Emissions of Wind Power

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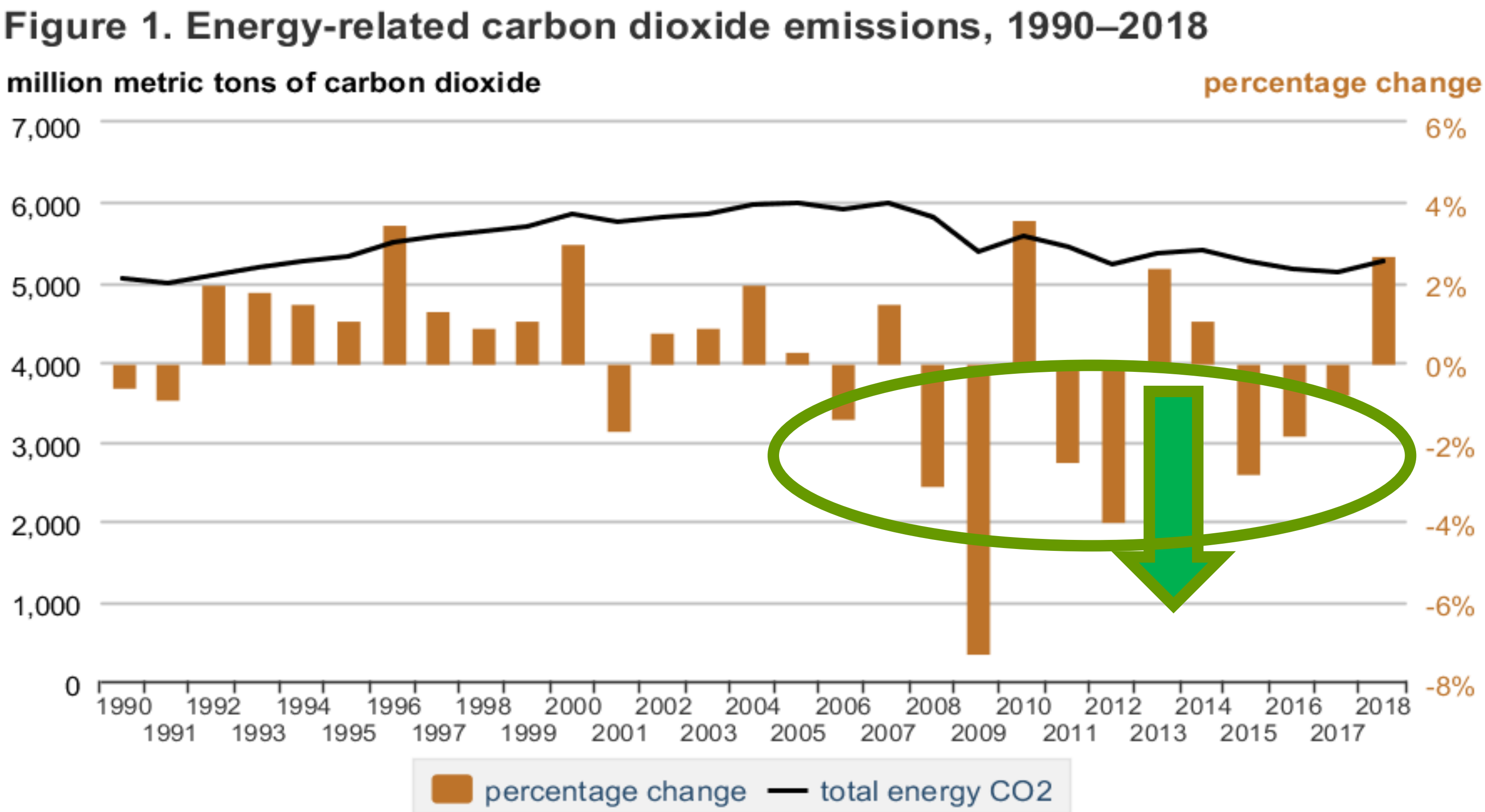
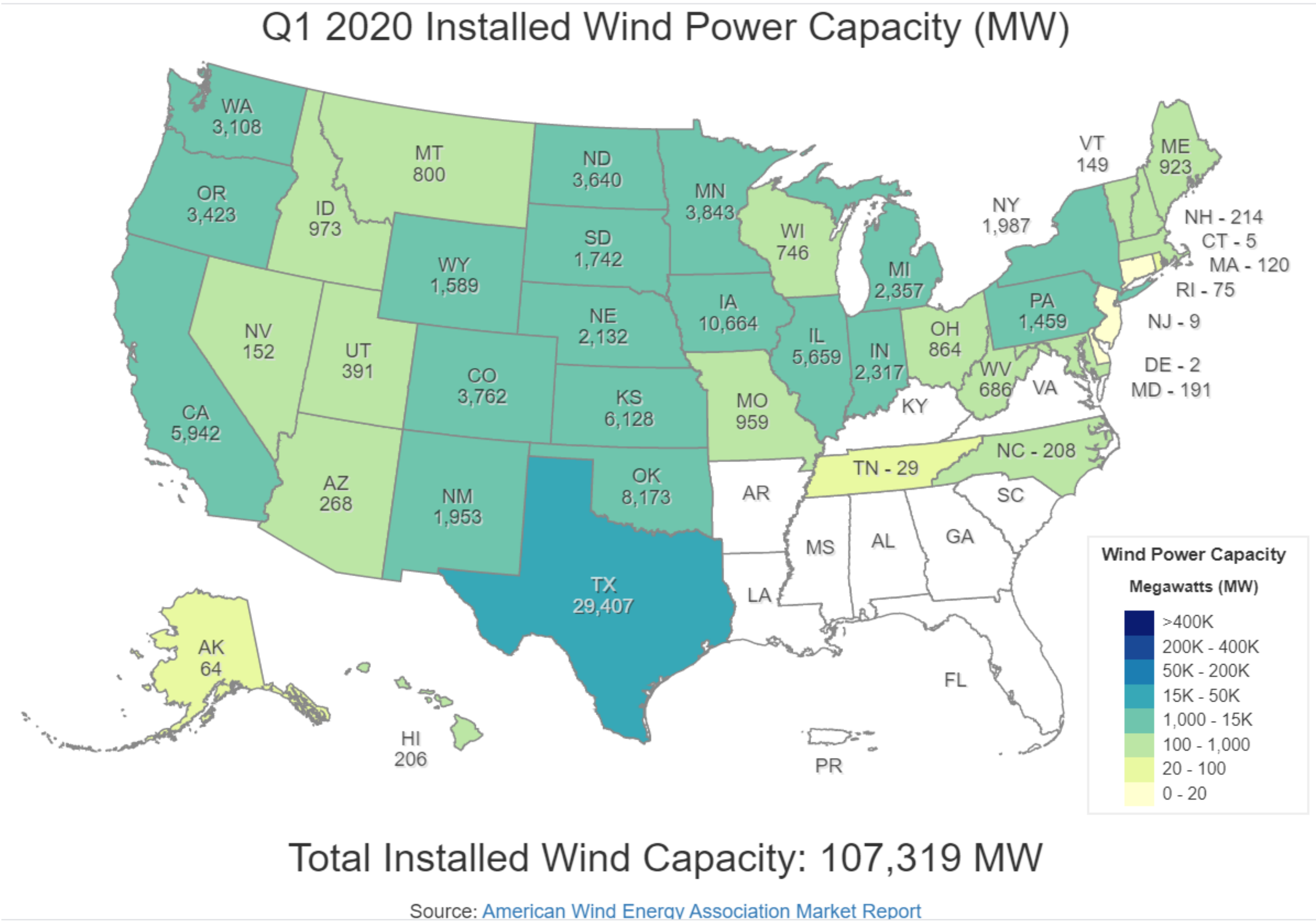
In 2018, U.S. Emissions

