WIND ENERGY

PRESENTED BY:

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OUTLINE

INTRODUCTION

1. TECHNICAL ASPECTS

2.ECONOMIC ASPECTS

3.GLOBAL SITUATION

4.POLITICAL AND ENVIRONMENTAL ASPECTS

CONCLUSION

INTRODUCTION TO WIND ENERGY

BEFORE DELVING DEEPER YOU HAVE TO UNDERSTAND SOME BASIC CONCEPTS

WIND is the movement of air caused by the uneven heating of the Earth's surface due to pressure differences created by temperature variations.

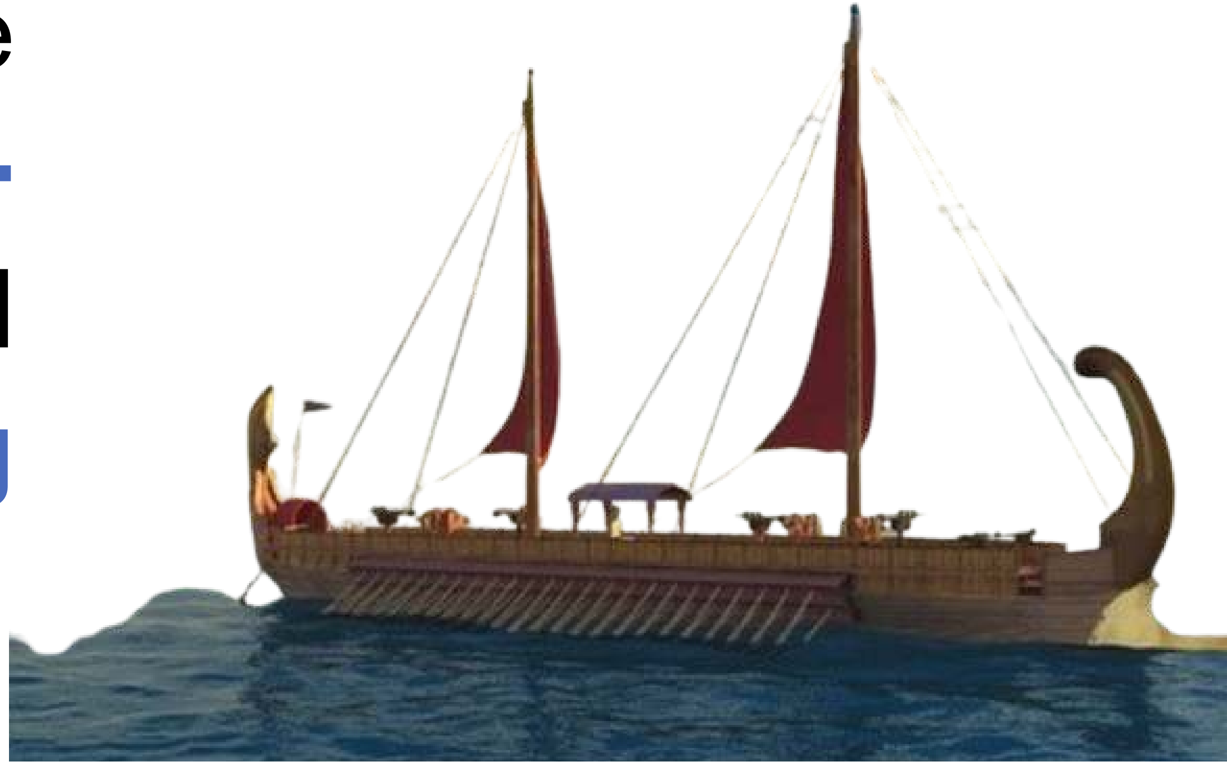
ENERGY is a fundamental property of physical systems that enables them to perform work

WIND ENERGY is the kinetic energy derived from the wind, which is converted into electricity through the use of wind turbines.

LET'S TAKE A TRIP INTO THE PAST ...

PEOPLE HAVE BEEN USING WIND ENERGY FOR THOUSANDS OF YEARS

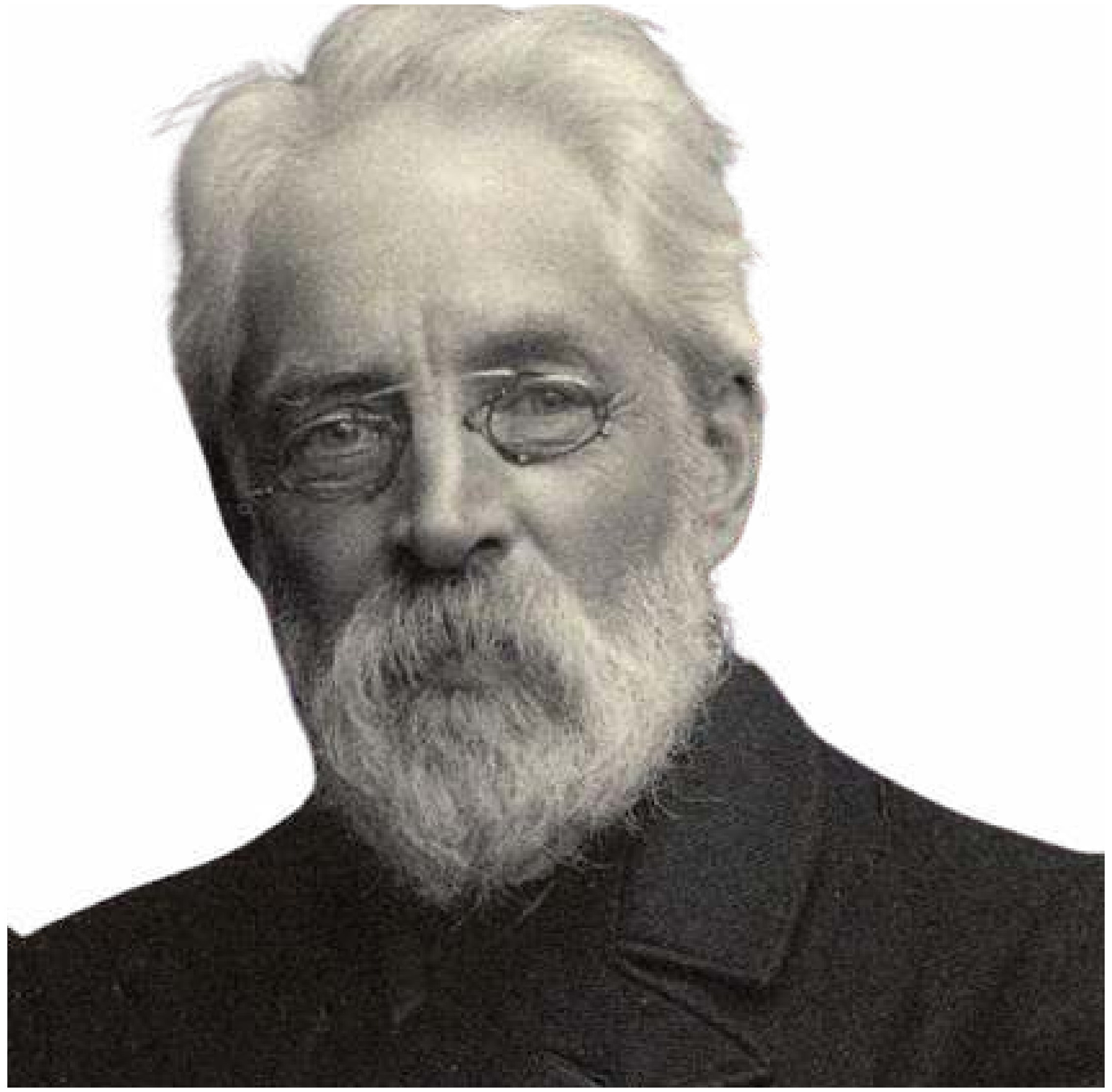
People used **wind energy to propel boats** along the Nile River as early as 5,000 BC. By 200 BC, simple **wind-powered water pumps** were used in China, and **windmills with woven-reed blades were grinding grain** in Persia and the Middle East.



By the 11th century, people in the Middle East were using **wind pumps and windmills extensively for food production**.

First wind turbine for electricity production

In 1866 , with t**he invention of the dynamo (or dynamo-electric machine)** – a generator that converts mechanical energy into electricity – the possibility of producing **electricity** using wind power was born! In 1888, an American scientist called **James Blyth** created the first wind turbine capable of generating electricity.

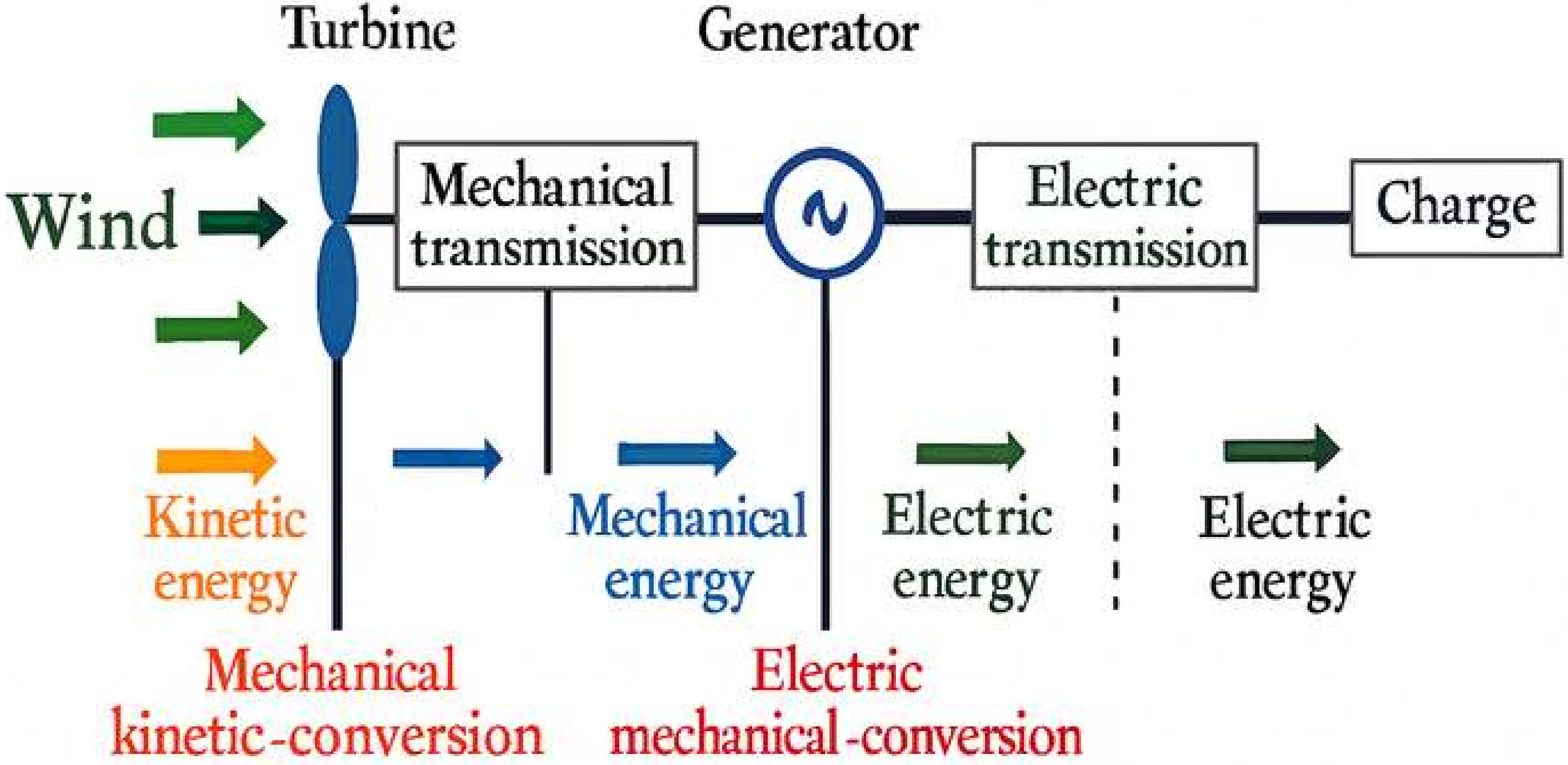


JAMES BLYTH

HOW DOES IT WORK FROM A TECHNICAL POINT OF VIEW?

PRINCIPLE OF WIND TURBINES

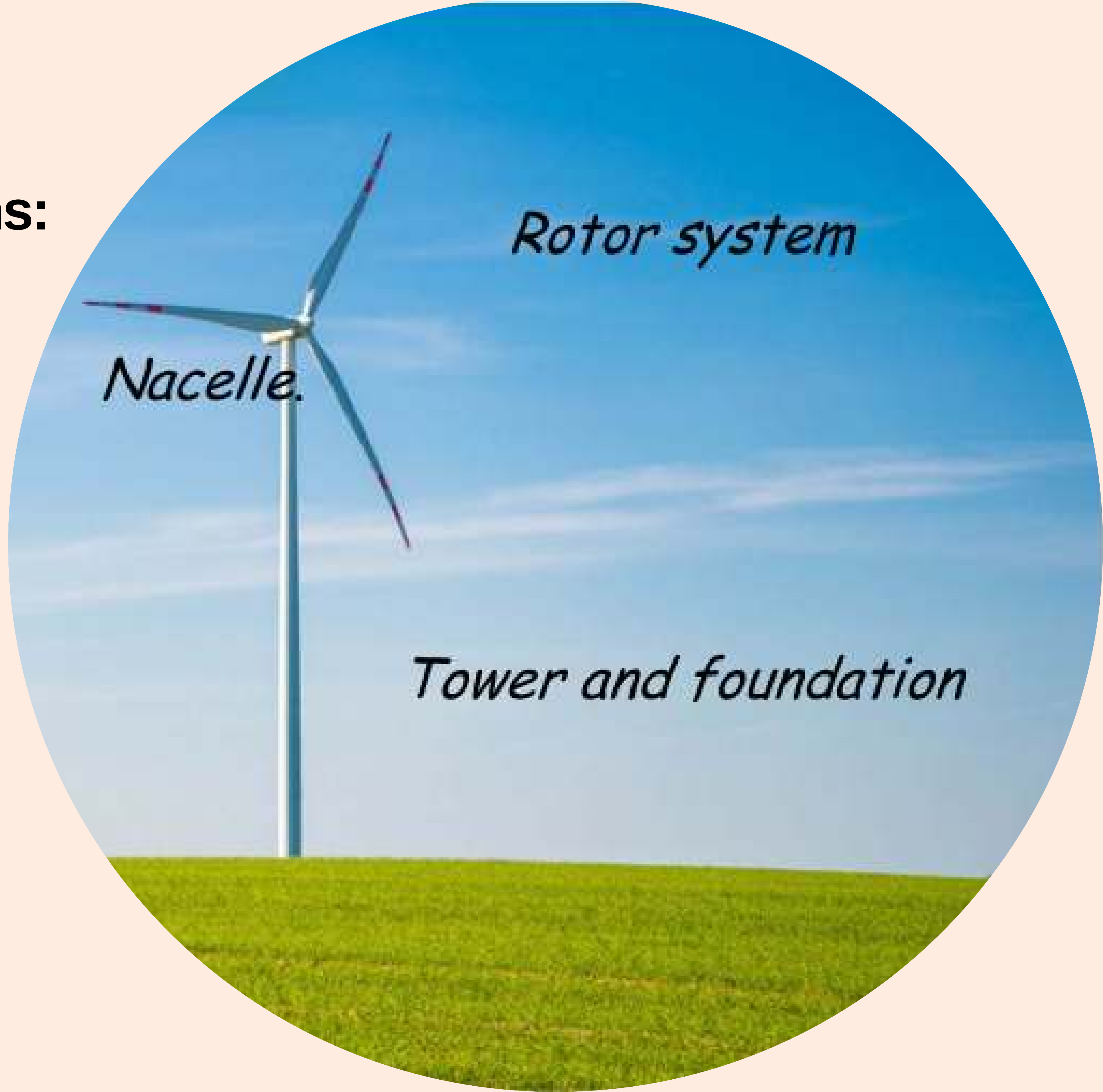
It's about energy conversion

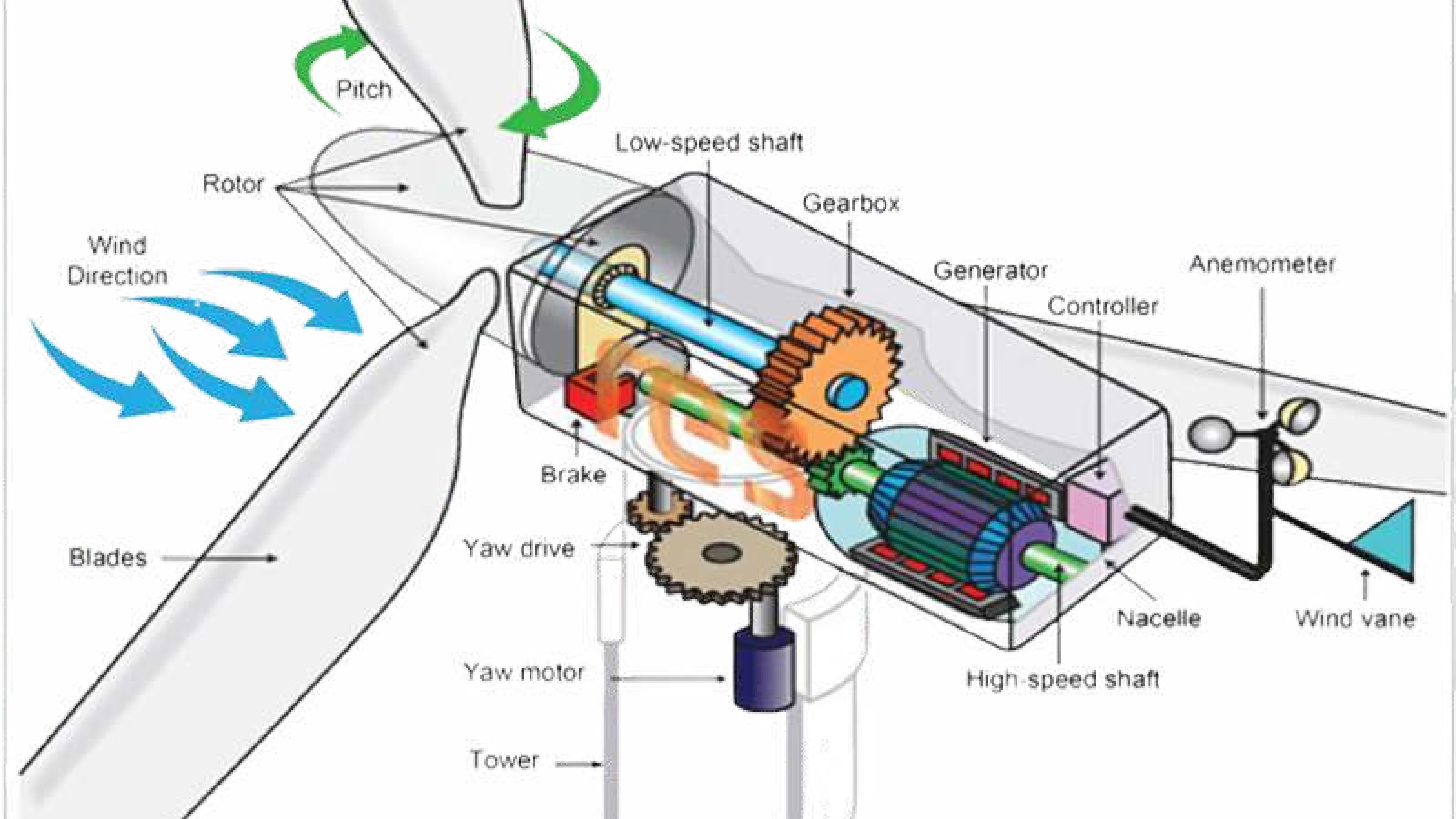


WIND TURBINE COMPONENTS

Wind turbine generator has three major systems:

- Rotor and blades
- Nacelle
- Tower and foundation




Pitch
Low-speed shaft
Rotor
Gearbox
Wind
Direction
Generator
Anemometer
Controller
Brake
Yaw drive
Blades
Nacelle
Wind vane
Yaw motor
High-speed shaft
Tower

ROTOR AND BLADES SYSTEM

The rotor system captures wind energy and converts into rotational kinetic energy. This is accomplished through the blades and the rotor hub.

