ANKARA UNIVERSITY
DEPARTMENT OF ENERGY ENGINEERING

INTRODUCTION TO WIND ENERGY AND TURBINE

INSTRUCTOR

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CONTENTS

INTRODUCTION

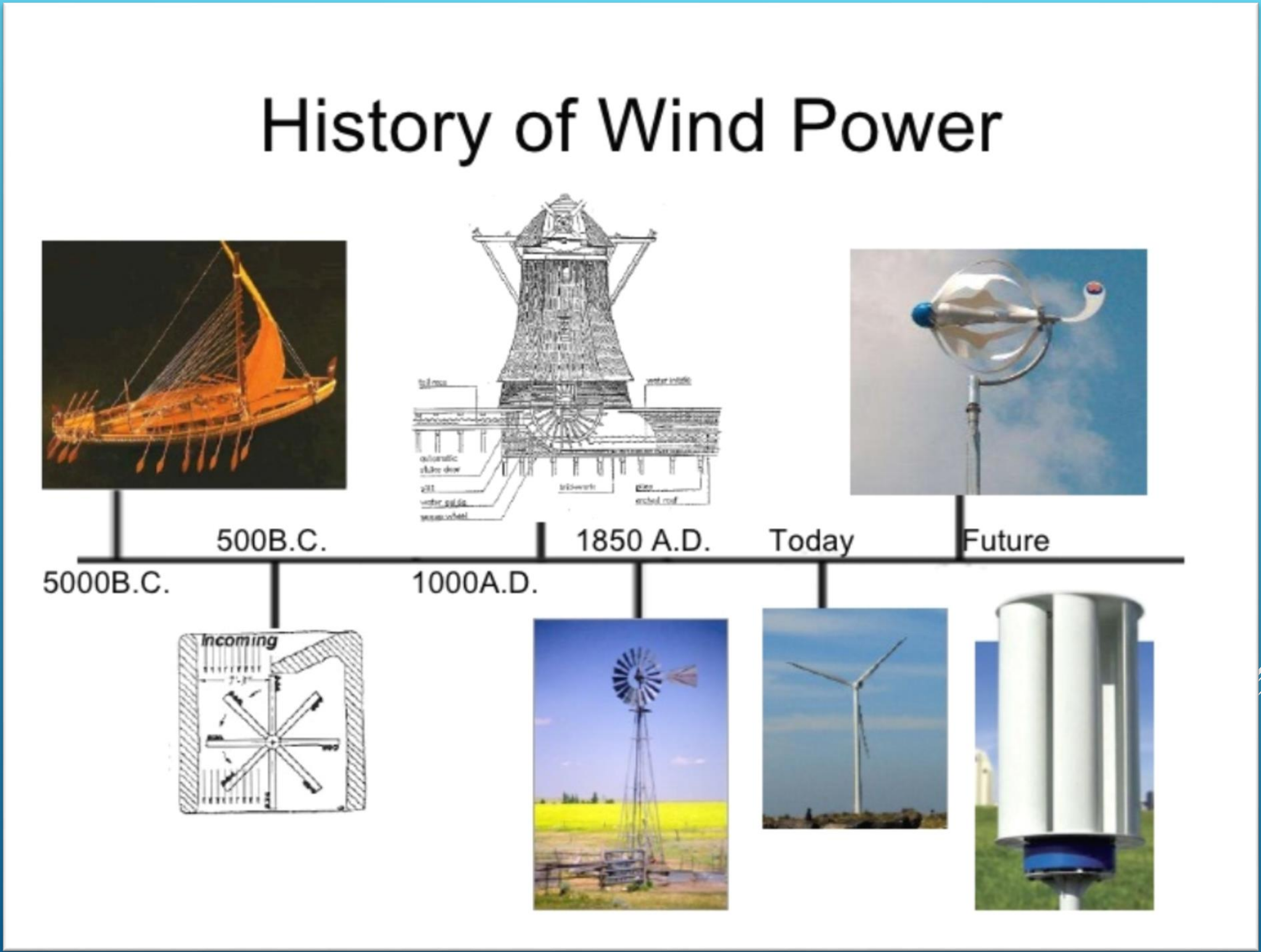
Wind energy, the world's fastest growing energy source, is a clean and renewable source of energy that has been in use for centuries in Europe and more recently in the United States and other nations.

And todays world wind is one of the cheapest and cleanest energy source.

HISTORY

The use of wind as an energy source begins in antiquity. Vertical-axis windmills for grinding grain were reported in Persia in the tenth century and in China in the thirteenth century. At one time wind was a major source of energy for transportation (sailboats), grinding grain, and pumping water. Windmills, along with water mills, were the largest power sources before the invention of the steam engine. Windmills, numbering in the thousands, for grinding grain and pumping drainage water were common across Europe, and some windmills were even used for industrial purposes, such as sawing wood.

FIGURE 1.1 Dutch windmills, World Heritage Site, Kinderdijk, The Netherlands.


History of Wind Power
5000B.C.
500B.C.
1000A.D.
1850 A.D.
Today
Future
Incoming

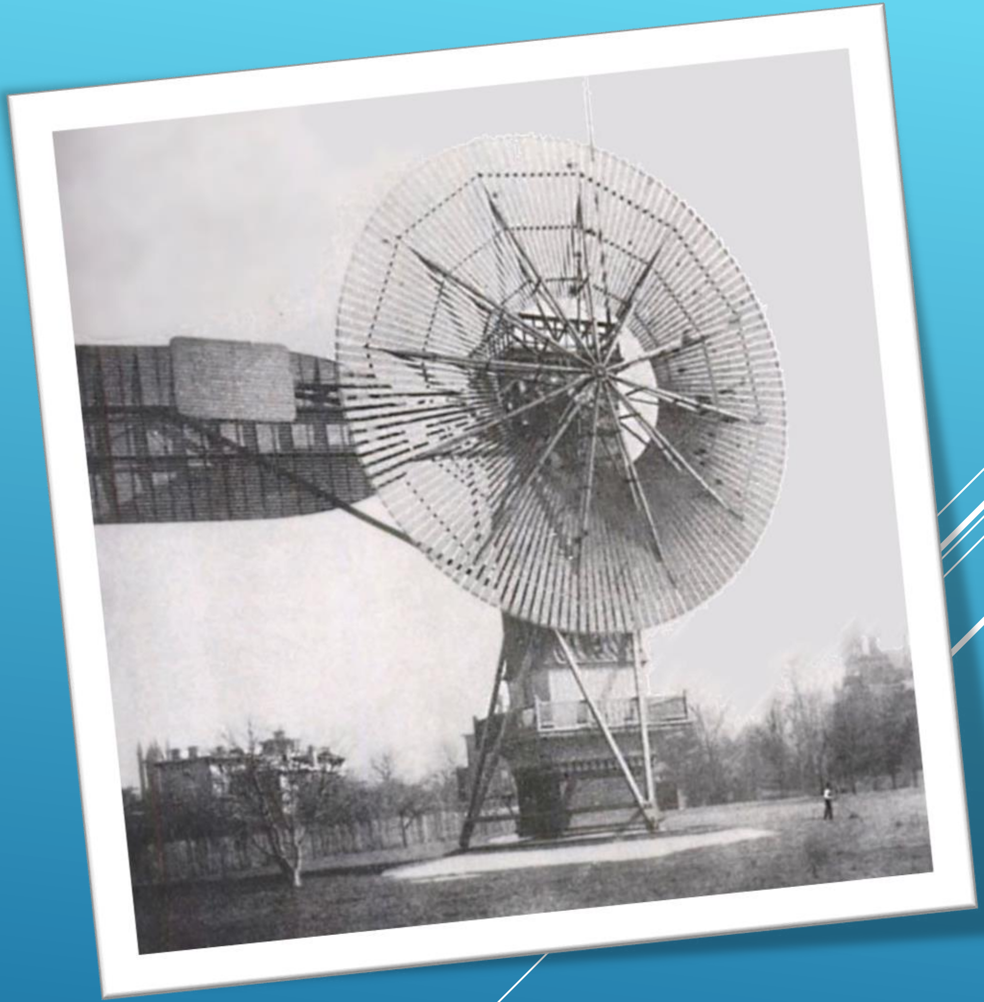
Brief History - Rise of Wind Powered Electricity

1888: *Charles Brush builds first large-size wind electricity generation turbine (17 m diameter wind rose configuration, 12 kW generator)*

1890s: *Lewis Electric Company of New York sells generators to retrofit onto existing wind mills*

1920s-1950s: *Propeller-type 2&3 blade horizontal-axis wind electricity conversion systems (WECS)*

1940s – 1960s: *Rural Electrification in US and Europe leads to decline in WECS use*

