324.7	97.4	38.1%
15	Madagascar	320.3	91.2	40.0%
16	South Africa	246.9	75.1	37.5%
17	United Republic of Tanzania	184.7	55.9	37.7%
18	Eritrea	179.3	49.5	41.3%
19	Namibia	139.1	38.3	41.4%
20	Djibouti	97.0	26.0	42.5%
21	Malawi	21.3	6.8	35.7%
22	Nigeria	9.4	2.9	36.9%
23	Zambia	7.7	2.5	35.3%
24	Mozambique	7.2	2.2	37.4%
25	South Sudan	3.5	1.1	37.5%
26	Botswana	1.9	0.6	33.4%
27	Zimbabwe	1.9	0.6	36.0%
28	Democratic Republic of the Congo	0.6	0.2	35.6%
29	Ghana	0.6	0.2	36.3%
30	Cameroon	0.6	0.2	36.9%

Source : Exploring Africa's untapped wind potential
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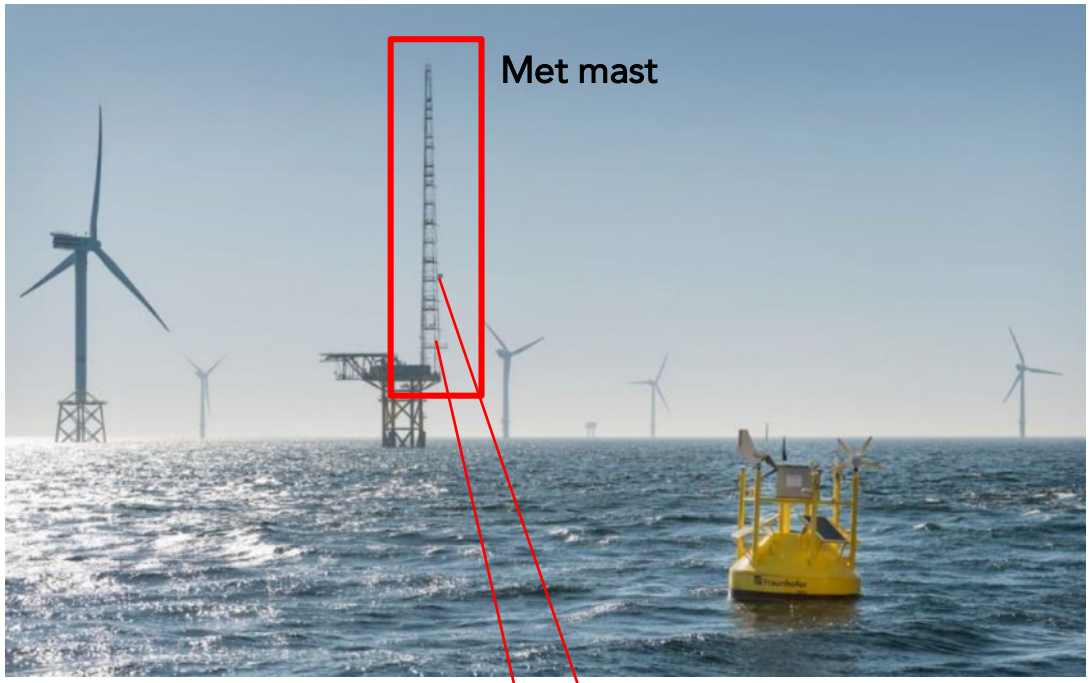
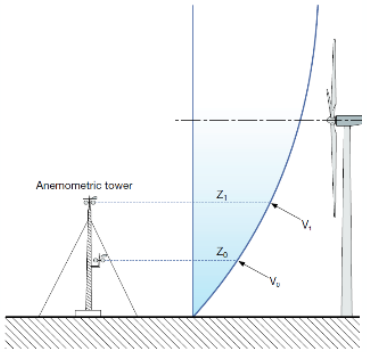
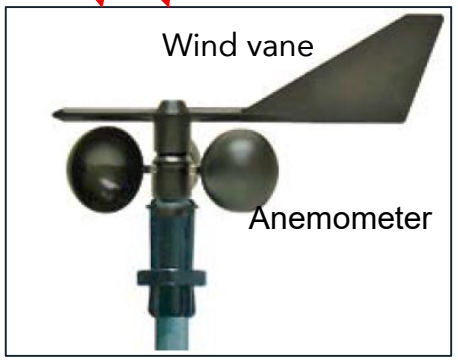
Wind measurement

- For siting processes and turbine development, a **characterization of the wind at a specific location** can be needed.
- **Data on the winds** needs to be collected in order **to assess the wind resource to select a site, or to be fed to a numerical simulation code**. It includes: wind direction, wind velocity, wind shear, temperature, pressure, humidity
- A usual way to collect data is to use a so-called '**met mast**' (or measurement tower). A met mast is equiped with instruments and sensors to measure wind characteristics.
- A met mast is usually equiped with **anemometers** (speed measurement) and **wind vanes** (direction measurement) at several vertical locations.
- This data can be used to calculate wind **veer** (direction gradient over height) or **shear**, and for example to fit a power law to model wind shear.
- It is also usually equipped with thermometers and pressure sensors.