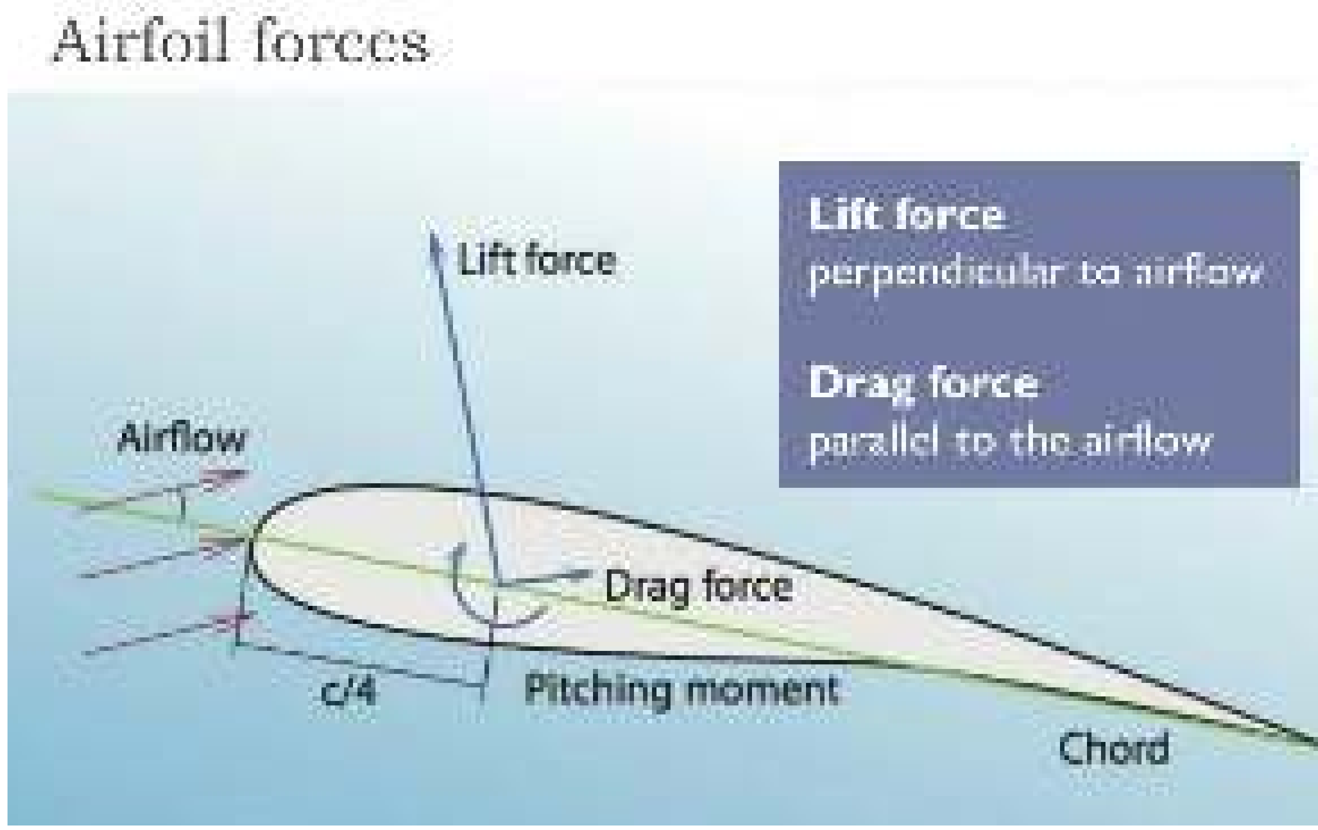
BLADES

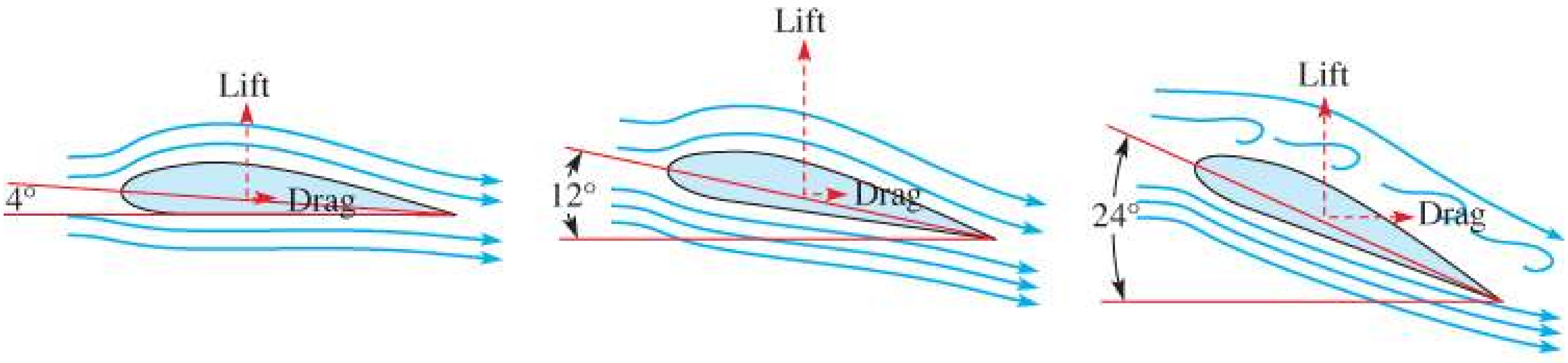
OVERVIEW

- Wind turbine blades are long, aerodynamic structures attached to the rotor.
- Their main function is to capture the wind’s kinetic energy and convert it into rotational motion.
- Modern turbines usually have three blades for optimal efficiency, stability, and reduced mechanical stress.
- Blade length typically ranges from 30 m to over 110 m, depending on turbine power.
- Their shape is similar to an airplane wing, enabling the generation of lift as wind flows over them

BLADES AERODYNAMICS

- Wind turbine blades are shaped like airplane wings, with one side curved and the other flatter.
- This shape creates lift when wind flows over it, just like a wing on a plane
- The lift force makes the rotor spin, turning wind energy into rotation.
- Blades can also rotate around their own axis using a pitch system, which changes their angle to control how fast the turbine turns.





(a) Angle = 4° (b) Angle = 12° (c) Angle = 24° (stall begins)

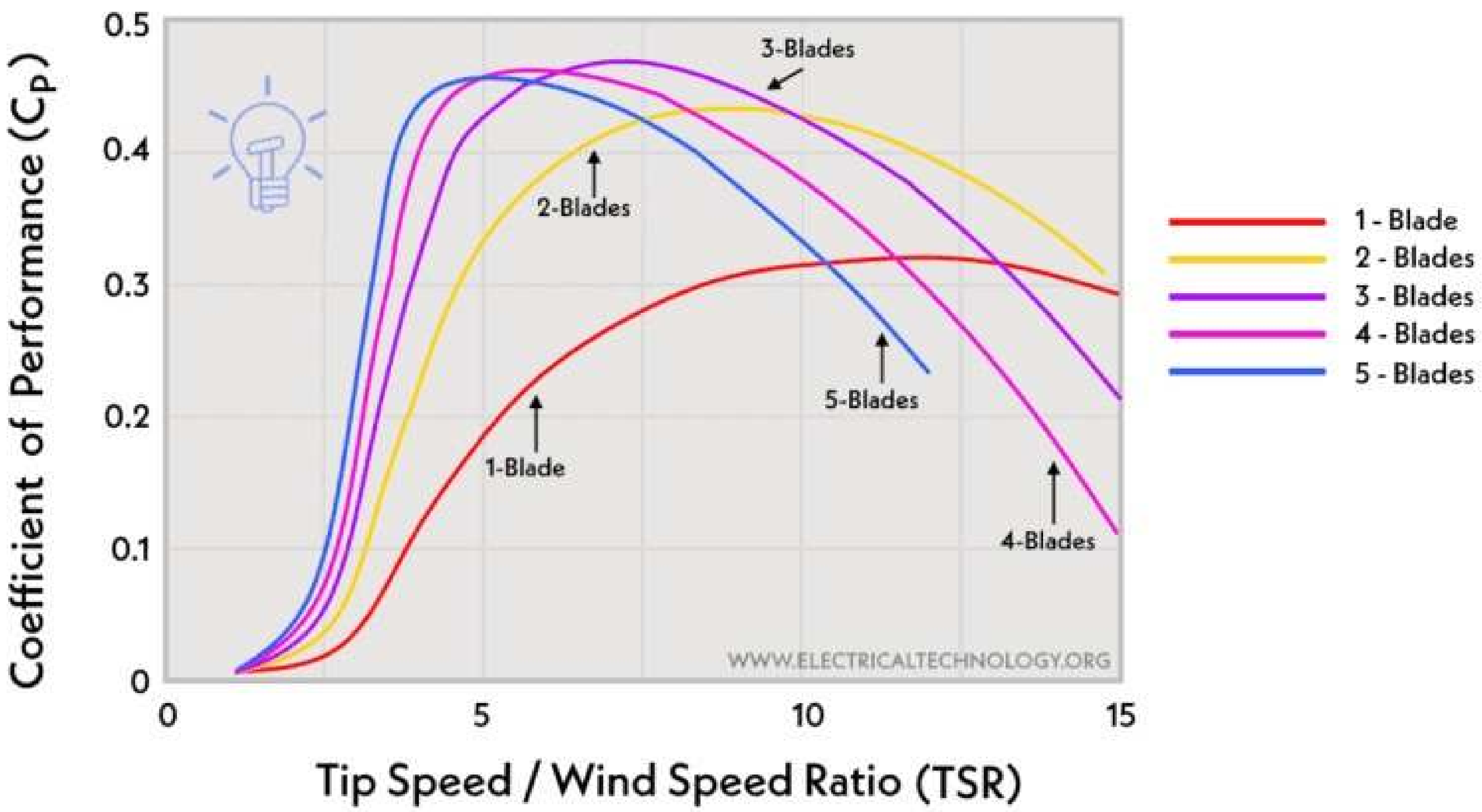
WHY DO WE GENERALLY USE 3 BLADES ?

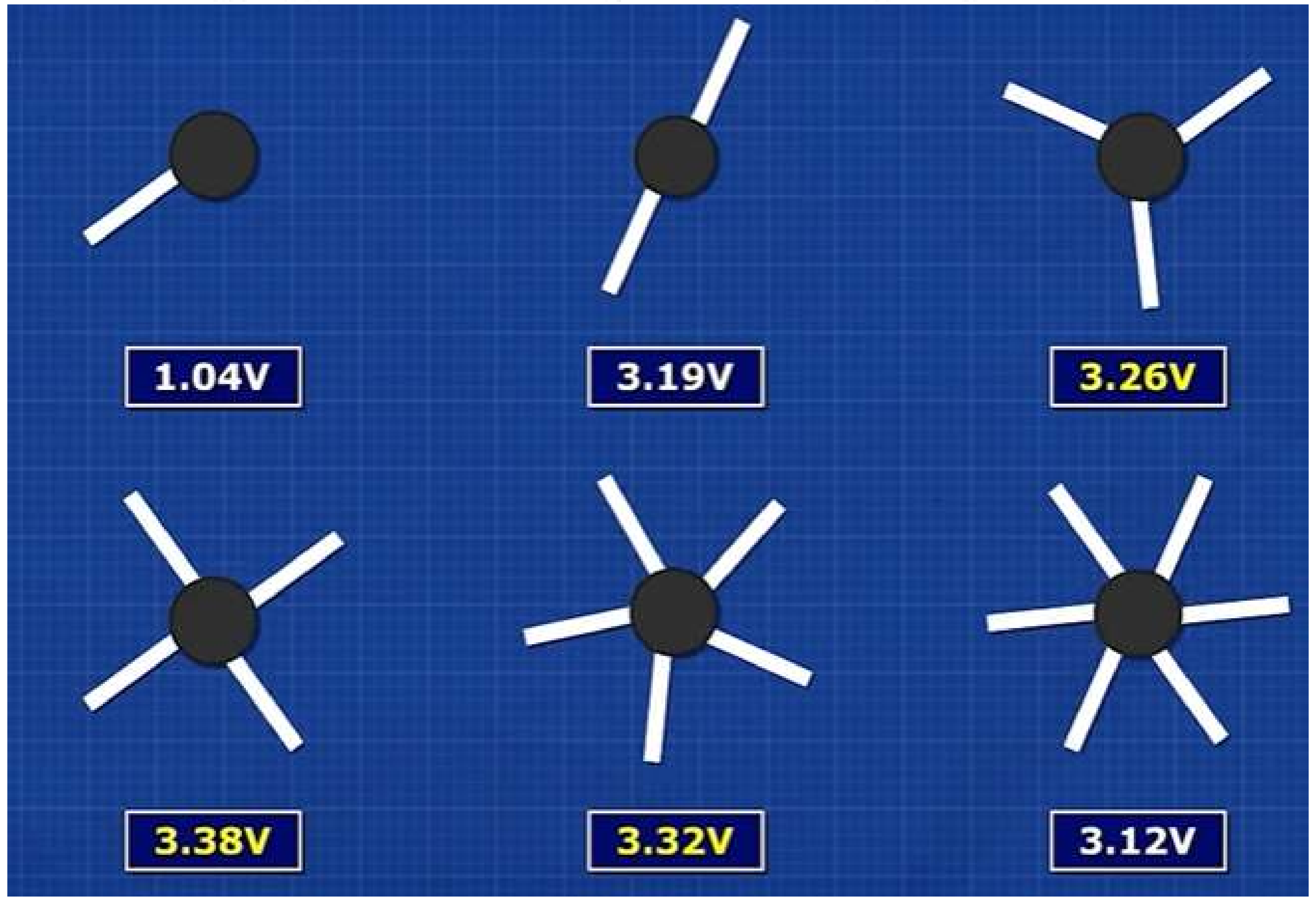
3 blades are optimal for wind turbines due to a balance between :

- **aerodynamic efficiency:** For optimal power generation, wind turbines must operate at an optimal TSR, which varies depending on the number of blades.

- **mechanical stability:** Three-bladed turbines offer better dynamic stability compared to turbines with more blades.

- **cost-effectiveness:** Manufacturing blades for wind turbines is a complex and costly process. Increasing the number of blades from three to four or five significantly raises production costs.



