Carnegie Mellon University

An Outline of Wind Power in India

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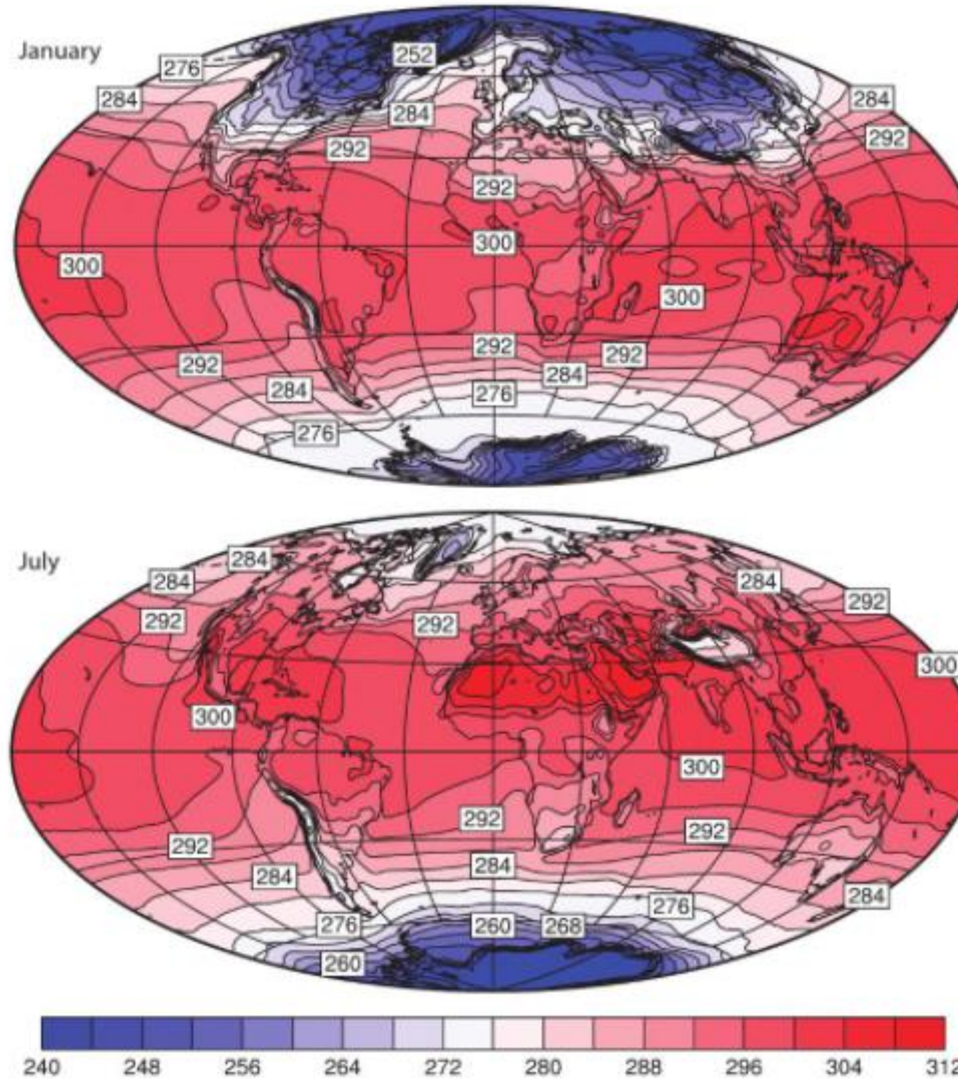
Overview

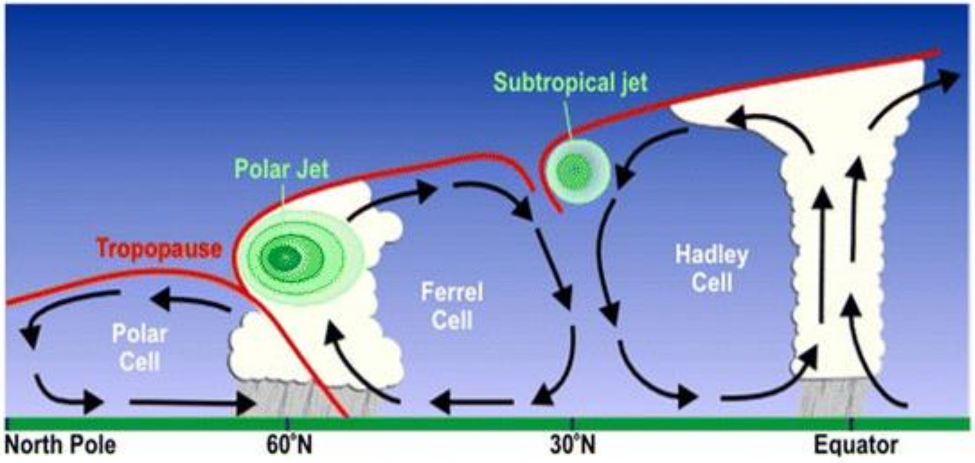
- Where wind comes from
- How we get energy from it
- How industry has evolved and why
- Discussion of current and future technologies
- Wind farms in India
- Pros and cons of wind energy use
- History of wind use and renewable policy in India
- Forecast for wind use globally and in India

