A Close Look into Wind Turbines

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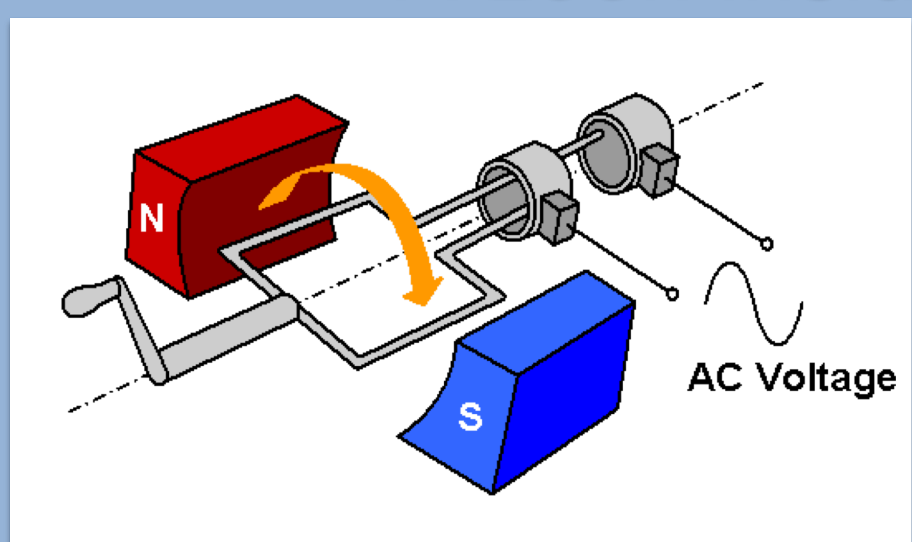
Introduction

Key Question: To what extent is wind technology a viable power source based on its affordability, reliability, and compatibility with our current power grid?

A Look Inside



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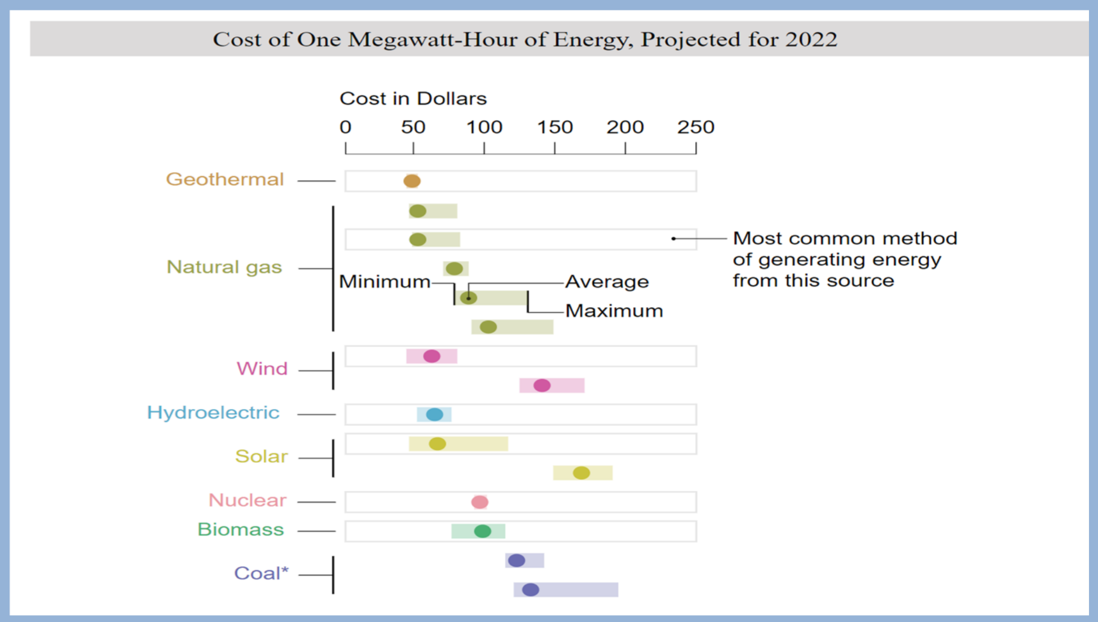
Faraday's Law: $\varepsilon = -\frac{d\Phi}{dt}$

ε: Induced emf (V)
$\frac{d\Phi}{dt}$: Change in magnetic flux
Minus sign: Lenz's Law

- Wind turbines act as generators that take advantage of Faraday's Law
- The wind causes the turbine blades to rotate, which in turn causes the crank to turn

Cost

Levelized Cost of Energy (LCOE): Total cost to generate 1 MWh of energy ($)



Anna Hazard. "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2018," U.S. Energy Information Administration. March 2018.