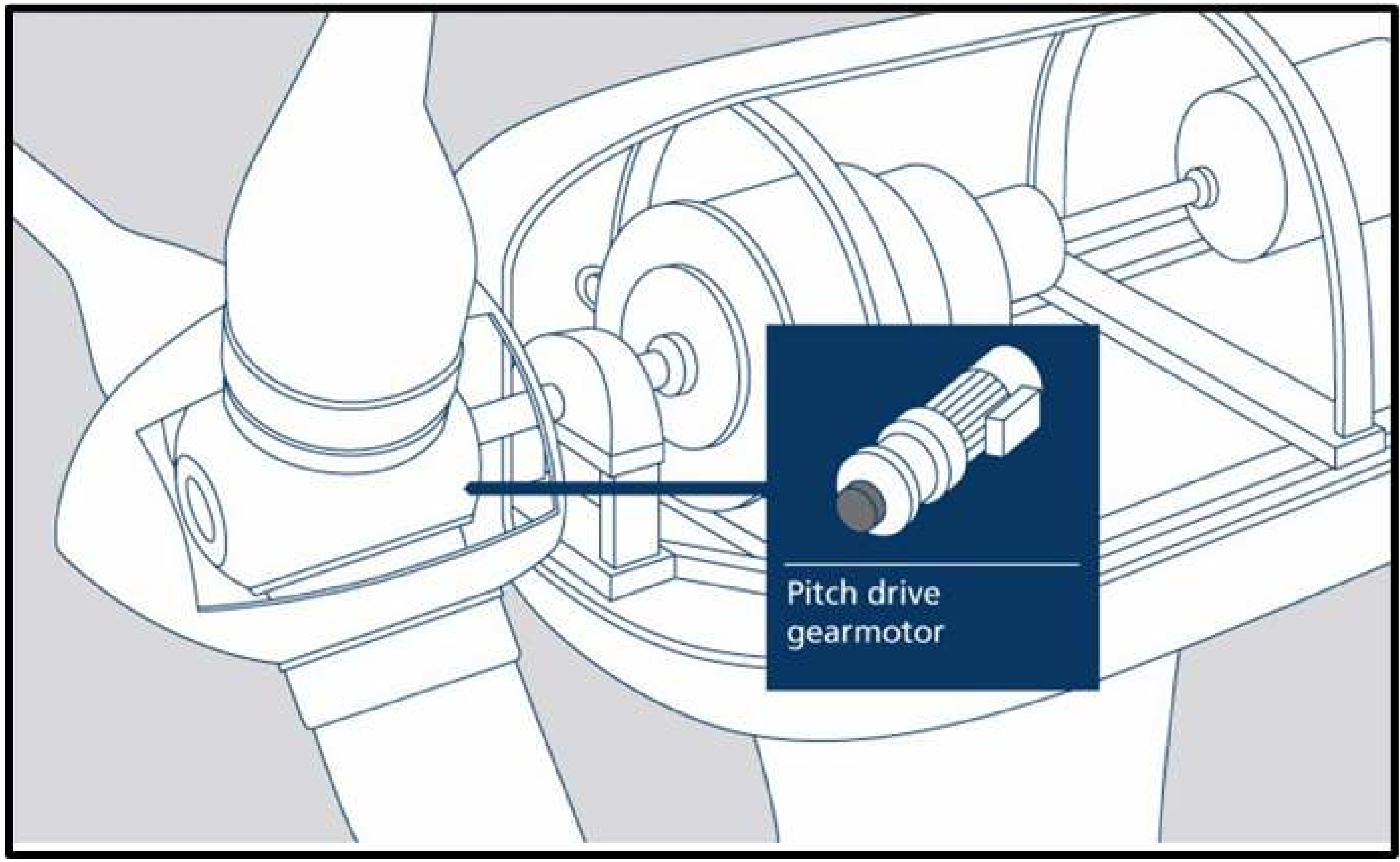


ROTOR HUB

Blades are radially bolted to the hub. On the axial end, the rotor hub is connected to the drive train. The hub is made of high-quality cast iron. It transfers load from the blades to the nacelle frame and to the drive train.

PITCH CONTROL

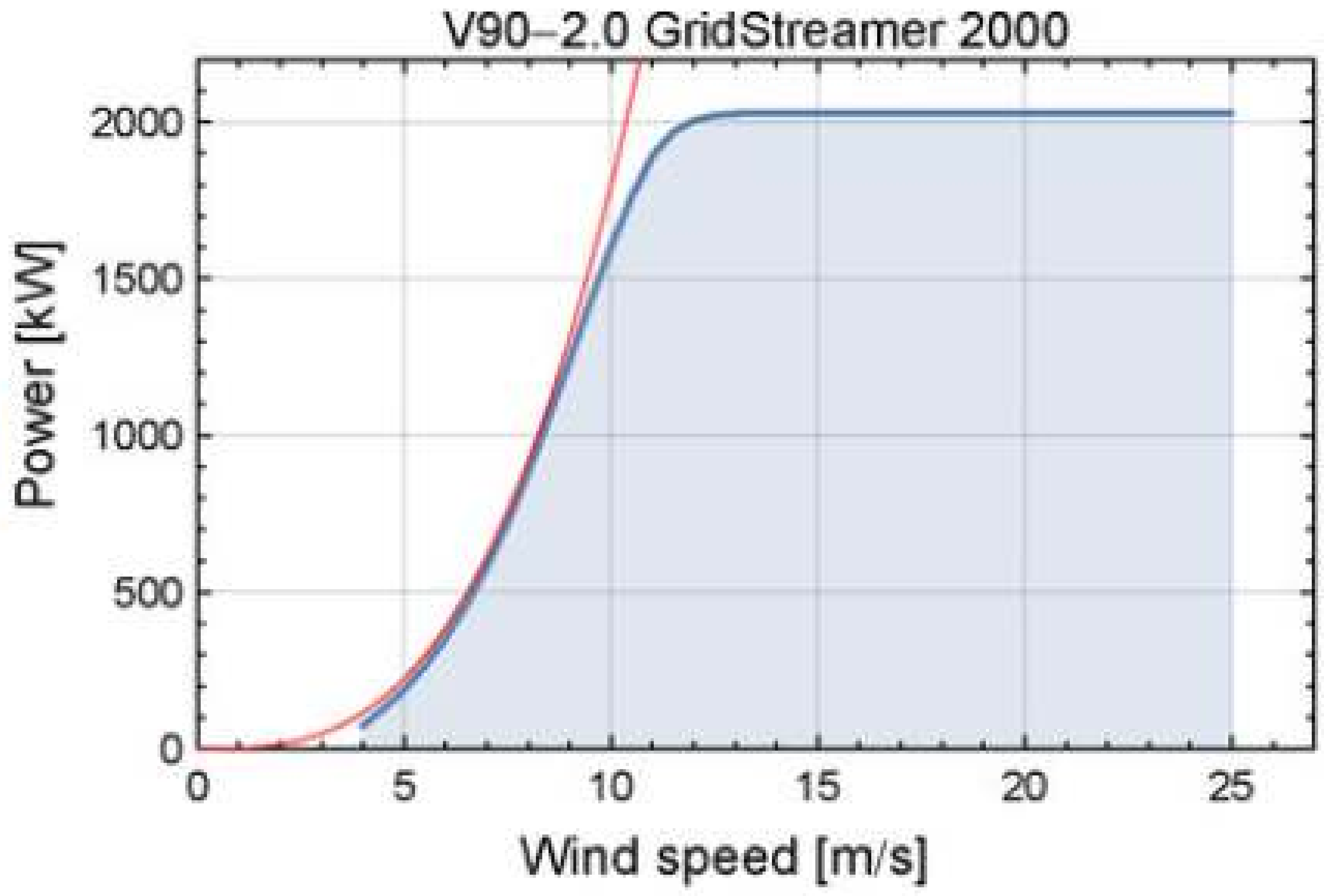
Pitch control gearboxes serve the essential purpose of setting wind turbine blades at the best angle to the wind to turn the rotor.



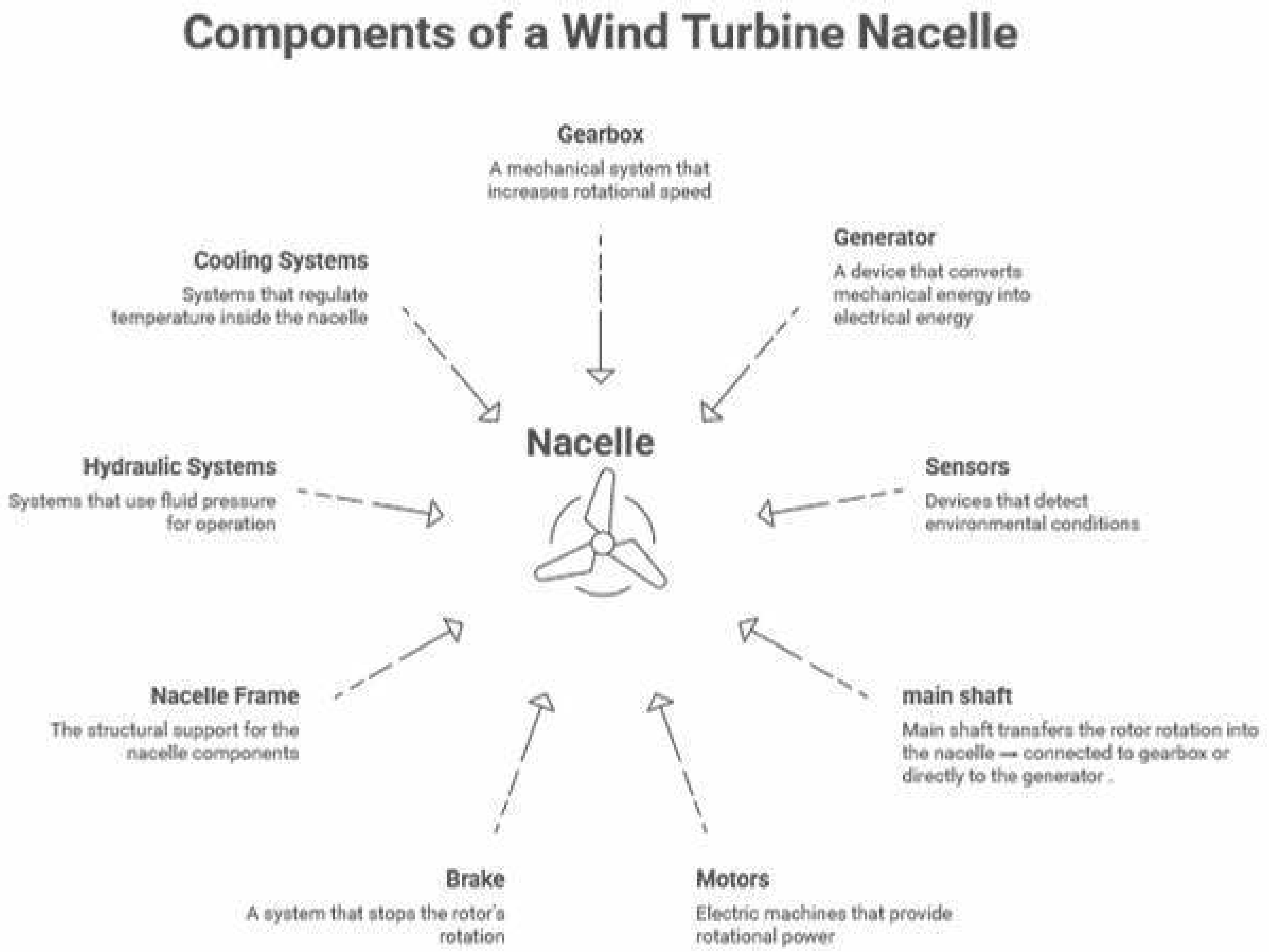
Minimum and Maximum Wind Speeds for Wind Turbines

The wind turbine can not start until a minimum wind speed is reached. As the wind speed increases the power also increases then at a certain wind speed the blades of the wind turbine brake to stop generating power. Brakes are activated to protect the wind turbine.

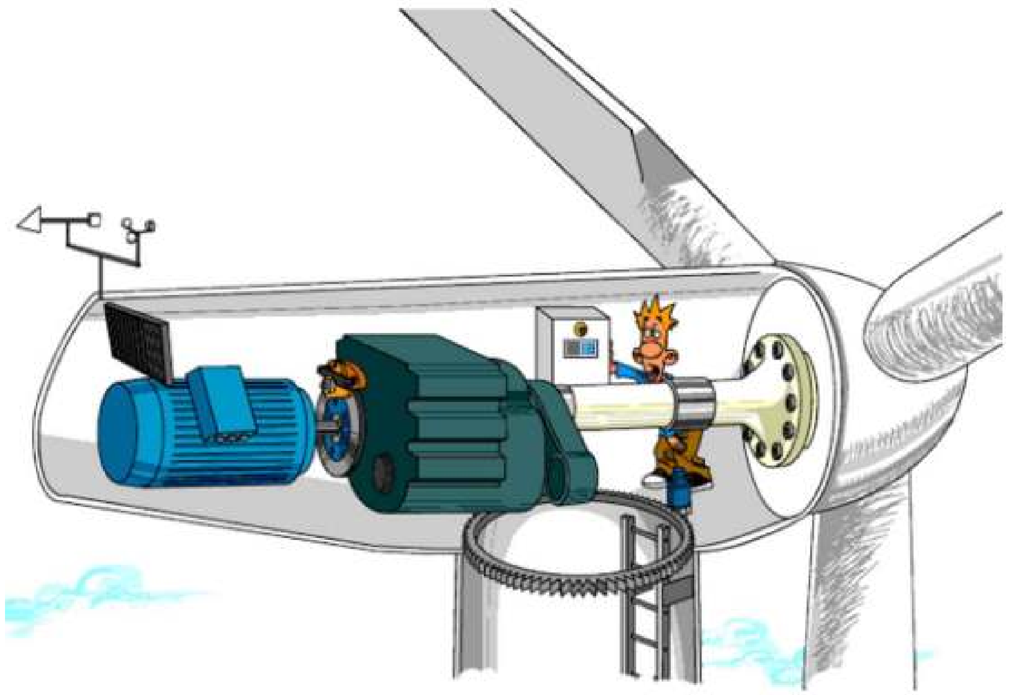
- **Minimum Speed (Cut-in Speed) :**
  between 3m/s and 5m/s
- **Optimal Speed (Rated Wind Speed) :**
  between 11 m/s and 14 m/s
- **Maximum Speed (Cut-out Speed) :**
  around 25m/s

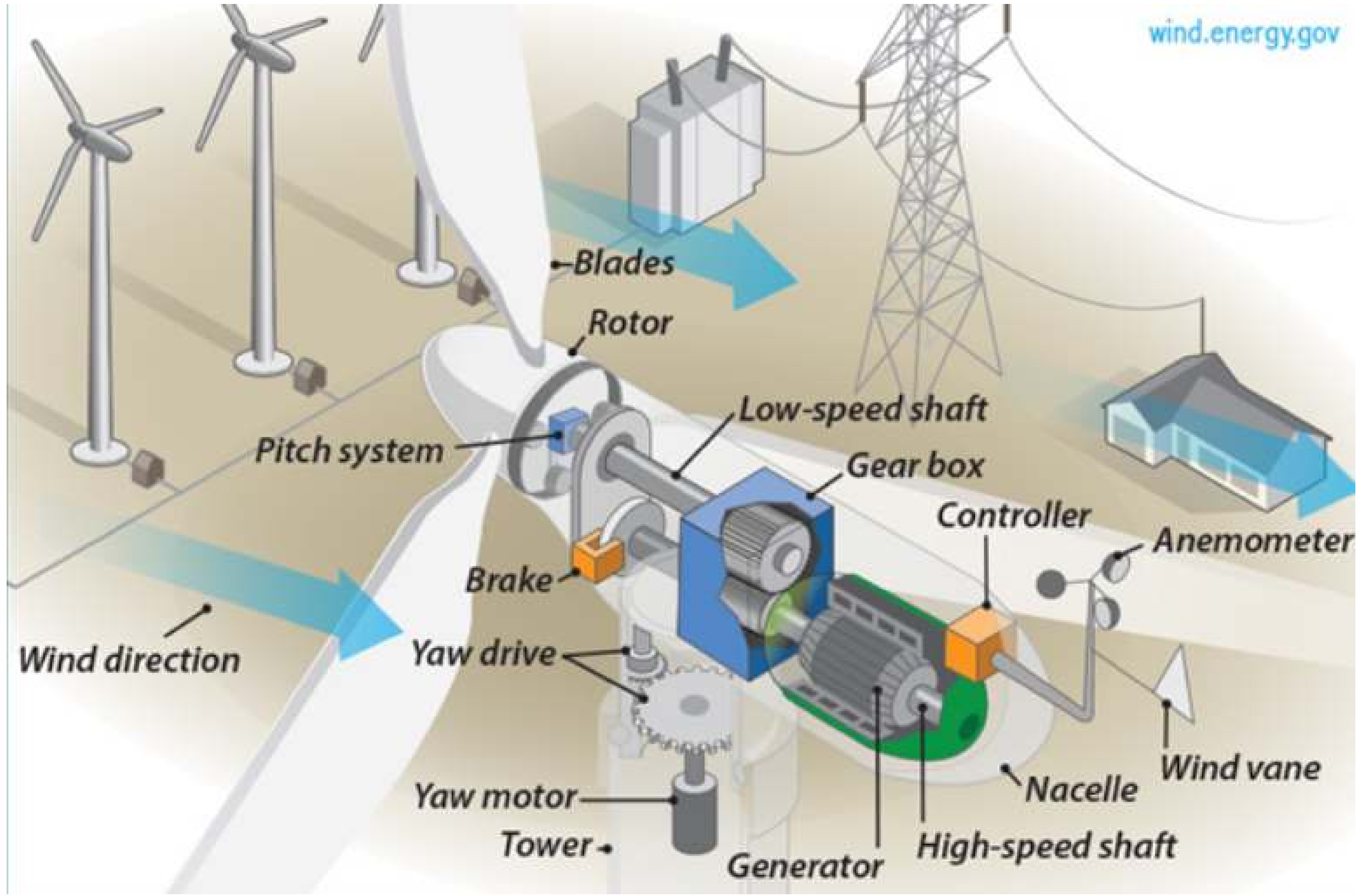


NACELLE



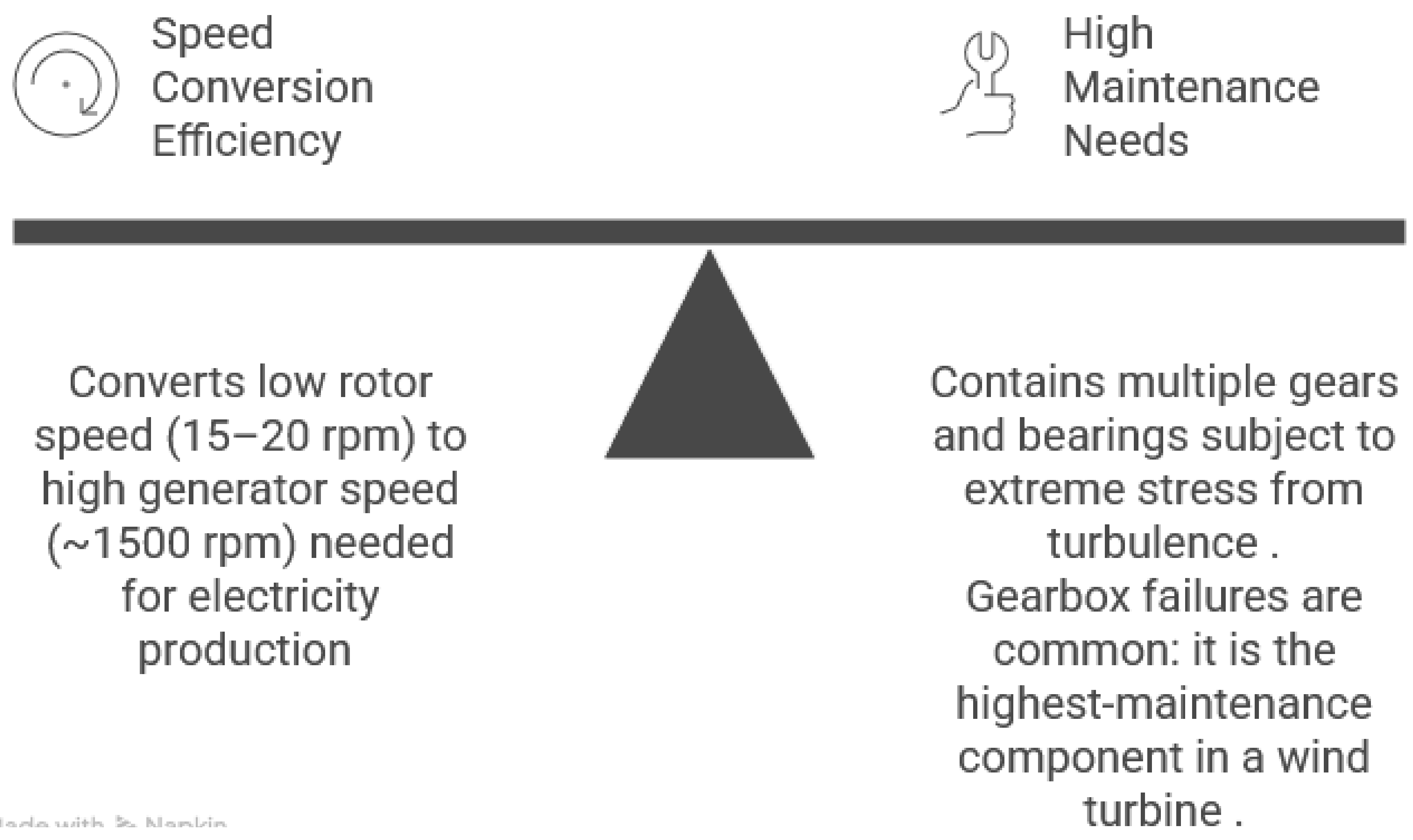
Components of a Wind Turbine Nacelle
Gearbox
A mechanical system that increases rotational speed
Generator
A device that converts mechanical energy into electrical energy
Cooling Systems
Systems that regulate temperature inside the nacelle
Nacelle
Hydraulic Systems
Systems that use fluid pressure for operation
Sensors
Devices that detect environmental conditions
Nacelle Frame
The structural support for the nacelle components
main shaft
Main shaft transfers the rotor rotation into the nacelle → connected to gearbox or directly to the generator .
Brake
A system that stops the rotor's rotation
Motors
Electric machines that provide rotational power



