EMISSION IMPACTS OF WIND POWER

Wind energy displaces fuel consumed in other power plants and thereby emissions from electricity generation will be reduced. As wind energy also increases balancing needs, it leads to less efficient use of other power plants as they cycle up and down to balance the system. However, studies show that emissions due to increased cycling of power plants are small compared to the benefits of reducing their overall generation and fuel use. In future, wind will also reduce emissions in other energy sectors due to electrification.

How does wind power reduce emissions?

Wind power is a renewable electricity generation source that does not emit CO_2 in operation. It has very low life cycle CO_2 emissions when compared with fossil fuelled generation. When wind power is generated, it will displace generation from power plants, reducing their fuel use and emissions of CO_2, NO_x, SO_x, and particulates. It can also increase electrification and thus decrease emissions in transport, heating and industry energy use.

What power plant generation and fuel will be displaced depends on the cost structure of operating power plants, as well as timing. During each hour, the generation that has most expensive operational costs will be reduced, usually fossil fuelled generation. Examples of studies showing the emission reductions of wind power can be seen in Figure 1. Electrification does not yet show in these examples but becomes more relevant when studying years after 2030.

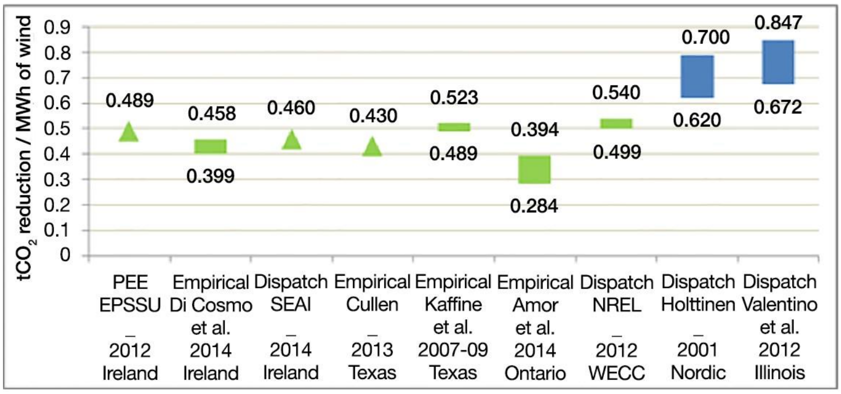

Figure 1. *Examples of wind power impact on emission reductions, as grams of CO_2 per kWh wind power generated. The green ones are from power systems where wind power replaced mostly gas-fired generation and the blue ones where mostly coal-fired generation is replaced (Source: Holttinen et al., 2015).*

Does wind power variability cause extra emissions?

At high levels of wind generation, other technologies will experience steeper ramps and start up and shut down more often, responding to fluctuations in renewables and demand. The overall impact of wind power variability on emissions depends on various factors, including the mix of other generation sources and the extent to which grid management practices and technologies like demand response and storage are implemented to mitigate variability.

When fossil fuel power plants start up, ramp output up or down, or operate below full load, they are less efficient in fuel use than when they run continuously at full load. This results in more CO_2 and other emissions.

However, studies have shown that extra emissions from these balancing needs are minimal compared to the substantial emission reductions from replacing coal and gas generated electricity. For example, providing 33% of annual electricity needs with wind and solar energy, balancing related emissions are less than 2% of the emission reductions from decreased electricity generation from fossil fuels. (Lew et al., 2013) (Figure 2 and 3).