Ultrasonic anemometer

Source : ABB Technical Papers No. 13

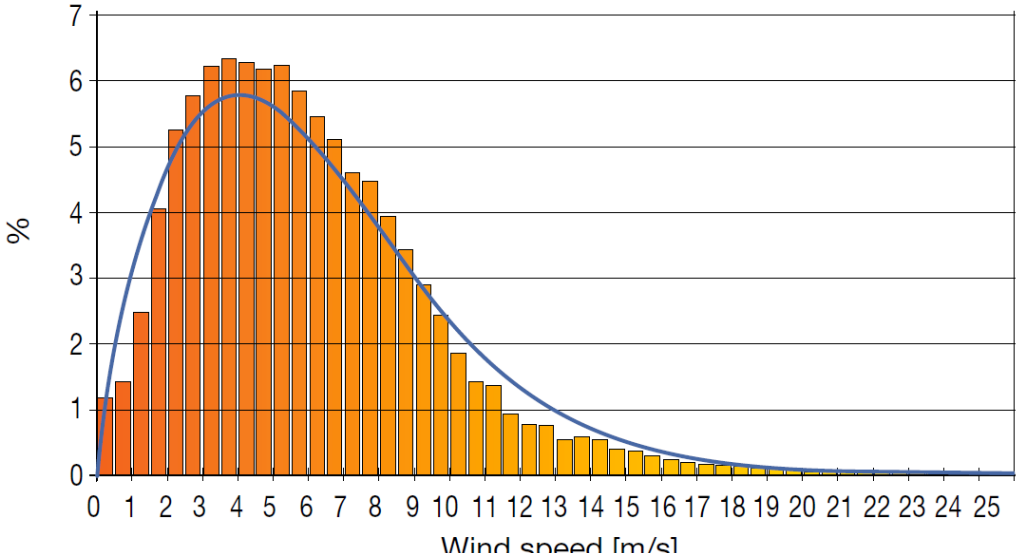
Siting

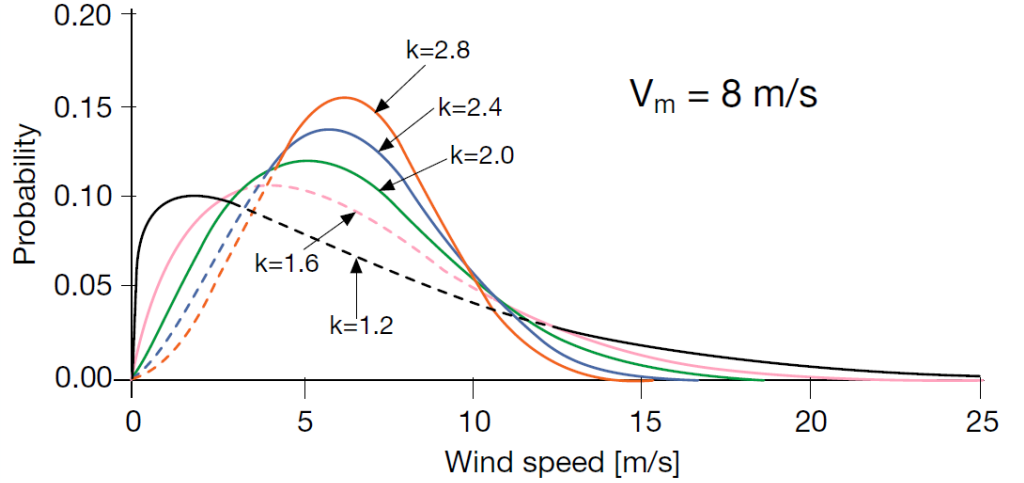
- During the siting process, wind data collected by measurement instruments is post-processed to get valuable information.
- A **probability distribution of the wind speed** can be calculated from the data collected by the anemometers.
- In practice the wind speeds are distributed around a mean value. The **Weibull function** is well adapted to fit this distribution.

$$f(v) = \frac{k}{A}\left(\frac{v}{A}\right)^{k-1} \exp\left(-\left(\frac{v}{A}\right)^{k}\right)$$

- The k parameter is related to the shape of the distribution. A low value will fit with asymmetric distribution, while a higher value will be adapted for symmetric ones.
- The A parameter is closely related to the mean wind speed.