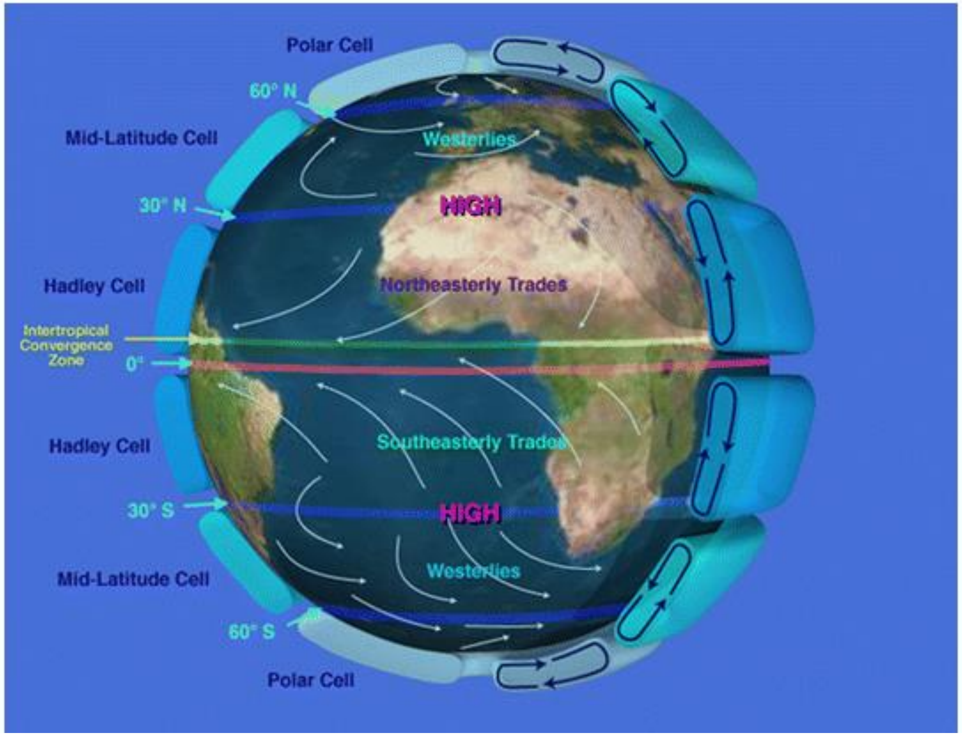
Two Primary Forces Produce Wind

- Uneven distribution of thermal radiation
- Spinning of the earth



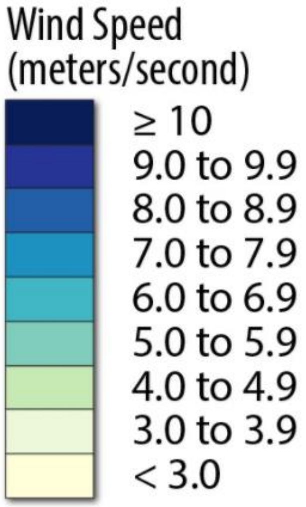
Reference 10

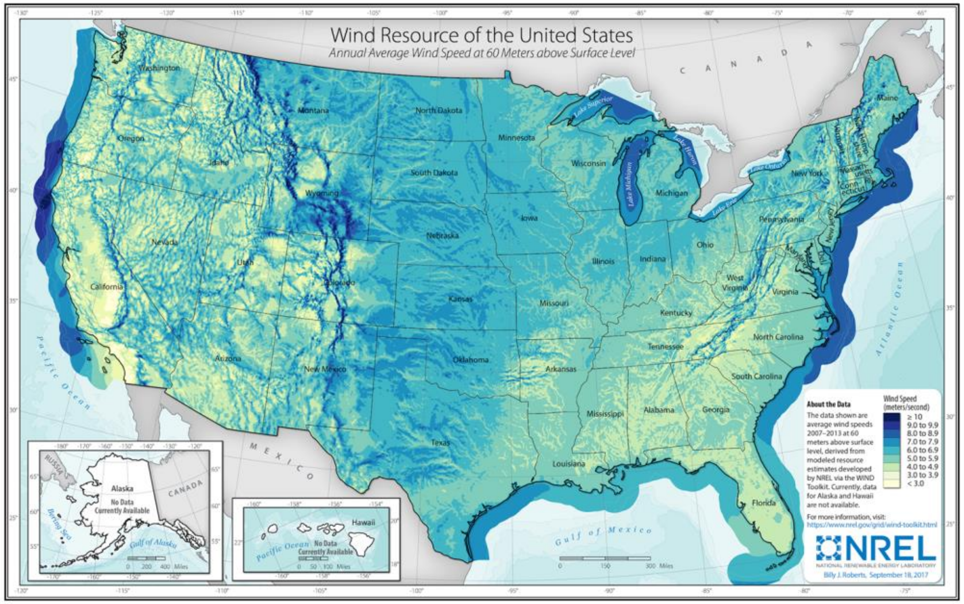

Subtropical jet
Polar Jet
Tropopause
Polar
Cell
Ferrel
Cell
Hadley
Cell
North Pole
60°N
30°N
Equator


Polar Cell
60° N
Mid-Latitude Cell
Westerlies
30° N
HIGH
Hadley Cell
Northeasterly Trades
Intertropical
Convergence
Zone
0°
Hadley Cell
Southeasterly Trades
30° S
HIGH
Mid-Latitude Cell
Westerlies
60° S
Polar Cell

Reference 9

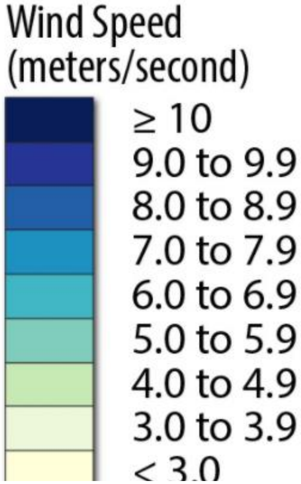
Annual Average Wind Speed 10 & 60 Meters