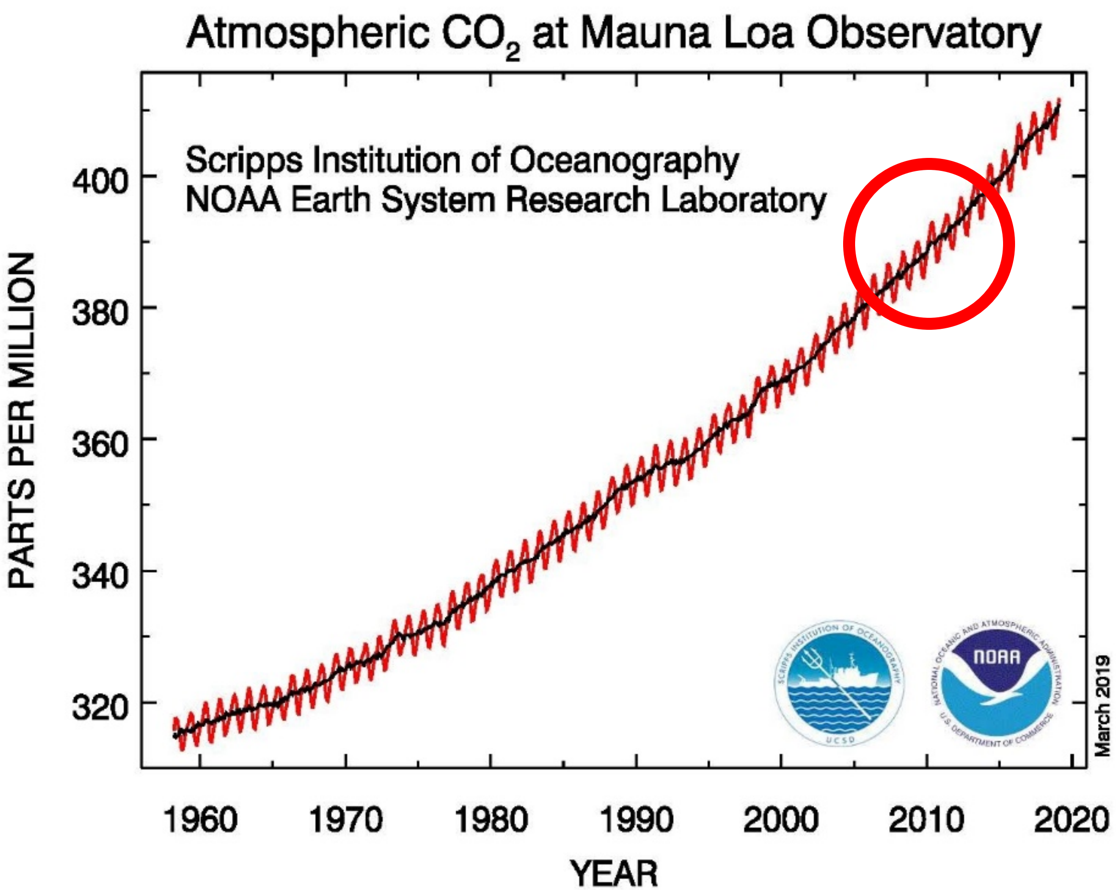


Source: U.S. Energy Information Administration, *Monthly Energy Review*, October 2019, Table 11.1, Carbon Dioxi

Good New: Wind is Rising
(U.S. EERE, 2020)



Bad News: Point of No Return? (NASA, 2019)