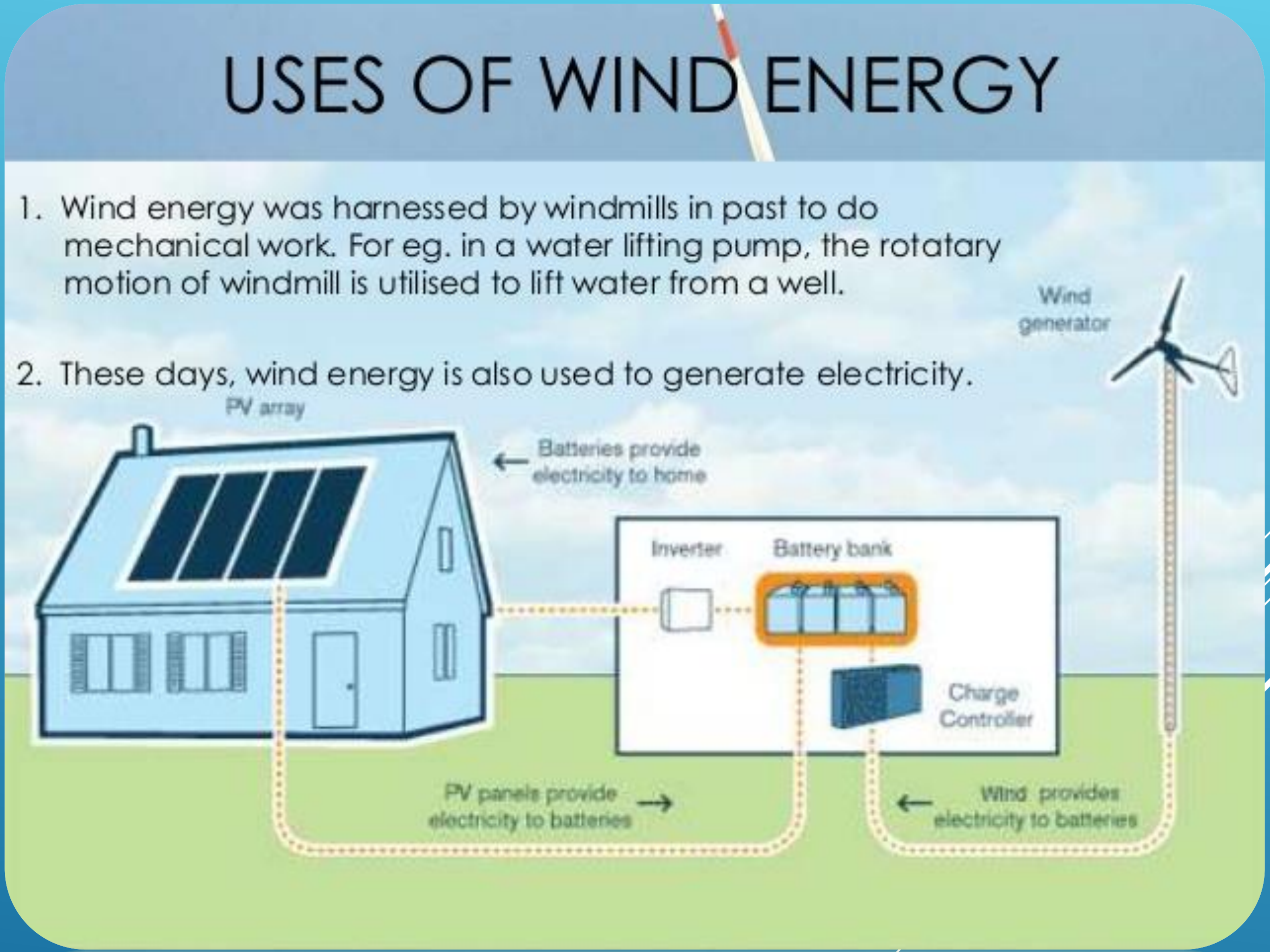


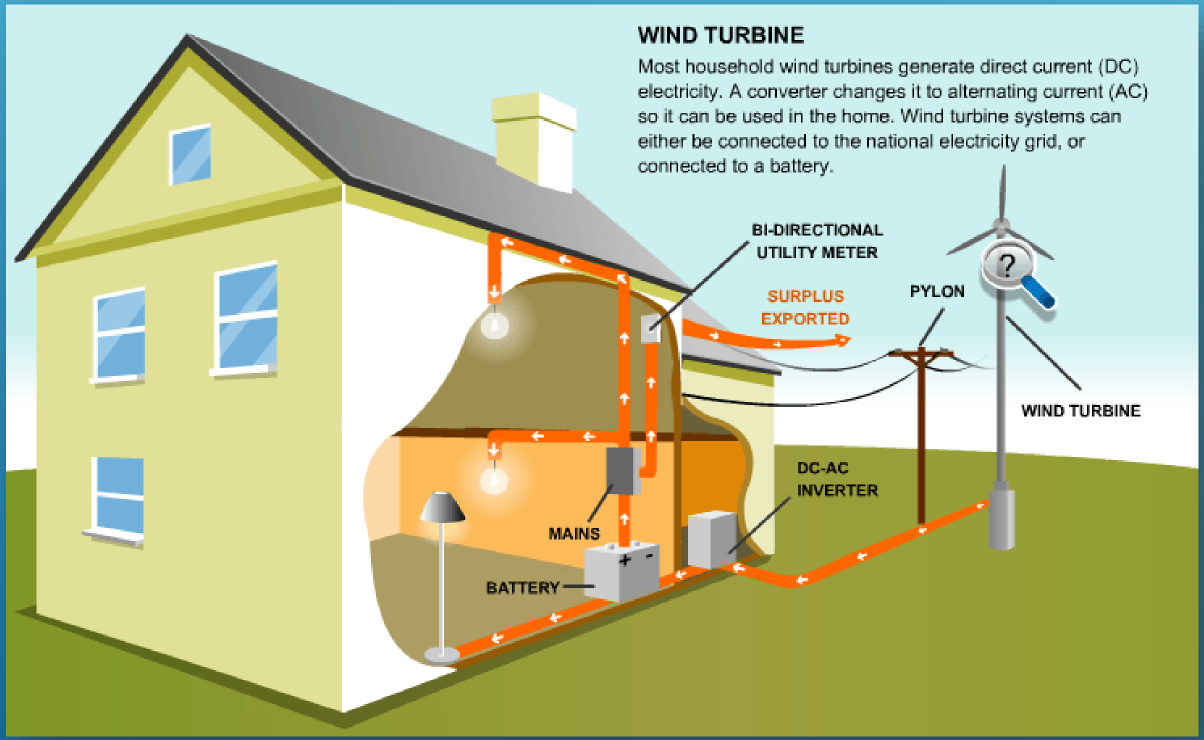
- *By the 13th century, grain grinding mills were popular in most of Europe*
- *The era of wind electric generators began close to 1900's.*
- *The first modern wind turbine, specifically designed for electricity generation, was constructed in Denmark in 1890.*
- *The first utility-scale system was installed in Russia in 1931.*
- *A significant development in large-scale systems was the 1250 kW turbine fabricated by Palmer C. Putman.*

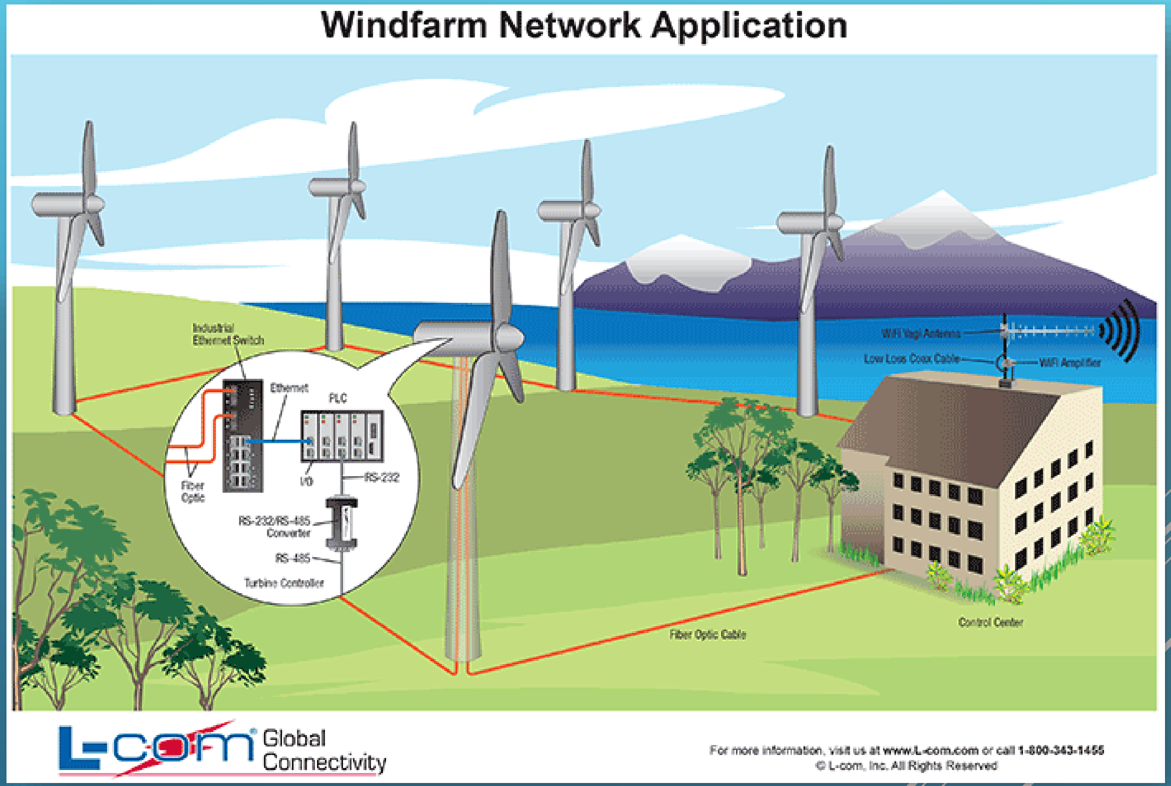
Old windmill.

USE OF WIND TRIBUNE

- *Electricity for homes and farms*
- *Electricity for communities*
- *Electricity in industry*
- *Supplying electricity for a nation*
- *Remote communities*




WIND TURBINE
Most household wind turbines generate direct current (DC) electricity. A converter changes it to alternating current (AC) so it can be used in the home. Wind turbine systems can either be connected to the national electricity grid, or connected to a battery.
BI-DIRECTIONAL UTILITY METER
SURPLUS EXPORTED
PYLON
WIND TURBINE
DC-AC INVERTER
MAINS
BATTERY


Windfarm Network Application
Industrial Ethernet Switch
Ethernet
PLC
Fiber Optic
I/O
RS-232
RS-232/RS-485 Converter
RS-485
Turbine Controller
WiFi Yagi Antenna
Low Loss Coax Cable
WiFi Amplifier
Fiber Optic Cable
Control Center
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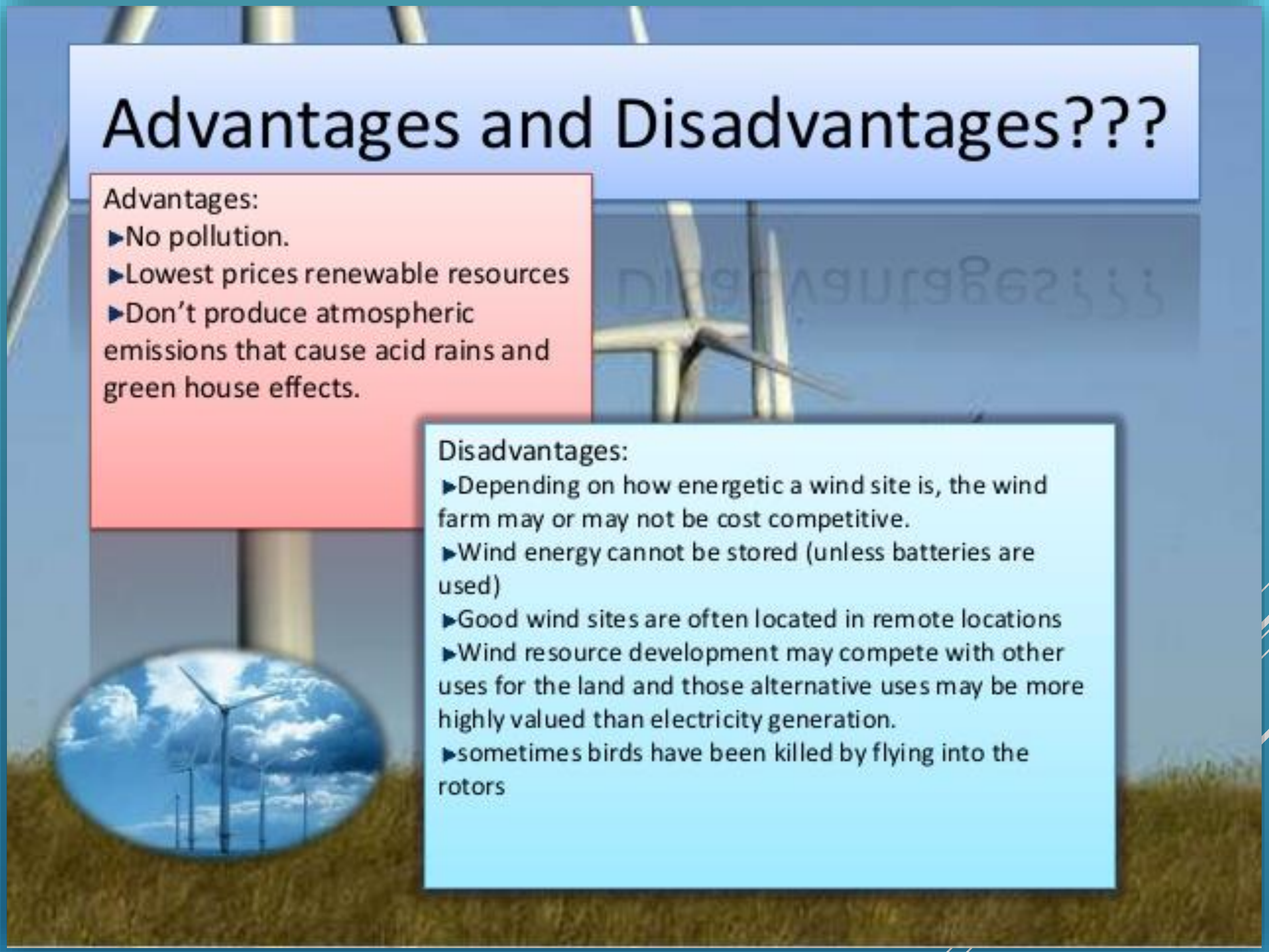
Advantages & Disadvantages of Wind Energy

Advantages

- *Wind Energy Is Renewable & Sustainable*
- *It Reduces Fossil Fuel Consumption*
- *Wind Energy is Free*
- *Both Industrial & Domestic Wind Turbines Are Available*
- *Wind Energy Can Provide Power to Remote Locations*
- *Wind Technology is Becoming Cheaper*
- *Wind creates jobs*

Disadvantages

- Wind Turbines Are Expensive
- Wind Turbines Pose a Threat to Wildlife
- Wind Turbines Are Noisy
- Wind Turbines Create Visual Pollution



What Wind Is ?

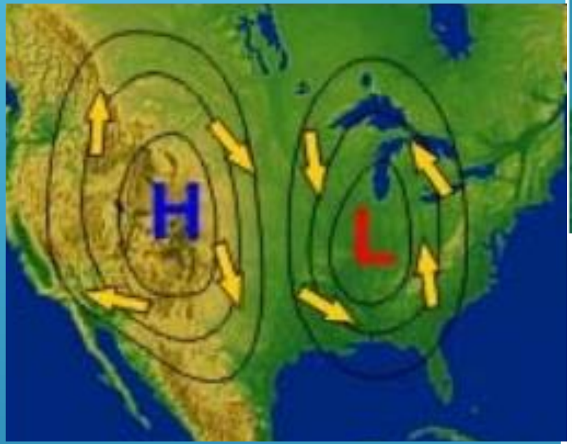
Wind is simply air in motion. It is caused by the uneven heating of the earth's surface by the sun.

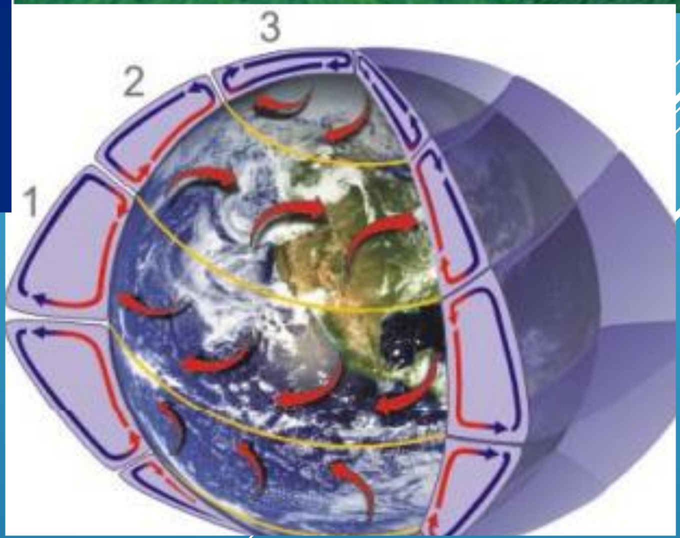
Since the earth's surface is made up of land, desert, water, and forest areas, the surface absorbs

the sun's radiation differently.