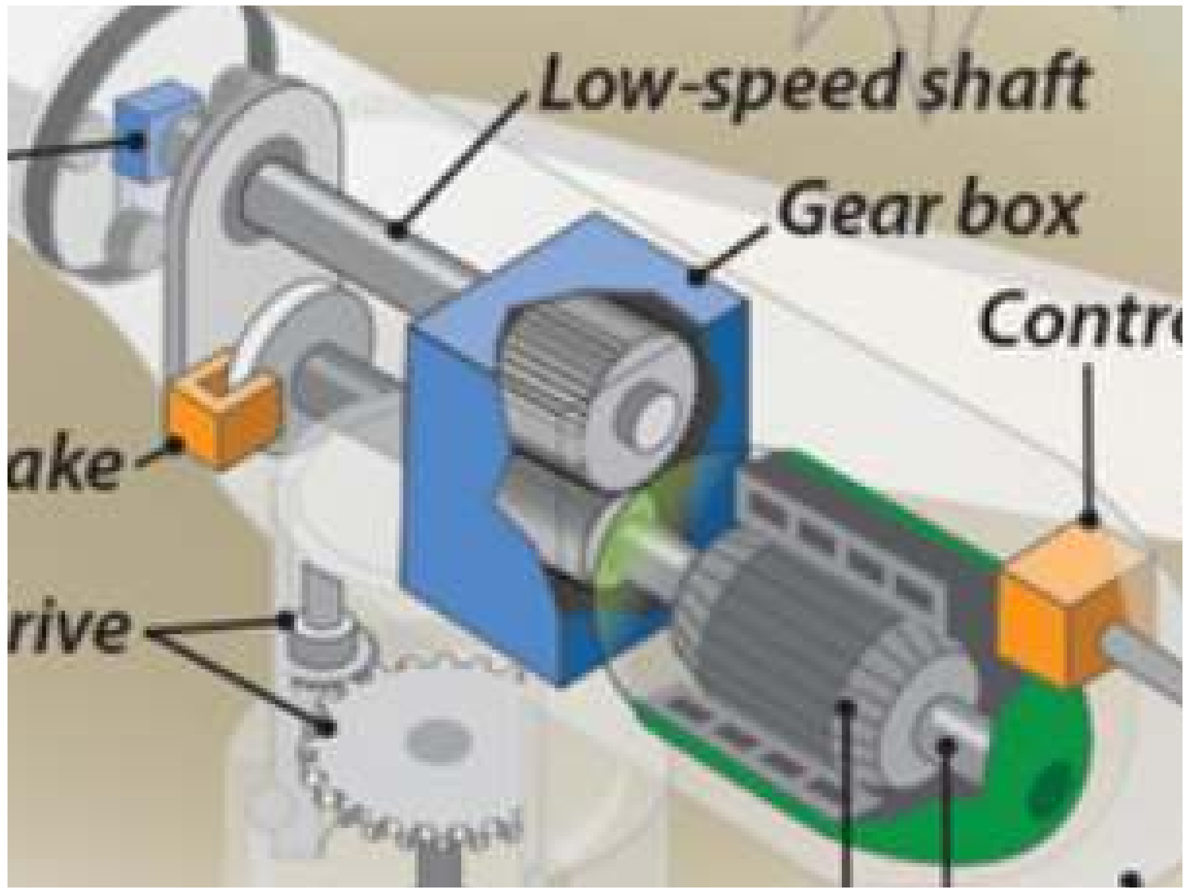


wind.energy.gov
Blades
Rotor
Low-speed shaft
Pitch system
Gear box
Controller
Anemometer
Brake
Wind direction
Yaw drive
Wind vane
Nacelle
Yaw motor
Tower
Generator
High-speed shaft

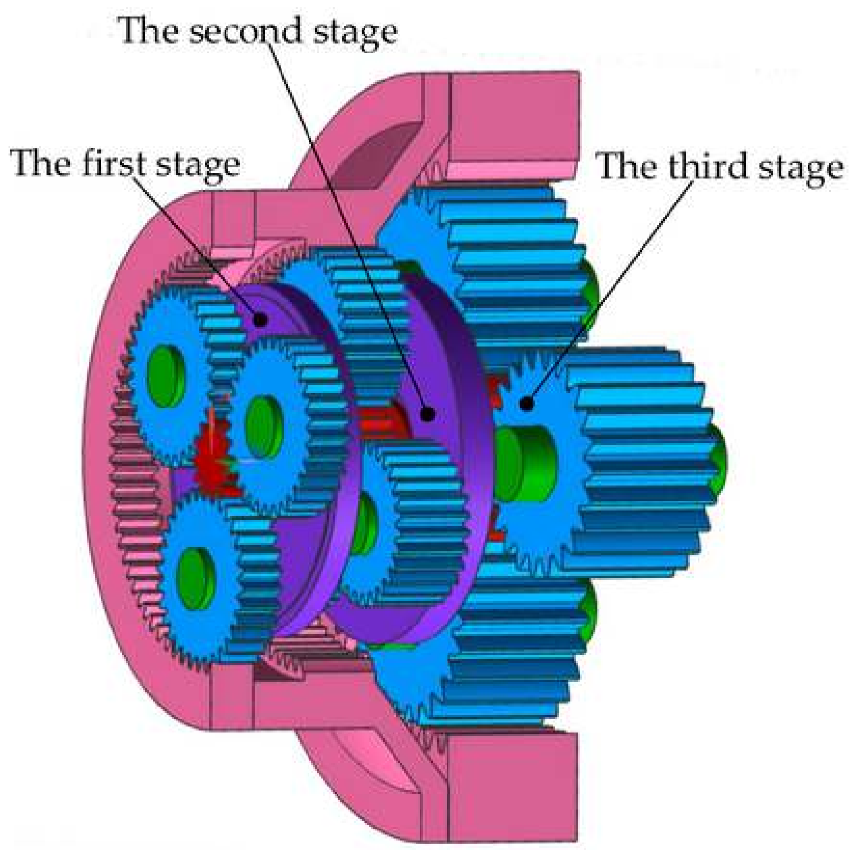
GEARBOX



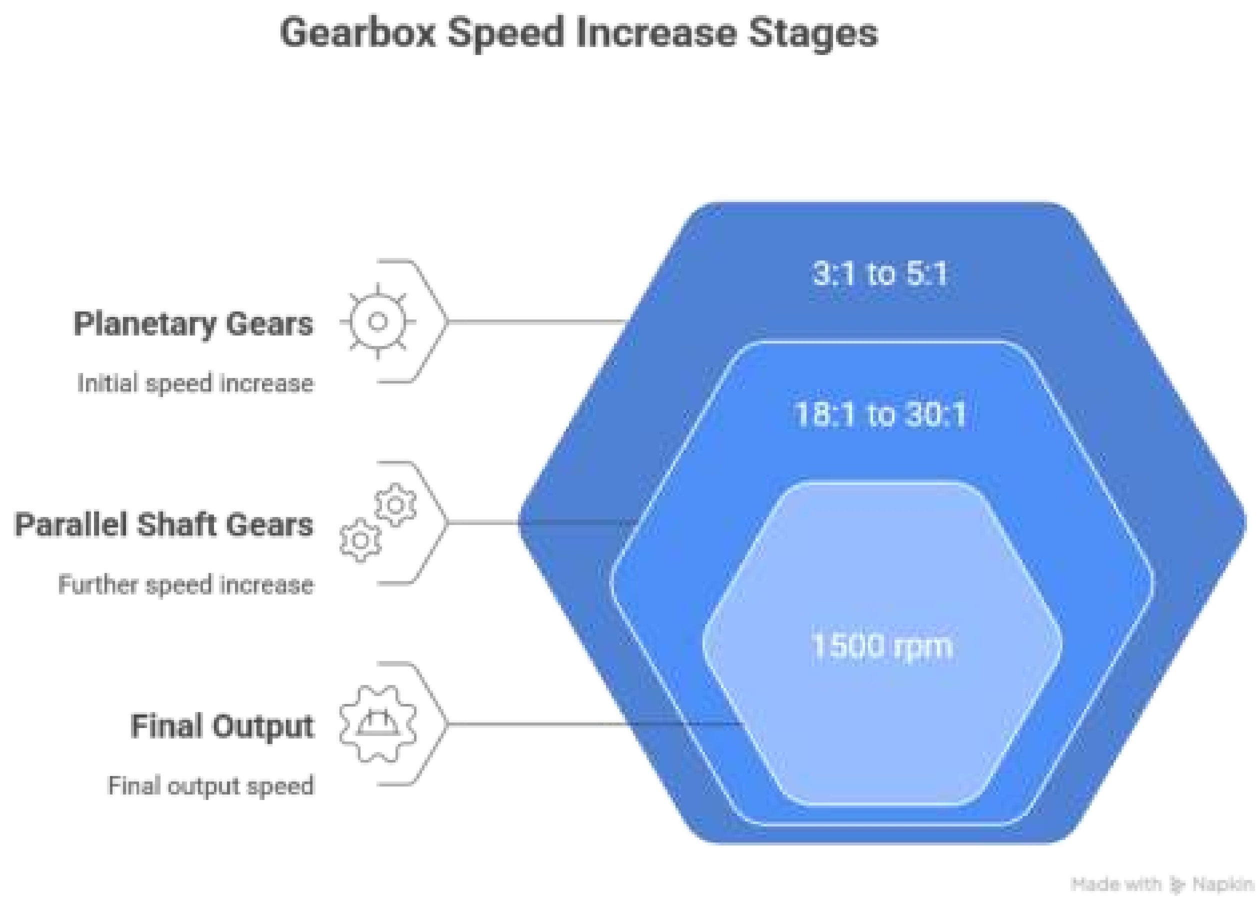
Speed Conversion Efficiency
High Maintenance Needs
Converts low rotor speed (15–20 rpm) to high generator speed (~1500 rpm) needed for electricity production
Contains multiple gears and bearings subject to extreme stress from turbulence . Gearbox failures are common: it is the highest-maintenance component in a wind turbine .



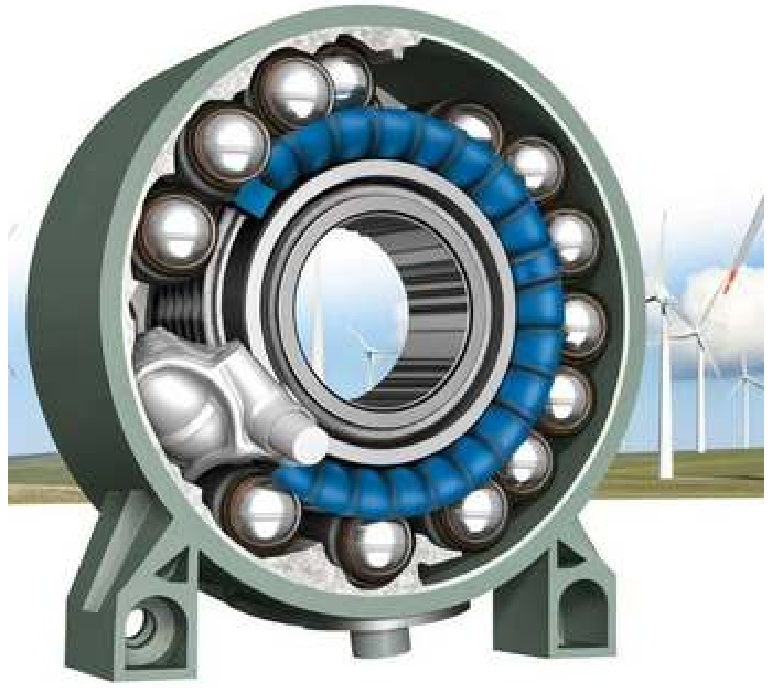
Low-speed shaft
Gear box



The second stage
The first stage
The third stage



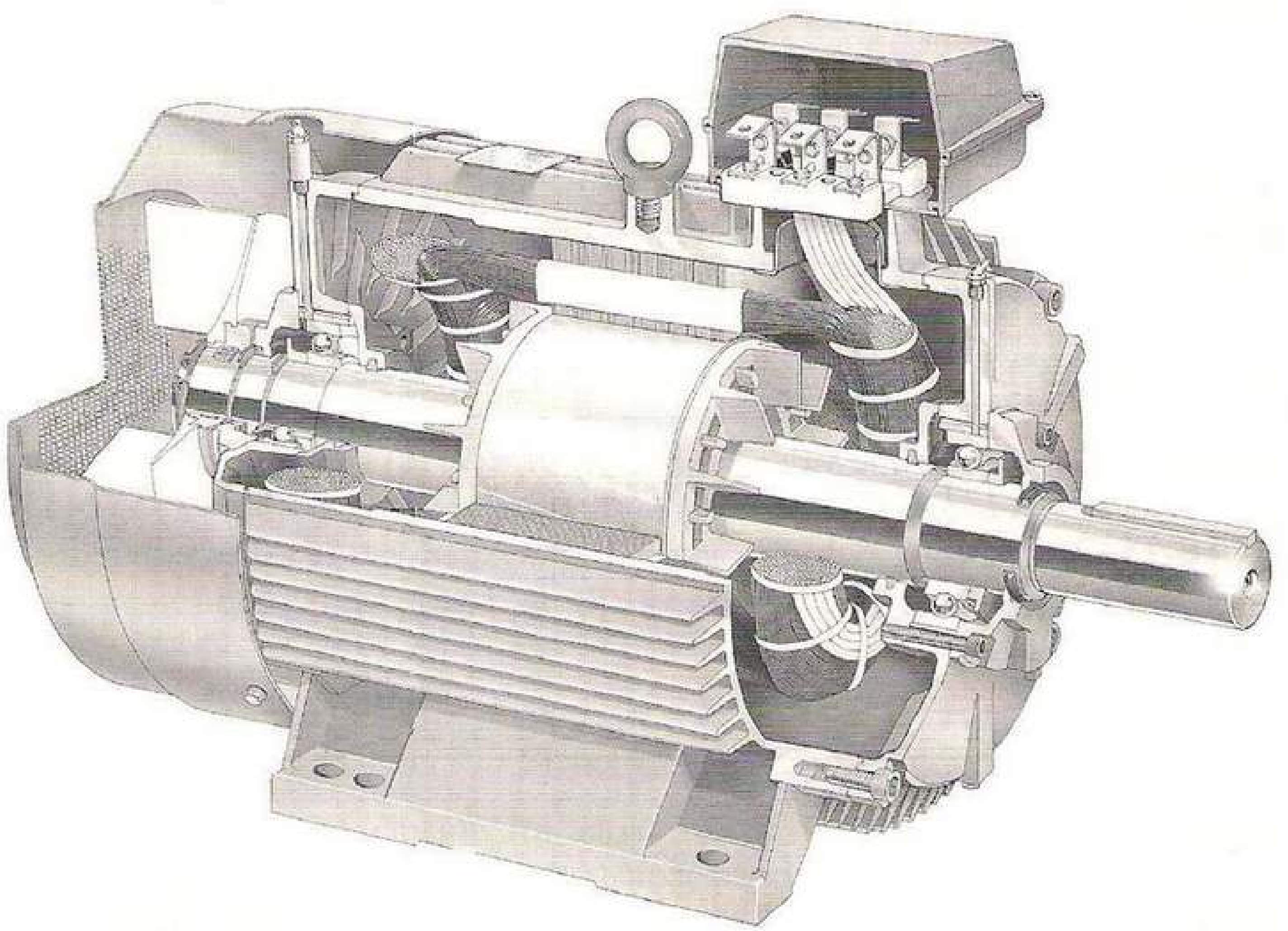
Gearbox Speed Increase Stages
Planetary Gears
Initial speed increase
Parallel Shaft Gears
Further speed increase
Final Output
Final output speed
3:1 to 5:1
18:1 to 30:1
1500 rpm



bearing


Gearbox Failure Causes
Bearing Fatigue
Gradual wear and tear of bearings due to repeated stress
Aging Materials
Degradation of materials under cyclic loads
Micropitting
Tiny surface cracks on gear teeth leading to wear
Misalignment
Improper alignment of shafts leading to strain
Poor Lubrication
Insufficient or inadequate lubrication causing friction
High Torque
Excessive force during storms causing stress

ELECTRICAL GENERATOR — CONVERTING ROTATION TO ELECTRICITY



The generator is mounted inside the nacelle, behind the rotor hub .

