Emissions of Wind Power

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In 2018, U.S. Emissions

Figure 1. Energy-related carbon dioxide emissions, 1990–2018

Source: U.S. Energy Information Administration, Monthly Energy Review, October 2019, Table 11.1, Carbon Dioxide
Good New: **Wind is Rising**
*(U.S. EERE, 2020)*

Q1 2020 Installed Wind Power Capacity (MW)

Total Installed Wind Capacity: 107,319 MW

Source: [American Wind Energy Association Market Report](#)
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

This map illustrates general wind resource potential only and is not suitable as a siting tool. More detailed site and wind speed data, as well as coordination with relevant authorities, are needed to thoroughly evaluate appropriate wind energy development at any given location. Data sources: AWS Truepower, National Renewable Energy Laboratory.
Generation Model

(Kalmikov and Dykes, 2020)

Generated Power

\[ P = Cp \frac{\rho Av^3}{2} \quad \text{Eq. (1)} \]

\[ v_2 \approx v_1 \left( \frac{h_2}{h_1} \right)^\alpha \quad \text{Eq. (2)} \]

\[ \text{Lifetime Energy Produced} = \left( \sum_{1/1 \ 11:00}^{12/31 \ 24:00} \text{Power Curve (Wind Speed)} \cdot 3600s \right) \cdot 20\text{yrs} \quad \text{Eq. (3)} \]
Speed Power Curve:

Nordex N-60 Power Curve

- Power Output (kW) vs. Wind Speed (m/s)
# Process Analysis:
(Raw Material Used)

<table>
<thead>
<tr>
<th>Material</th>
<th>Assigned Energy Content (MJ/kg)</th>
<th>Assigned CO$_2$ Emissions Factor (kg CO$_2$-eq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>30</td>
<td>2.5</td>
</tr>
<tr>
<td>GRP</td>
<td>65.25</td>
<td>3.0</td>
</tr>
<tr>
<td>Concrete</td>
<td>3</td>
<td>0.2</td>
</tr>
<tr>
<td>Copper</td>
<td>85</td>
<td>6.33</td>
</tr>
<tr>
<td>Oil Products</td>
<td>9.13</td>
<td>1.44</td>
</tr>
</tbody>
</table>
Energy and Emissions (Raw Materials)

\[ \text{Energy Input} = \text{Mass} \times \text{Energy Content} \quad (\text{Eq. 6}) \]

\[ \text{CO}_2 \text{ Emissions} = \text{Mass} \times \text{CO}_2 \text{ Emission Factor} \quad (\text{Eq. 7}) \]
Environmentally-Extended Input/Output Analysis (EEIOA):

- Manufacturing,
- Transportation,
- Construction, and
- Overhead.
Economic Sector: **Factors**

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

\(\text{CO}_2 \) Emissions \((g - \text{CO}_2) = \) 
Component Cost \((\$) \times \) 
**Emissions Economic Factor** \(\left( \frac{g-\text{CO}_2}{\$} \right)\) \((\text{Eq}\)
## Sample Data

<table>
<thead>
<tr>
<th>Manufacturing Sector</th>
<th>CO₂ Emissions Factor (kg- CO₂ /$)</th>
<th>Energy Emissions Factor (MJ/$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission Equipment</td>
<td>0.86</td>
<td>11.66</td>
</tr>
<tr>
<td>Fabricated Steel Plate Work</td>
<td>1.16</td>
<td>16.31</td>
</tr>
<tr>
<td>Plastics</td>
<td>2.07</td>
<td>31.94</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>Unit Price ($/mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper and copper-base alloy</td>
<td>6,340</td>
</tr>
<tr>
<td>Steel castings</td>
<td>2,196</td>
</tr>
<tr>
<td>Carbon steel, plate, cut lengths</td>
<td>488</td>
</tr>
<tr>
<td>Carbon steel, wire rods</td>
<td>387</td>
</tr>
<tr>
<td>Lubricating oils</td>
<td>340</td>
</tr>
<tr>
<td>Concrete</td>
<td>48.5</td>
</tr>
</tbody>
</table>
## Results Raw Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Total Energy Input (TJ)</th>
<th>Total CO$_2$ Emissions (Mg-CO$_2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>6.7</td>
<td>558</td>
</tr>
<tr>
<td>Glass fiber Reinforced Plastic</td>
<td>1.57</td>
<td>72.3</td>
</tr>
<tr>
<td>Concrete</td>
<td>10.5</td>
<td>70</td>
</tr>
<tr>
<td>Coper</td>
<td>0.17</td>
<td>12.6</td>
</tr>
<tr>
<td>Oil Products</td>
<td>0.011</td>
<td>1.81</td>
</tr>
<tr>
<td><strong>Total Raw Materials (PA Model)</strong></td>
<td><strong>9.5</strong></td>
<td><strong>715</strong></td>
</tr>
</tbody>
</table>
## Results: Processes (EEIOA)