Types of Wind

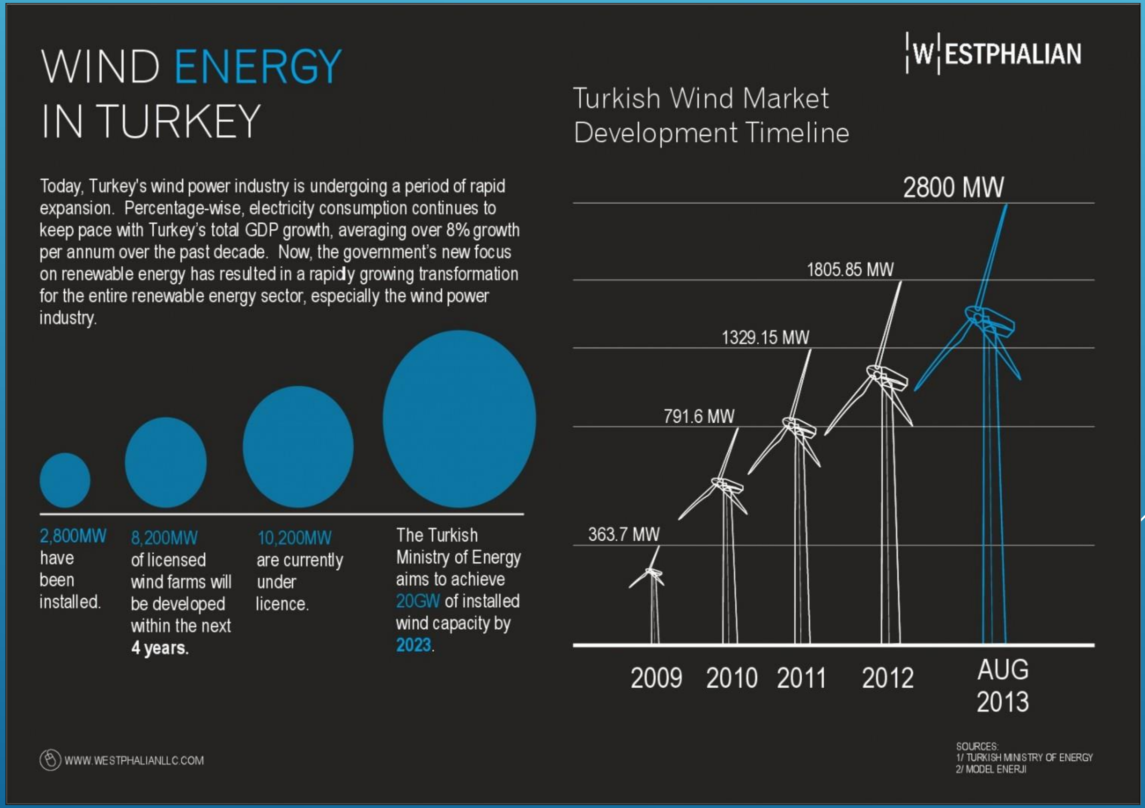
- *Planetary circulations:*
  - *Jet stream*
  - *Trade winds*
  - *Polar jets*
- *Geostrophic winds*
- *Thermal winds*
- *Gradient winds*
- *Katabatic / Anabatic winds – topographic winds*
- *Bora / Foehn / Chinook – downslope wind storms*
- *Sea Breeze / Land Breeze*
- *Convective storms / Downdrafts*
- *Hurricanes/ Typhoons*
- *Tornadoes*
- *Gusts*
- *Nocturnal Jets*
- *Atmospheric Waves*