Example of wind distribution fitted by a Weibull function



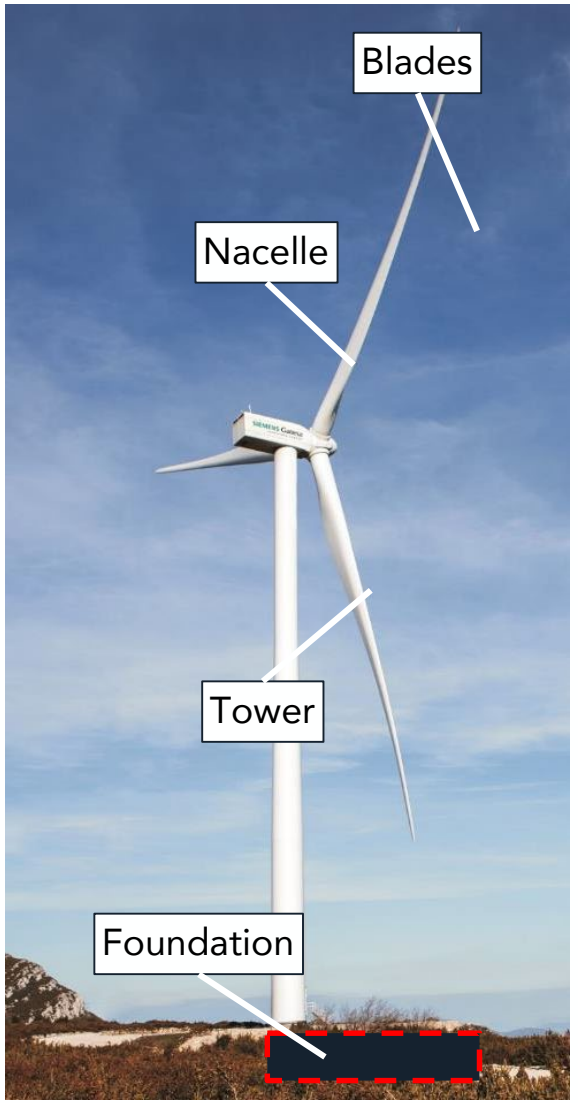


Source : ABB Technical Papers No. 13

Wind turbine features

Overview of a wind turbine

- Let's start with some vocabulary…
- The **nacelle** is the part containing the main systems of the machine. It is mounted on the **tower**, which is fixed to the ground by the **foundation**.
- The **blades** extract the wind energy. They are connected to the nacelle by the **hub**. The hub+blades assembly is called '**rotor**'.
- The acronym 'RNA' is often used to refer to the '**Rotor-Nacelle Assembly**'.