<table>
<thead>
<tr>
<th>Major Components</th>
<th>Sub - Component</th>
<th>Total Energy Input (TJ)</th>
<th>Total CO₂ Creation (Mg- CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transportation</strong></td>
<td>Sea Freight</td>
<td>2.30</td>
<td>174</td>
</tr>
<tr>
<td></td>
<td>Truck</td>
<td>1.76</td>
<td>133</td>
</tr>
<tr>
<td><strong>Construction</strong></td>
<td>Site Prep</td>
<td>0.101</td>
<td>7.56</td>
</tr>
<tr>
<td></td>
<td>Remote Monitoring</td>
<td>0.101</td>
<td>7.56</td>
</tr>
<tr>
<td></td>
<td>Erection/Commissioning</td>
<td>0.302</td>
<td>22.7</td>
</tr>
<tr>
<td></td>
<td>Foundation</td>
<td>0.462</td>
<td>34.8</td>
</tr>
<tr>
<td><strong>Overhead</strong></td>
<td>Overhead</td>
<td>0.134</td>
<td>10.9</td>
</tr>
<tr>
<td><strong>Manufacturing</strong></td>
<td>Mechanical Power Transmission Equipment</td>
<td>4.59</td>
<td>340</td>
</tr>
<tr>
<td></td>
<td>Fabricated Plate Work</td>
<td>2.14</td>
<td>153</td>
</tr>
<tr>
<td></td>
<td>Plastics Materials Resin</td>
<td>4.19</td>
<td>272</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>(EEIOA Model)</td>
<td>16.08</td>
<td>1,155.52</td>
</tr>
</tbody>
</table>
## TOTALS

**Energy Density and Emission Density**

<table>
<thead>
<tr>
<th>Material</th>
<th>Total Energy Input (TJ)</th>
<th>Total CO₂ Emissions (Mg- CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Materials (PA Model)</td>
<td>9.5</td>
<td>715</td>
</tr>
<tr>
<td>Manufacturing and Construction (EEIOA Model)</td>
<td>16.08</td>
<td>1,155.52</td>
</tr>
<tr>
<td><strong>Total (Lifetime)</strong></td>
<td><strong>25.58</strong></td>
<td><strong>1,870.52</strong></td>
</tr>
</tbody>
</table>
Finally:

<table>
<thead>
<tr>
<th>Energy</th>
<th>Total Energy Output (TJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Energy Output</td>
<td>23.3 TJ/Year</td>
</tr>
<tr>
<td>Lifetime (20 Years) Output Energy</td>
<td>466 TJ/Lifetime = 129,444,444 kWh</td>
</tr>
<tr>
<td>Energy Intensity (Wind)</td>
<td>54.9 Wh/kWh</td>
</tr>
<tr>
<td>CO$_2$ Emissions Intensity (Wind)</td>
<td>14.45 g-CO$_2$/kWh</td>
</tr>
<tr>
<td>Payback Time of Energy</td>
<td>25.58 TJ/23.3 TJ/Year = 1.1 Years</td>
</tr>
<tr>
<td>Energy Intensity (Coal)</td>
<td>157 Wh/kWh</td>
</tr>
<tr>
<td>CO$_2$ Emissions Intensity (Coal)</td>
<td>792 g-CO$_2$/kWh</td>
</tr>
</tbody>
</table>
Conclusions
Compared to Coal

- Wind produces 98.2% less emissions!
- Wind uses 65% less energy!
- But, it does produce 1.8% Emissions!
In 2019 U.S. Produced 286.6 Billion kWh of Wind Power, roughly 7%.

That’s 4.12 MT of CO₂!

By 2050 ~ 50% Wind?

Need to plant trees!
Closing
References:

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References:


Please:

- Comments?
- Critiques?
- Questions?