- Wind LCOE: From $85 (2009) to $47 (2017) (Lazard 2018)
- Wind technology is projected to remain market-competitive (Hazard 2018)

Capacity

Capacity Value: how much power a given technology generates (MW)

Part I: Analyzing Global Trends

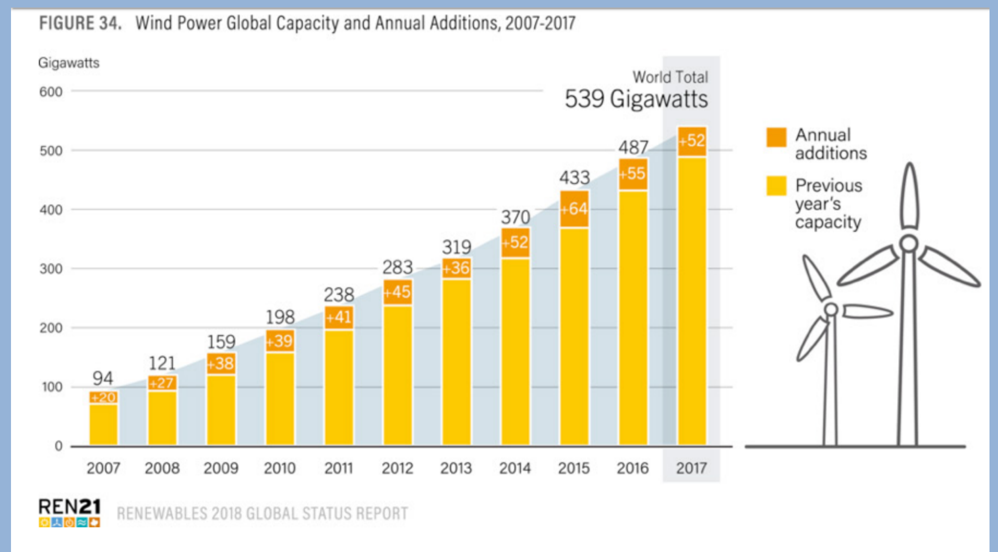
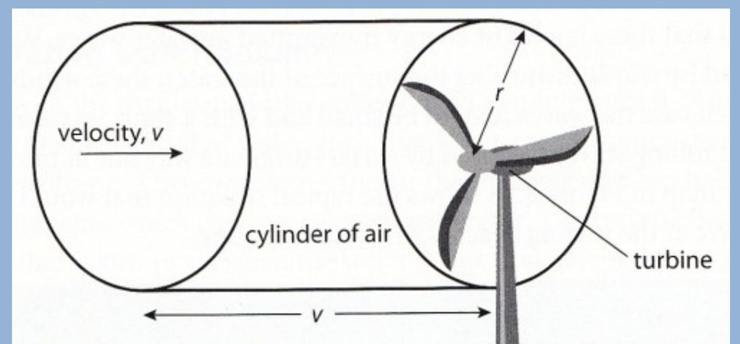


Image: REN21, 2018, *Renewables 2018 Global Status Report*, REN21 Secretariat

- ~500% increase in wind power global capacity between 2007 and 2017
- Peak in annual new increase in 2015
- Wind energy has been shown to generate between 12 and 14% of all US electricity (EIA 2019)