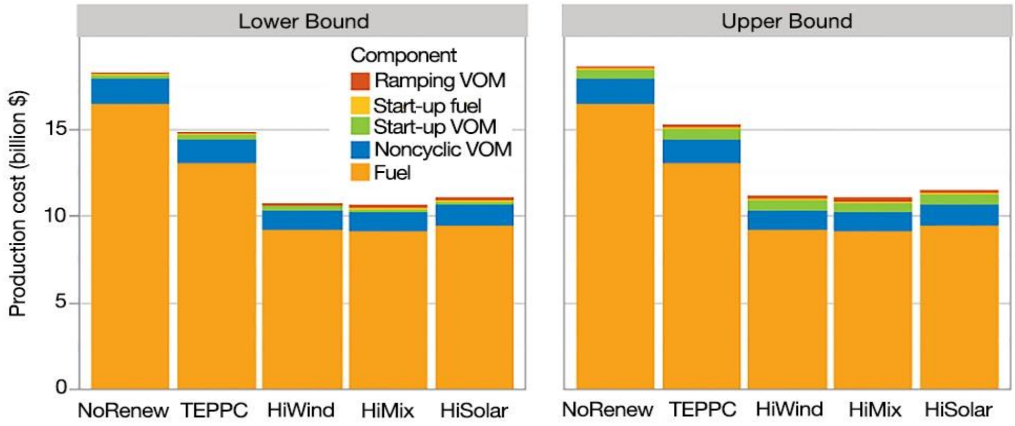

Figure 2. *Most of the operation costs and emissions result from fuel use. Ramping and start-ups present less than 1% share of the costs over a year, even with a high share of variable renewables. Example of simulated Western U.S. operational costs from one year, with up to 33% share of wind and solar (Source: Lew et al., 2013).*

How can operators ensure lower extra emissions from balancing power systems?

When anticipating larger shares of wind and solar energy in a power system, it will be important to increase the flexibility of new fossil fuelled power plants. Increased flexibility can decrease the operational costs and emissions of the overall power system because it provides more options for balancing. Flexibility can be shared with neighbouring regions using transmission interconnections (trading electricity). Wind and solar power plants can offer fast response. Another new source of flexibility is offered by the consumer side, called demand response.

Emission reductions for future low carbon energy systems

Deeper decarbonisation means electrifying other energy sectors like transport and heating. This brings new electricity consumption. For studies reaching beyond 2030, emission reductions from other sectors than electricity need to be taken into account when assessing the benefits of wind energy.

	Emission Reduction Due to Renewables	Cycling Impact
CO_2	260–300 billion lbs 29% – 34%	Negligible Impact
NO_x	170–230 million lbs 16% – 22%	3–4 million lbs
SO_2	80–140 million lbs 14% – 24%	3–4 million lbs

Figure 3. *The increase in plant emissions from cycling to accommodate variable renewables is very low compared to the overall reduction in CO_2, NO_x, and SO_2 due to adding renewables. (Source: WWSIS2, 2013, https://www.nrel.gov/docs/fy13osti/57874.pdf) (1 million lbs = .45 million Kg).*

Associated publications

- Holttinen, H. et al. (2021). **Design and operation of energy systems with large amounts of variable generation**. Final summary report, IEA WIND TCP Task 25. https://doi.org/10.32040/2242-122X.2021.T396
- Holttinen, H. et al. (2015) **Reduction of CO2 emissions due to wind energy - methods and issues in estimating operational emission reductions**. IEEE Power & Energy Society General Meeting, 26 - 30 July 2015, Denver, USA: IEEE. Proceedings. https://doi.org/10.1109/PESGM.2015.7286288
- Lew, D. et al. (2013). **The Western Wind and Solar Integration Study Phase 2**. NREL/TP-5500-55588. National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy13osti/55588.pdf
- SEAI (2014). **Quantifying Ireland's Fuel and CO_2 Emissions Savings from Renewable Electricity in 2012**. www.seai.ie/News_Events/Press_Releases/2014/245m-of-fossil-fuel- savings-from-use-of-renewable-electricity-in-2012.html
- Millstein, Dev. et al. (2024). **Climate and air quality benefits of wind and solar generation in the United States from 2019 to 2022**. Cell Reports Sustainability, 1(6), 100105. https://doi.org/10.1016/j.crsus.2024.100105

More information

This Fact Sheet draws from the work of IEA Wind TCP Task 25, a research collaboration among 17 countries. The vision in the start of this network was to provide information to facilitate the highest economically feasible wind energy share within electricity power systems worldwide. IEA Wind TCP Task 25 has since broadened its focus to analyze and further develop the methodology to assess the impact of wind and solar power on power and energy systems.

See our website at

https://iea-wind.org/task25/

See also other fact sheets

Storage for Power Systems
Balancing Power Systems with Large Shares of Wind and Solar Energy
Flexibility Through Electrification
Wind and Solar Integration Issues