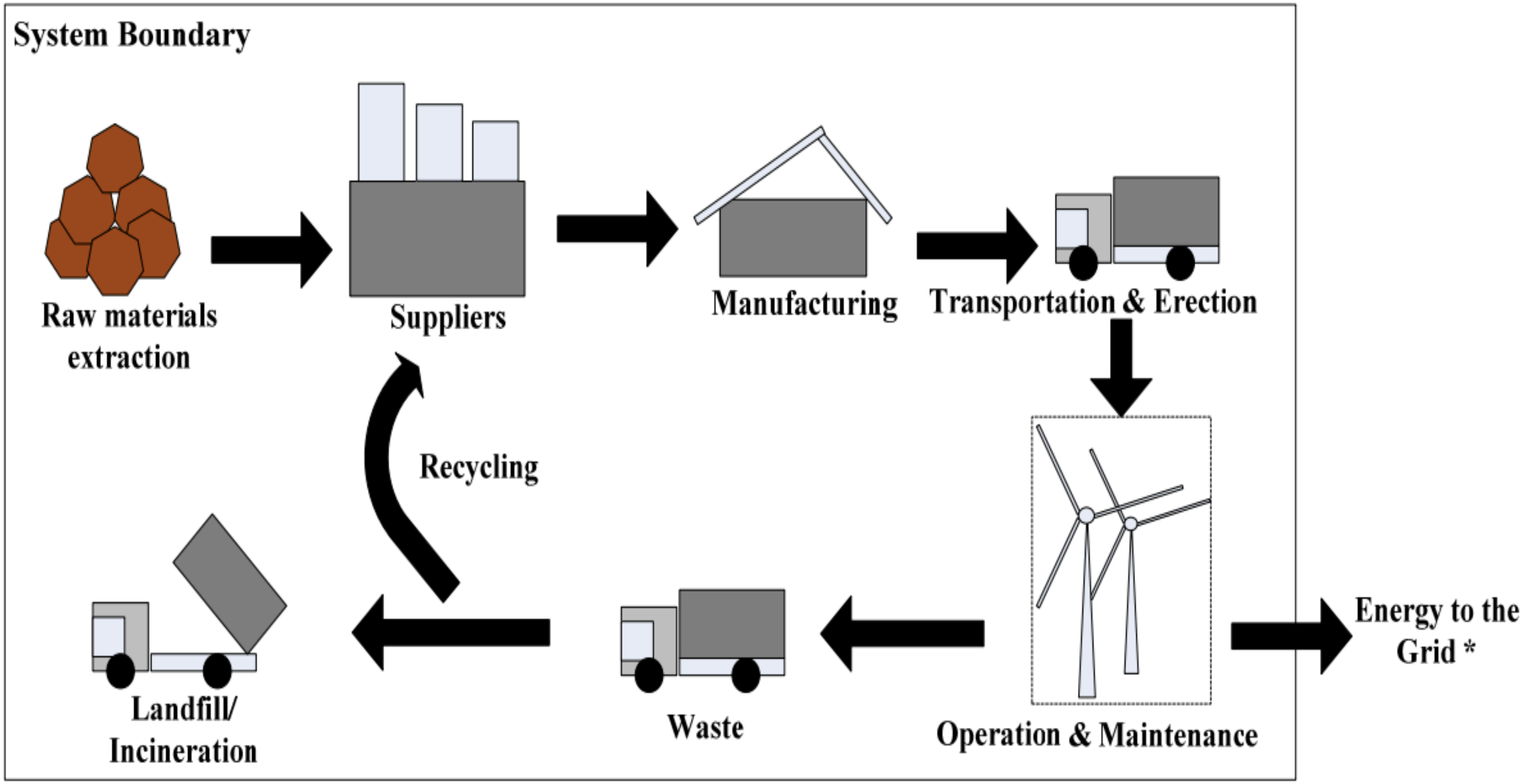
Warning: NOAA

(NOAA, Fahey, SOLAR 2018 Conference)

- It's time to remove carbon!
- In 2019 U.S. produced 286.6 Billion kWh of wind power, roughly 7% (Wind Power Monthly, 2020A).
- How Much Emissions is that?