- Rotor speed (5–20 rpm) is too slow → gearbox increases speed for generator operation .

To match the grid (50 or 60 Hz), generator must rotate fast:

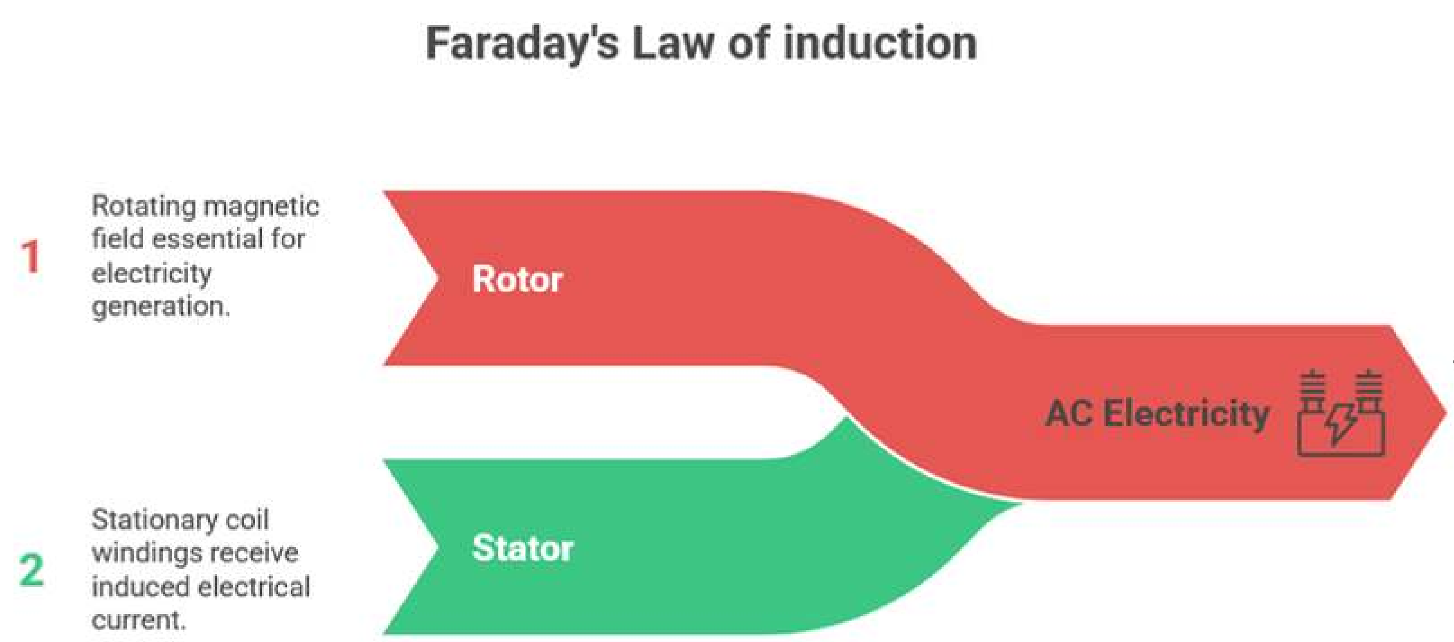
→ around 1500 rpm for 50 Hz

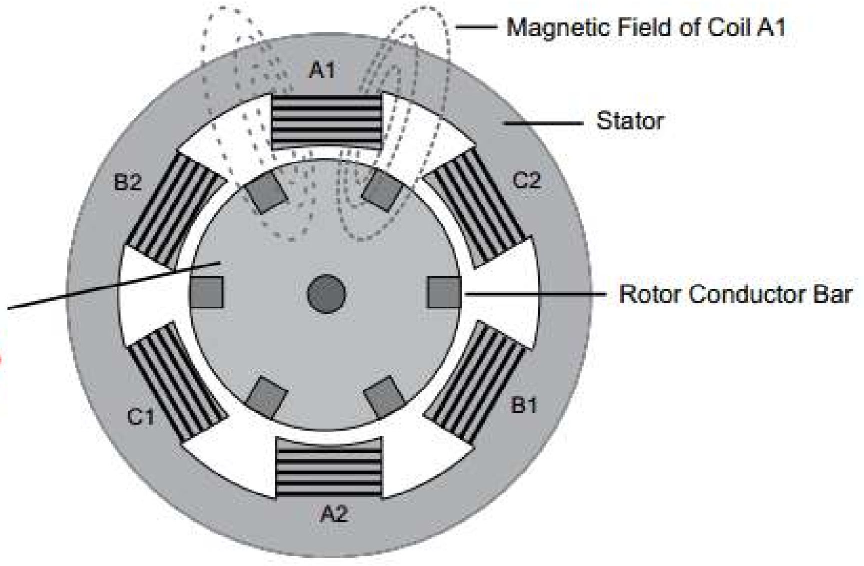
→ around 1800 rpm for 60 Hz

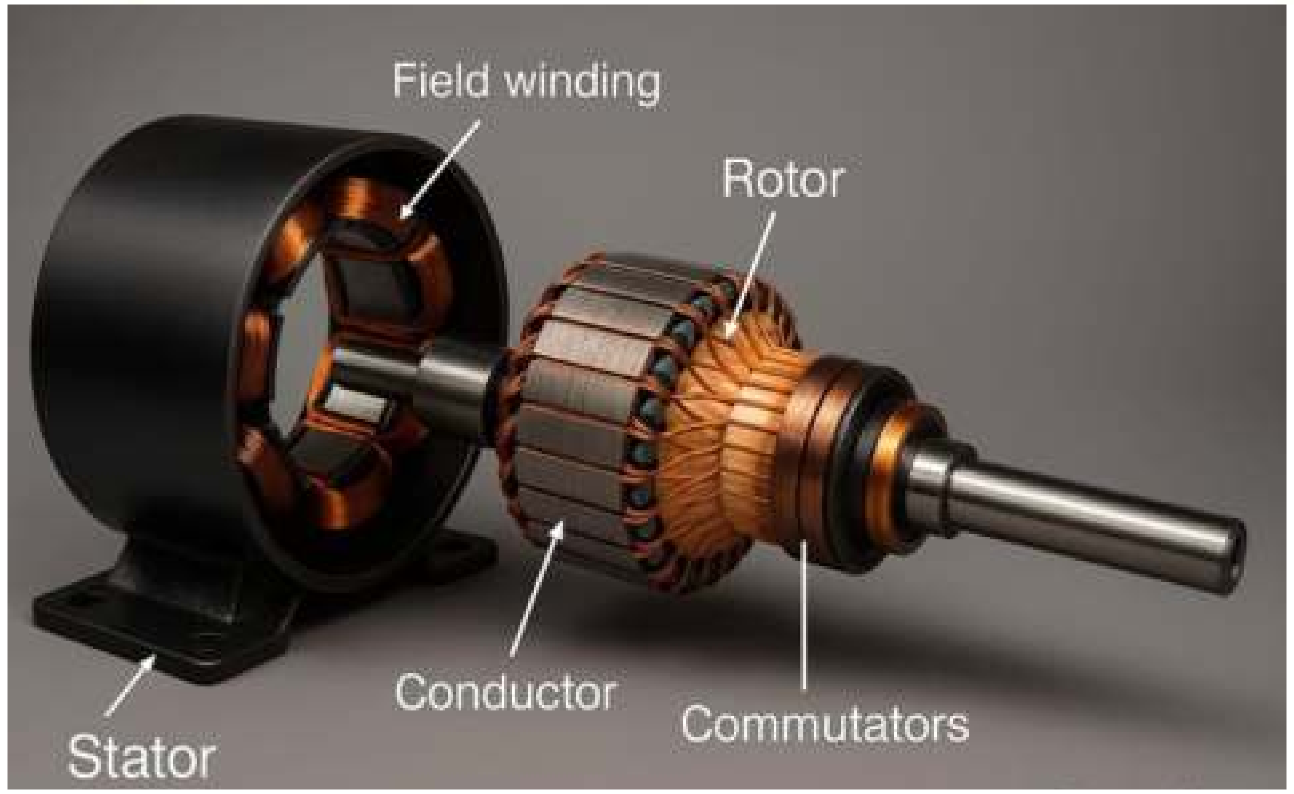
Thus:

- Rotor speed (10–20 rpm) must be increased drastically

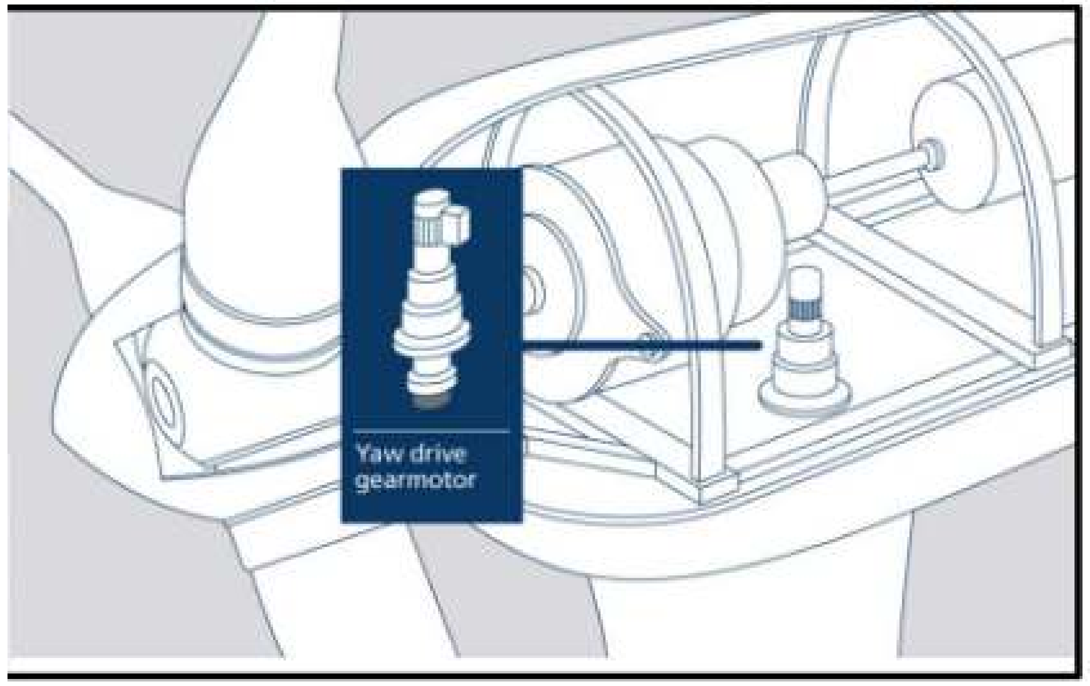
- Directly connected generators typically operate between 750 and 3600 rpm .
- Gearbox also helps reduce generator size and cost .



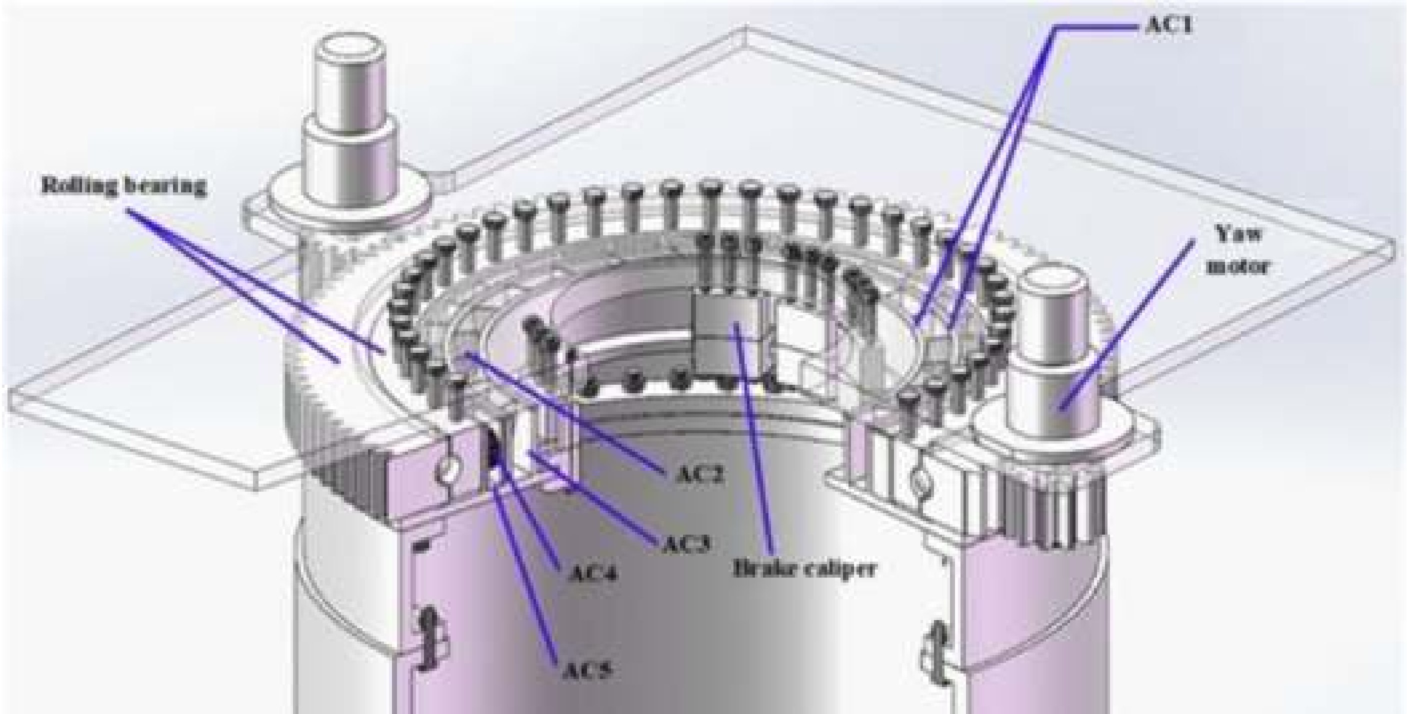


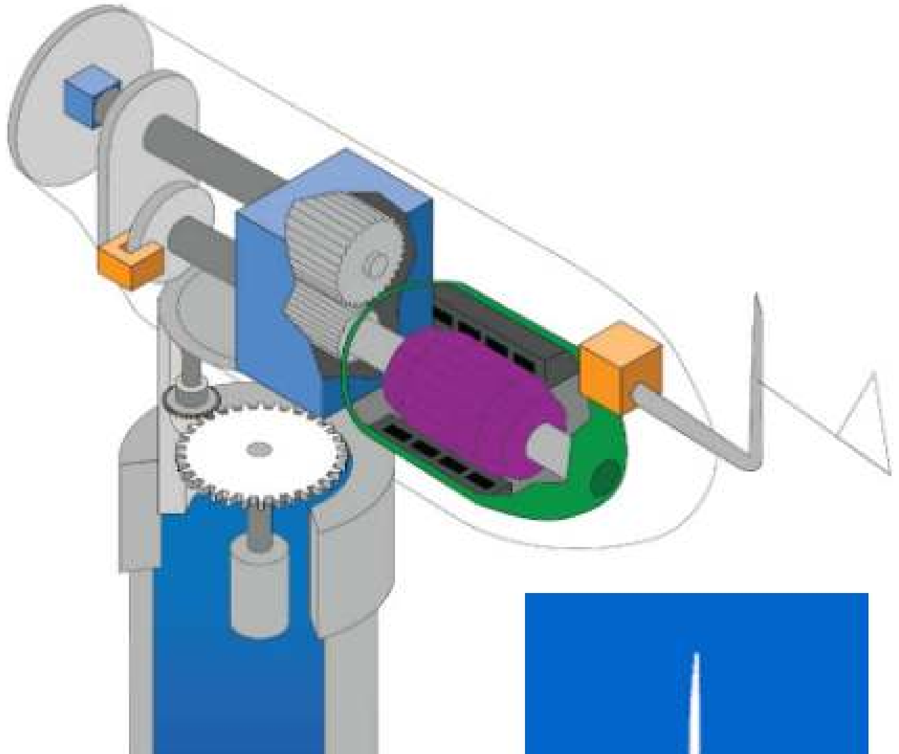


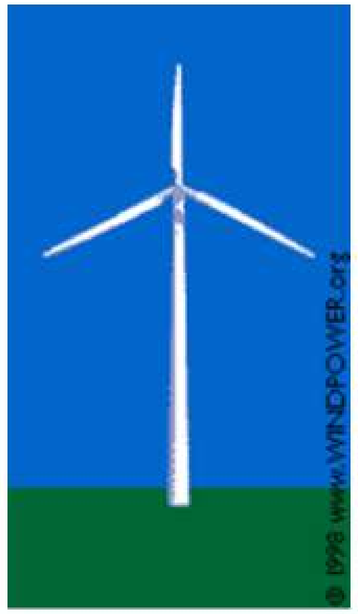
YAW CONTROL



- Yaw = rotation of the nacelle around the vertical axis to ensure rotor faces the wind .
- Large modern turbines use active yaw control: wind vane measures wind direction; motors rotate the nacelle .
- Some small or older turbines use passive yaw systems (tail vane or downwind configuration) .
- Yaw system includes: .