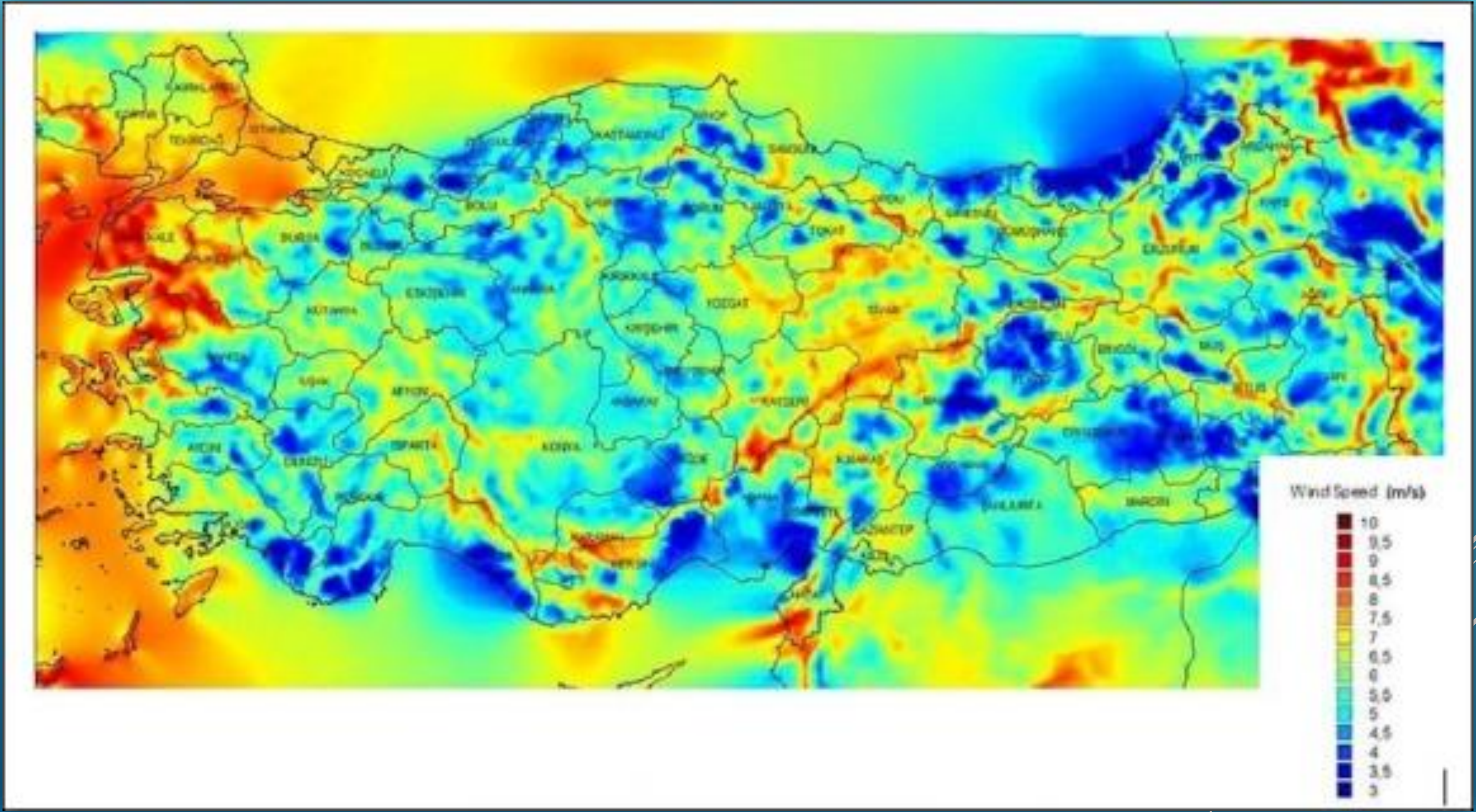


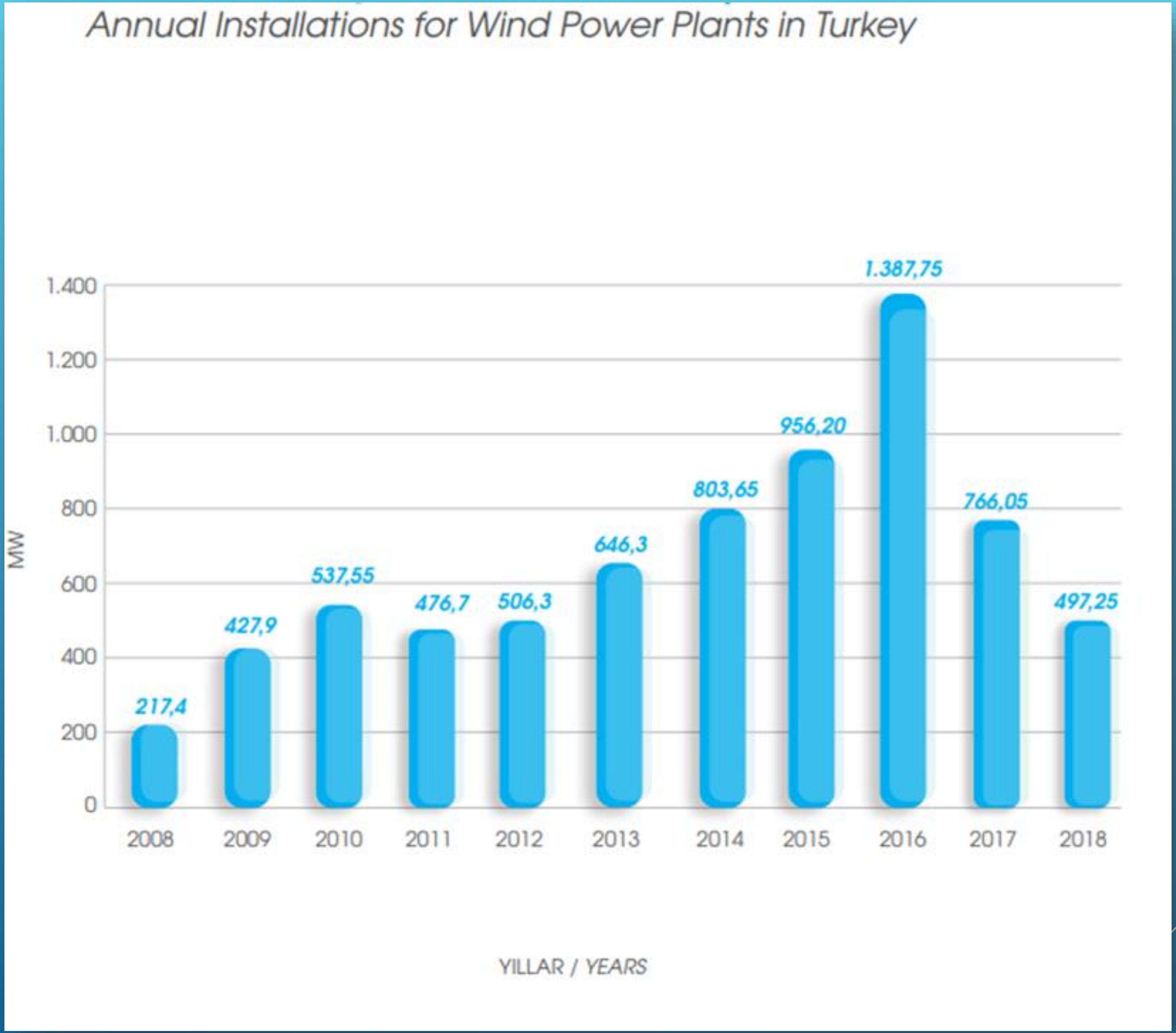


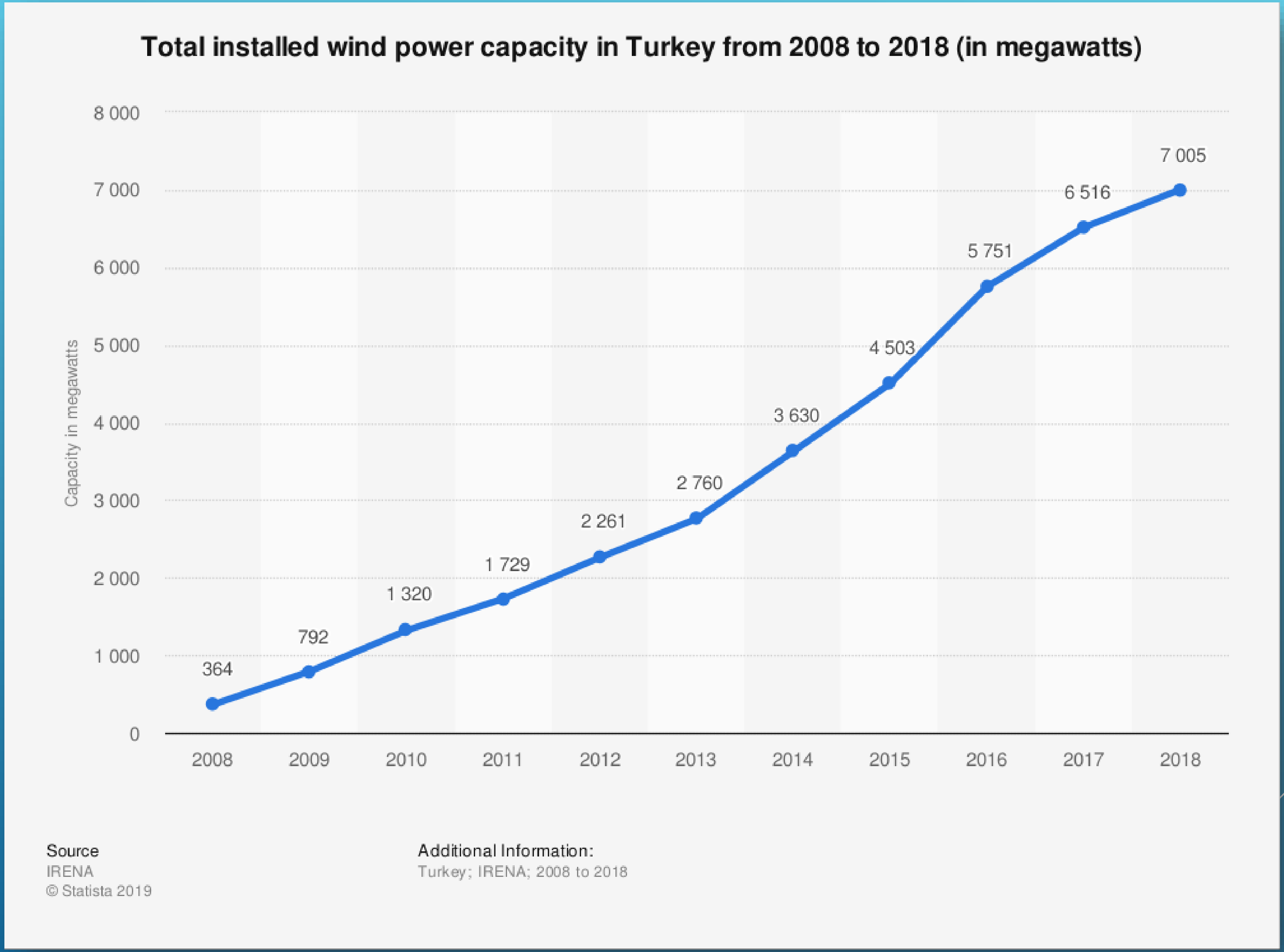
WIND ENERGY IN TURKEY

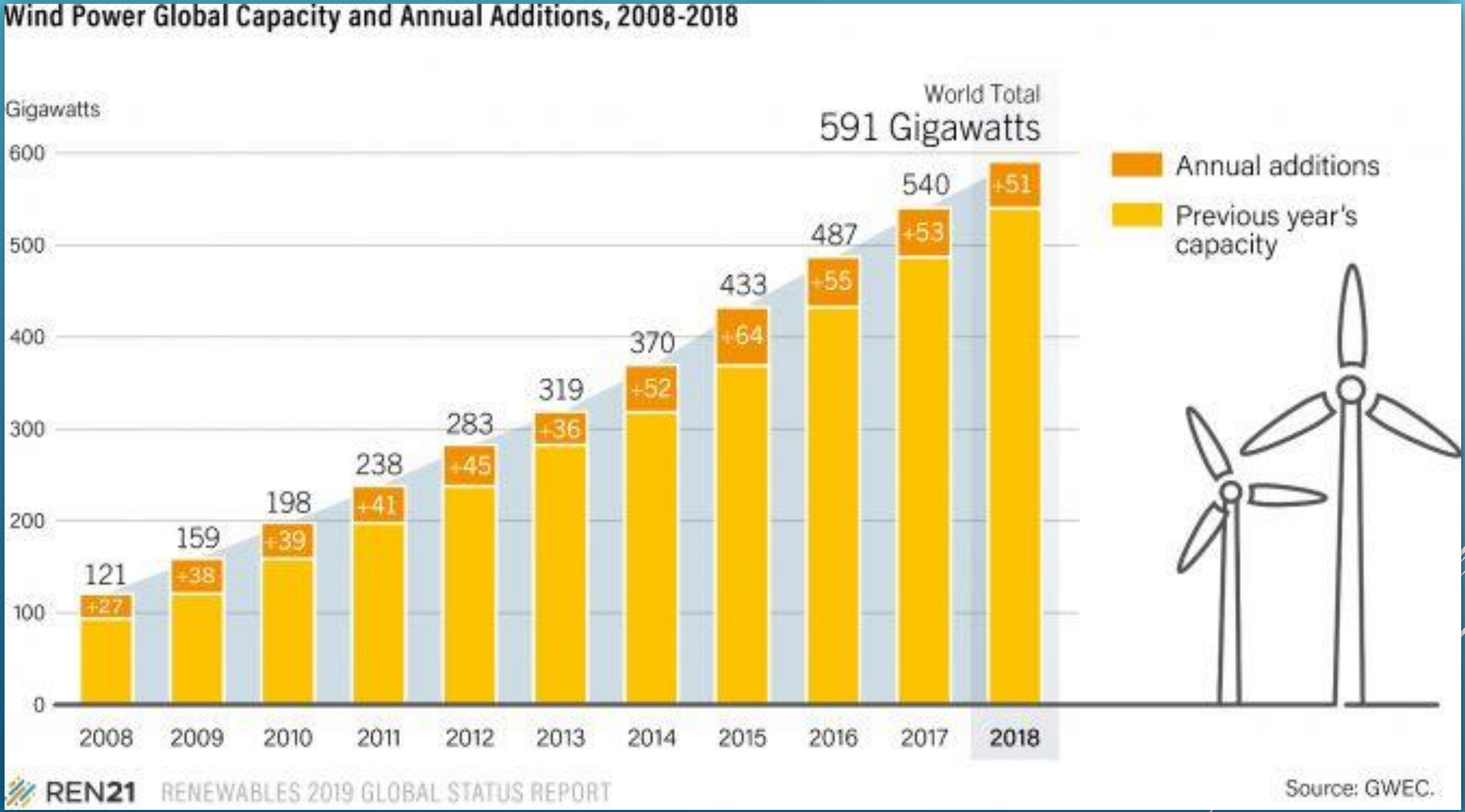
Turkish wind energy association was founded in 1992. by the help of energy ministry first turbines built at İzmir-Çeşme-Alaçatı by Ares –Güç Birliği co. This turbines produces 7,2 MW energy. In the same years Demirer Holding built turbines at Çanakkale-Bozcaada which produces 10,2 MW. Today working is still going on to built new turbines at İzmir-Çeşme, Çanakkale- Karacaören, Muğla–Datça, Balıkesir- Bandırma.



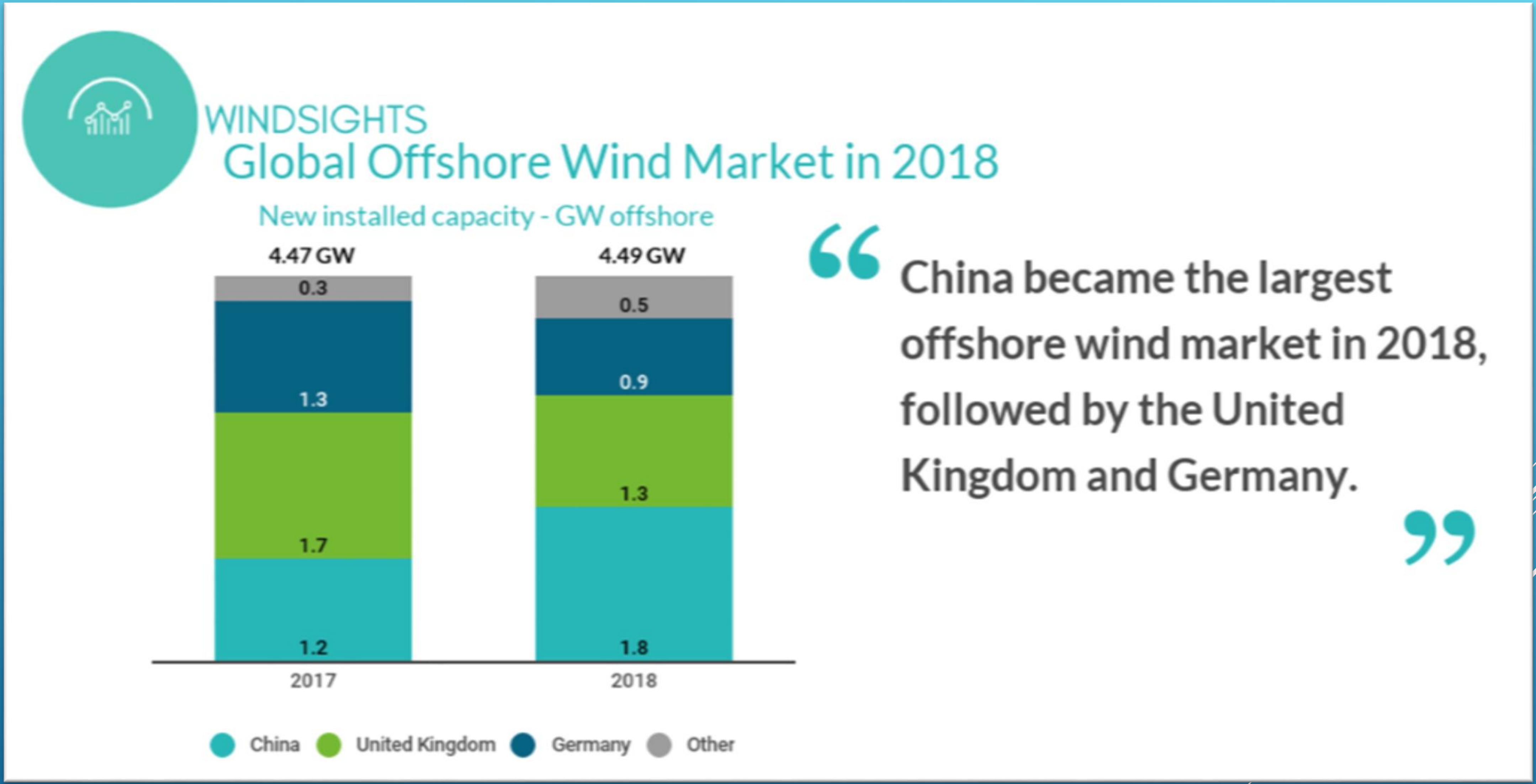

Wind Speed (m/s)
10
9,5
9
8,5
8
7,5
7
6,5
6
5,5
5
4,5
4
3,5
3

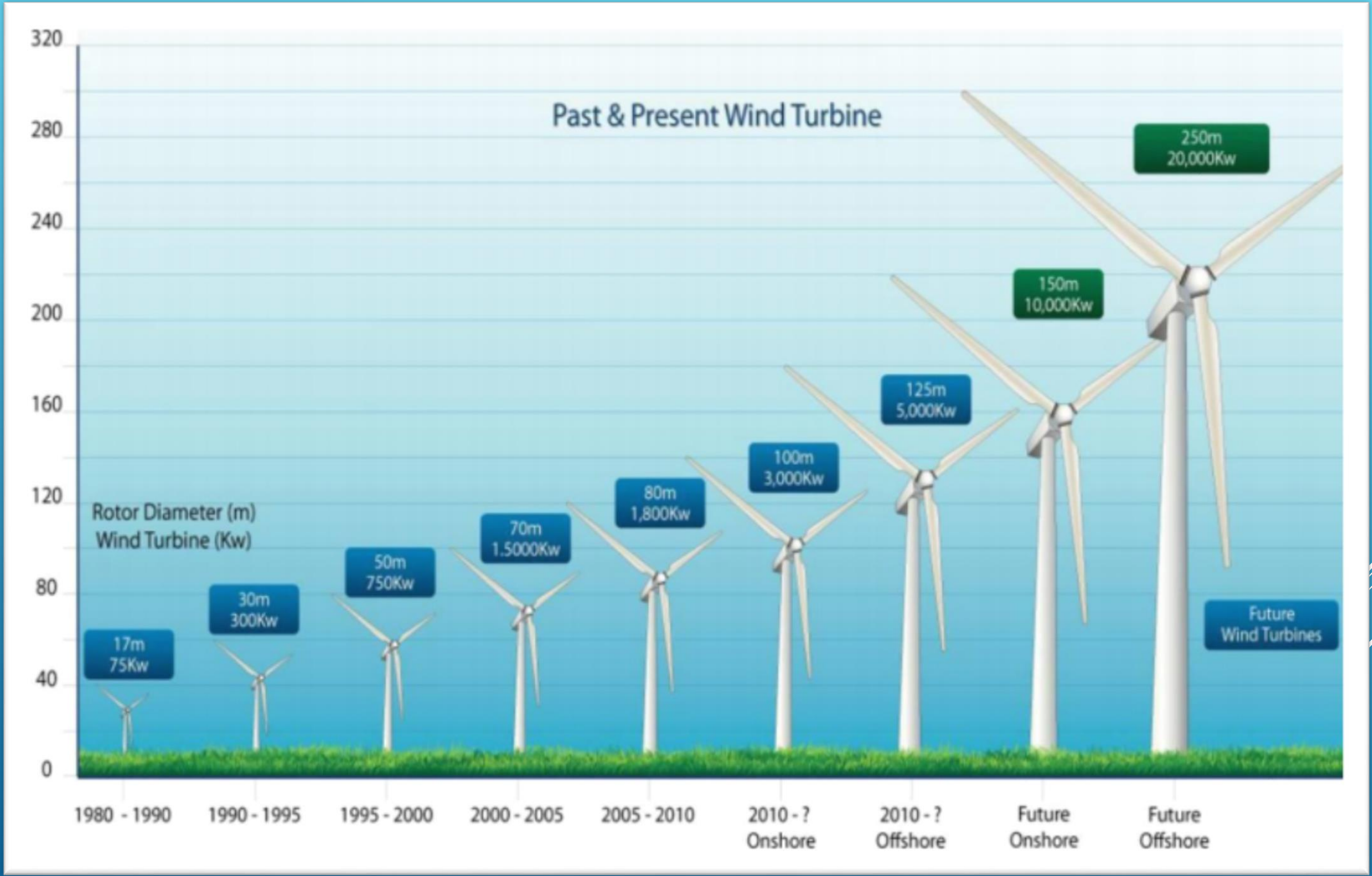

Annual Installations for Wind Power Plants in Turkey
1.400
1.200
1.000
800
600
400
200
0
MW
217,4
427,9
537,55
476,7
506,3
646,3
803,65
956,20
1.387,75
766,05
497,25
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
YILLAR / YEARS