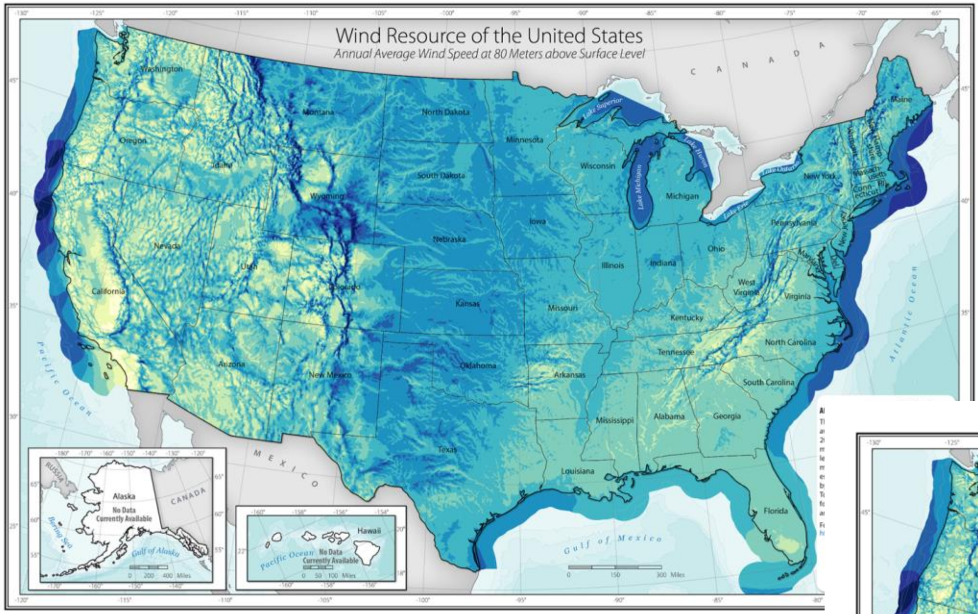


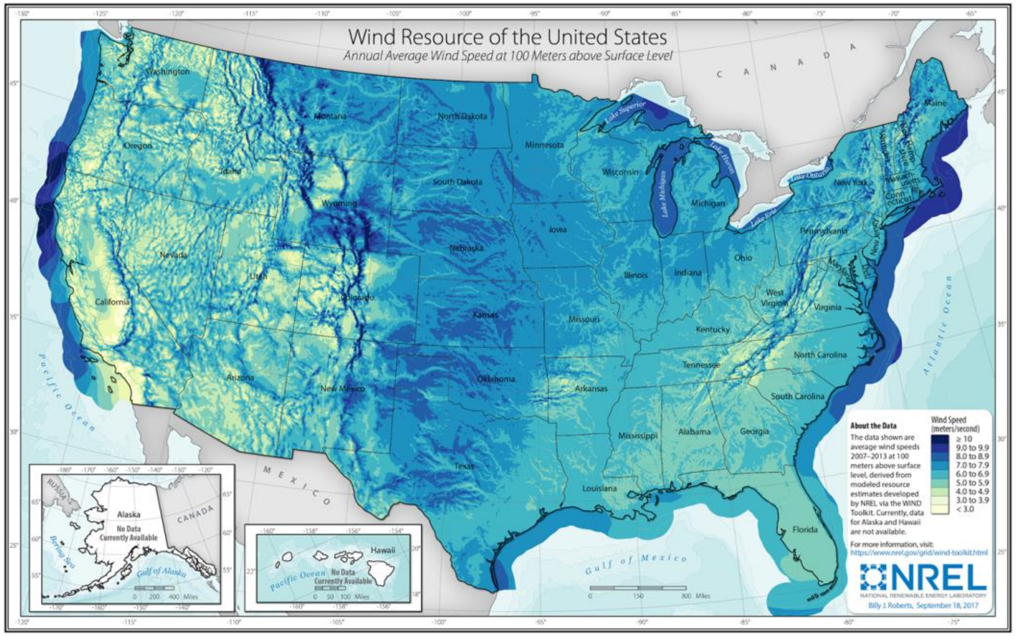


Reference 7

Annual Average Wind Speed 80 & 100 Meters







Reference 7

Wind Power Density Map of India 80 Meters

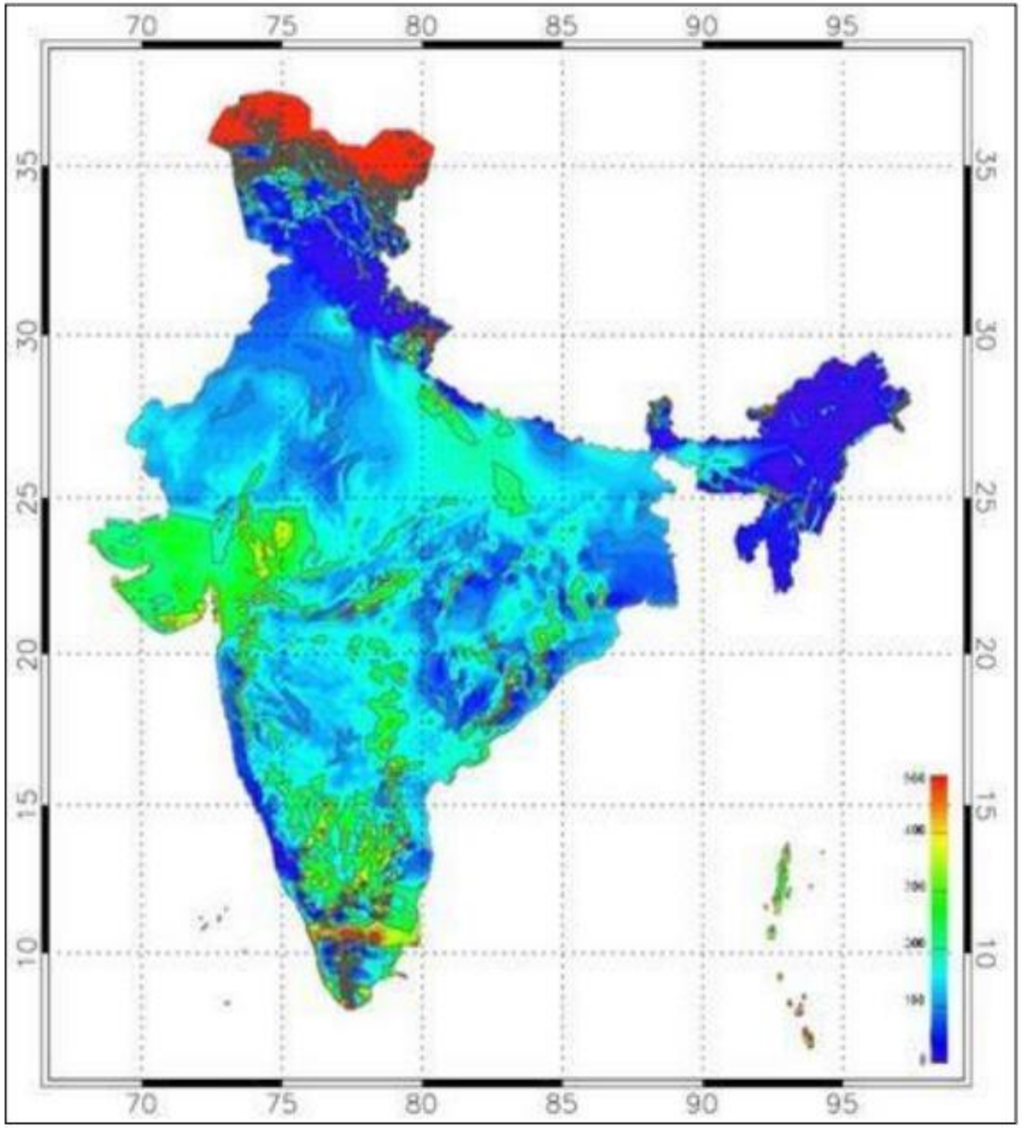
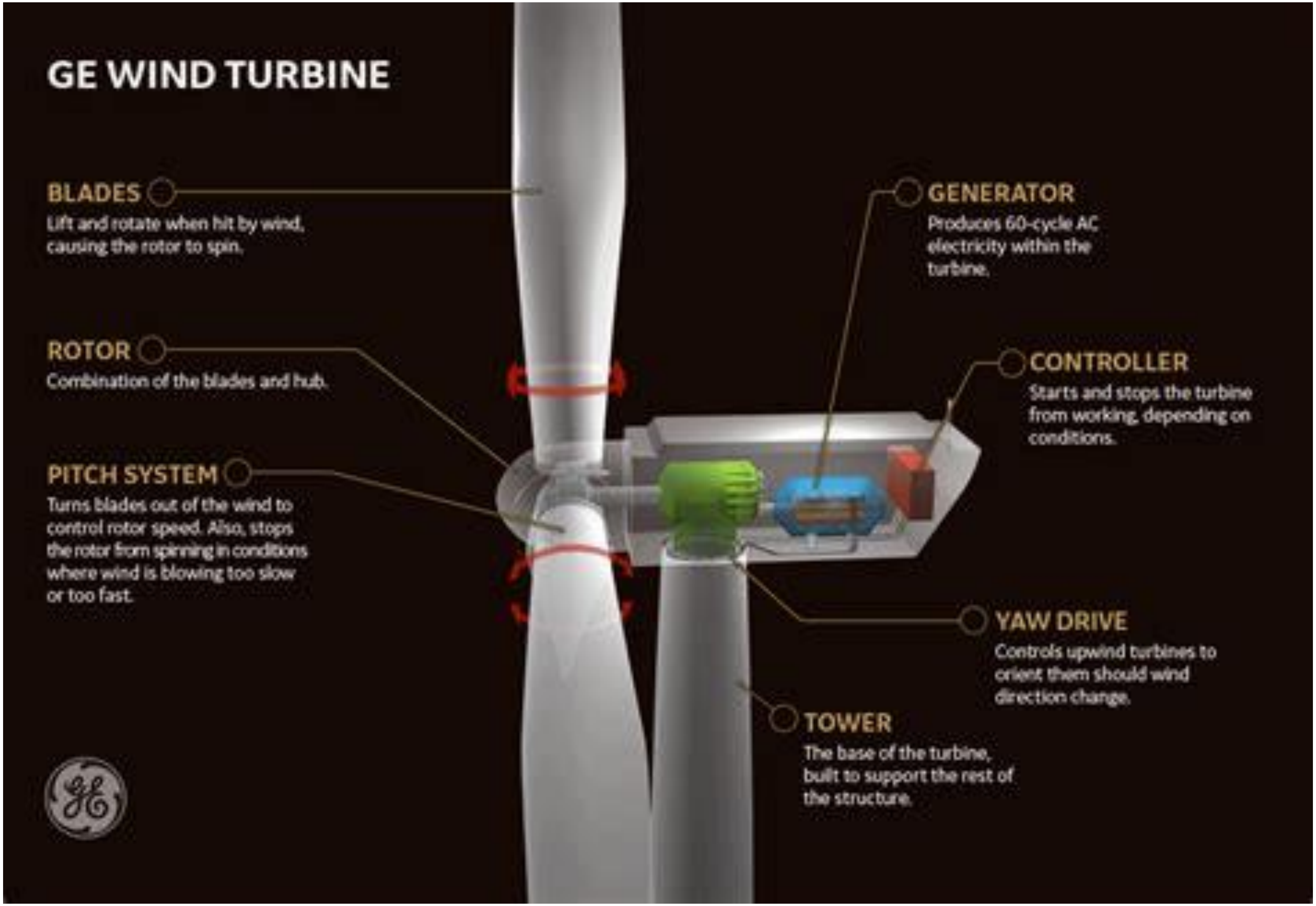


Figure 4: Wind Power Density Map of India at 80m agl

Reference 22



Reference 11

Wind Power $P_W = \frac{1}{2}\,\rho\, A\, v^3$

Density [kg/m³]

Small changes with elevation & temperature.

