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Wind LCA Harmonization

Deployment of wind technologies in the United States has increased dramatically in recent years--from just over 9 GW at the end of 2005 to over 60 GW at the end of 2012 (AWEA 2012). Part of its appeal is its potential to reduce greenhouse gas (GHG) emissions from the power sector. As clean energy increasingly becomes part of the national dialogue, lenders, utility executives, and lawmakers need the best, most precise information on GHG emissions about various sources of energy to inform policy, planning, and investment decisions for future electric sector growth. The National Renewable Energy Laboratory (NREL) recently led the Life Cycle Assessment (LCA) Harmonization Project, a study that gives decision makers and investors more exact estimates of GHG emissions for renewable and conventional generation, clarifying inconsistent and conflicting estimates in the published literature, and reducing uncertainty.

Over the last thirty years, thousands of LCAs have been conducted and published for a variety of electricity generation technologies. These LCAs have had wide-ranging results. Inconsistencies can be attributed to technologies evaluated (i.e., differing system designs, commercial versus conceptual systems, system operating assumptions, technology improvements over time) and LCA methods and assumptions. Analysts developed and applied a systematic approach to review LCA literature, identify primary sources of variability and, where possible, reduce variability in life cycle GHG emissions estimates through a process called "harmonization." This study assessed more than 2,100 published LCA studies on utility-scale electricity production from wind, solar photovoltaic (PV), solar concentrating solar power (CSP), nuclear, natural gas, and coal technologies. Approximately 240 published LCAs of wind systems, including land-based and offshore technologies, were evaluated.

For wind power systems, "harmonization" was performed by adjusting published GHG estimates to achieve consistency in:

1. *Capacity factor*, the ratio of actual to maximum potential electricity generation (30% for land-based and 40% for offshore systems).
2. *Operating lifetime* of the wind turbine and its components (20 years).
3. *System boundary*.
4. *Global warming potentials* (GWPs) for methane and nitrous oxide.

Other potential sources of variability that were not considered in this study include the upstream electricity mix used in manufacturing processes, transmission infrastructure, and wind power class.

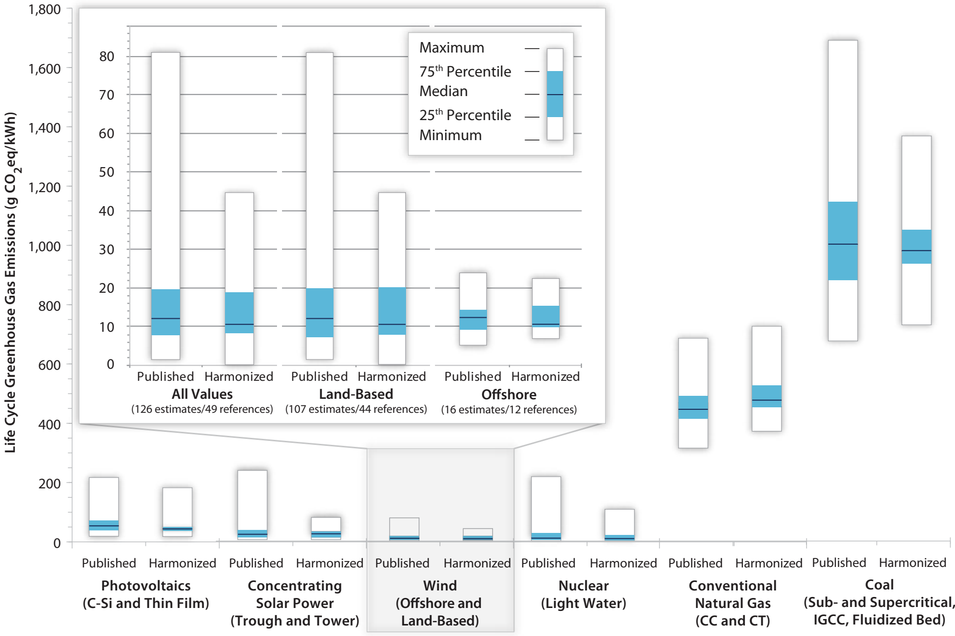
Life Cycle Stages	Upstream Processes	Operational Processes	DownstreamProcesses
Wind 	• Raw Materials Extraction • Module Manufacture • Parts Manufacture • Wind/Turbine/Farm Construction	• Power Generation • Plant Operation and Maintenance	• Wind Turbine/Farm Decommissioning
~10 g CO_2eq/kWh	~86%	~9%	~5%
Coal 	• Raw Materials Extraction • Construction Materials Manufacture • Power Plant Construction	• Coal Mining • Coal Preparation • Coal Transport • Coal Combustion • Power Plant Operation and Maintenance	• Power Plant Decommissioning • Waste Disposal • Coal Mine Land Rehabilitation
~1000 g CO_2eq/kWh	<1%	>98%	<1%