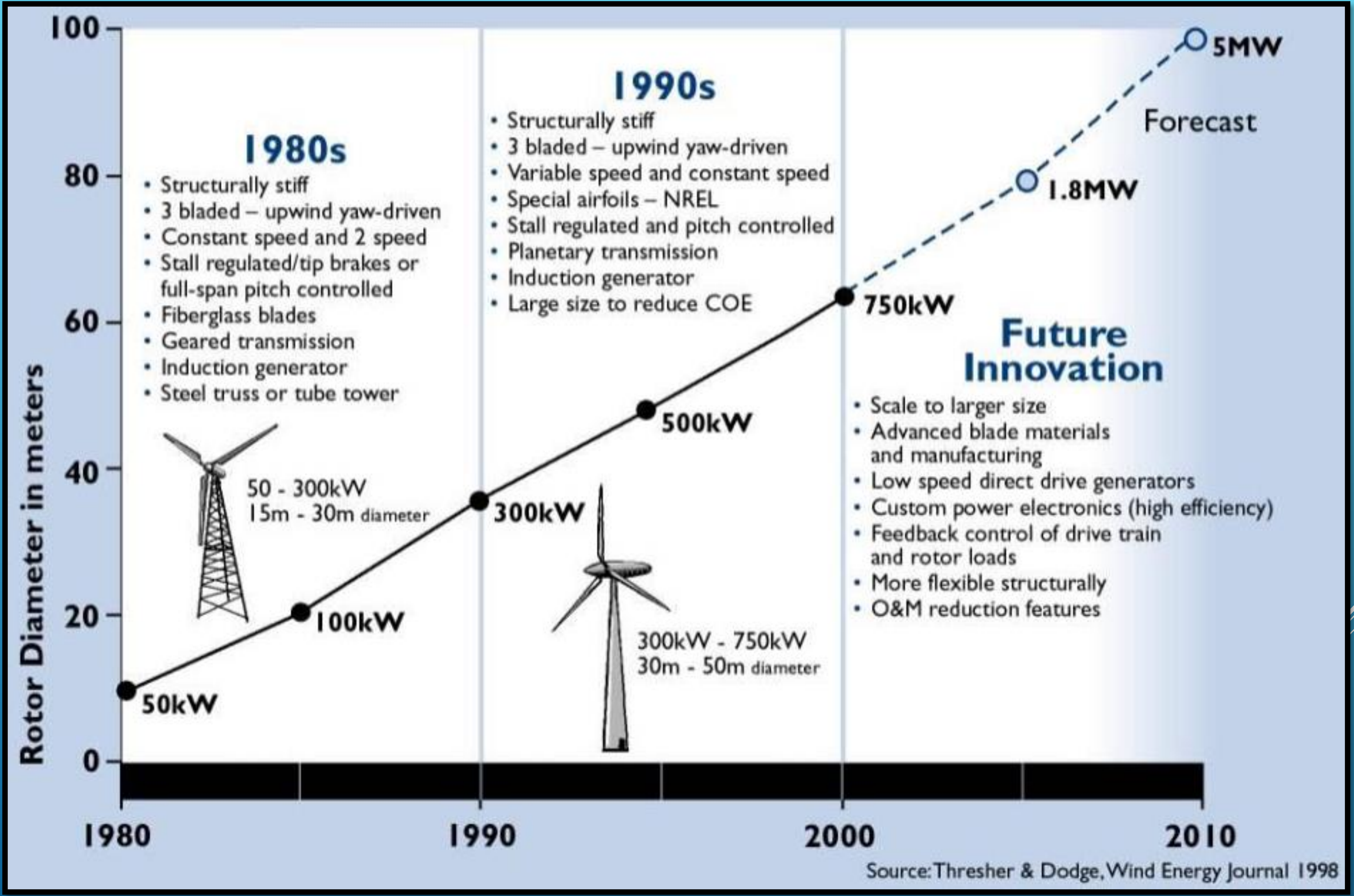

Total installed wind power capacity in Turkey from 2008 to 2018 (in megawatts)
Capacity in megawatts
8 000
7 000
6 000
5 000
4 000
3 000
2 000
1 000
0
364
792
1 320
1 729
2 261
2 760
3 630
4 503
5 751
6 516
7 005
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Source
IRENA
© Statista 2019
Additional Information:
Turkey; IRENA; 2008 to 2018



Wind Power Global Capacity and Annual Additions, 2008-2018
Gigawatts
World Total
591 Gigawatts
600
500
400
300
200
100
0
121
+27
159
+38
198
+39
238
+41
283
+45
319
+36
370
+52
433
+64
487
+55
540
+53
+51
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Annual additions
Previous year's capacity
REN21
RENEWABLES 2019 GLOBAL STATUS REPORT
Source: GWEC.


WINDSIGHTS
Global Offshore Wind Market in 2018
New installed capacity - GW offshore
4.47 GW
4.49 GW
0.3
1.3
1.7
1.2
0.5
0.9
1.3
1.8
2017
2018
China
United Kingdom
Germany
Other
“China became the largest offshore wind market in 2018, followed by the United Kingdom and Germany.”


Past & Present Wind Turbine
Rotor Diameter (m)
Wind Turbine (Kw)
17m 75Kw
30m 300Kw
50m 750Kw
70m 1.5000Kw
80m 1,800Kw
100m 3,000Kw
125m 5,000Kw
150m 10,000Kw
250m 20,000Kw
Future Wind Turbines
320
280
240
200
160
120
80
40
0
1980 - 1990
1990 - 1995
1995 - 2000
2000 - 2005
2005 - 2010
2010 - ? Onshore
2010 - ? Offshore
Future Onshore
Future Offshore



Rotor Diameter in meters
100
80
60
40
20
0
1980
1990
2000
2010
1980s
• Structurally stiff
• 3 bladed – upwind yaw-driven
• Constant speed and 2 speed
• Stall regulated/tip brakes or full-span pitch controlled
• Fiberglass blades
• Geared transmission
• Induction generator
• Steel truss or tube tower
1990s
• Structurally stiff
• 3 bladed – upwind yaw-driven
• Variable speed and constant speed
• Special airfoils – NREL
• Stall regulated and pitch controlled
• Planetary transmission
• Induction generator
• Large size to reduce COE
Future Innovation
• Scale to larger size
• Advanced blade materials and manufacturing
• Low speed direct drive generators
• Custom power electronics (high efficiency)
• Feedback control of drive train and rotor loads
• More flexible structurally
• O&M reduction features
Forecast
5MW
1.8MW
750kW
500kW
300kW
100kW
50kW
50 - 300kW
15m - 30m diameter
300kW - 750kW
30m - 50m diameter
Source: Thresher & Dodge, Wind Energy Journal 1998

Table 1.1 Installed Wind Turbine Capacity Throughout the World, January 2001

Location	Installed capacity (MW)
Germany	5432
Denmark	2281
Spain	2099
Netherlands	444
UK	391
Total Europe	**11831**
California	1622
Total USA	**2568**
Total World	**16461**

Courtesy of Windpower Monthly News Magazine

TABLE II. – *World wind power production*(2).

Land/Region	Total installed rated power up to the end of 2015 [GW]
China	145
USA	74
Germany	45
Spain	23
India	25
UK	14
Italy	9
France	10
Canada	11
Brazil	9
Remaining countries	67
Total	432

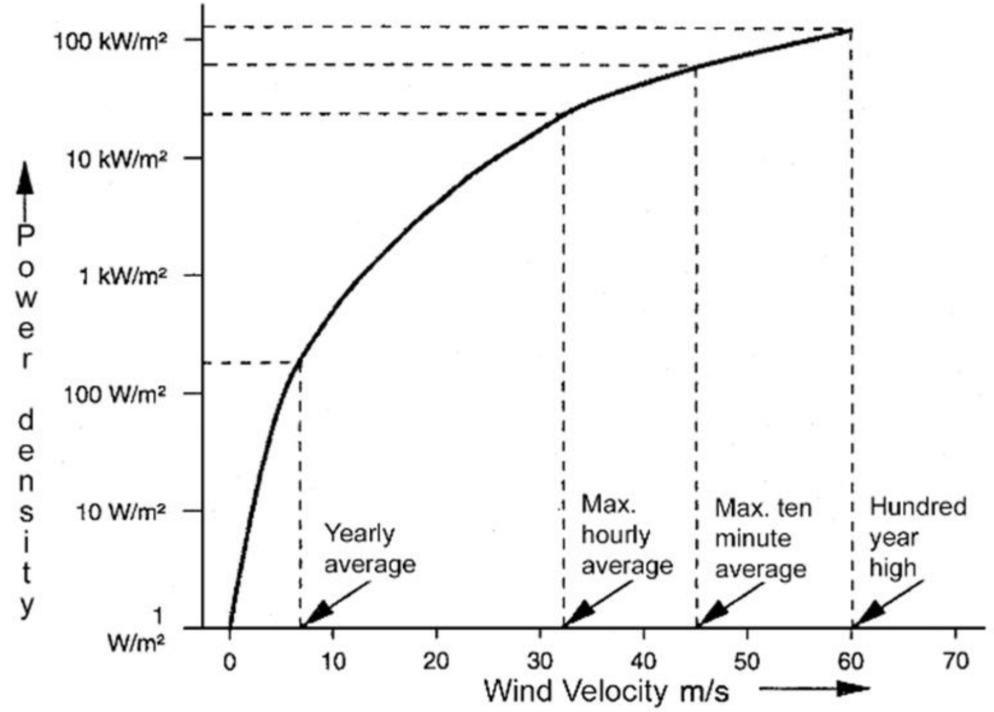


Fig. 2. – Relationship between wind velocity and power output (yearly average valid for Germany)(1).