Area [m²]

Squared effect of changes in radius.

Velocity [m/s]

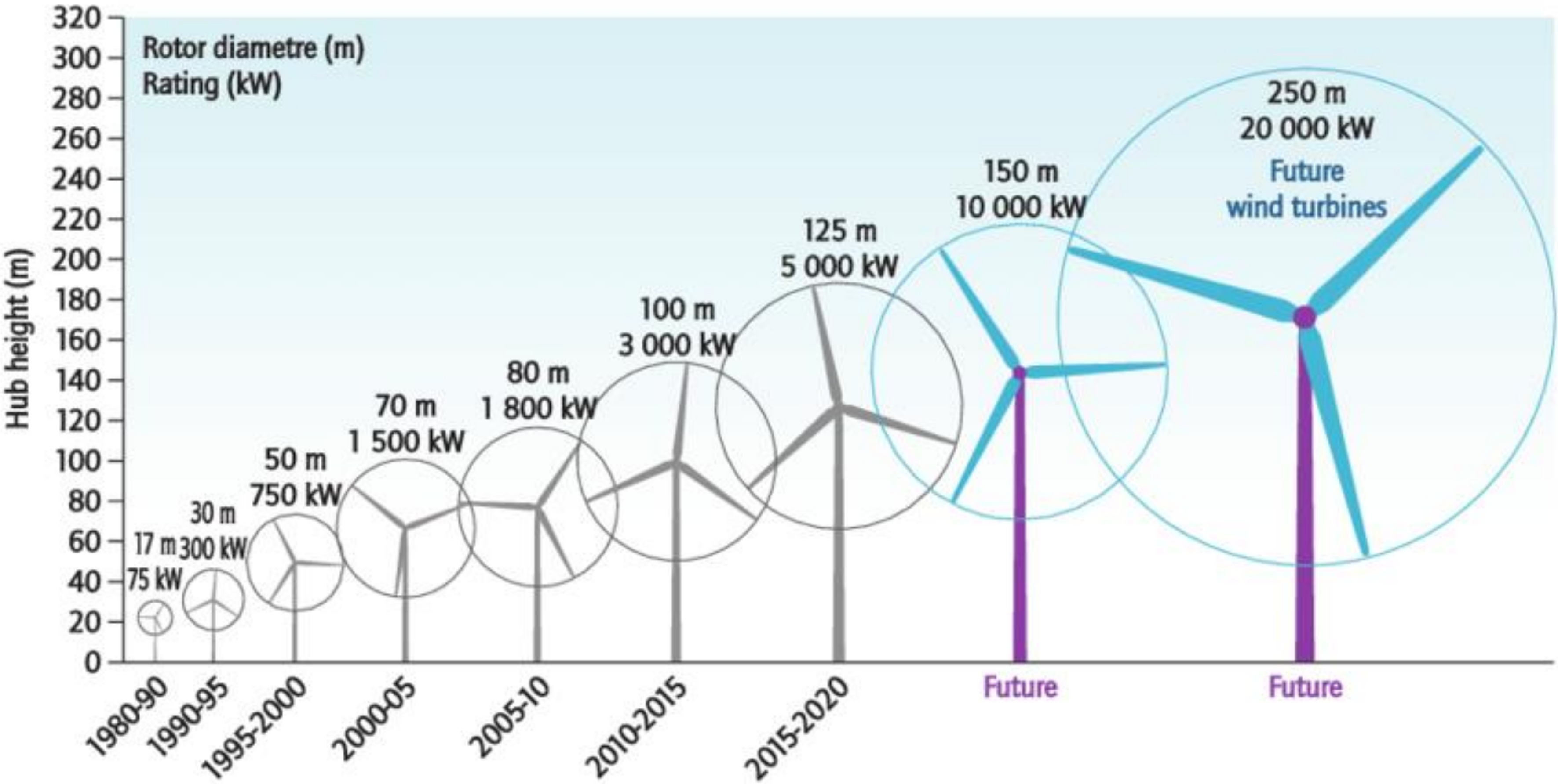
Cubic effect of changes in wind speed.

Reference 2

The Value of Higher Speed Winds

Average Wind Speed (m/s)	Average Wind Speed (mph)	Wind-Power Density (W/m²)
1	2.24	1
2	4.47	9
3	6.71	32
4	8.95	75
5	11.18	146
6	13.42	253
7	15.66	401
8	17.90	599
9	20.13	853
10	22.37	1,170
11	24.61	1,557
12	26.84	2,022

Reference 1



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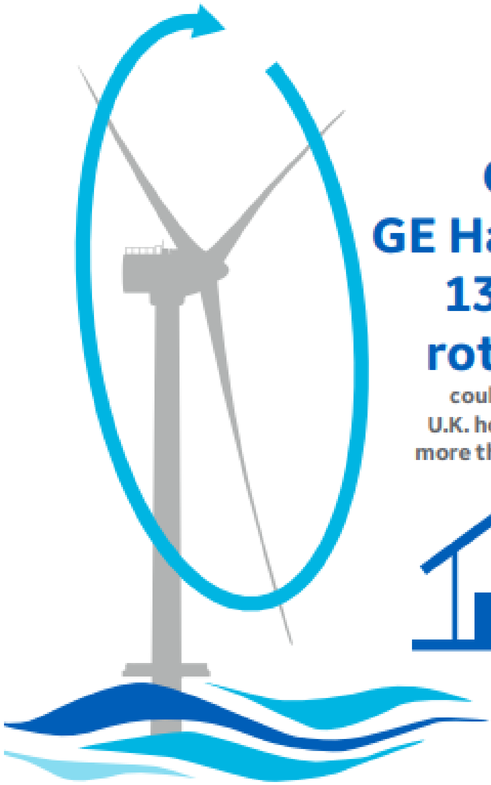
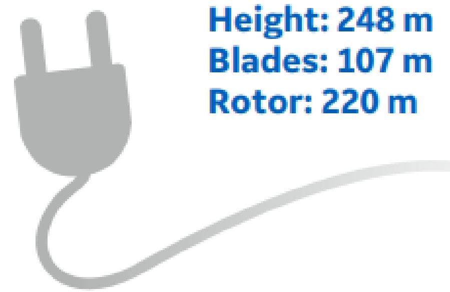


One GE Haliade-X 13 MW rotation

could power a U.K. household for more than two days.