Comparison of life cycle processes and green house gas emissions for wind and coal power by life cycle stage.

LCA of Energy Systems

LCA can help determine environmental burdens from "cradle to grave" and facilitate comparisons of energy technologies. Comparing life cycle stages and proportions of GHG emissions from each stage for wind and coal shows that, for coal-fired power plants, fuel combustion during operation emits the vast majority of GHGs. For wind power plants, the majority of GHG emissions are upstream of operation.

Source: *Dolan and Heath. (2012) and Whitaker et al. (2012), NREL 21205 andiStock/1627655, Top (left to right): Photo from iStock/13737597, NREL 19893, iStock/12123595, NREL 16933, NREL 18381, NREL 19163*



	Photovoltaics	Concentrating Solar Power	Wind	Nuclear	Conventional Natural Gas	Coal
Estimates	46	36	126	99	51	164
References	17	10	49	27	42	53

Comparison of published and harmonized estimates of life cycle greenhouse gas emissions for selected electricity generation technologies. Inset compares land-based and offshore wind technologies.

The life cycle GHG emissions for land-based and offshore wind power are compared with other electricity generation technologies in the figure on this page. These results show that:

- Wind energy's total life cycle GHG emissions are similar to other renewables and nuclear energy, and much lower than fossil fuel.
- Harmonization increases the precision of life cycle GHG emission estimates for wind, reducing the overall range by 47%.
- Harmonization reduces the median value of life cycle GHG emissions estimates for wind systems by 10% (from 12 grams [g] to 11 g of CO_2eq per kilowatt hour of generation [g CO_2eq/kWh]).
- Land-based and offshore wind technologies have similar life cycle GHG emissions; the median life cycle GHG emission estimate for both technologies is 11 g CO_2eq/kWh after harmonization.

Of the harmonization parameters investigated, adjusting to a consistent capacity factor had the greatest impact on reducing variability in GHG emissions estimates. Capacity factors for wind vary due to site-specific wind conditions, wind turbine sizes and designs, and the frequency and duration of maintenance. In the LCA literature, capacity factors for wind systems varied widely, ranging from 11% to 71%. When these values were adjusted to 30% for land-based and 40% for offshore systems, which were the values selected for harmonization and reflect current deployment experience (Wiser and Bolinger 2011; Tegen et al. 2012), the variability in the range of estimated life cycle GHG emissions for all wind technologies was reduced by 42%.

See also:

- For further information about the LCA Harmonization project, including links to Whitaker et al. (2012) on coal as well as other technologies: www.nrel.gov/harmonization
- For data visualization and downloading: http://en.openei.org/lca
- For further details of the harmonization of wind LCAs: Dolan, S.; Heath, G. (2012). "Life Cycle Greenhouse GasEmissions of Utility-Scale Wind Power: Systematic Review and Harmonization." *Journal of Industrial Ecology* (16:S1); pp. S136-S154, http://onlinelibrary.wiley.com/doi/10.1111/j.1530-9290.2012.00464.x/pdf.

Systems-Level Impacts of Increasing Penetration of Wind Generation

There are many potential systems-level effects associated with integrating variable and uncertain wind resources into the existing grid that are not typically considered in LCAs. For example, with increasing penetration of wind power, conventional fossil-fired power plants may be required to adjust their output level or start up or shut down more frequently. Recent assessments indicate that while the emissions impacts of generator cycling and part-loading can be significant, these impacts are modest compared to the overall benefits of replacing fossil fuel generation with variable renewable generation (Lew et al. 2012). Additional consequential LCAs would enhance understanding of true life cycle GHG emissions of wind power, although those are not likely to fundamentally change the comparison of wind to other electricity sources.

References

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