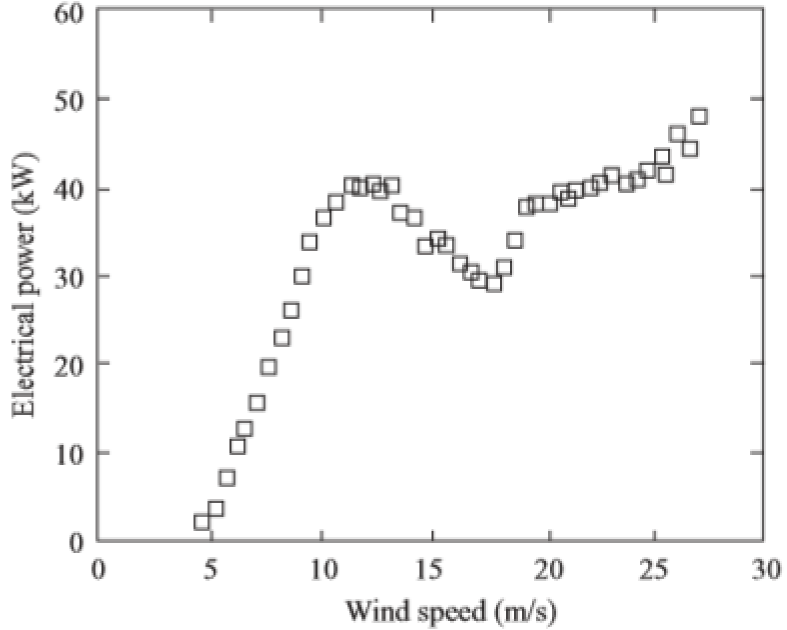
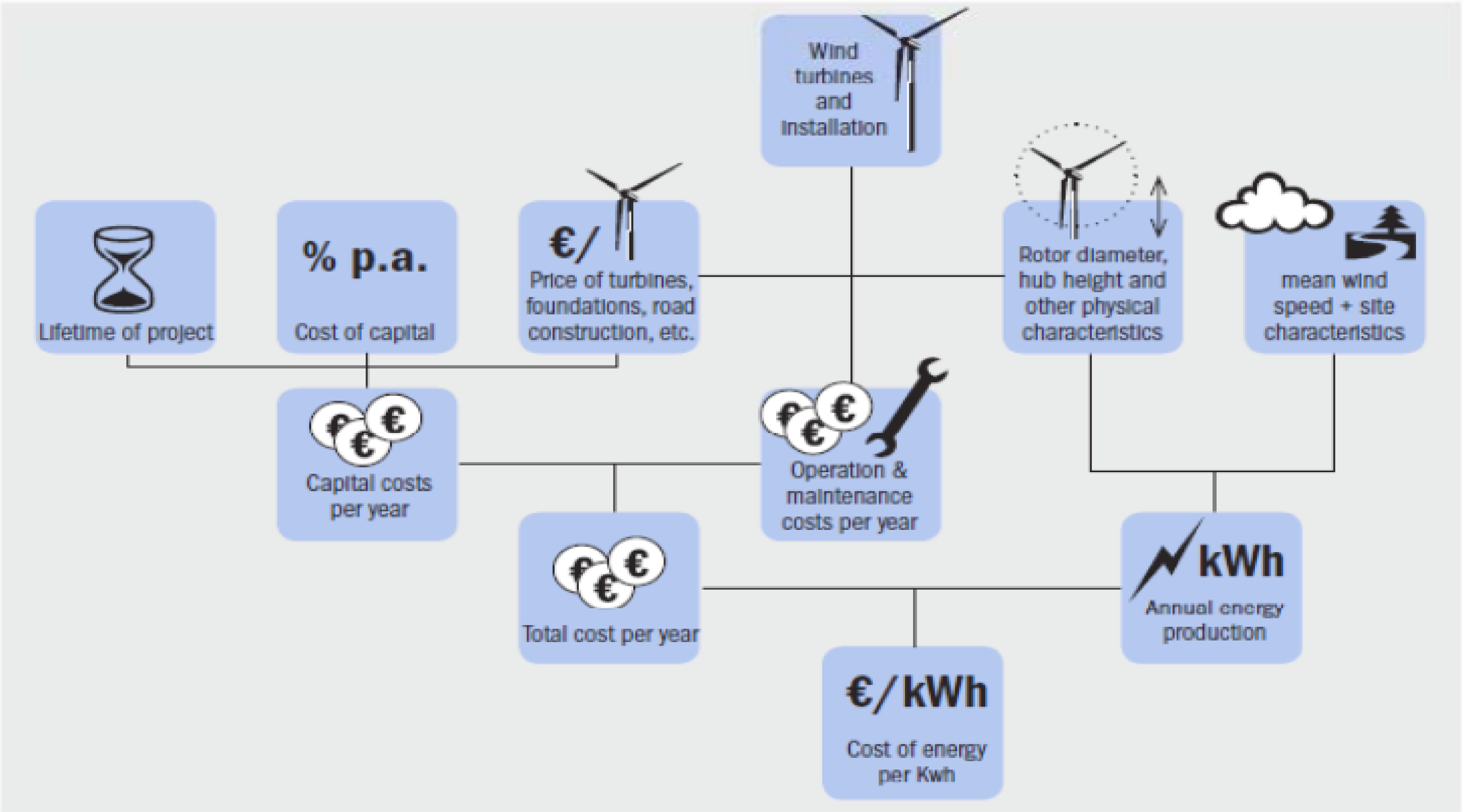
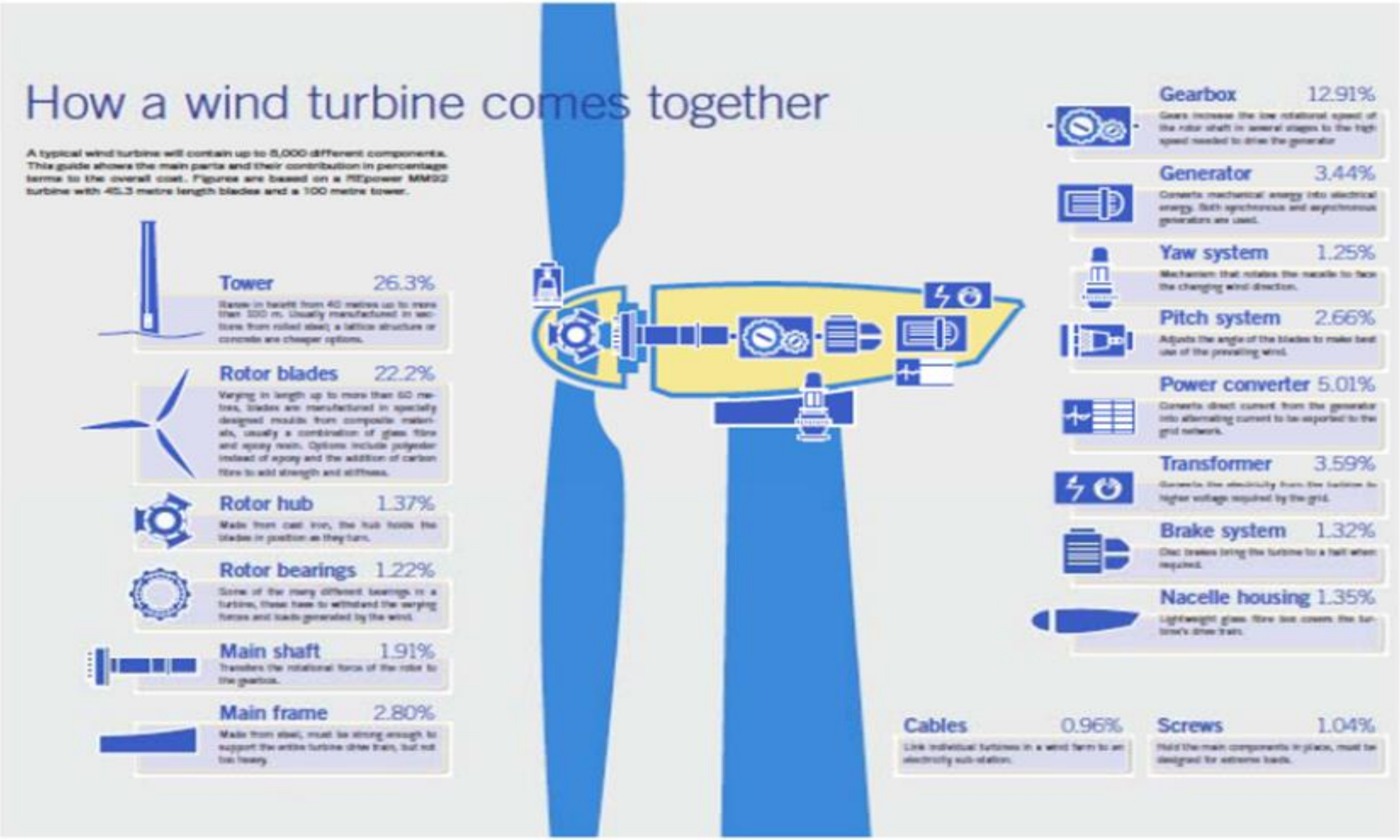


Figure 4.11 Power *versus* Wind Speed Curve from the Binned Measurements of a Three-blade Stall Regulated Turbine