TOWERS

TYPES

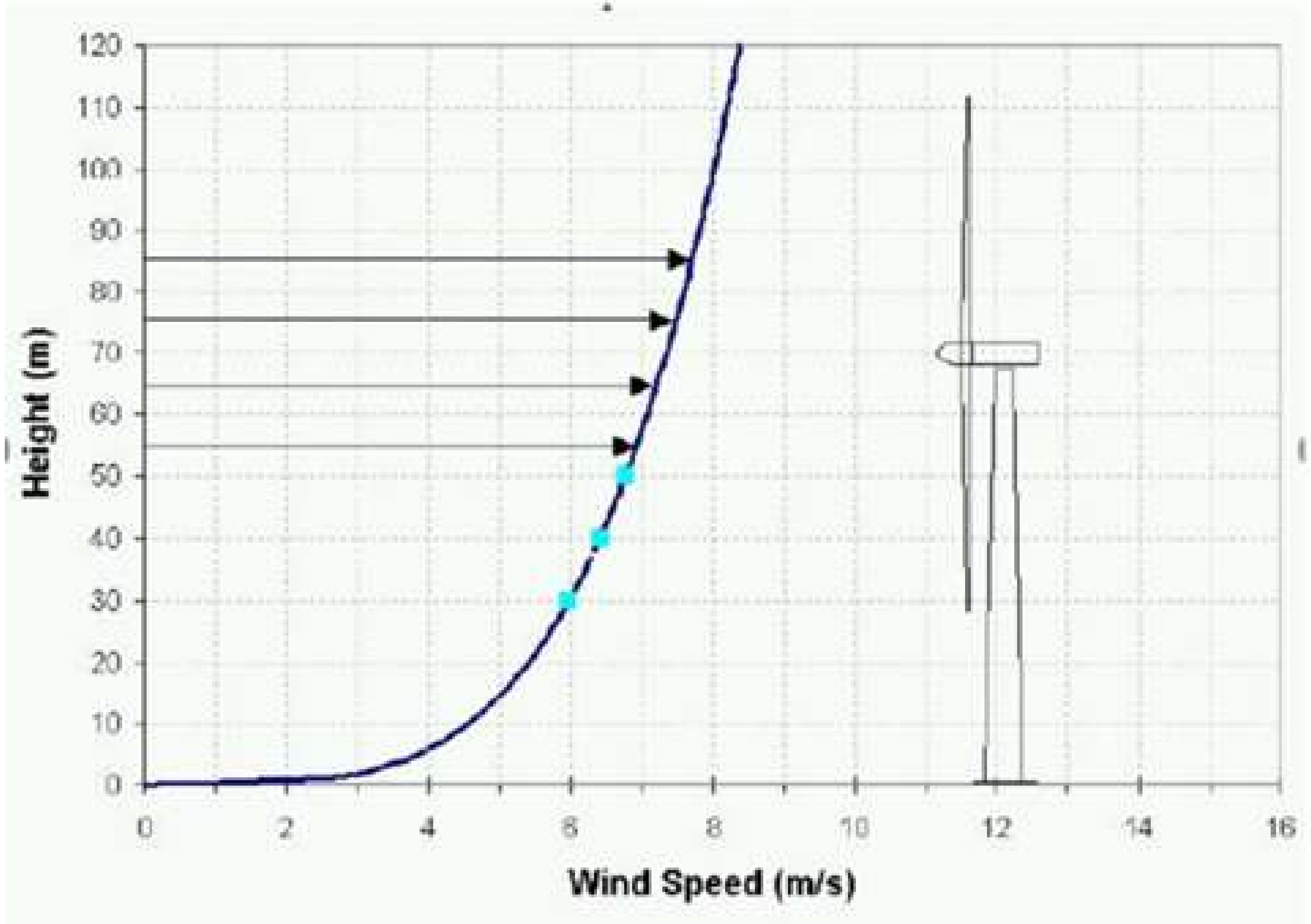
The tower of the wind turbine carries the nacelle and the rotor. Towers for large wind turbines may be either:

- **Tubular steel towers,**
- **Lattice towers,**
- **Concrete towers.**
- **Guyed tubular towers are only used for small wind turbines (battery chargers etc.)**

Tubular steel tower Tubular concrete Lattice tower Three-legged tower Guy-wired pole tower

TOWER HEIGHT

Wind velocities increase at higher altitudes due to surface aerodynamic drag and the viscosity of the air. The variation in velocity with altitude, is called wind shear



FOUNDATIONS

Address Weight

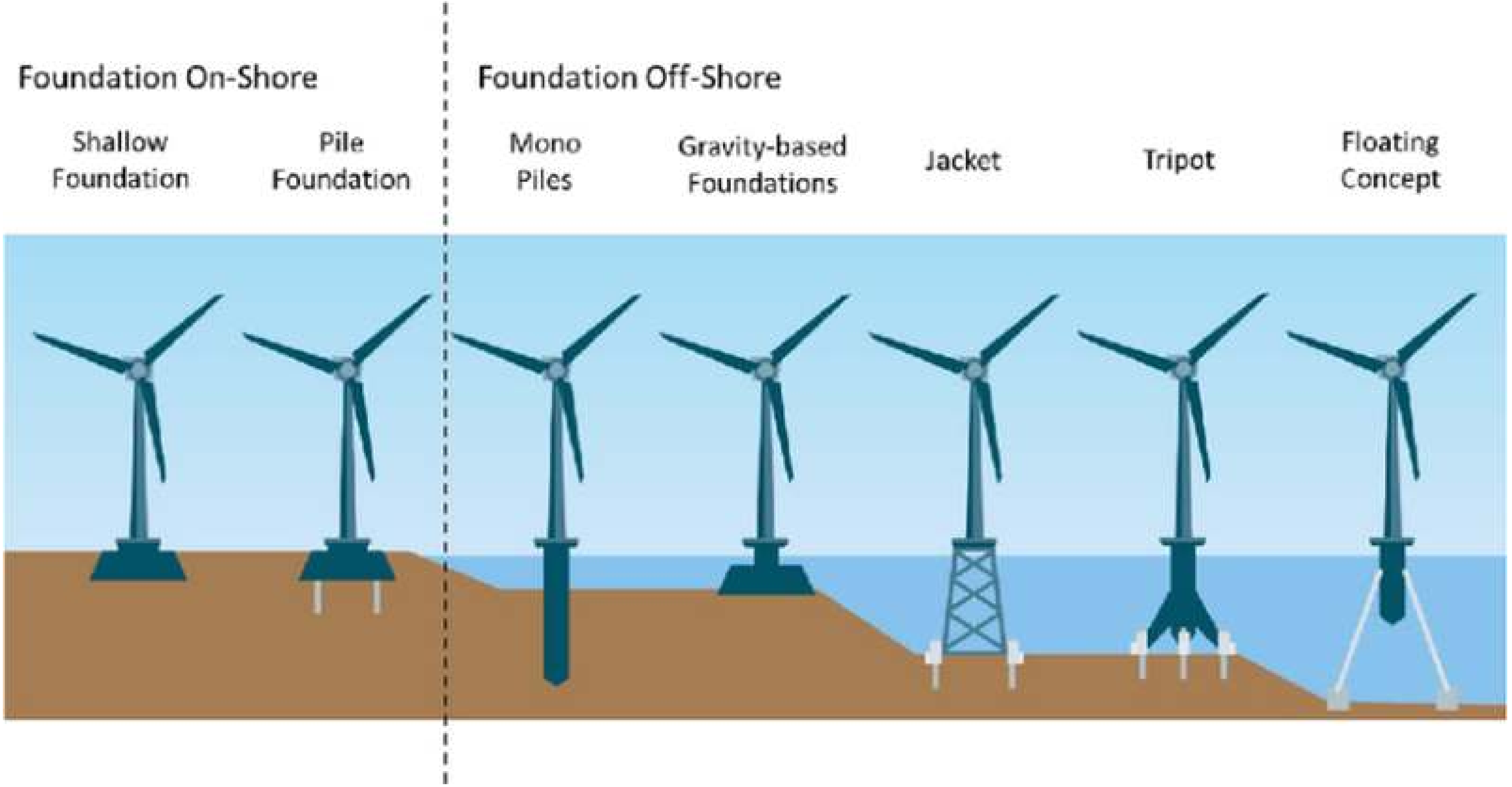
Ensure the foundation can support the structure's weight to prevent sinking.

Resist Bending Moment

Design the foundation to counteract the overturning effect of the bending moment.

Manage Tension & Compression

Account for tension on the upwind side and compression on the downwind side to maintain stability.



OPERATING PRINCIPLE OF A WIND TURBINE

Kinetic Energy of the Wind

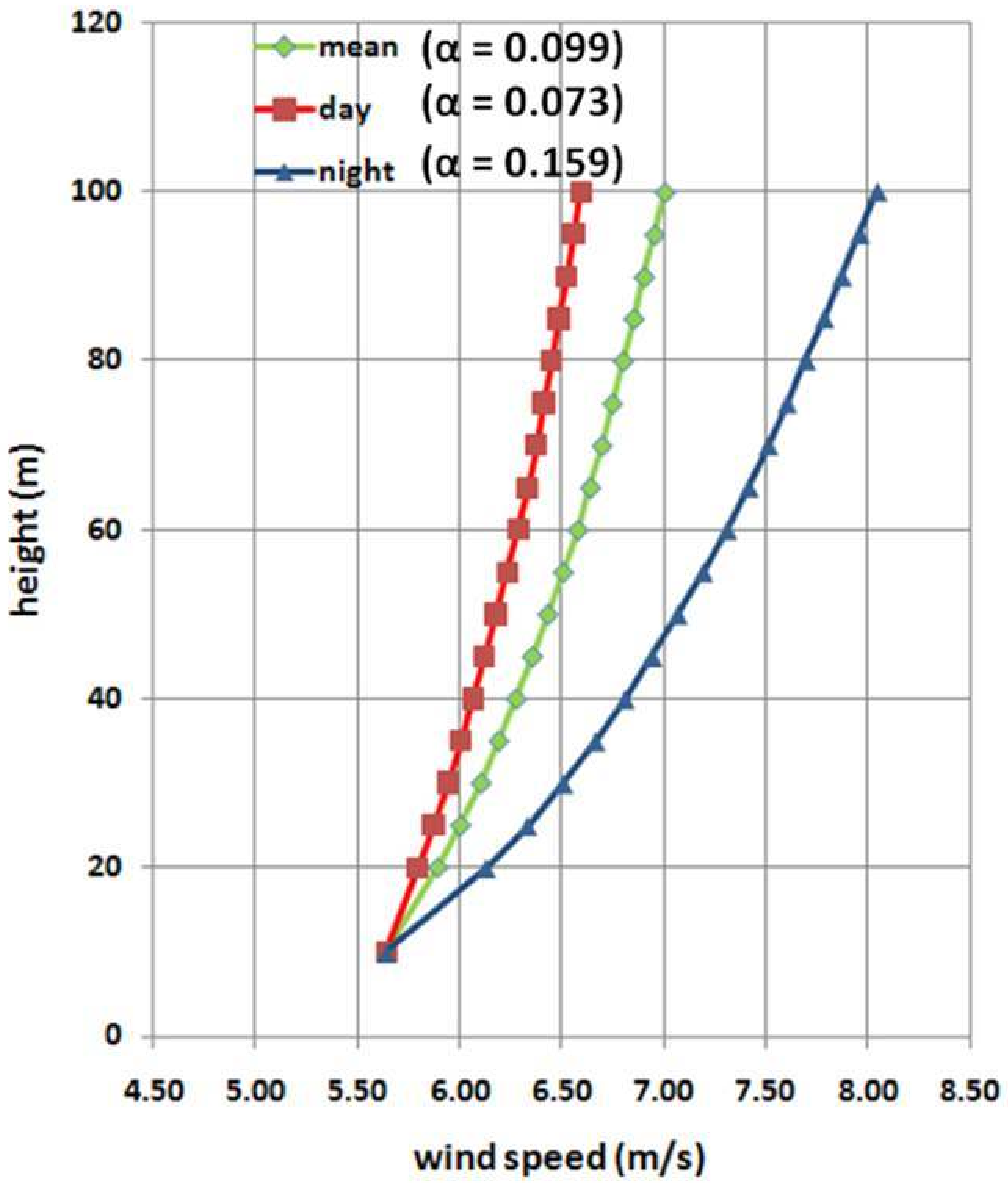
Wind possesses kinetic energy because it is air in motion.
The kinetic energy per second (power) available in the wind is:

$$P_{\text{wind}} = \frac{1}{2}\rho A v^3$$

Where:

- **ρ = air density**
- **A = swept area of the rotor**
- **v = wind speed**

As it can be seen from the formula above that when the wind speed doubles, the power available increases by a factor of 8.



Betz Limit

Not all the energy of the wind can be extracted.

The German physicist Albert Betz demonstrated that only a portion of the wind's kinetic energy can be extracted because some must remain for airflow continuity. It states that the maximum theoretical efficiency of a wind turbine is 59.3%(or 16 \ 27) of the available kinetic energy

$$P_{\max} = \frac{16}{27} \cdot \frac{1}{2} \rho A v^3$$

The real power extracted is:

$$P_{\text{turbine}} = C_p \cdot \frac{1}{2} \rho A v^3$$

Where
Cp: power coefficient

The power coefficient Cp depends on the turbine's design and operating conditions

Conversion to Electrical Energy via Generator

Not all the energy of the wind can be extracted.

Once the wind's kinetic energy is converted into rotational mechanical energy by the turbine rotor, this rotation is transferred to the generator (Inside the generator, coils of wire rotate relative to a magnetic field) which produces electricity.

The actual electrical power output Pelec of the turbine can be expressed as:

$$P_{\text{elec}} = \eta_{\text{total}} \cdot P_{\text{turbine}}$$

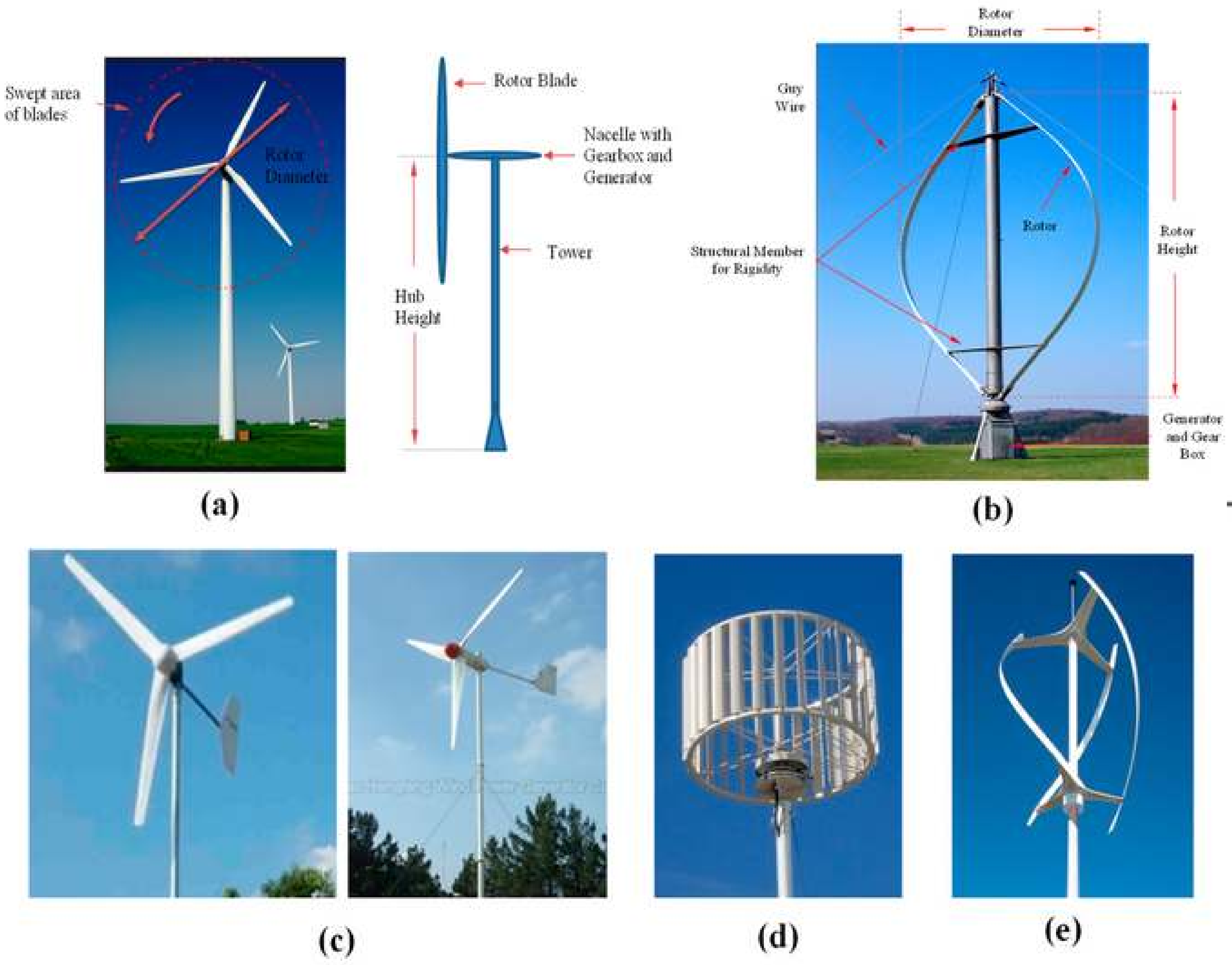
Where:

ηtotal = overall system efficiency,

including:

- *generator efficiency (~90–96%)*
- *gearbox efficiency (if present, ~95–98%)*
- *other mechanical and electrical losses*

TYPES OF WIND TURBINES



Horizontal-Axis Wind Turbines (HAWT)

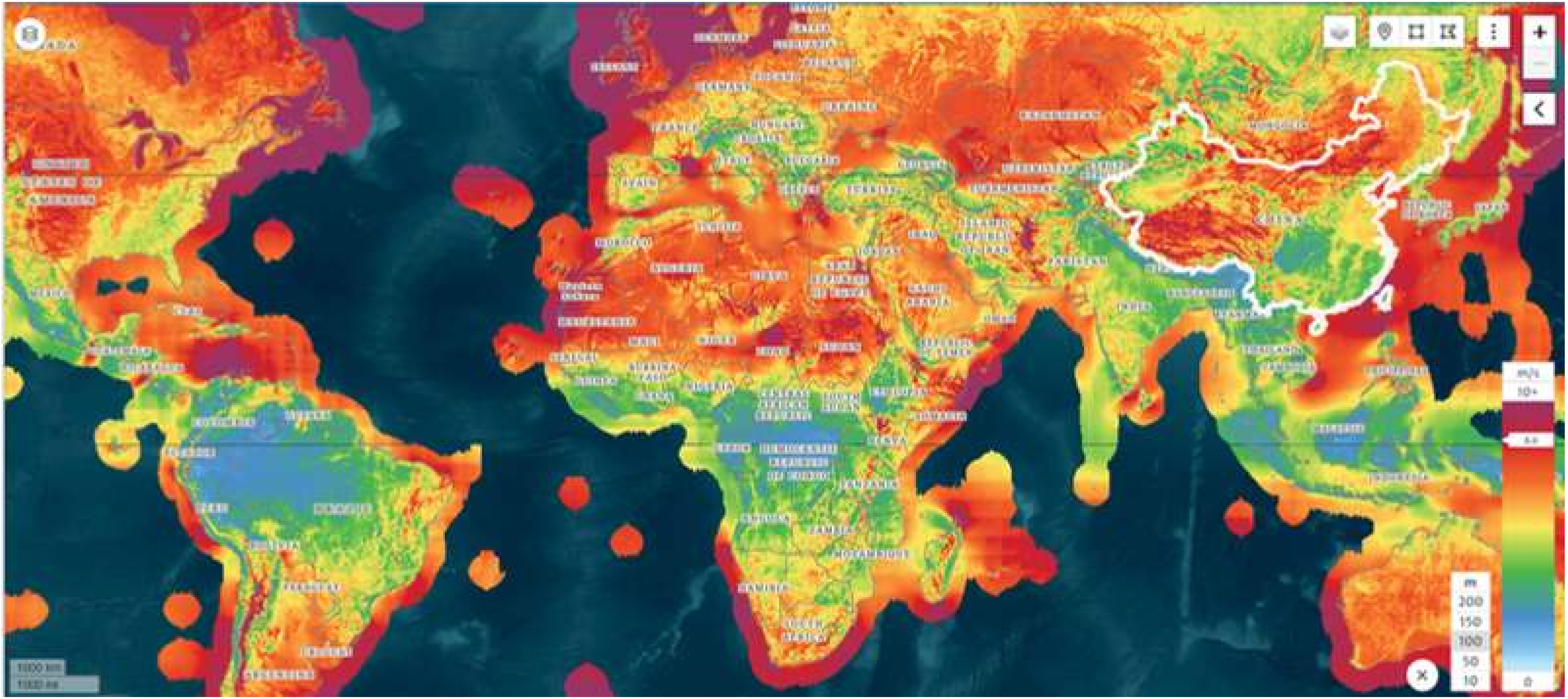
Higher efficiency, suitable for open ,rural, offshore areas, requires yaw control

Vertical-Axis Wind Turbines (VAWT)

Compact, quieter
Works from any wind direction
Better for cities or build-up zones.
Generally less efficient

ONSHORE AND OFFSHORE WIND TURBINES

feature	Onshore	Offshore
Location	Land	Sea
Wind Speed	Moderate	Strong, steady
Cost	Lower installation	Higher investment
Maintenance	Easier	More complex
Example	USA, Spain	UK, Denmark



GLOBAL WIND RESOURCE MAP (GLOBAL WIND ATLAS, 2025).