It’s Rather Complicated

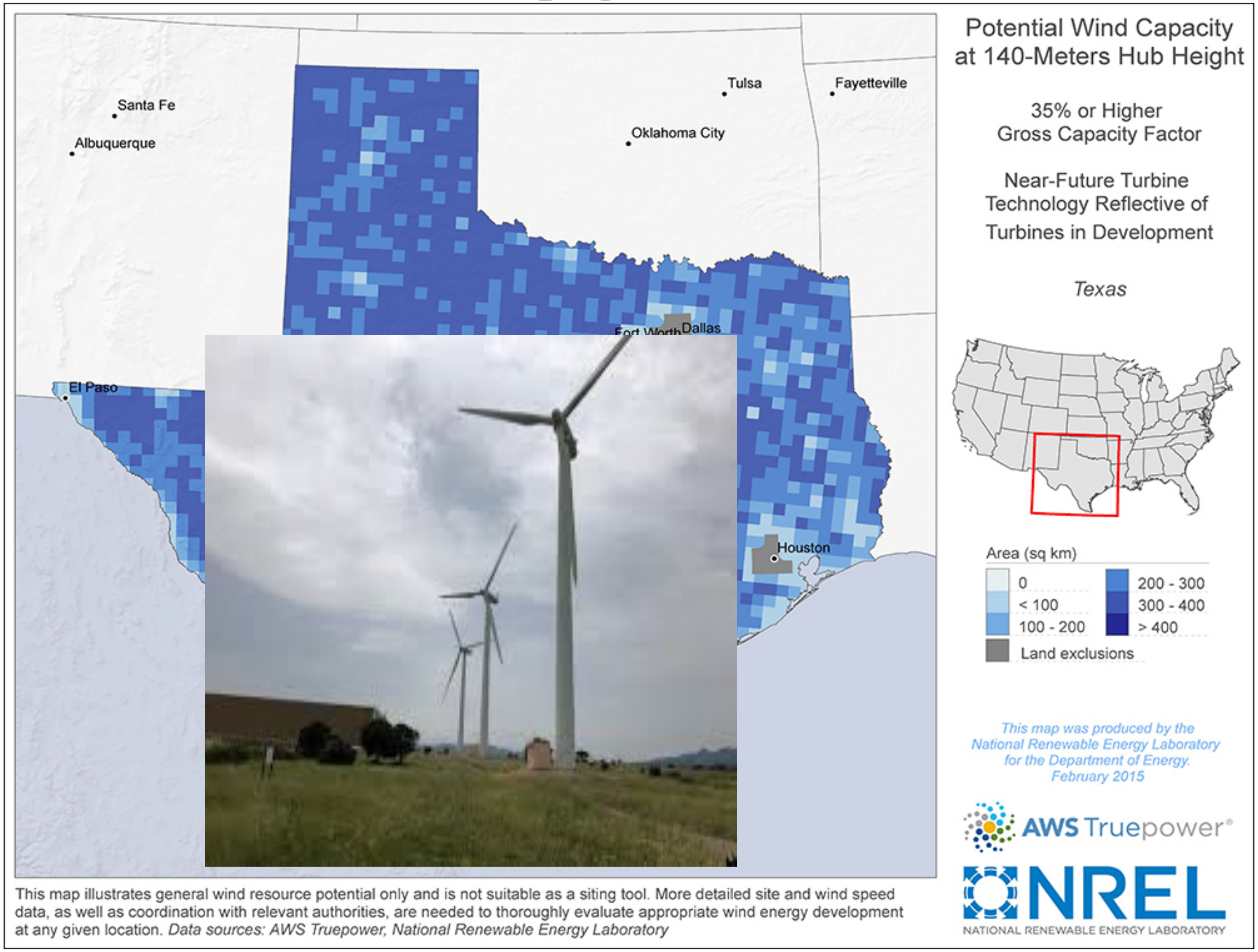
(ISO, 2006) (Garabedian, 2020)



Modeling

- **Lifetime electricity Production?** (Typical Meteorological Year 3 - TMY3- data (NREL 2015).
- **Raw Materials** (Process Analysis)
- **Manufacturing , Transportation, Construction, Overhead** (EEIOA Model)