Part II: The Fluid-Mechanical Wind Power Equation



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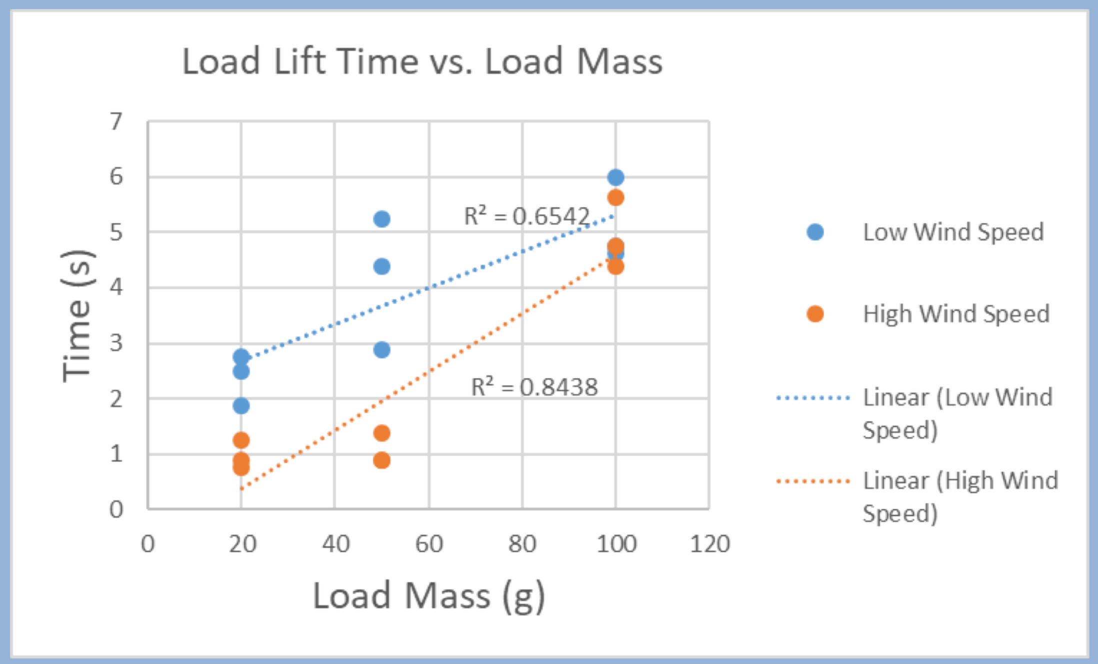
$$\bar{P}_{out} = \frac{1}{2}\rho A v^3 C_P$$

$\bar{P}$: Average Power (W)
ρ: Density of the air $(\frac{kg}{m^3})$
A: Swept Area (m^2)
v: Average wind speed $(\frac{m}{s})$
C_P : Wind Power Coefficient

- Large variability in wind speed
- Since $\bar{P} \sim v^3$, there is large variability in power output
- $C_{P,\,max} = 0.59$, $C_{P,\,avg} = 0.15$

Part III: Experimental Test of Turbine with Test Load



Agarwal and Crossley 2019.