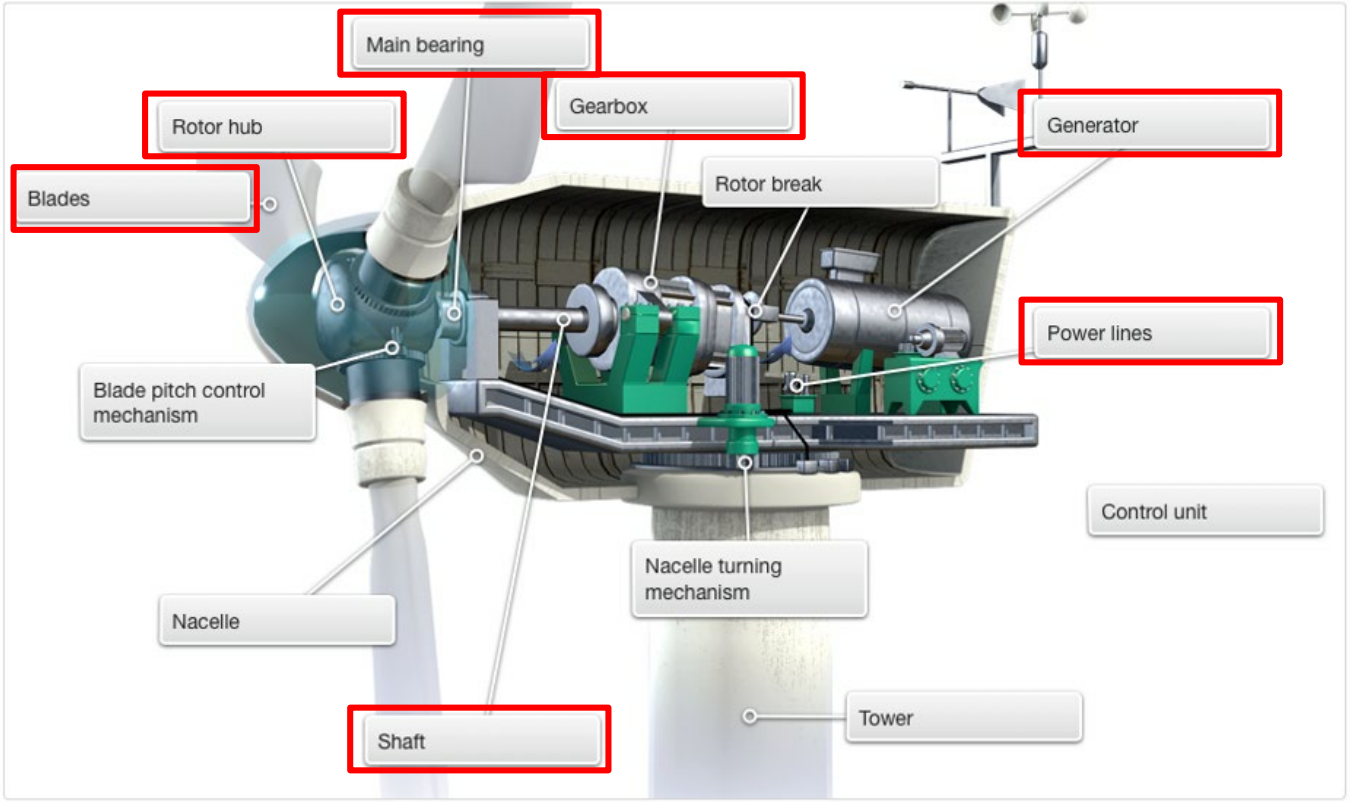


A wind turbine **extracts energy from the incoming wind** through its blades to make its rotor rotate. The rotation motion is transfered to a generator that converts the mechanical energy into electricity.

Source: Siemens Gamesa Renewable Energy

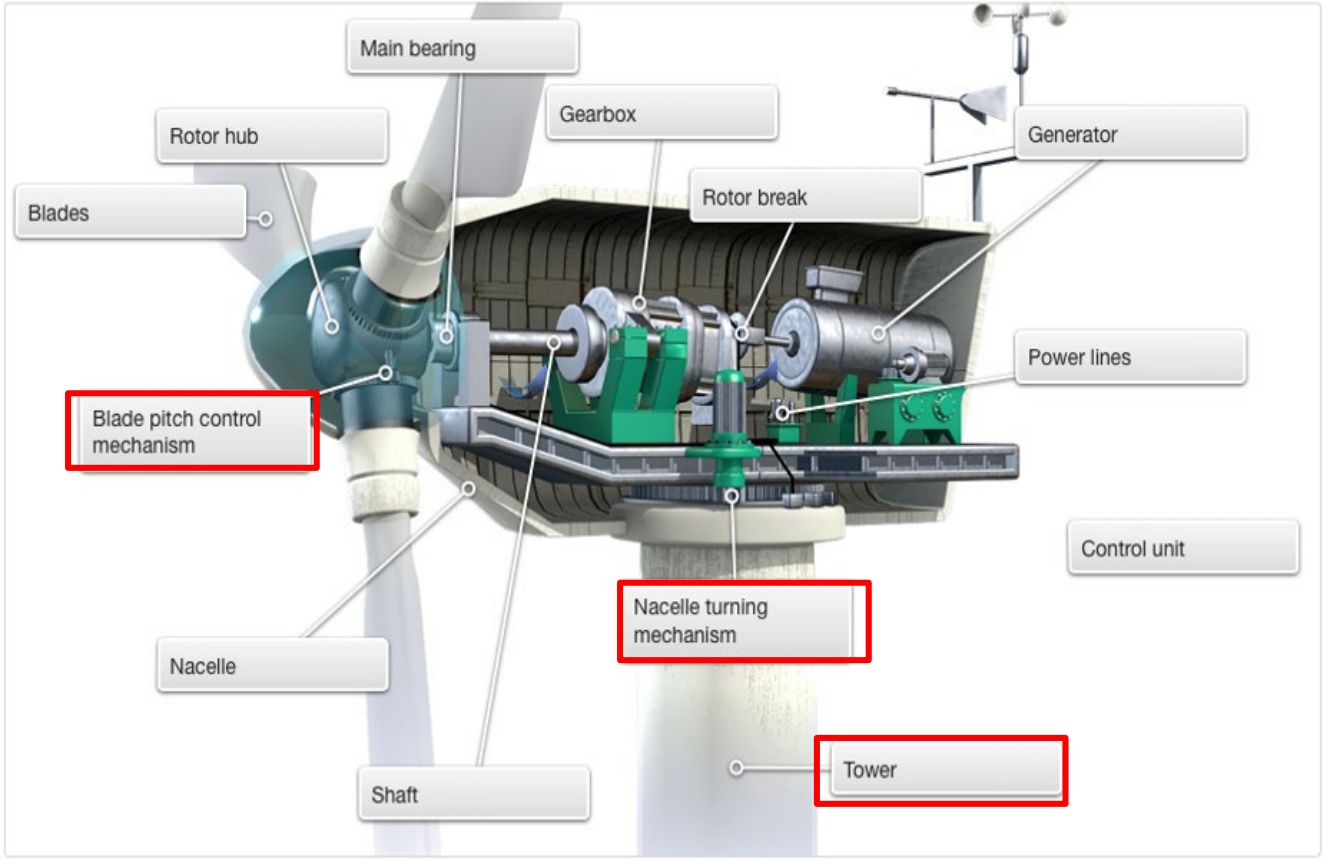
Wind turbine features
Inside the nacelle

- The blade power is transmitted to the generator through the hub, 2 **shafts** and a **gearbox**.
- The low-speed shaft connects the hub to the gearbox input. The high-speed shaft connects the gearbox output to the generator.
- The gearbox transform the high torque and low rotation speed of the rotor (~10 rpm) for the generator (low torque and high rotation speed ~1000 rpm).
- Large bearings help the shafts to transmit power smoothly.
- The electric power produced by the generator is transmitted to a **transformer** (not shown) then down the tower through **power lines**.