Swept area: 38,000 m²

13 MW generation capacity

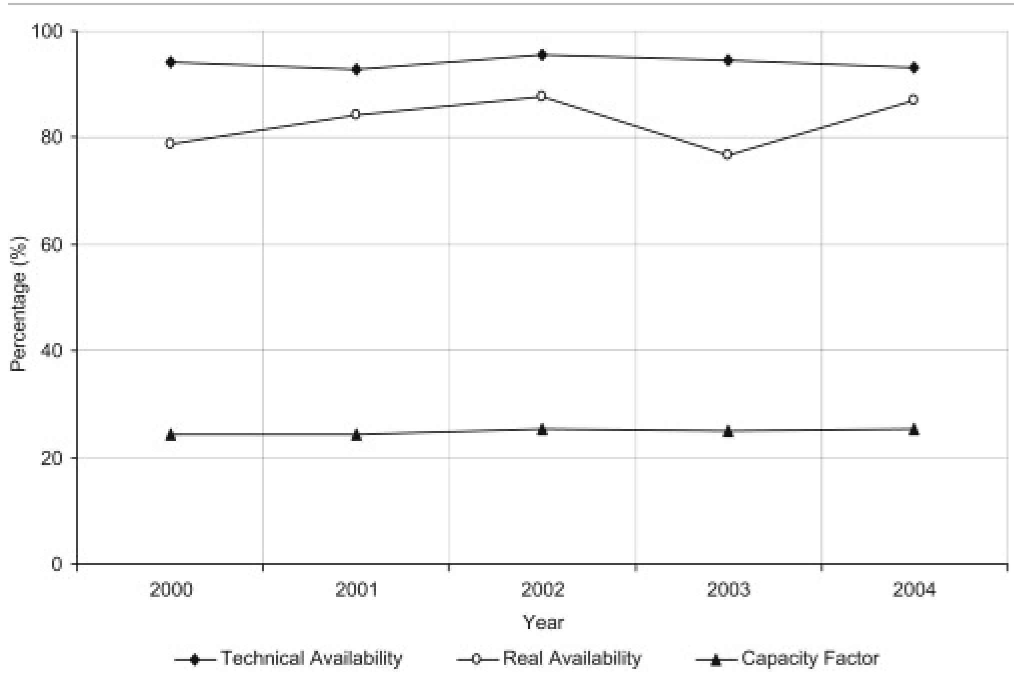


Height: 248 m
Blades: 107 m
Rotor: 220 m

Reference 8

Latest Data on Muppandal Wind Farm Capacity Factor

"The capacity factor was found to vary from 24.41% in 2001–25.3% in 2002. The average capacity factor for five years was 24.9%."



https://www.sciencedirect.com/science/article/pii/S0960148110001904

ENERGY CONVERSION

Wind energy plants are classified on the basis of their capacity and area of operation as:

•Small scale plants: Have a capacity of less than 100 kilowatts and is capable of powering a smaller area like a house or single business

•Utility scale plants: Have a capacity of more than 100 kilowatts and electricity is provided to the grid and then supplied to a region

•Offshore wind plants: Erected in large bodies of water on continental shelf. They are generally larger than land based turbines

Reference 14,15,16

Historic Evolution of Wind Conversion Technologies-I

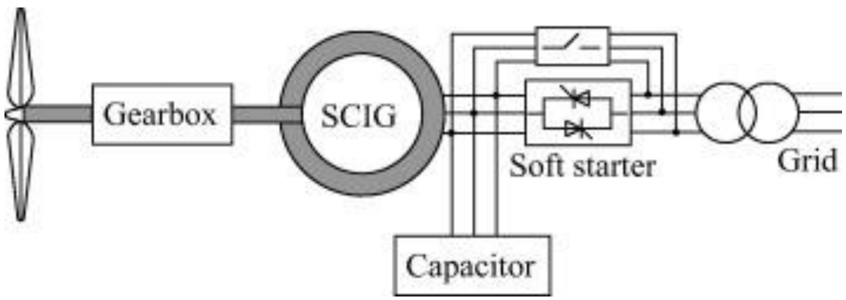
Year	Development
Around 1000 AD	Windmills were used for pumping seawater to make salt in China and Sicily
1180s	Vertical Windmills are used in Northwestern Europe for grinding flour
1887	First known wind turbine was created by Prof James Blyth of Anderson's College, Glasgow to produce electricity
1888	First known US wind turbine was created in Ohio by Charles Brush
1900	Around 2500 windmills with a combined capacity of 30 megawatts were used across Denmark for mechanical purposes
1927	'Jacobs Wind Factory' was founded in Minnesota, which produced wind energy for use on farms, generally used to charge batteries
1931	A vertical axis wind turbine design called the Darrieus wind turbine was patented by a French aeronautical engineer, which is still in use today for certain applications like on boats
1931	A horizontal axis wind turbine, similar to the one in use currently, was developed in Yalta. The wind turbine has 100 kW of capacity, a 32-meter-high tower and 32% load factor
1957	Johannes Juul, built a horizontal-axis wind turbine of 24 meters diameter and 3 blades, similar to the one in use currently. It has a capacity of 200 kW and employs a new invention, aerodynamic tip breaks.
1975	A NASA wind turbine program to develop utility-scale wind turbines is introduced. It had novel features: steel tube towers, variable speed generators, composite blade materials, partial-span pitch control and aerodynamic, structural and acoustic design capabilities

Historic Evolution of Wind Conversion Technologies-II

Oil Shortage in 1970s created an interest in alternative sources of energy, which gave impetus to the rise of wind energy.

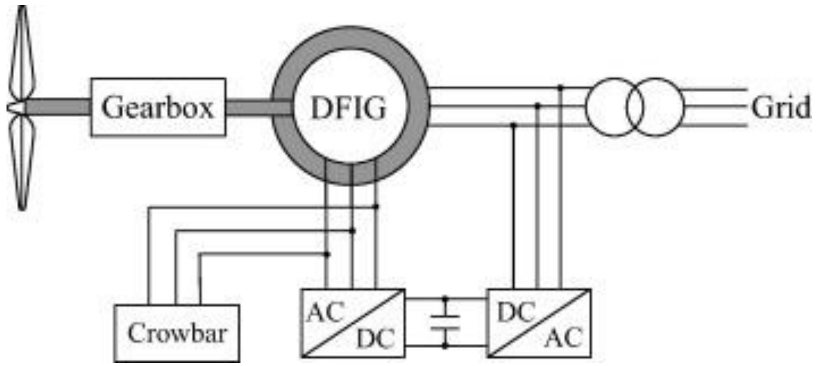
1975	First US wind farm is put online, producing power for 4149 homes
1980	World's first wind farm including 20 wind turbines is put online
1981	California implements tax credits for wind turbines
1992	The United States implements Production Tax Credit (PTC) for wind power
1998	Global wind power reaches 10200 megawatts, from 6100 megawatts in 1996
2005	226 wind farms are online in the US, providing enough power for 2.2 million homes
2009	The first large-capacity floating wind turbine in the world begins operating off the coast of Norway
2012	USA becomes world's largest wind power market
2013	GE produces wind turbines that incorporate energy storage

WECS: Wind Energy Conversion Systems



- Directly connected to the grid
- Used in 1980s/1990s due to simplicity, low cost, reliability
- Requires a reactive power source to establish power source

Constant speed WECS with multi-stage gearbox and a SCIG (Squirrel-cage induction generator)



- Rotor of the DFIG (Doubly Fed Induction Generator) is connected to grid through back to back converter while stator is connected to grid
- It can deliver speed from supersynchronous to subsynchronous speeds
- Active power of the rotor-side can be optimized