Load lift at constant velocity

$$P = \frac{d}{dt}\left(mgh + \frac{1}{2}mv^2\right)$$

Eventually

$$P = mg\frac{\Delta h}{\Delta t}$$

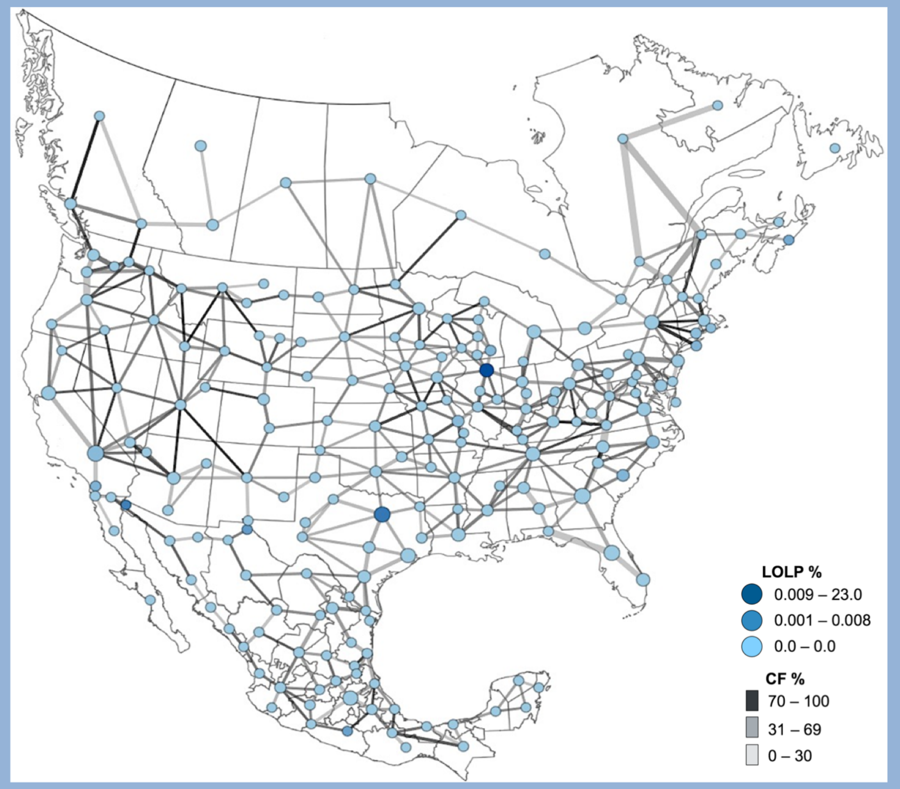
$$\Delta t = \frac{g\Delta h}{P}m$$

Connection

Loss of Load Expectation (LOLE): measurement of predicted power loss (h/4392 h)

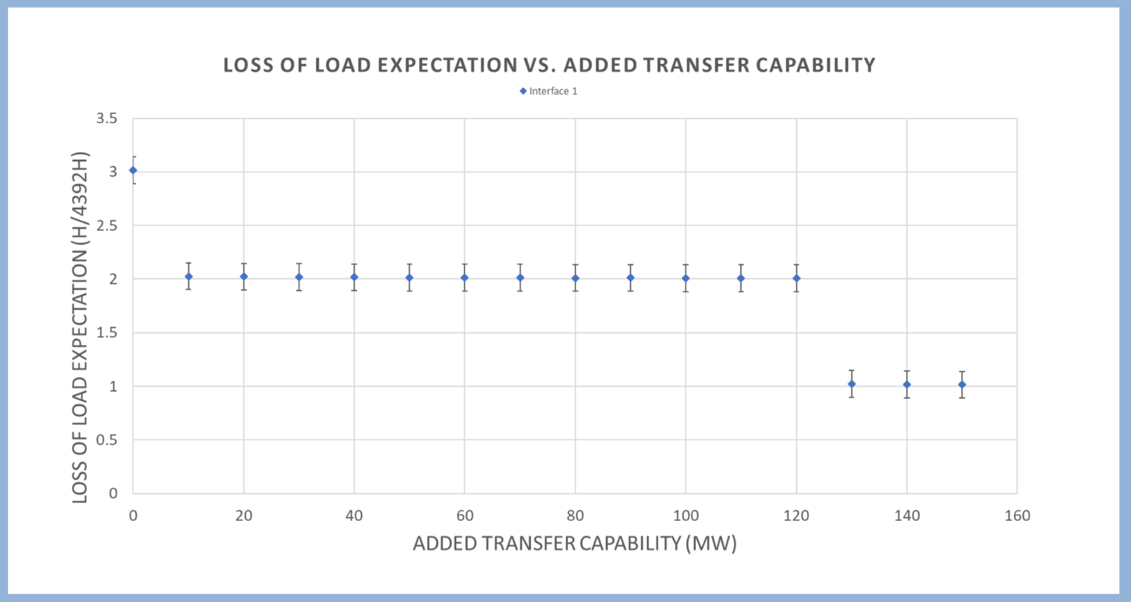
Capacity Factor (CF): measurement of the amount of power sent from one site to another as a fraction of the total possible power distribution (%)

Key Insight: By isolating power outages and congestion areas, grid reliability can be improved



Ashley Suh, NREL: Data Visualization. 2018.

Transmission Capacity: Added power sharing between two regions



Agarwal 2018.

Acknowledgments

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