Wind Energy Costs

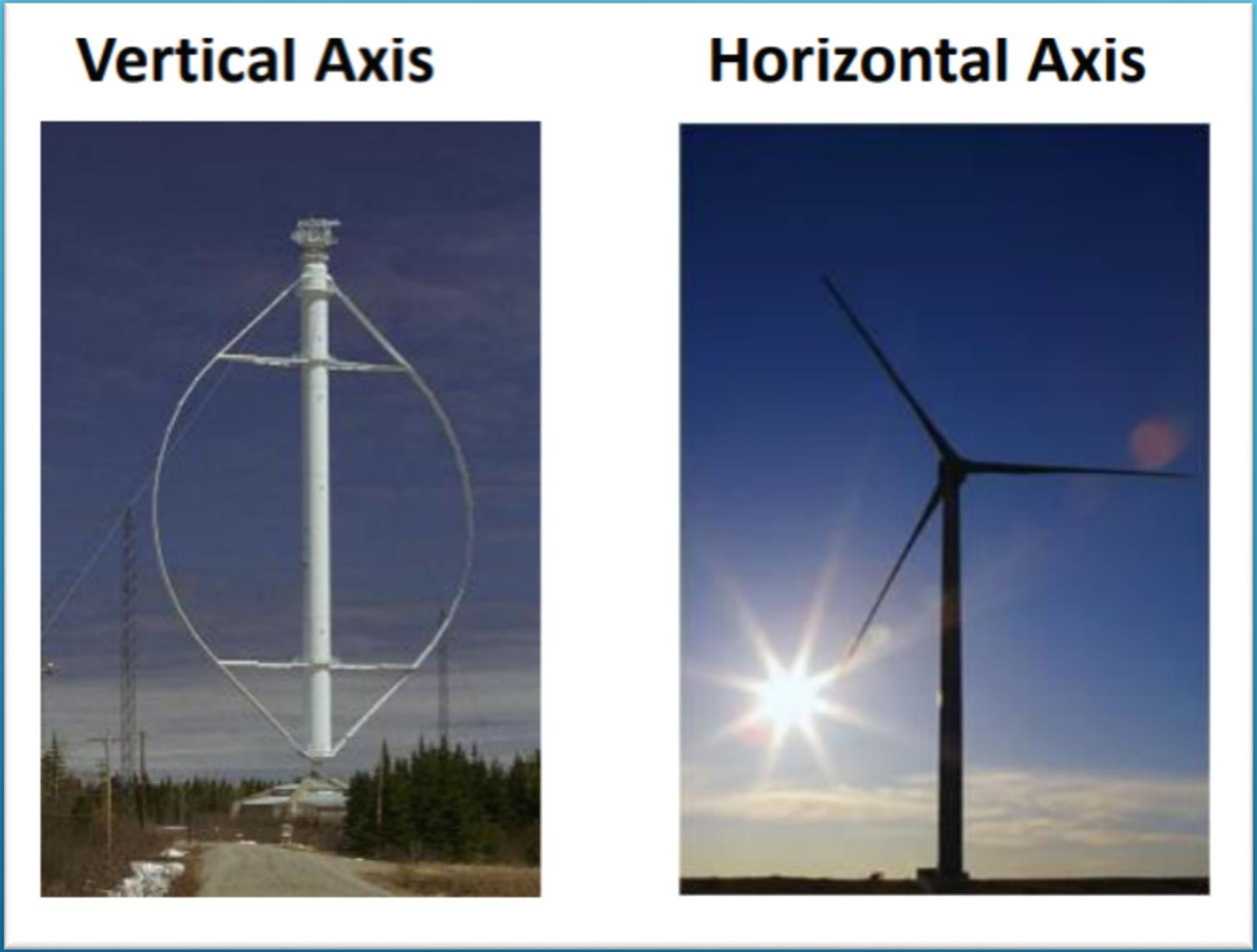


% Cost Share of 5 MW Turbine Components



Source: EWEA, 2009, citing Wind Direction, Jan/Feb, 2007

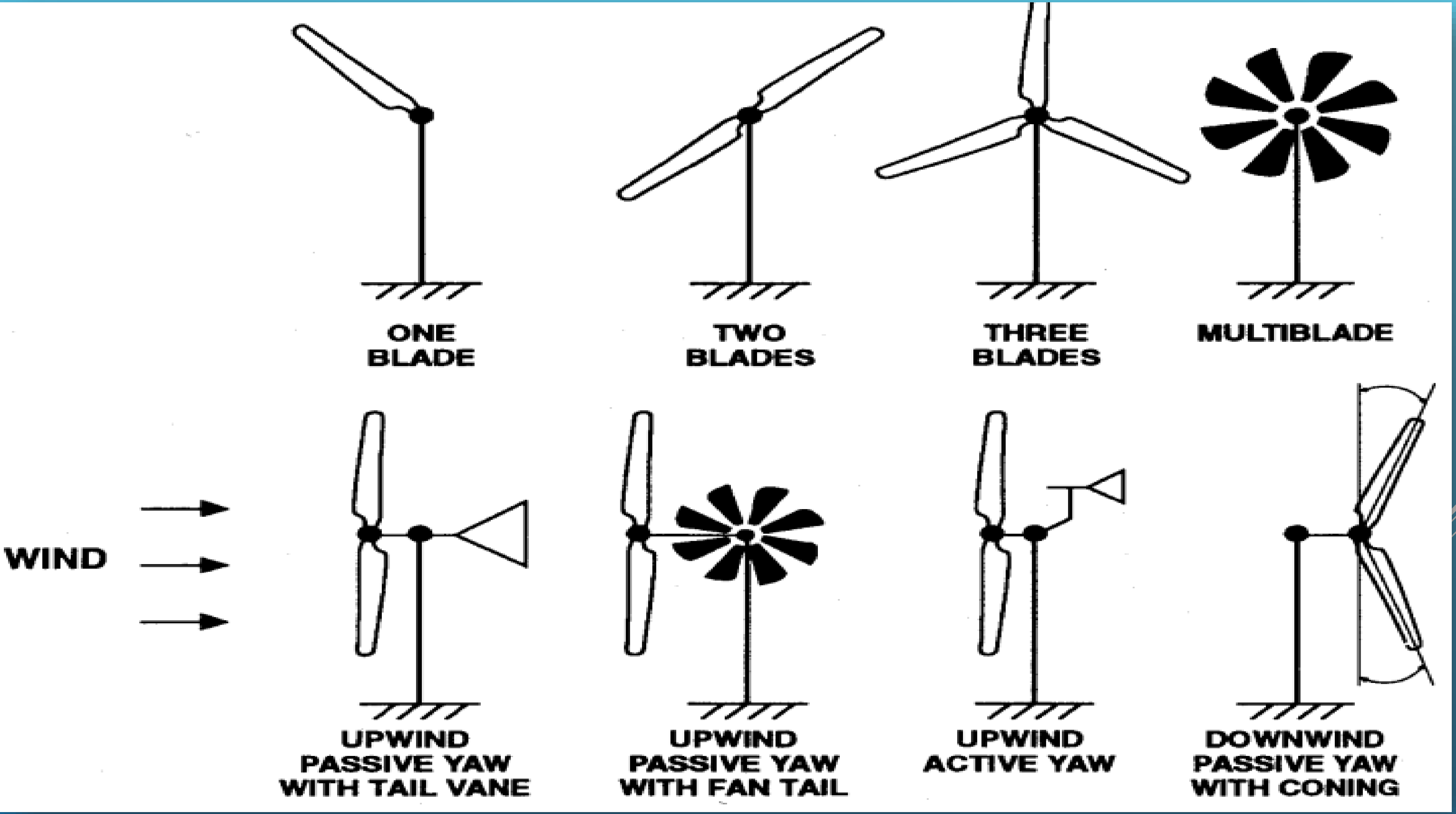
WIND TURBINE CONFIGURATIONS



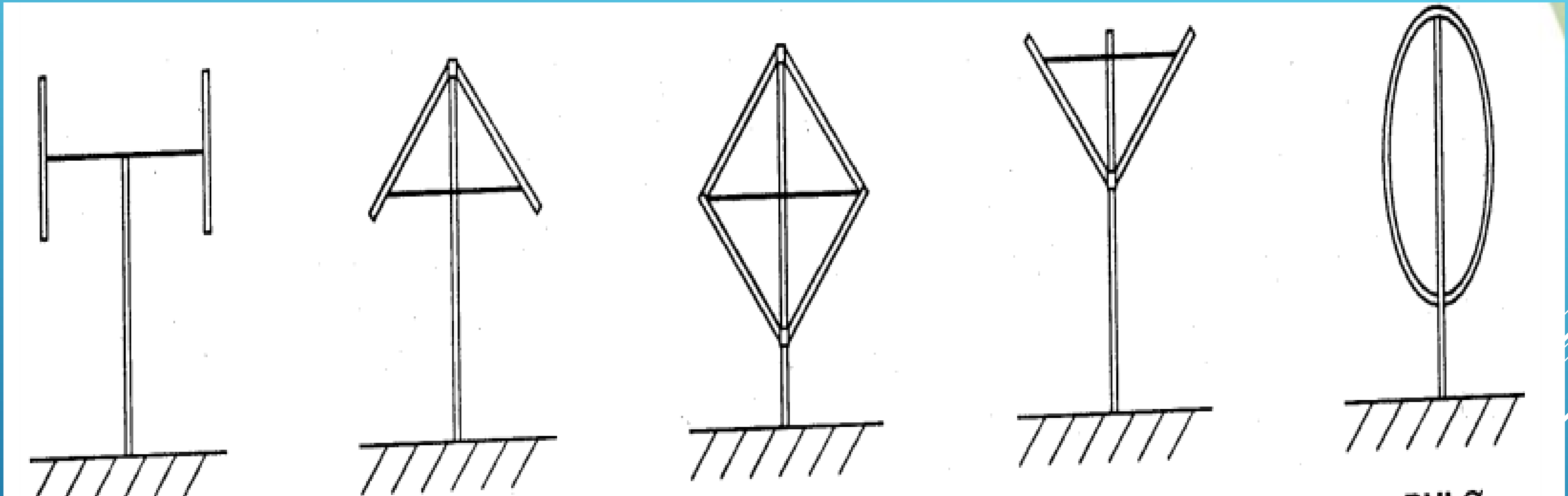
Turbines can be categorized into two overarching classes based on the orientation of the rotor

Types of Wind Turbine Generators

1. Horizontal Axis



2.Vertical Axis



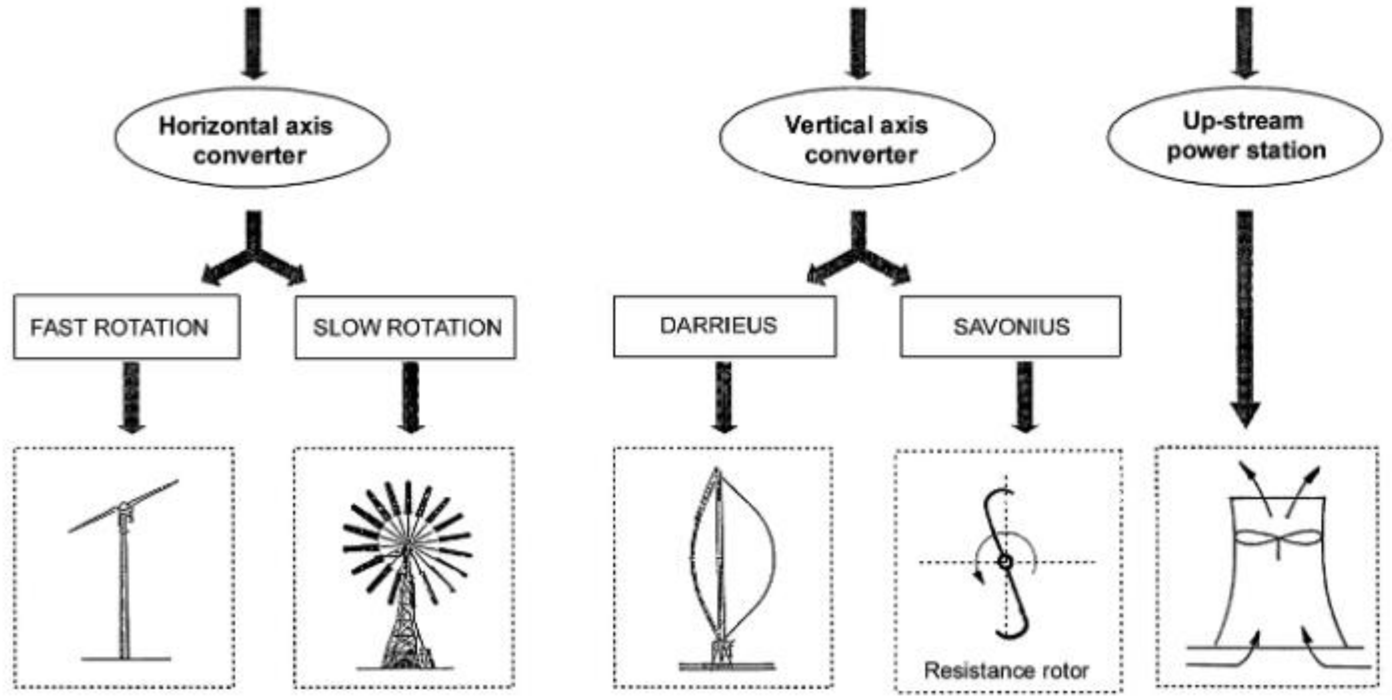


Fig. 1. – Overview of the different types of wind turbines.

Today there are various types of wind turbines in operation. The most common device is the horizontal-axis wind turbine. This turbine consists of only a few aerodynamically optimised rotor blades, which for the purpose of regulation usually can be tumbled about their long axis (Pitch-regulation). A another type of turbine is known as DARRIEUS a vertical-axis construction. Their advantage is that they do not depend on the direction of the wind. To start, they need the help of a generator working as motor or the help of an SAVONIUS rotor in-stalled on top of the vertical axis.

The kinetic energy of the moving air mass is:

$$\Delta E = \frac{1}{2} m v^2 = \frac{1}{2} \rho A \Delta x v^2$$

Rotor swept area → $A = \pi r^2$

Cylindrical mass of air of length → Δx

End cap are → A

Air density → ρ

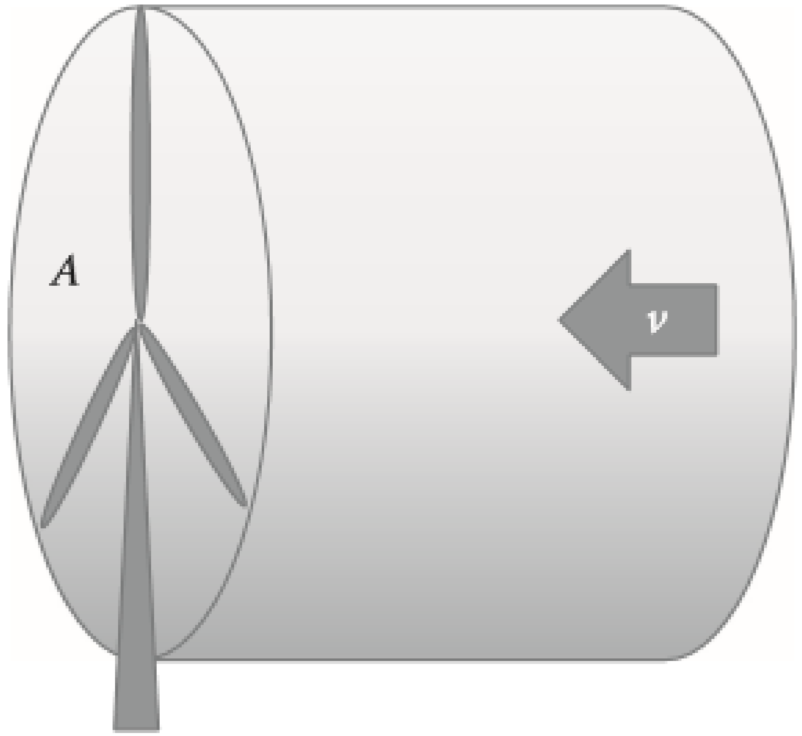


Figure 7.6 Moving cylindrical volume of air incident onto a circular area *A*.

Power in The Wind

The moving molecules of air have kinetic energy, so locally the amount of air molecules moving across some area during some time period determines the power. This area is not the surface area of the earth, which was referred to in the estimation of extractable power and energy, but the area perpendicular to the wind flow. The mass, m, in the volume of the cylinder that will pass across the area, A, in time, t, can be determined from the density of the air, l, and the volume of the cylinder, V. The power is the kinetic energy (KE) of the air molecules divided by the time:

$$\rho = m/V$$

↓

$$P = KE/t = 0.5\ m\ v^2/t \qquad V = \text{area x length} = A \text{ x } L$$

↓

$$m = \rho .\ V = \rho .\ A\ .\ L$$

Only those molecules with a velocity, $v = L/t$, will cross the area in time, t, and those further to the left will not, so the power is given by

$$P = 0.5\,\rho\,A\,L\,v^2/t = 0.5\,\rho\,A\,L/t\,v^2 = 0.5\,\rho\,A\,v\,v^2 = 0.5\,\rho\,Av^3$$

The power/area, referred to as wind power potential or wind power density, is:

$$P/A = 0.5\,\rho\,v^3$$

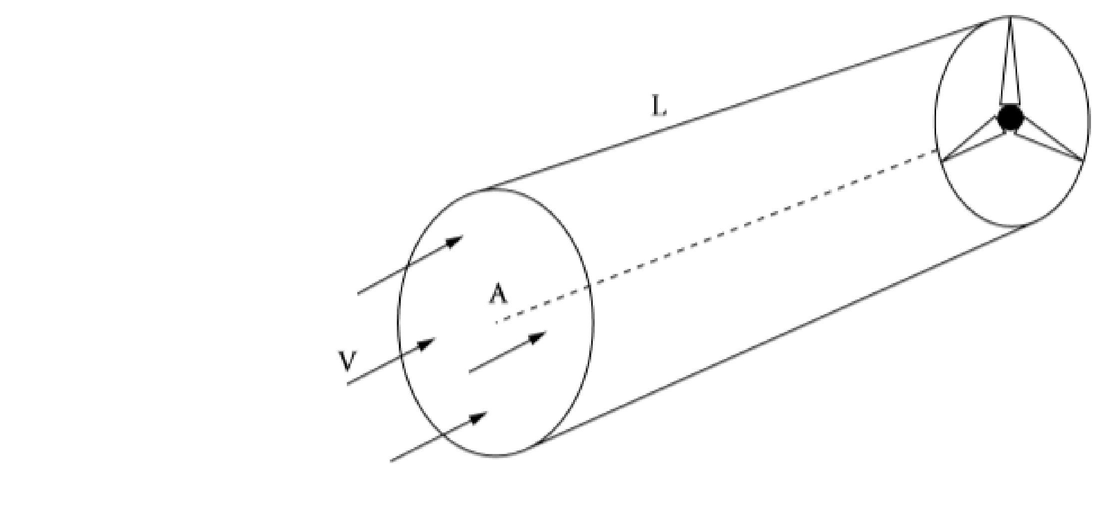


FIGURE 3.3 Flow of wind through a cylinder of area *A*.

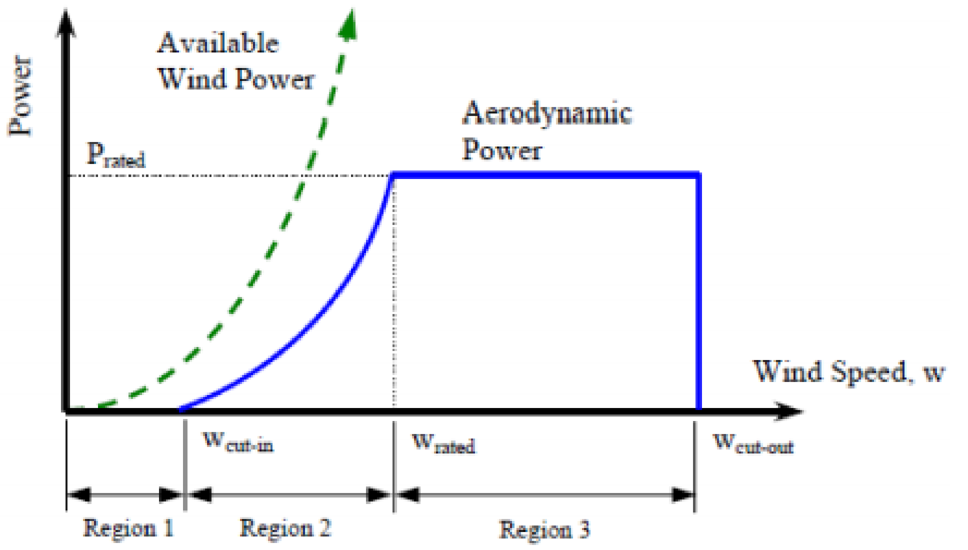


Figure 2. Power operating regions of wind turbines

Since $\Delta x = v\Delta t$ and the power may be written as $p = \Delta E/\Delta t$, we find for the power incident on area A as

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

When the wind is incident on a turbine, only a fraction of this power C_P , known as the power coefficient, is extracted by the turbine. Thus, we may write with complete generality for the extracted power:

$$p = C_P\, p_{\text{wind}}\, \frac{1}{2} C_P \rho A v^3$$

The wind does depend not only on the power for the average wind speed but also on the nature of its variation in time. Fortunately, while the wind speed may vary in an unpredictable manner from moment to moment, the distribution in wind speeds over a long period does follow a regular pattern.