Wind turbine features
Inside the nacelle

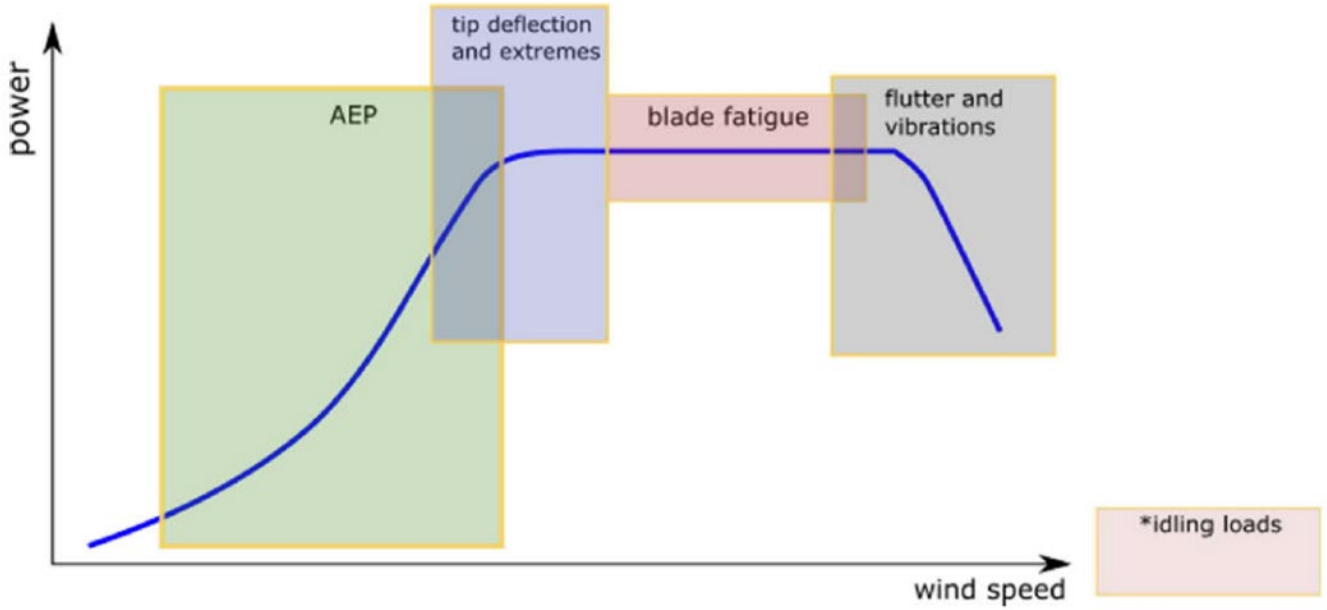
- The **blade pitch system** allows for the blade to rotate around its axis.
- The **nacelle yaw system** allows for the whole RNA to rotate around the tower axis.
- A **hydraulic unit** (not shown) makes oil circulate through systems that require it (gearbox, etc.).
- A **cooling unit** (not shown) evacuates heat produced by the generator outside.
- Hundreds of **sensors** inside and outside the nacelle constantly monitor the turbine state. It includes different types of sensor (accelerometers, thermometers, **anemometers**, strain gauges, rpm sensors, etc.).
- A complex **control system** (not shown) processes the sensor signals to control different turbine components.



Wind turbine features
Turbine design targets

- The design of a wind turbine is driven by 3 main factors:

- **Performance**
  - The turbine should produce an AEP as high as possible
  - It should be designed to extract as much power as possible from the wind below the wind speed
- **Loads**
  - The turbine should resist to the fatigue and extreme loads
  - Especially around and above rated wind speed
- **Stability**
  - The turbine should not vibrate because of mode resonance and aero-elastic instabilites