Variable speed WECS with multi-stage gearbox and a power scale converter

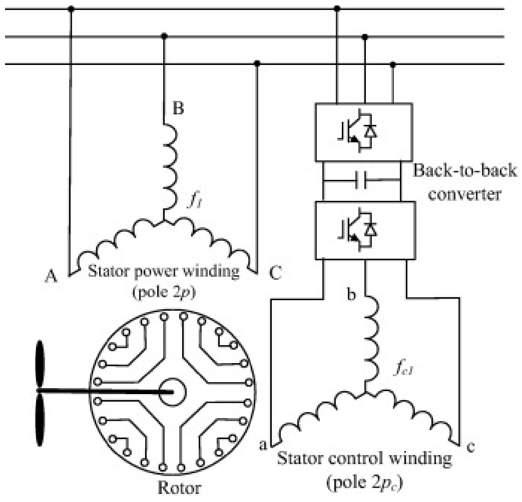
Reference 17

Comparison of WECS

Abbreviation	Full form
C-SCIG–MG	constant speed WECS with a SCIG and multiple-stage gearbox
DFIG–MG	variable speed WECS with a DFIG and multiple-stage gearbox
EESG–DD	direct-drive WECS with a EESG
PMSG–DD	direct-drive WECS with a PMSG
PMSG–1G	WECS with a PMSG and a single-stage gearbox
DFIG–1G	WECS with a DFIG and a single-stage gearbox

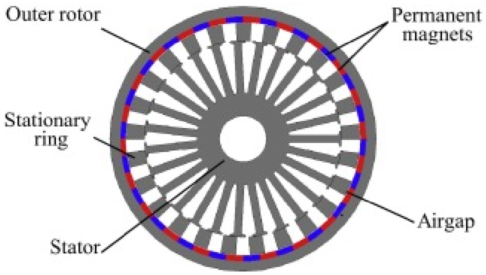
- EESG-DD and PMSG-DD have the maximum generator volume, whereas EESG-DD has the highest generator weight.
- All the WECSs have a similar system volume and weight, and vary by a factor of 10%.
- The cost of C-SCIG-MG seems to be the least due to low maintenance but the energy yield of the constant speed system is much lower than that of the variable speed system.

Latest Developments in WECS



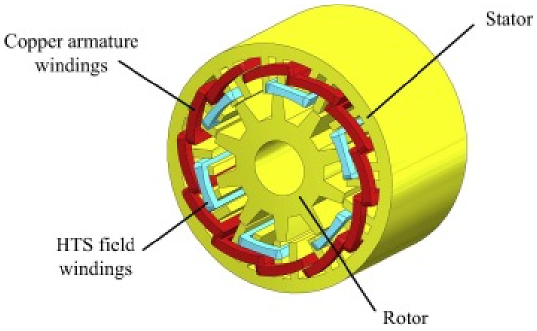
Brushless Doubly-Fed Induction Generator

- Capable of replacing tradition DFIG
- Brushes and Slip Rings absent
- Offers high reliability and low maintenance requests



Magnetic-geared permanent magnet generator

- Adopts a coaxial topology
- Rotor magnetic field can be modulated
- Offers reduced acoustic noise, minimum vibration, improved reliability



Flux switching HTS machine

- High temperature superconductor
- Offers high power density, high efficiency
- Can be integrated with direct drive system which is known to have bulky volume and heavy weight

Reference 17

Other Notable WECS Developments

•Stator Permanent Magnet Generators

•Superconducting Generator

•Dual Power flow WECS with electrical variable transmission

•Variable speed WECS with constant-frequency double-rotor generator

•Direct grid-connected WECS without converters

Wind Farms in India

Current

Muppandal Wind Farm, South India
[1500 MW]

Jaisalmer Wind Park, West India
[1064 MW]

Brahmanvel Wind Park, West India
[528 MW]

Dhalgaon Wind Farm, West India
[278 MW]

Features:
1. Largest offshore plant
2. Located in Tamil Nadu

System Type:
Doubly Fed Machine with speed and power controlled through IGBT (insulated-gate bipolar transistor) converters and pulse width modulation (PWM) electronic control.

Advantages:
1. Gives active & reactive power control with low harmonic content
2. Minimal losses
3. Lower noise emissions due to aerodynamic design of fire blades

Reference 18-21

IMPACTS & POLICY

Benefits of Wind Energy

01	Environmentally Clean	• Truly 100% Renewable • Inexhaustible • Non-Polluting
02	Low Cost	• In many places, including India, it has become cheaper to implement wind technology rather than operating existing coal-fired plants
03	Independence	• Utilizing wind on the local scale can allow countries to become less dependent on fossil fuel imports

Barriers to Wind Implementation

Environmental

- Risk to birds, bats, and sea life
- Sound & Visual Pollution
- Climatic change localized to wind farms

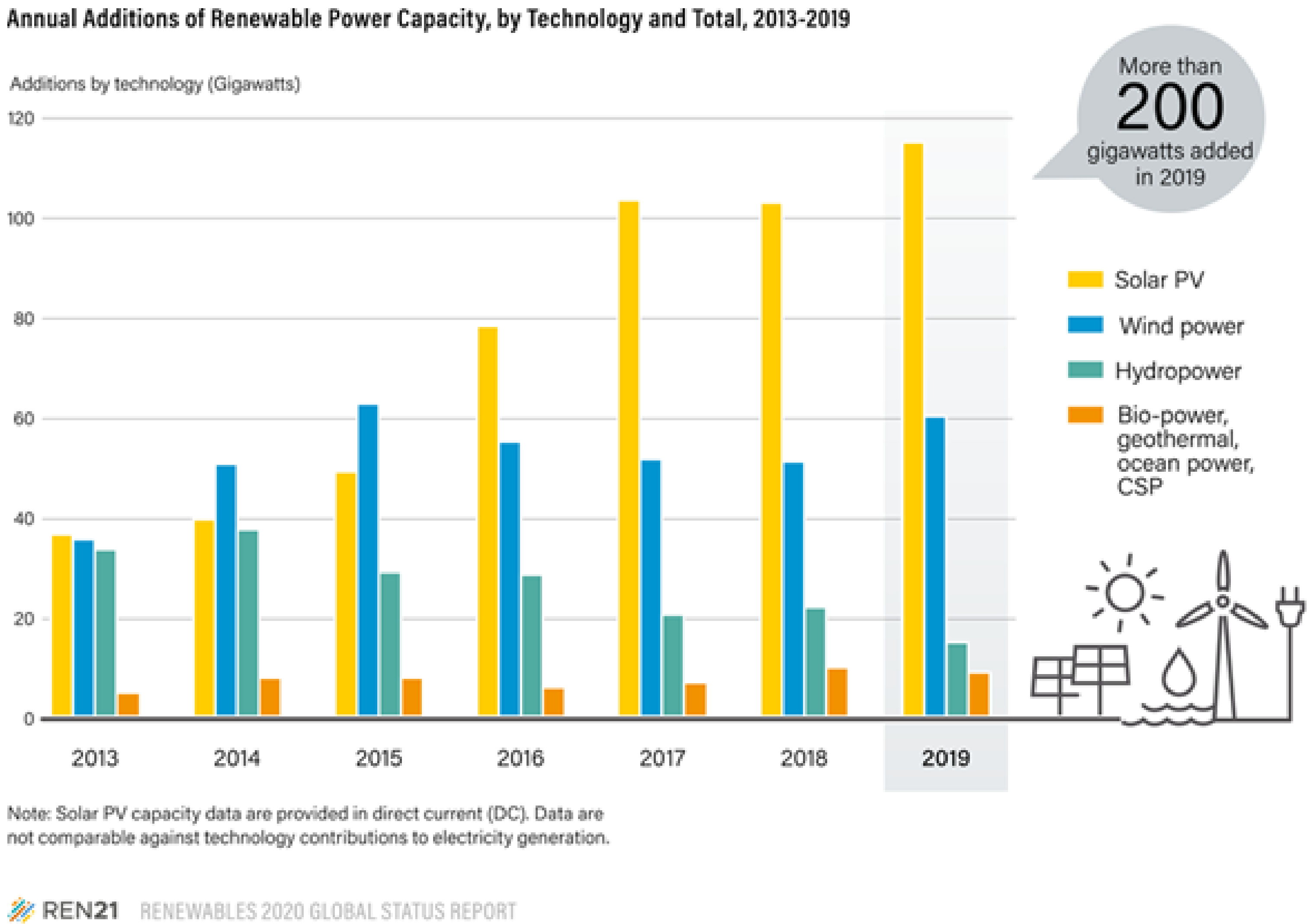
Socio-Economic

- NIMBY - Not in My Backyard
- Inconsistent Policy Applications
- Land Availability