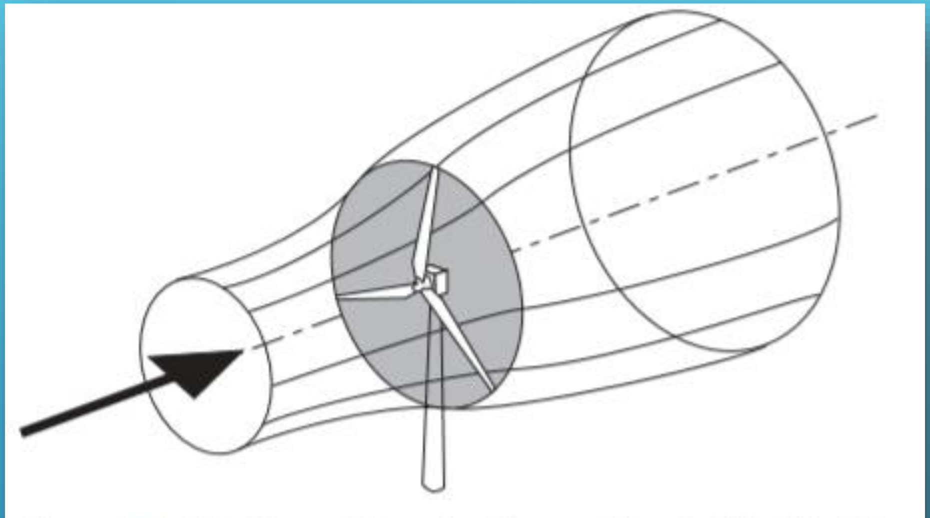


Figure 3.1 The Energy Extracting Stream-tube of a Wind Turbine

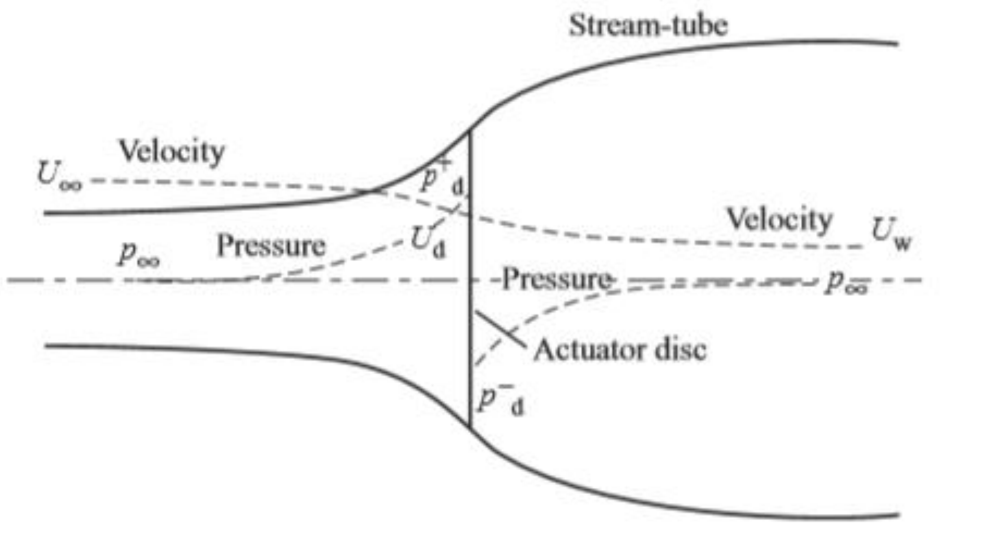


Figure 3.2 An Energy Extracting Actuator Disc and Stream-tube

A wind turbine is a device for extracting kinetic energy from the wind. The affected mass of air remains separate from the air which does not pass through the rotor disc and does not slow down a boundary surface can be drawn containing the affected air mass and this boundary can be extended upstream as well as downstream forming a long stream-tube of circular cross section.

The symbol ∞ refers to conditions far upstream, d refers to conditions at the disc and w refers to conditions in the far wake.

A , the rotor area, and the free stream velocity U, is replaced by U . Wind turbine rotor performance is usually characterized by its power coefficient , C_P :

$$C_P = \frac{P}{\frac{1}{2}\rho U^3 A} = \frac{\text{Rotor power}}{\text{Power in the wind}}$$

Betz limit

The Betz limit is the theoretical maximum efficiency for a wind turbine, conjectured by German physicist Albert Betz in 1919. Betz concluded that this value is 59.3%, meaning that at most only 59.3% of the kinetic energy from wind can be used to spin the turbine and generate electricity. In reality, turbines can not reach the Betz limit, and common efficiencies are in the 35-45% range.

The Betz limit, $C_{P,\,max} = 16/27$,

is the maximum theoretically possible rotor power coefficient.

In practice three effects lead to a decrease in the maximum achievable power coefficient:

- Rotation of the wake behind the rotor
- Finite number of blades and associated tip losses
- Non-zero aerodynamic drag

$$C_{P_{max}} = \frac{16}{27} = 0.593$$

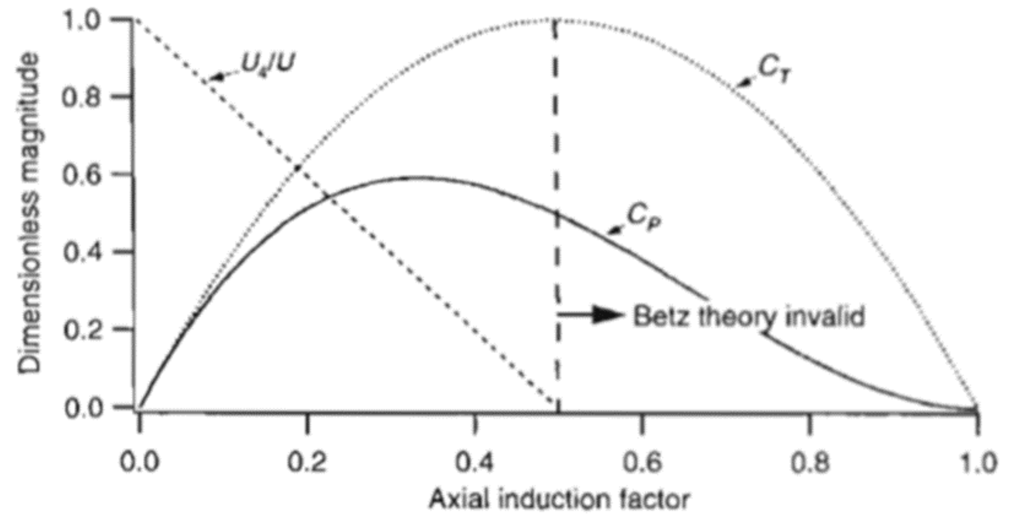


Figure 3.2 Operating parameters for a Betz turbine; U, velocity of undisturbed air; U_4, air velocity behind the rotor,; C_P, power coefficient; C_T, thrust coefficient

Constant Rotational Speed Operation

The majority of wind turbines currently installed generate electricity. Whether or not these turbines are grid connected they need to produce an electricity supply which is of constant frequency or else many common appliances will not function properly. Consequently, the most common mode of operation for a wind turbine is constant rotational speed. Connected to the grid a constant speed turbine is automatically controlled whereas a stand-alone machine needs to have speed control and a means of dumping excess power.

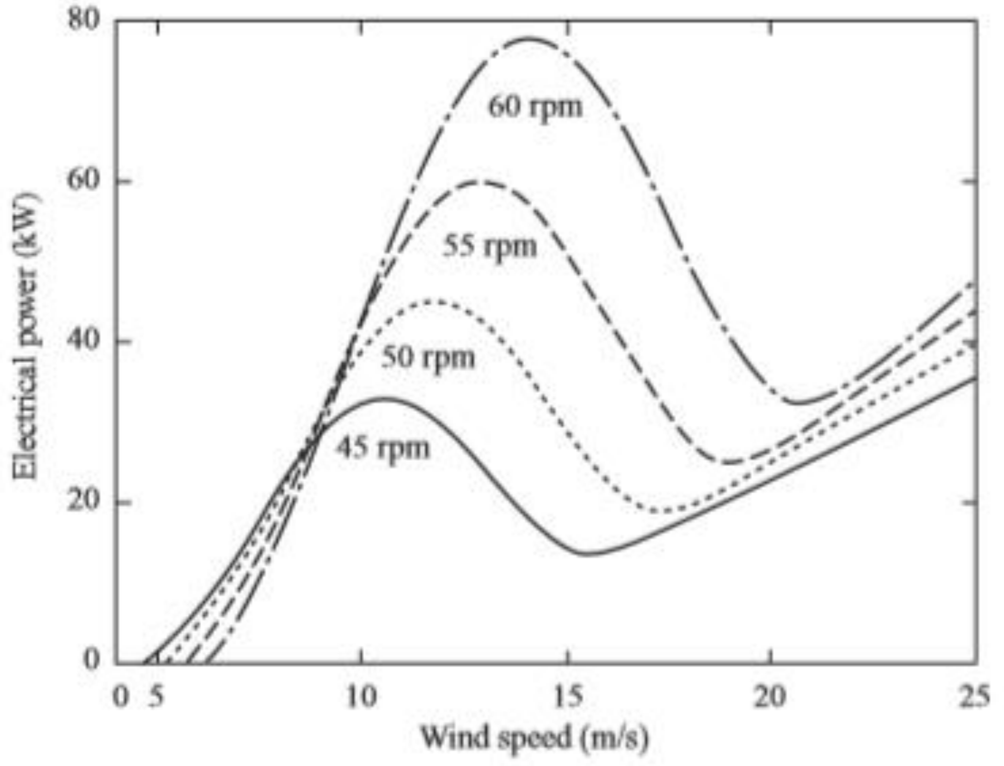


Figure 4.7 Effect on Extracted Power of Rotational Speed

If a low rotation speed is used the power reaches a maximum at a low wind speed and consequently it is very low. To extract energy at wind speeds higher than the stall peak the turbine must operate in a stalled condition and so is very inefficient. Conversely, a turbine operating at a high speed will extract a great deal of power at high wind speeds but at moderate wind speeds it will be operating inefficiently because of the high drag losses.

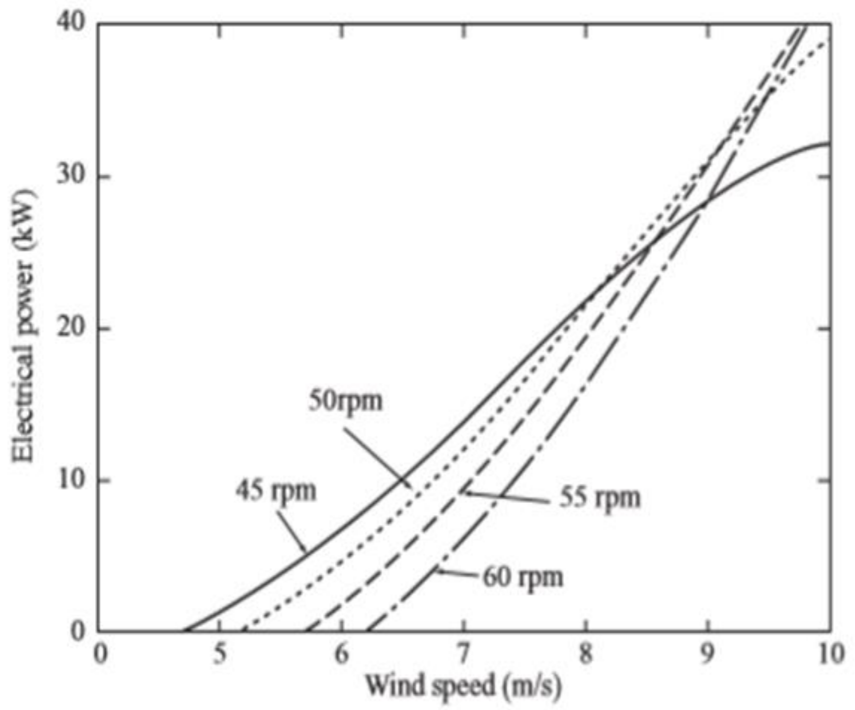


Figure 4.8 Effect on Extracted Power of Rotational Speed at Low Wind Speeds

Variable Speed Operation

By interposing a frequency converter between the generator and the network, it is possible to decouple the rotational speed from the network frequency. As well as allowing the rotor speed to vary, this also allows the generator air-gap torque to be controlled.

Variable-speed operation has a number of advantages:

Below rated wind speed, the rotor speed can be made to vary with wind speed to maintain peak aerodynamic efficiency

The reduced rotor speed in low winds results in a significant reduction in aerodynamically-generated acoustic noise – noise is especially important in low winds, where ambient wind noise is less effective at masking the turbine noise;

- The rotor can act as a flywheel, smoothing out aerodynamic torque fluctuations before they enter the drive train – this is particularly important at the blade passing frequency;

- Direct control of the air-gap torque allows gearbox torque variations above the mean rated level to be kept very small;

- Both active and reactive power can be controlled, so that unity power factor can be maintained. It is even possible to use a variable speed wind farm as a source of reactive power to compensate for the poor power factor of other consumers on the network; variable speed turbines will also produce a much lower level of electrical flicker.


WIND TURBINE
www.LearnEngineering.org
A YouTube PARTNER...

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