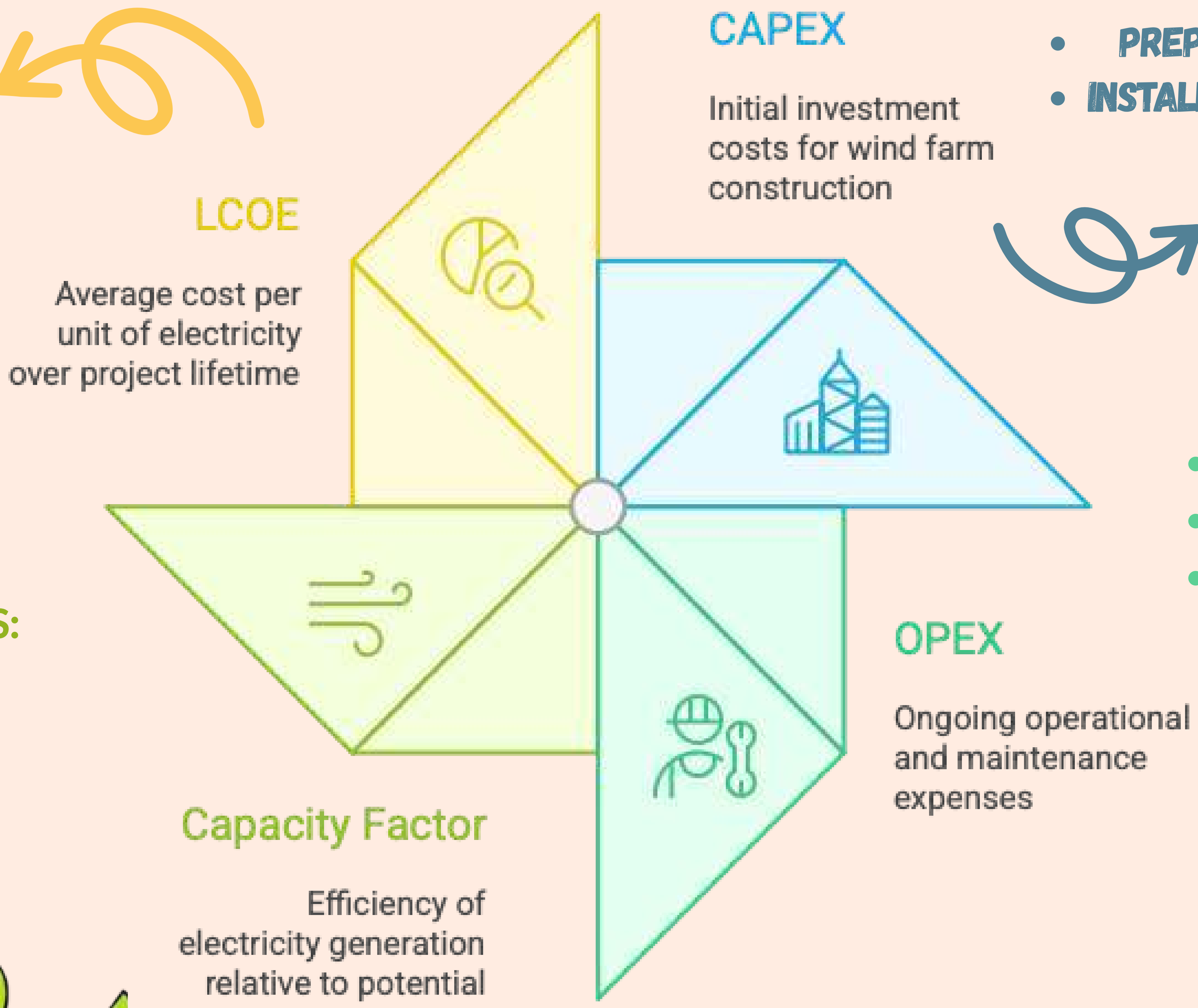
ECONOMIC ASPECTS OF WIND ENERGY

WIND ENERGY IS NOT JUST GREEN

- GOOD FOR THE ENVIRONMENT
- ECONOMIC ENGINE
- DRIVES ECONOMIC GROWTH

KEY ECONOMIC CONCEPTS

- MAINTENANCE AND REPAIRS,
- TECHNICAL STAFF AND MONITORING,
- INSURANCE,



IT INCLUDES:

- PURCHASING THE TURBINES,
- TRANSPORTING THE EQUIPMENT,
- PREPARING THE LAND OR SEA FOUNDATION,
- INSTALLING CABLES AND ELECTRICAL SYSTEMS,

- MAINTENANCE AND REPAIRS,
- TECHNICAL STAFF AND MONITORING,
- INSURANCE.

A HIGHER CAPACITY FACTOR MEANS:

- BETTER USE OF THE TURBINE,
- MORE ELECTRICITY PRODUCED,
- MORE REVENUE OVER TIME.

BALANCING COST AND OUTPUT: ONSHORE VS OFFSHORE

S

Cost-Effective Energy

- Cost-Effectiveness
  $2.5 TO $4 MILLION PER TURBINE
- Accessibility and Maintenance
- Established Infrastructure
- Contribution to Local Communities

W

Environmental Impact Concerns

- Visual and Noise Pollution
- Land Use Challenges
- Variability in Wind Patterns

O

Efficiency and Expansion

- Efficiency Improvements
- Technological Advancements
- Policy Support : Tax benefits, Subsidies..

T

Public Opposition Risks

- Public Opposition
- Environmental Regulations : must ensure: protection of wildlife, minimal deforestation, respect for local ecosystems.
- Grid Connection Issues : Weak grid capacity, high infrastructure costs.

BALANCING COST AND OUTPUT: ONSHORE VS OFFSHORE

S

High Energy Output

- Higher Wind Speeds
- Larger Turbines
- Reduced Impact on Residential Areas

W

High Initial Investment

- High Installation Costs

TENS OF MILLIONS TO OVER $100 MILLION OR MORE PER TURBINE

- High Maintenance Costs
- Accessibility Issues

O

Scalable Renewable Projects

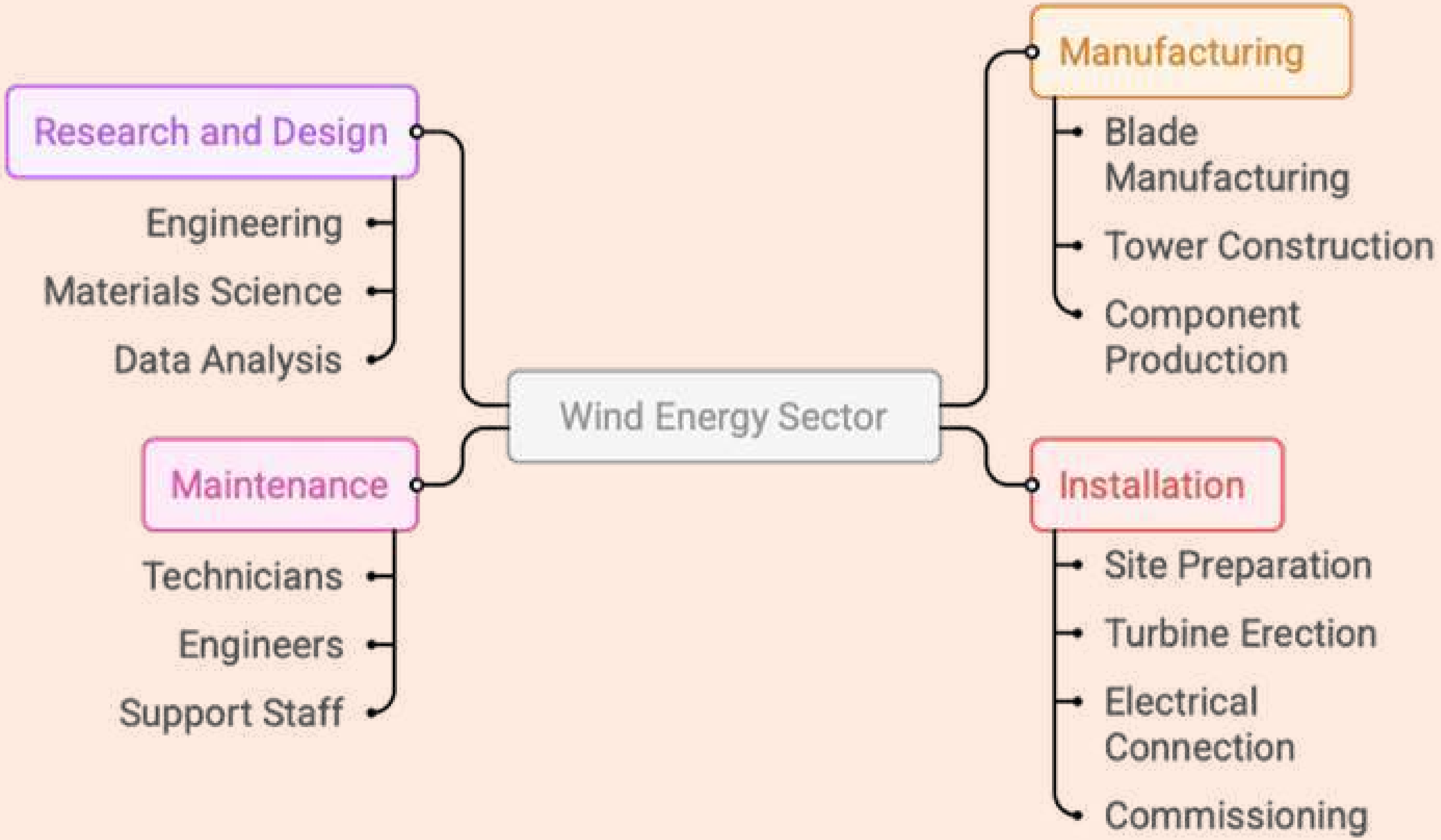
- Large-Scale Renewable Projects
- Coastal Area Electricity Demand

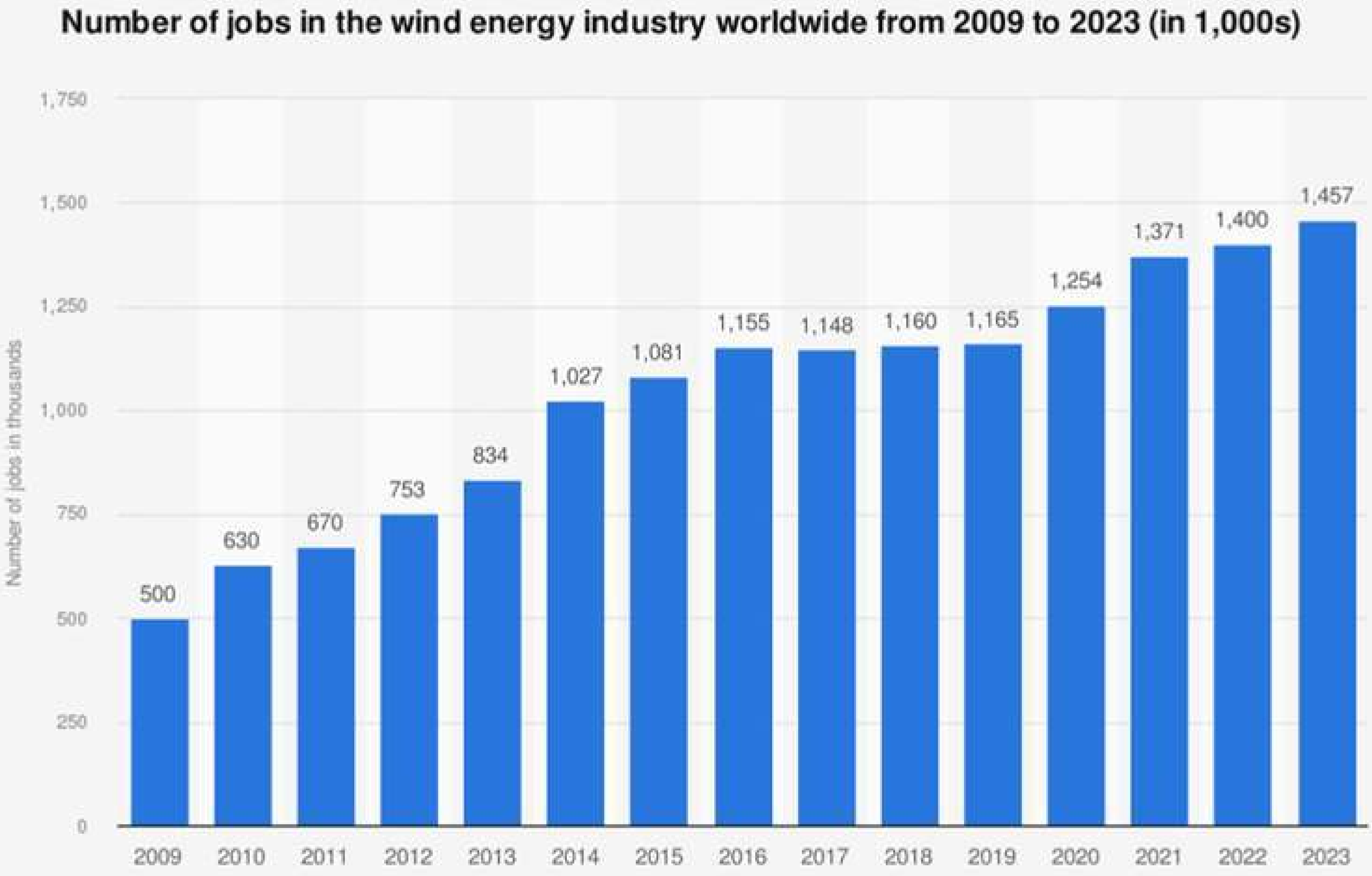
T

Environmental and Technical

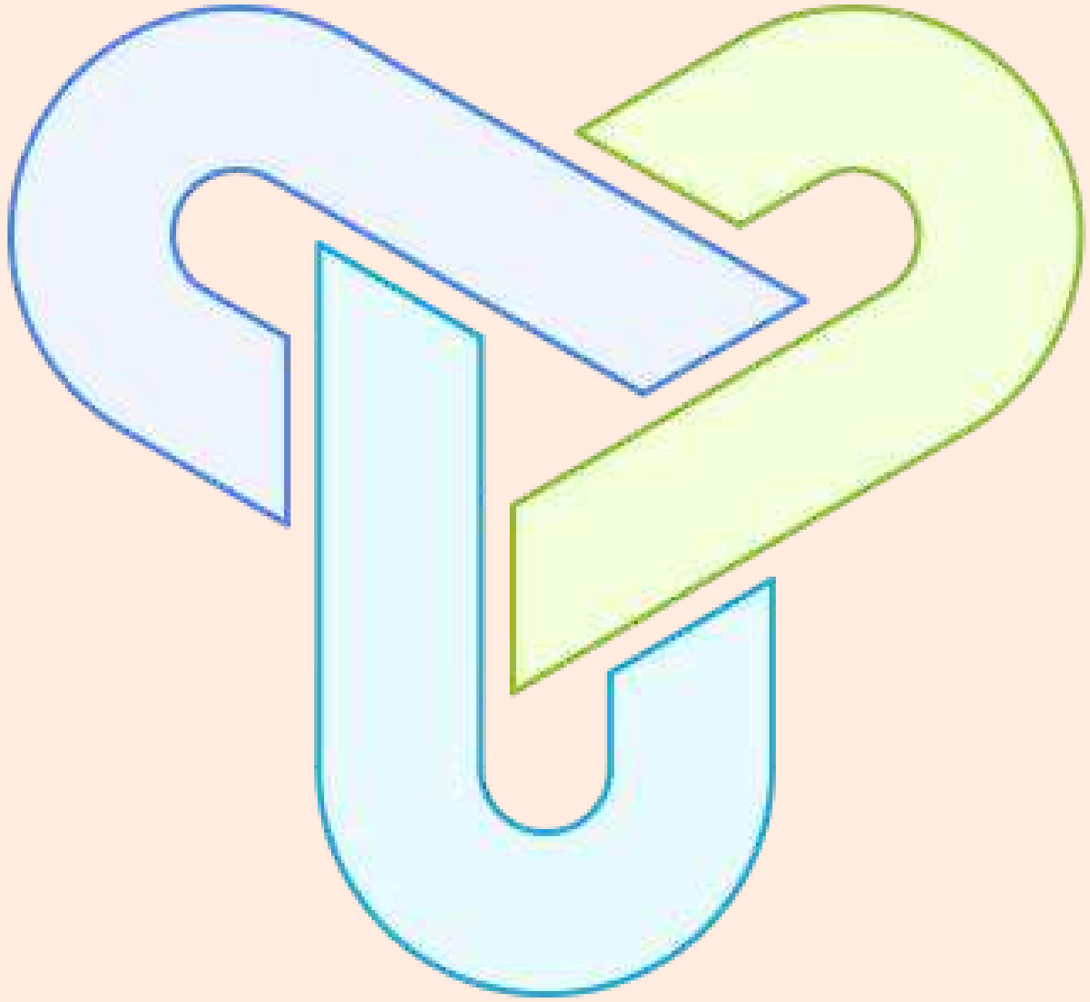
- Environmental Concerns : impact on marine ecosystems
- Dependence on Advanced Technology