Technical

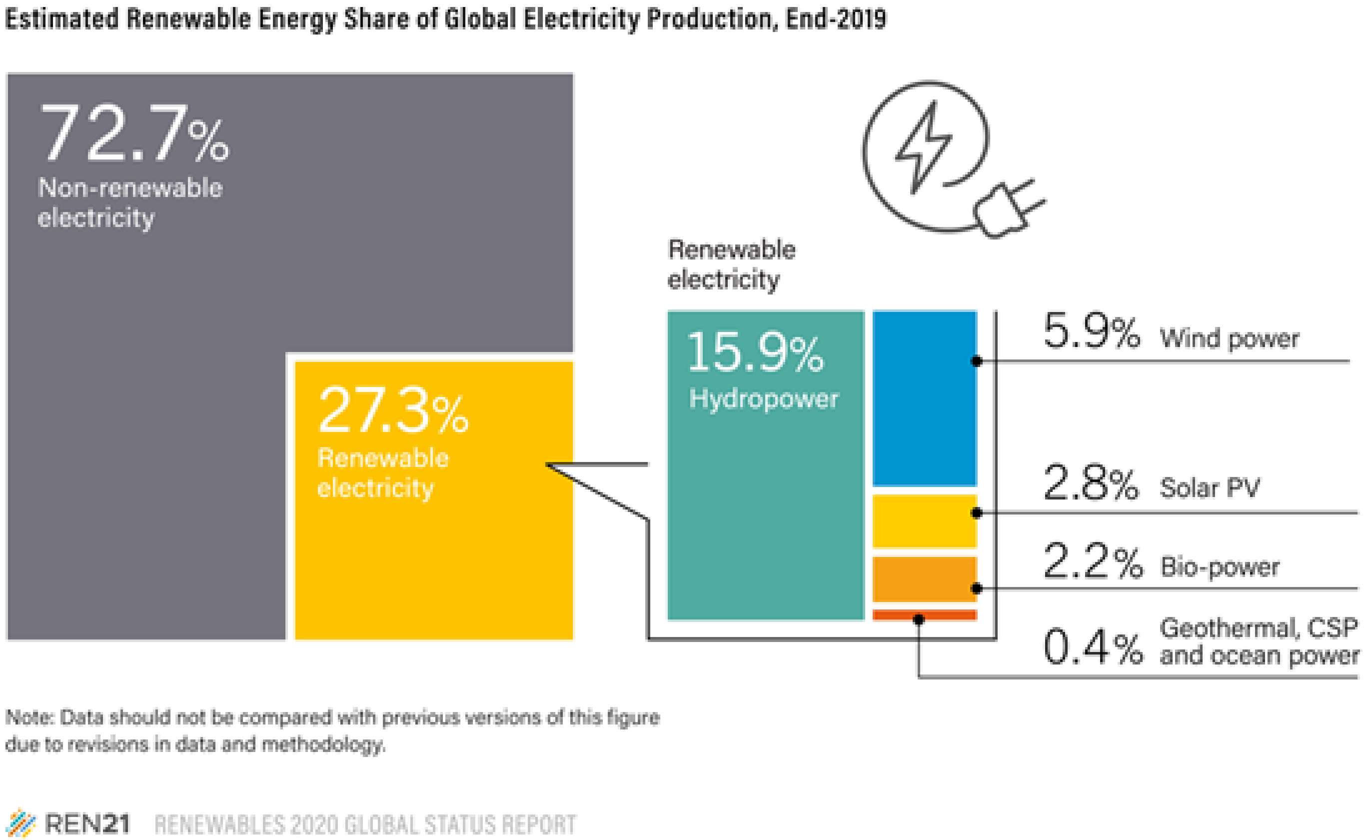
- Grid integration and stability
- Modernization of older wind turbines
- Accounting for Variable Nature of Wind Power

Global Forecast



Reference 5

Global Forecast

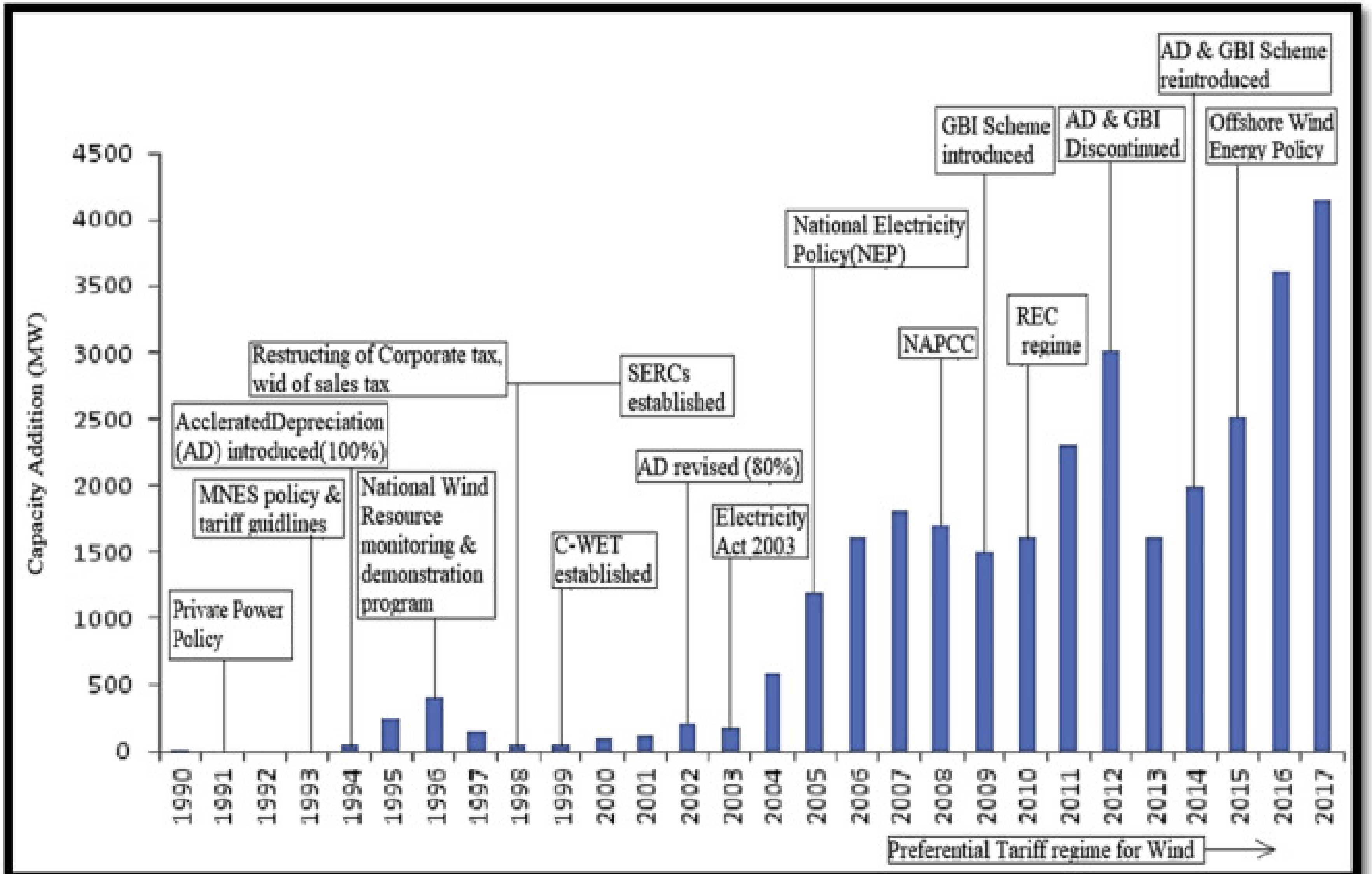


Reference 5

- 77 Countries have committed to net zero carbon emissions by 2050.
- Global investment increased by $301.7 Billion USD in 2019 with Wind outweighing all other forms for the first time since 2009.