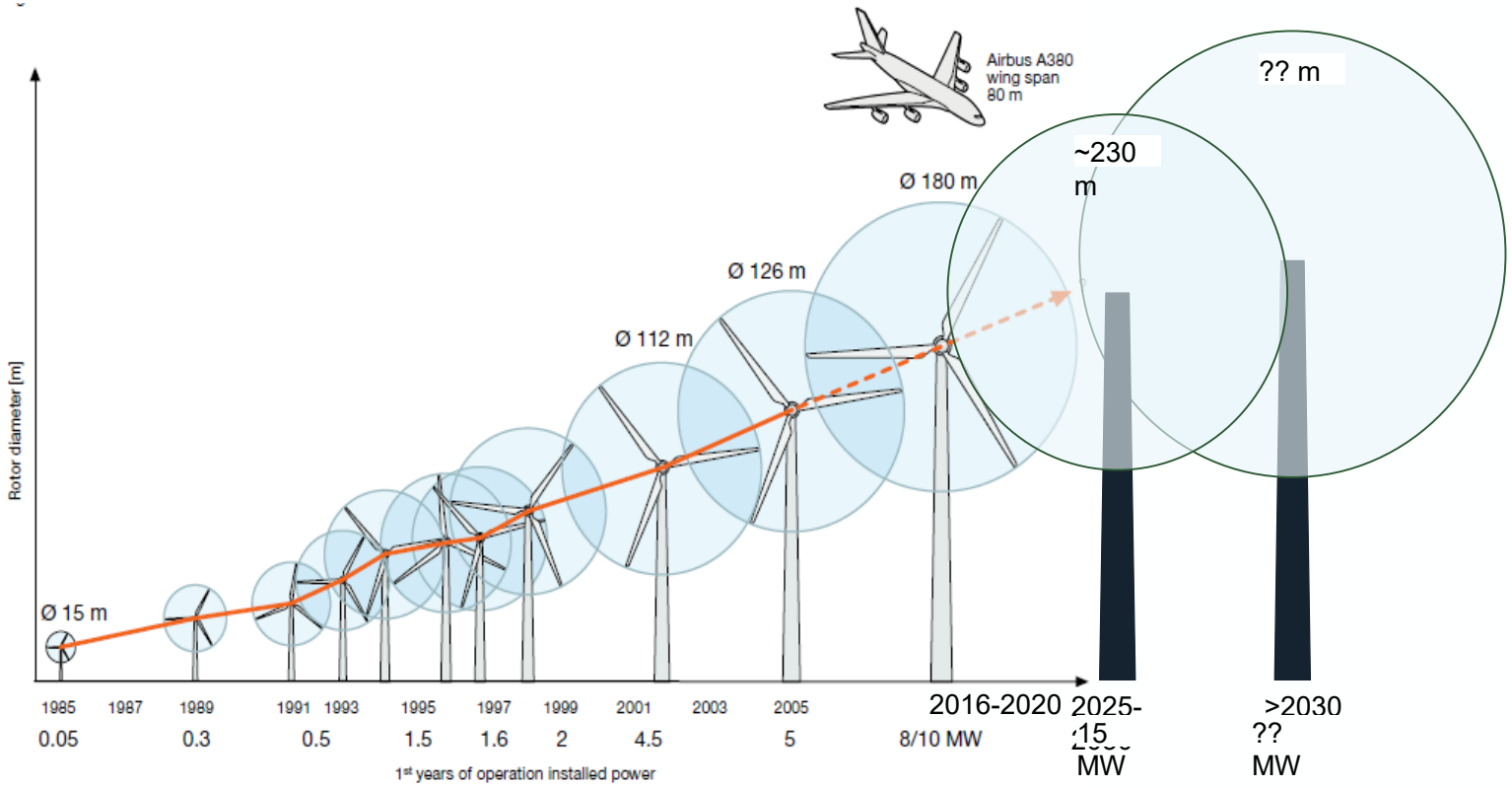


→ The turbine controller is a key component to reach those targets

Wind technology evolution

Evolution of wind turbines

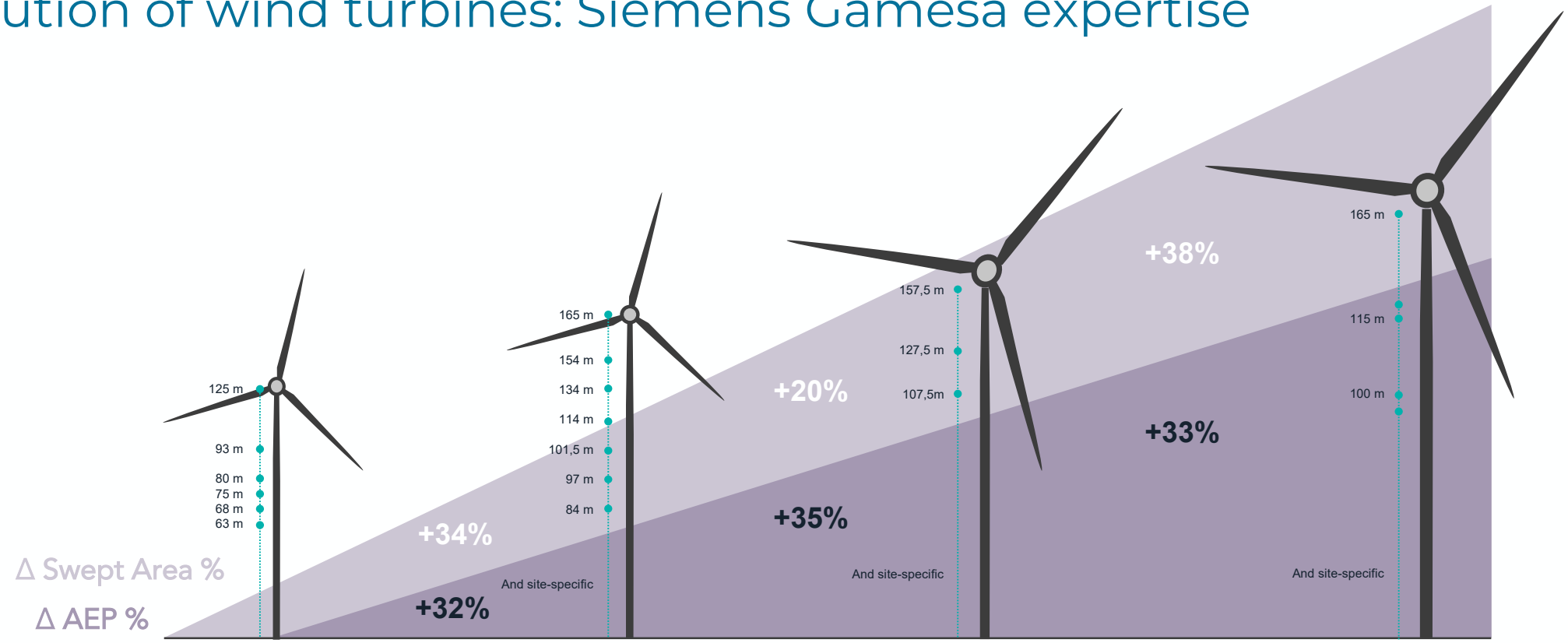
- Starting in the 90s, wind turbines have been industrialized, with a power output of the order of magnitude of 100 kW.
- To increase turbine competitiveness, **rotor size and power output have rapidly increased during the last decades**.
- Today, usual onshore turbines have a power output between 4-7 MW for a rotor diameter between 130-180 m.