1.3 MW Nordix in Texas



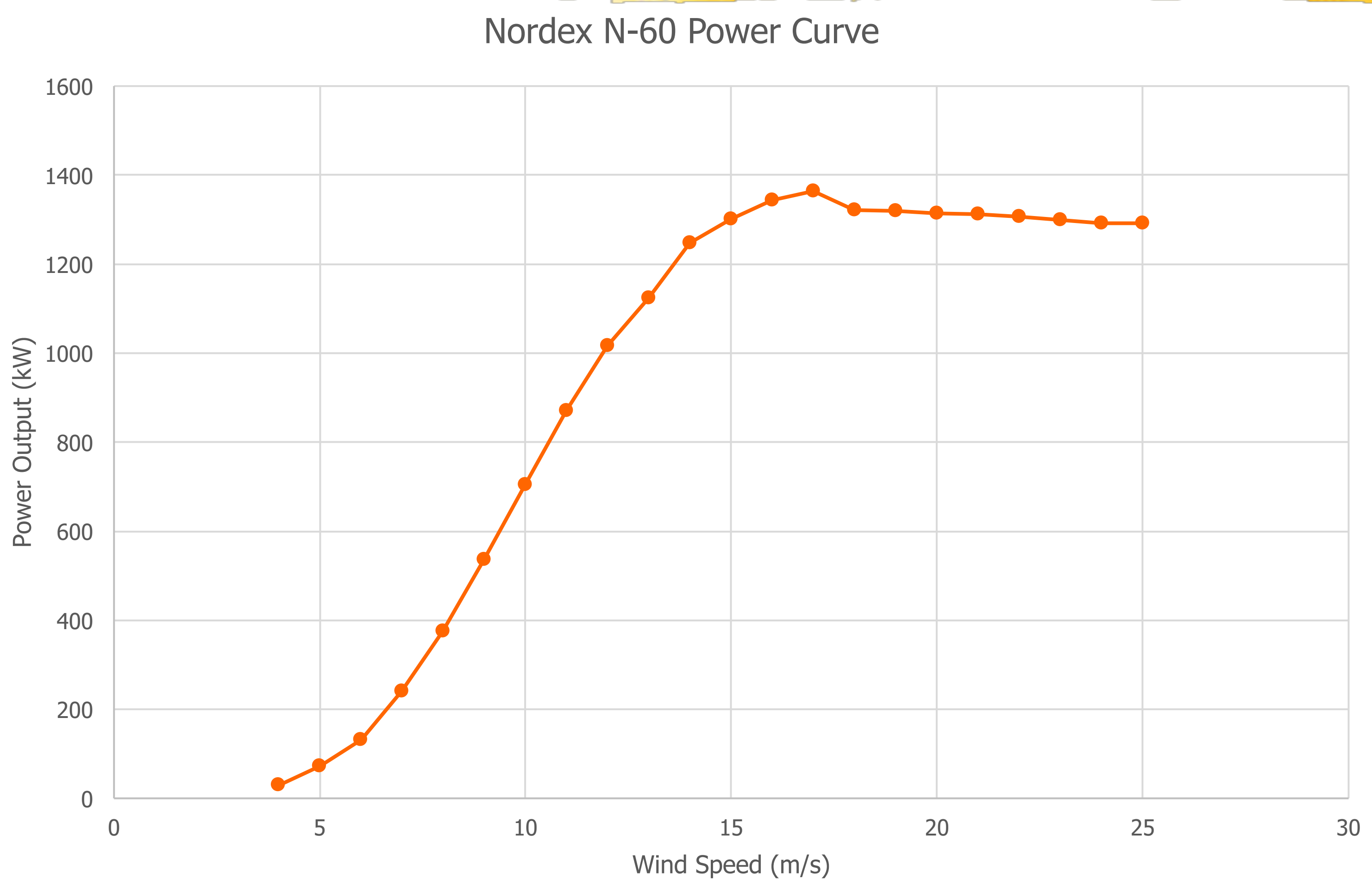
Generation Model

(Kalmikov and Dykes, 2020)

Generated Power

- $P = Cp\frac{\rho A v^3}{2}$ $\quad Eq.(1)$
- $v_2 \cong v_1 \left({}^{h_2}/_{h_1}\right)^{\alpha}$ $\quad Eq.(2)$
- $\boldsymbol{Lifetime\ Energy\ Produced = \left(\sum_{1/1\ 1:00}^{12/31\ 24:00} Power\ Curve(Wind\ Speed)\cdot 3600s\right)\cdot 20yrs}$ $\quad \boldsymbol{Eq.\ (3)}$

Speed Power Curve:



Process Analysis:
(Raw Material Used)