History of Wind Energy in India

- Oil Crisis of 70's let to Commission in 1981 to increase use of renewable energy
- By 1985, 600 wind monitoring stations were set up across India for assessment
- A series of 5 year "National Plans" have happened since spearheading a variety of financial incentives and policies
- The Ministry of New and Renewable Energy was established in 2006
- 55% of India's electricity from renewables comes from wind energy



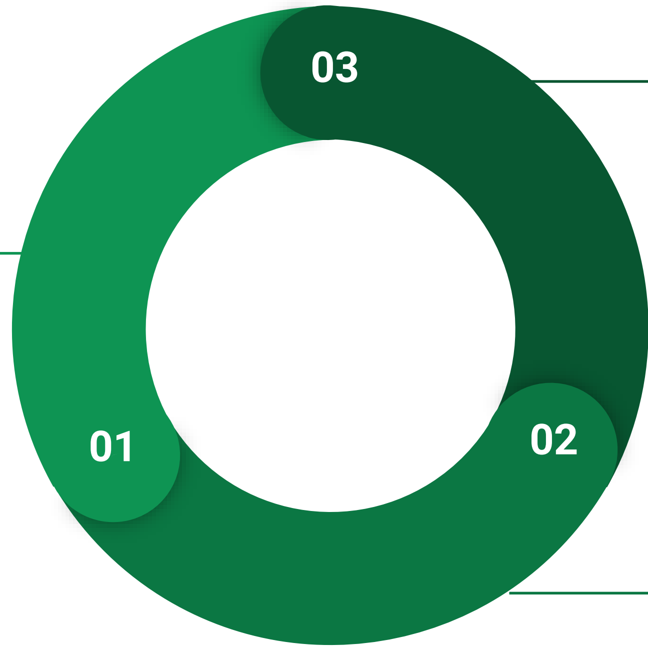
Capacity Addition (MW)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Private Power Policy
MNES policy & tariff guidlines
AccleratedDepreciation (AD) introduced(100%)
Restructing of Corporate tax, wid of sales tax
National Wind Resource monitoring & demonstration program
C-WET established
SERCs established
AD revised (80%)
Electricity Act 2003
National Electricity Policy(NEP)
NAPCC
GBI Scheme introduced
REC regime
AD & GBI Discontinued
AD & GBI Scheme reintroduced
Offshore Wind Energy Policy
Preferential Tariff regime for Wind

Reference 3

Current Policies

REC - Renewable Energy Certificate

Currency of renewable energy market. Purchase of one represents one MW of green generated energy. Allows support of renewable energy not geographically near purchaser.



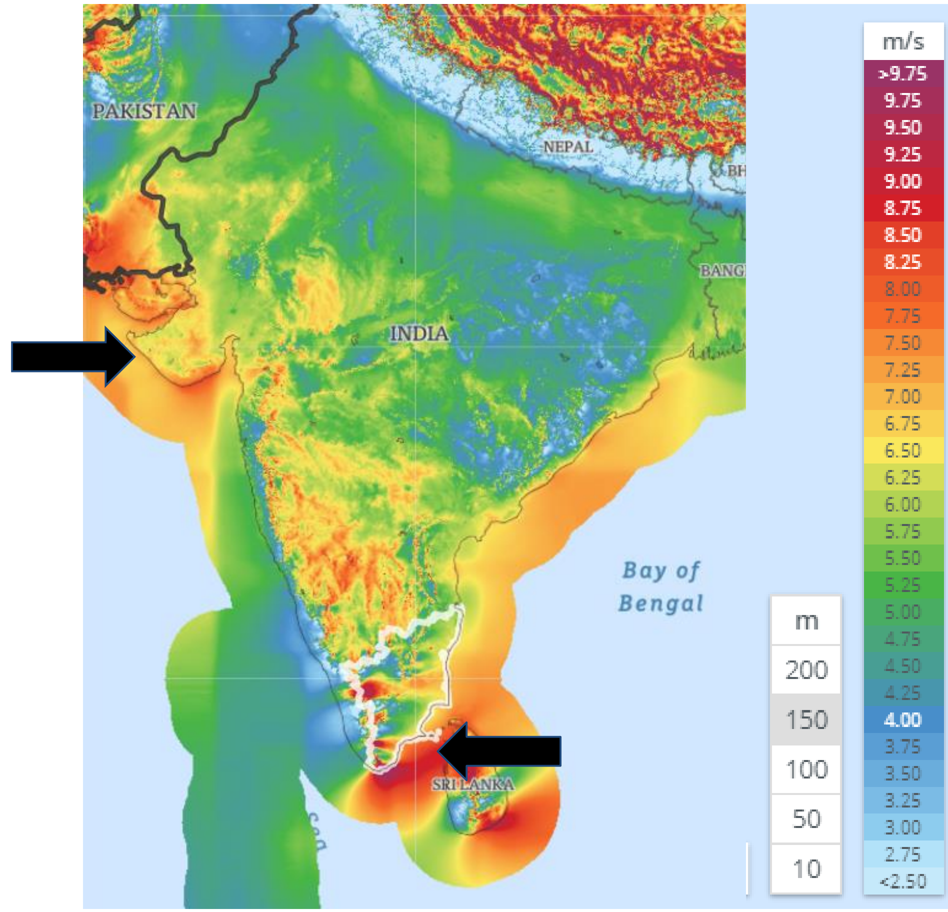
Tariffs

Feed in tariffs - fixed prices paid to wind producer for each unit of energy produced and injected into the grid. Individual states were also allowed to participate in fixed tariffs where energy prices were set for specific timeframes.

GBI - Generation Based Incentive

Providers can access up to 0.50 per unit wind electricity generation between 4 - 10 years. Increased foreign investment 100% in early 2010’s

The Future: Offshore Developments



Reference 6 & 12

Which Way is the Wind Blowing?

- Offshore Development
  - Currently, India is planning to install up to 5 GW by 2032 in Gujarat and Tamil Nadu regions
  - Partnering with Global Wind Energy Council
- At Home Manufacturing
  - COVID has brought to the forefront the need to make turbines parts and components in India
  - As this develops and less is purchased from China, both offshore and traditional turbine use will increase
- Policy Recommendations
  - Solidification of a long term plan is critical to growth of wind and renewable sector
  - Improvement upon solar/wind hybrid policy initiatives will also lead to huge growth

Conclusion

- Where wind comes from
- How we get energy from it
- How industry has evolved and why
- Discussion of current and future technologies
- Wind farms in India
- Pros and cons of wind energy use
- History of wind use and renewable policy in India
- Forecast for wind use globally and in India

Questions?

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