JOB CREATION IN WIND ENERGY SCETOR




Number of jobs in the wind energy industry worldwide from 2009 to 2023 (in 1,000s)
1,750
1,500
1,250
1,000
750
500
250
0
Number of jobs in thousands
500
630
670
753
834
1,027
1,081
1,155
1,148
1,160
1,165
1,254
1,371
1,400
1,457
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023

BENEFITS OF WIND FARMS FOR LANDOWNERS & COMMUNITIES :



Increased Local Spending

Boosts local economy through construction and operation

Rental Income for Landowners

Provides stable income for hosting turbines

Minimal Disruption to Land Use

Allows continued agricultural activities

BENEFITS OF WIND FARMS FOR THE GOVERNMENTS :

Tax Revenue

Generates income through land, company, and income taxes

Reduced Fuel Imports

Decreases reliance on foreign fossil fuels

Stable Electricity Prices

Provides affordable and predictable energy costs

- No fuel cost --> cheap electricity

ECONOMIC &. ENVIRONMENTAL IMPACT :

Country	2023-2027	New wind installations (MW)	FTE jobs created over wind farm lifetimes (jobs)	Gross value added to economy over wind farm lifetimes ($)	Homes powered by clean energy annually from 2027 (homes)	Tons of carbon emissions saved over wind farm lifetimes (tons)	Litres of water saved annually from 2027 (litres)
Argentina	BAU	1,500	112,000	3.3 billion	1.7 million	71 million	12 million
	Wind Acceleration	1,965	176,000	4.7 billion	2.2 million	93 million	16 million
	Potential Upside	465	64,000	1 billion	0.5 million	21 million	4 million
	% increase	31%	57%	45%	30%	30%	31%
Colombia	BAU	2,700	191,000	4.9 billion	5.5 million	233 million	15.5 million
	Wind Acceleration	3,900	339,000	8.1 billion	7.8 million	336 million	22.5 million
	Potential Upside	1,200	148,000	3 billion	2.3 million	103 million	7 million
	% increase	44%	77%	65%	43%	44%	44%
Egypt	BAU	2,602	242,000	3.5 billion	6.5 million	225 million	21 million
	Wind Acceleration	3,758	406,000	5.6 billion	9.2 million	326 million	31 million
	Potential Upside	1,158	164,000	2.1 billion	2.8 million	101 million	10 million
	% increase	45%	68%	60%	43%	45%	45%
Indonesia	BAU	450	34,000	1.2 billion	1 million	23 million	2.6 million
	Wind Acceleration	565	51,000	1.6 billion	1.2 million	29 million	3.2 million
	Potential Upside	115	17,000	400 million	0.2 million	6 million	0.7 million
	% increase	26%	50%	36%	24%	26%	26%
Morocco	BAU	1,500	99,000	2.1 billion	4.7 million	77 million	8.6 million
	Wind Acceleration	2,138	174,000	3.4 billion	6.6 million	110 million	12.3 million
	Potential Upside	638	75,000	1.3 billion	1.9 million	12.3 million	3.7 million
	% increase	43%	76%	63%	40%	42%	43%

WHAT IS THE CURRENT POLITICAL SITUATION OF WIND ENERGY IN THE WORLD ?

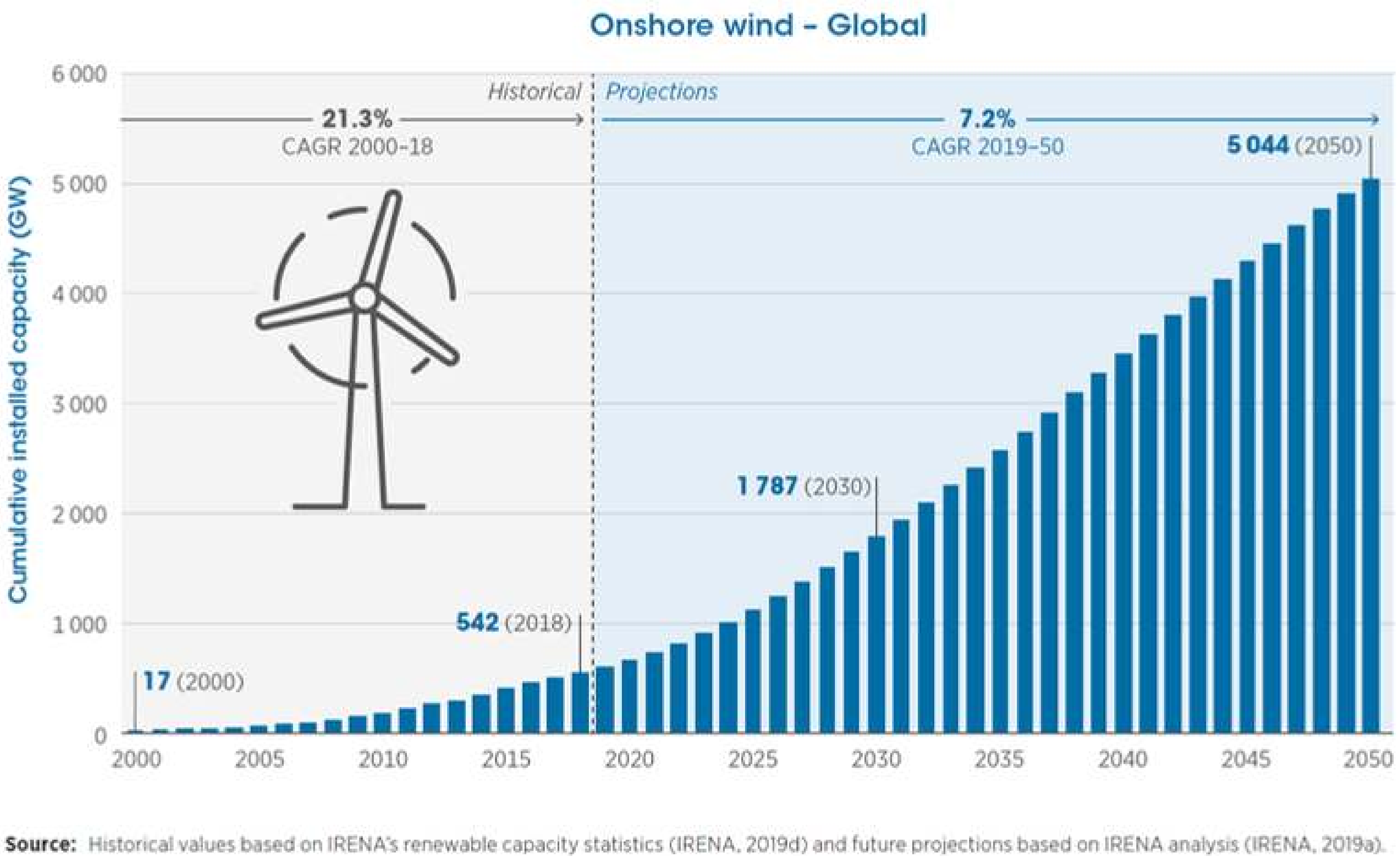
IRENA
International Renewable Energy Agency

GWEC
GLOBAL WIND ENERGY COUNCIL

WORLD ENERGY COUNCIL | FUTURE ENERGY LEADERS

iea International Energy Agency

GLOBAL WIND ONSHORE CAPACITY HISTORY AND FUTURE OUTLOOK



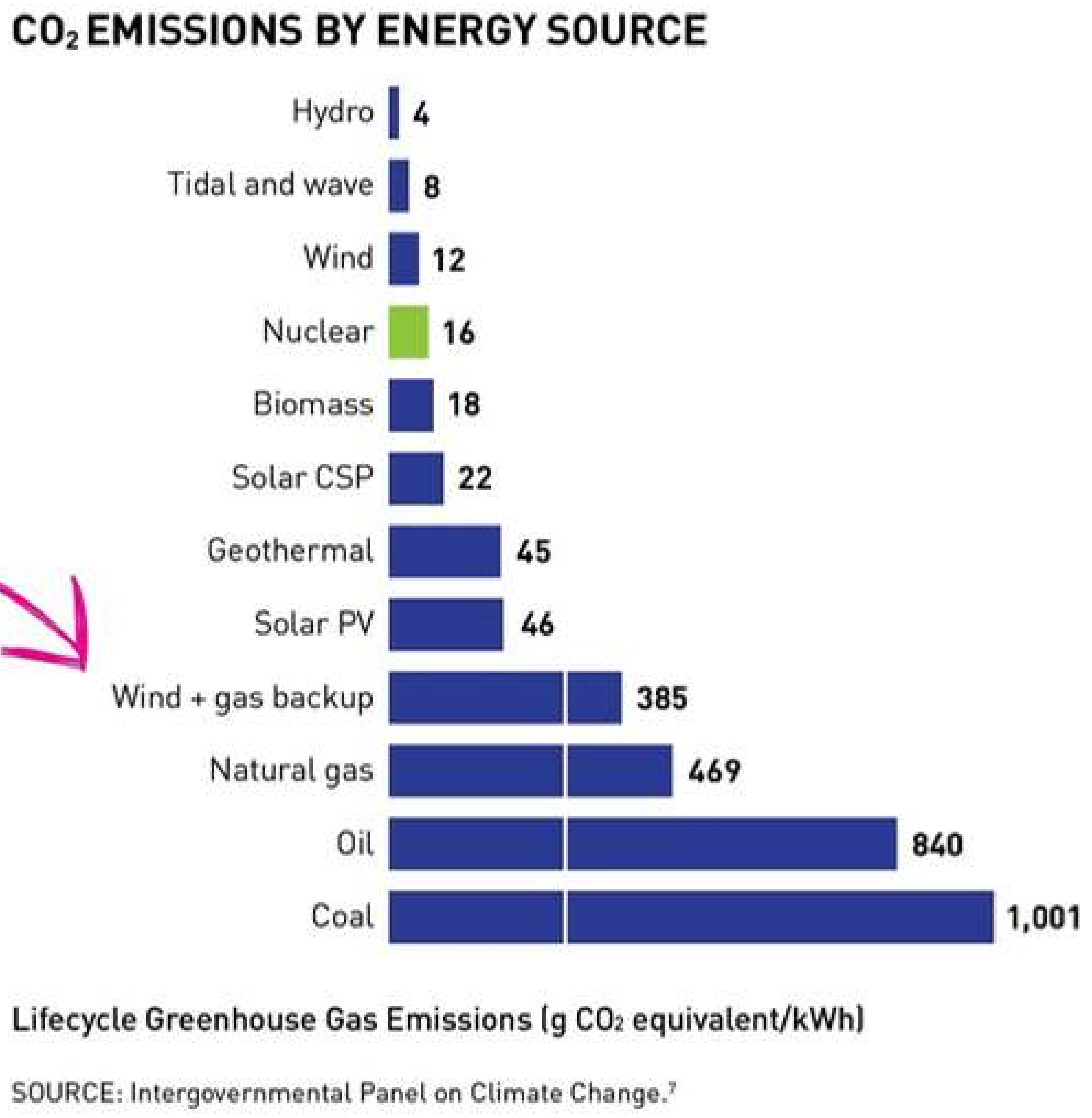
Evolution of the global installed onshore wind capacity, Source : IRENA

THE DIFFERENT ENERGY SOURCE AND CARBON RELEASE IN THE ENVIRONMENT

Hydro , Geothermal, Tidal and wave

Onshore /offshore wind energy CO_2 release

Oil, Coal and Natural Gas



CO_2 Emissions by different energy sources in 2023, SOURCE : IPCC

WIND ENERGY AND ENVIRONMENT

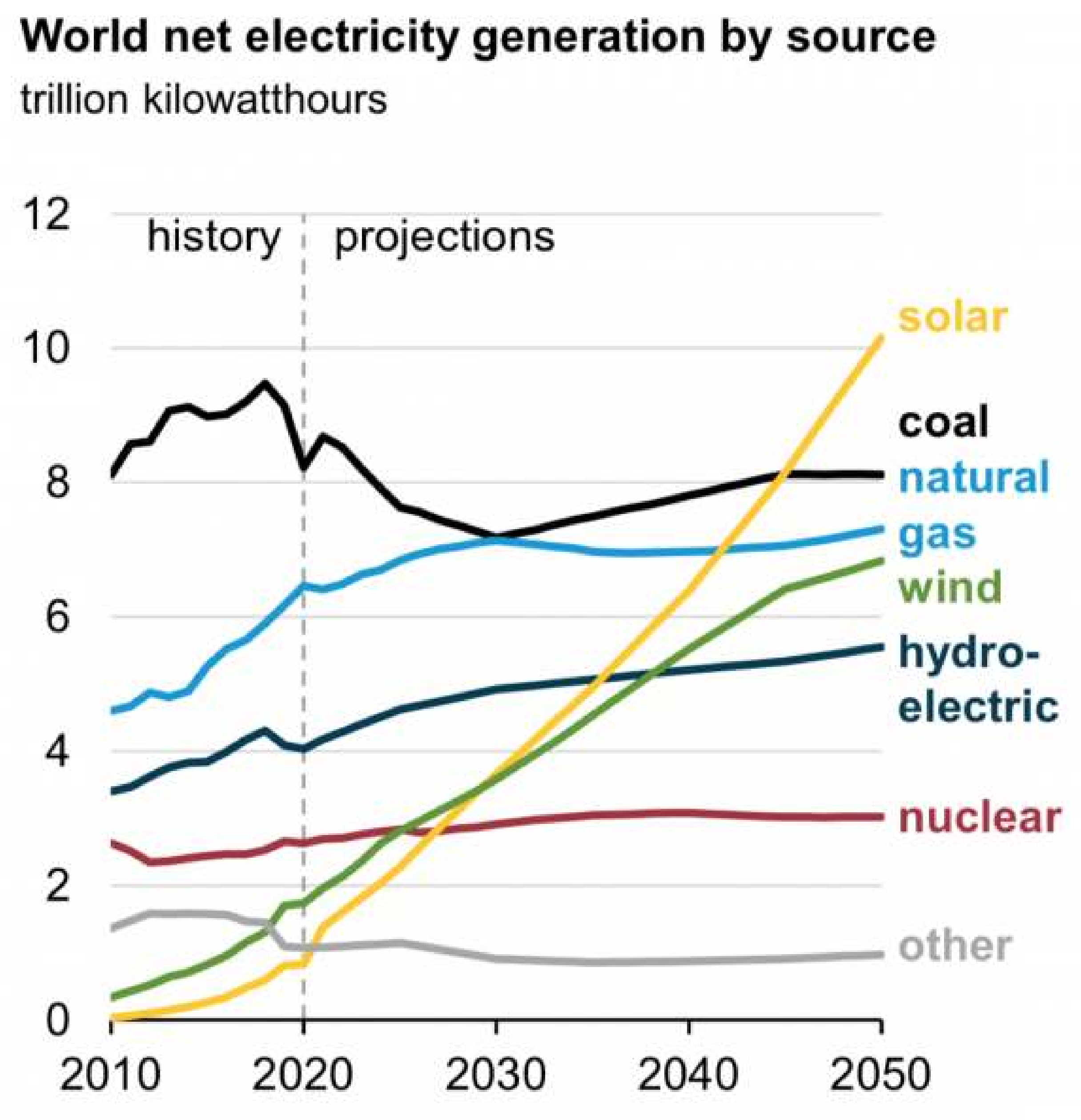
WHAT'S THE IMPACT OF WIND ENERGY IN THE ENVIRONMENT ?

- Acceleration of energy transition

- Climate change mitigation

ACCELERATION OF ENERGY TRANSITION

- Rapid adoption of Wind energy
- Decarbonization of energy systems
- A diversified renewable energy mix



World net electricity generation by source, SOURCE: IEA

CLIMATE CHANGES MITIGATION

- Offshore wind turbines : A 15MW Nominal power in 2026 (Source : IEA)

- Reduction of fossil fuels generated energy

- Low-carbons emissions

REFERENCES

- https://www.weforum.org/stories/2024/05/how-wind-energy-is-reshaping-the-future-of-global-power-and-politics/#:~:text=Nations%20are%20using%20wind%20energy%20for%20more%20than,energy%20as%20a%20major%20element%20in%20global%20geopolitics.
- https://cna.ca/fr/c02-emissions-by-energy-source-2/
- file:///C:/Users/pc/Downloads/NY-Wind-Energy-Guide-1.pdf
- https://www.zf.com/products/en/wind/home/wind.html
- https://www.intechopen.com/chapters/38933
- https://rindustry.org/wp-content/uploads/2021/06/RIndustry-Wind-Technology-Session-4.
- https://bvgassociates.com/december-2023-newsletter/
- https://www.zoliov.com/resource/blog/onshore-vs-offshore-wind-farms-differences/
- https://www.statista.com/

THANK YOU!