Material	Assigned Energy Content (MJ/kg)	Assigned CO_2 Emissions Factor (kg CO_2-eq/kg)
Steel	30	2.5
GRP	65.25	3.0
Concrete	3	0.2
Copper	85	6.33
Oil Products	9.13	1.44

Energy and Emissions (Raw Materials)

- $$Energy\ Input = Mass * Energy\ Content \qquad (Eq.6)$$

- $$CO2\ Emissions = Mass * CO_2\ \ Emission\ Factor \qquad (Eq.7)$$

Environmentally-Extended Input/Output Analysis (EEIOA):

- **Manufacturing,**
- **Transportation,**
- **Construction, and**
- **Overhead.**

Economic Sector: Factors

- $$Energy\ Consumption\ (MJ) = Component\ Cost\ (\$) * Energy\ Economic\ Factor\ \left(\frac{MJ}{\$}\right) \quad (Eq.8)$$

- $$CO_2\ Emissions\ (g - CO_2) = Component\ Cost\ (\$) * Emissions\ Economic\ Factor\ \left(\frac{g-CO_2}{\$}\right) (Eq$$

Sample Data

Manufacturing Sector	CO_2 Emissions Factor (kg- CO_2 /$)	Energy Emissions Factor (MJ/$)
Transmission Equipment	0.86	11.66
Fabricated Steel Plate Work	1.16	16.31
Plastics	2.07	31.94

Material	Unit Price ($/mt)
Copper and copper-base alloy	6,340
Steel castings	2,196
Carbon steel, plate, cut lengths	488
Carbon steel, wire rods	387
Lubricating oils	340
Concrete	48.5

Results Raw Materials

Material	Total Energy Input (TJ)	Total CO_2 Emissions (Mg-CO_2)
Steel	6.7	558
Glass fiber Reinforced Plastic	1.57	72.3
Concrete	10.5	70
Coper	0.17	12.6
Oil Products	0.011	1.81
Total Raw Materials (PA Model)	**9.5**	**715**

Results: Processes (EEIOA)

Major Components	Sub - Component	Total Energy Input (TJ)	Total CO_2 Creation (Mg- CO_2)
Transportation	Sea Freight	2.30	174
	Truck	1.76	133
Construction	Site Prep	0.101	7.56
	Remote Monitoring	0.101	7.56
	Erection/Commissioning	0.302	22.7
	Foundation	0.462	34.8
Overhead	Overhead	0.134	10.9
Manufacturing	Mechanical Power Transmission Equipment	4.59	340
	Fabricated Plate Work	2.14	153
	Plastics Materials Resin	4.19	272
Total	**(EEIOA Model)**	**16.08**	**1,155.52**

TOTALS
Energy Density and Emission Density

Material	Total Energy Input (TJ)	Total CO_2 Emissions ($Mg\text{-}CO_2$)
Raw Materials (PA Model)	9.5	715
Manufacturing and Construction (EEIOA Model)	16.08	1,155.52
Total (Lifetime)	**25.58**	**1,870.52**

Finally:

Energy	Total Energy Output (TJ)
Annual Energy Output	23.3 TJ/Year
Lifetime (20 Years) Output Energy	466 TJ/Lifetime = 129,444,444 kWh
Energy Intensity (Wind)	54.9 Wh/kWh
CO_2 Emissions Intensity (Wind)	14.45 g-CO_2/kWh
Payback Time of Energy	25.58 TJ/23.3 TJ/Year = 1.1 Years
Energy Intensity (Coal)	157 Wh/kWh
CO_2 Emissions Intensity (Coal)	792 g-CO_2/kWh

Conclusions

Compared to Coal

- Wind produces 98.2% less emissions!
- Wind uses 65% less energy!
- But, it does produce 1.8% Emissions!

Closing

- **In 2019 U.S. Produced 286.6 Billion kWh of Wind Power, roughly 7%.**
- **That's 4.12 MT of CO_2 !**
- **By 2050 ~ 50% Wind?**
- **Need to plant trees!**

Closing

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- Please:
- Comments?
- Critiques?
- Questions?

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