- Larger and larger turbines are developed for the offshore market, with a power output up to 14 MW for a blade length above 100 m.



Source : ABB Technical Papers No. 13

Wind technology evolution

Evolution of wind turbines: Siemens Gamesa expertise



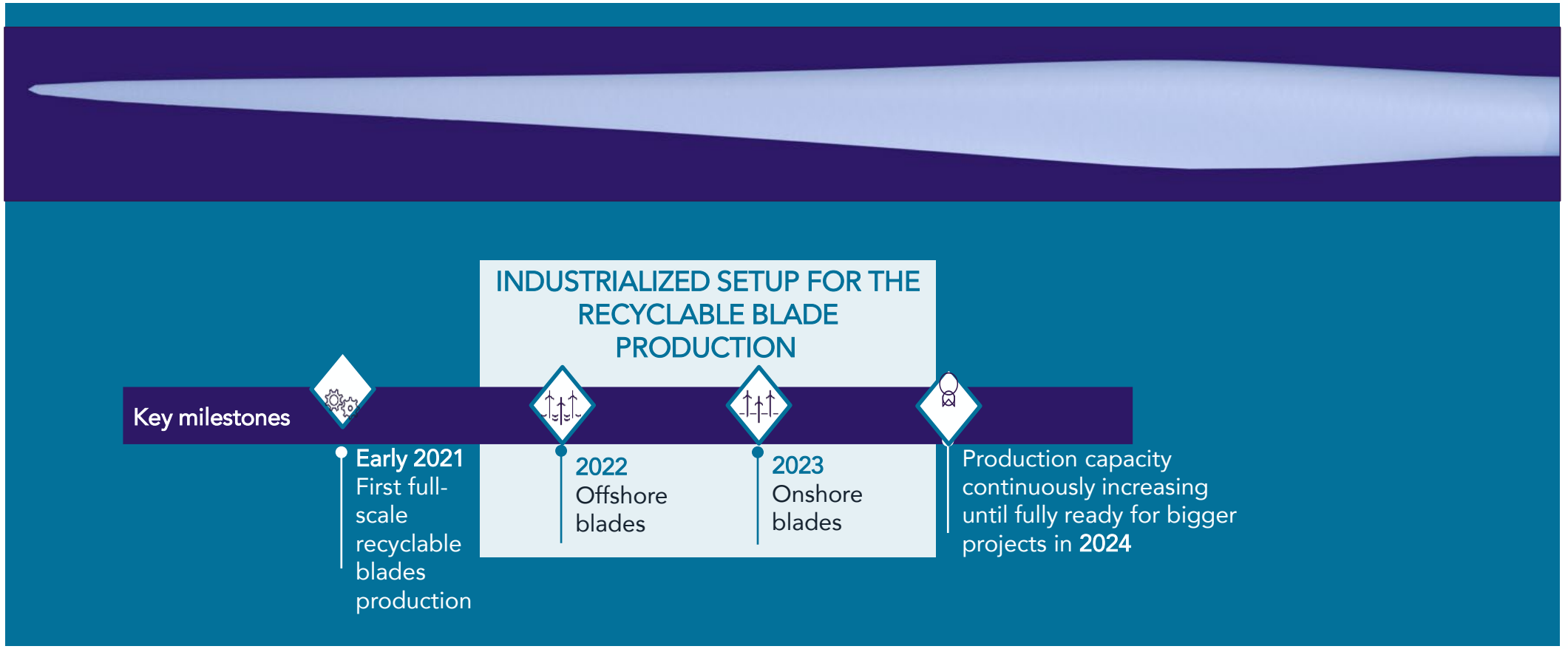
	SG 2.6-114	SG 3.4-132	SG 5.0-145	SG 6.6-170
	Medium-high winds	Medium-high winds	Medium high-winds	Medium winds
Prototype	2Q 2015	3Q 2016	2Q 2019	4Q 2021
Certification	4Q 2015	2Q 2017	4Q 2019	3Q 2022

AEP at 7.5m/s @ 100m and same hub height

By increasing the swept area, turbine annual production is maximized, reducing the cost of the energy generated

Wind technology trends

Recyclability: RecyclableBlade, a pioneering blade solution that enables blade materials to be recovered and recycled



Wind technology trends

Same means same product quality, strength, warranties and service process

The RecyclableBlade utilizes the same design criteria as before (IntegralBlade or Butterfly).
Only change: recyclable resin.

The recyclable resin is structurally comparable to current resin systems, with the added benefit that it has the ability to be dissolved again after decommissioning.

Using the RecyclableBlade in a wind power plant is no different from any other SGRE blade. Same blade design with same maintenance criteria and warranties.

Wind technology trends

RecyclableBlade process

Decommission

Disassemble and transport

Immerse in mild acidic solution

Resin dissolves in mild acidic solution at elevated temperature after a few hours

Reclaim separated components

Filter and coagulate resin + rinse and dry glass fiber etc

Reuse

Glass fiber, resin, wood and metal can now be reused

A simple and fast pioneering process

Load adaptations

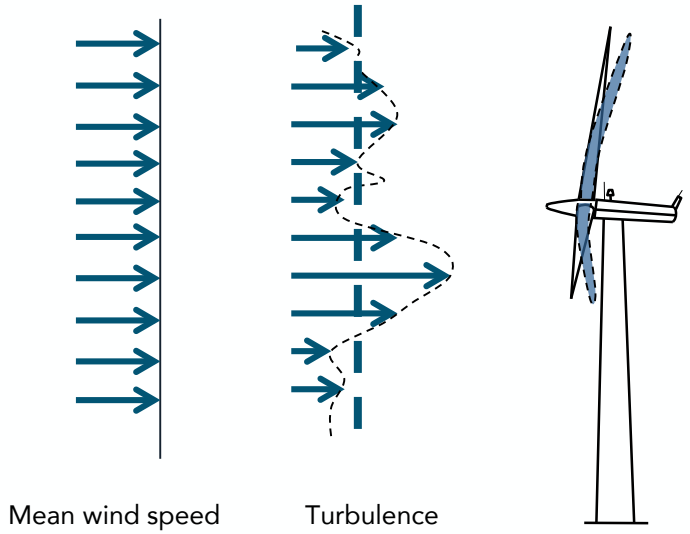
Real-time load management

Load management

- Avoid turbine overloading and excessive fatigue.
- Provides different load-mitigating control actions.

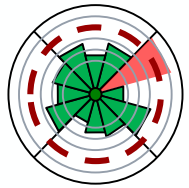
Energy production

- Limit turbine complete shut-downs to prevent overloading.
- Control actions are prioritized such that the least production costly action is applied first.



Intelligently activates necessary curtailment measures only

Traditional Sector Management



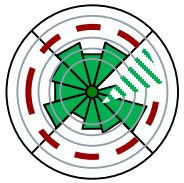
Description

- Predefined load regulation based on past observations
- Shut-down of the turbine in critical sectors
- Significant energy losses possible

What is the effect?

- **Turbulence exceeding limit** in one sector and consequent predefined **shut-down**

Adaptive Control Strategy



Description

- Real time monitoring of main turbine loads
- Several load reduction handles:
  - Switch the optimum pitch settings
  - Reduce speed and power references
  - Increase the sideways damping
- Limited production losses

What is the effect?

- Turbine **maintained in operation** with minimal reduced energy output

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