Integrating renewables into the grid: An energy dispatch model

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Summary

Using a novel approach, I model the operating behavior of an electric grid to predict the maximum practical reduction in CO_2 emissions from and costs associated with very large expansions in wind and solar capacity. I estimate the practical limit in emissions reductions for wind and solar individually is 50% (35% vs. 1990 levels) and show this is not increased by mixing wind and solar together. However, it is extended to 72% (50% vs. 1990 levels) with a modest increase in nuclear capacity.

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Introduction

• **Variable zero-carbon sources of energy** such as wind and solar can be used to reduce CO_2 emissions from electricity generation. However, as they do not provide on-demand electricity, the impacts of large increases in renewables capacity on grid operations absent meaningful storage are difficult to estimate. I present a model that predicts the effects of greatly increasing wind and solar capacity on **grid CO_2 emissions** and the **overall cost of generation**.

Methods

• I present results from a **mixed-integer quadratic program** that estimates grid behavior with varying renewables capacities by minimizing hourly grid operating cost to mimic a competitive electricity market. Unlike previous methods, my model incorporates **realistic operating characteristics** of different generation technologies, such as varying efficiencies at part load operation, maximum ramp rates, minimum operation rates and cycling costs. I also correct for the uncertainty in renewables production.

• My model **accurately predicts dispatch behavior, emissions and overall cost of generation** for a grid under current operating conditions (*i.e.* no renewables).

	CO_2 emissions *(lbs / MWh)*	Overall cost *($ / MWh)*
Predicted values	1,209	90.9
AZ-NM-SNV Actual	1,311	91.1
Error	*-7.77%*	*-0.19%*

Table – Model predicted values vs. actual grid operating data

Results

#1 **– Wind by itself** is limited in how much it can practically reduce grid CO_2 emissions but is relatively cost-effective at doing so.

• Adding 100% wind capacity would **reduce CO_2 emissions by 45%** while only **increasing the overall cost of generation by 50%**

#2 **– Solar by itself** can practically reduce CO_2 emissions more than wind by itself, but is substantially more expensive than wind.

• Adding 100% solar capacity would **reduce CO_2 emissions by 49%** but **increase overall cost of generation by 164%**

#3 **– Wind and solar's offsetting variability** does not meaningfully increase the maximum practical amount the grid can reduce CO_2 emissions with the two resources, but does enable some minor cost savings.

#4 **– A modest expansion in nuclear power** greatly extends the maximum practical reduction in CO_2 emissions from wind and solar capacity.

• A grid with 50% wind, 25% solar and 25% nuclear capacity would **reduce CO_2 emissions by 72%** while only **increasing the cost of generation by 63%**

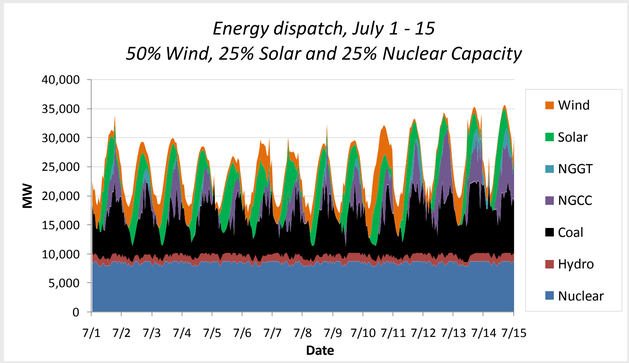

Figure – Example model results from a two-week period in July for a grid with 50% wind, 25% solar and 25% nuclear capacities

Discussion

• Based on current technology, wind is more cost-effective in reducing CO_2 emissions than solar. However, both have **rapidly decreasing marginal effectiveness** or, equivalently, increasing marginal costs of abatement, and costs that are much higher than currently proposed carbon taxes.

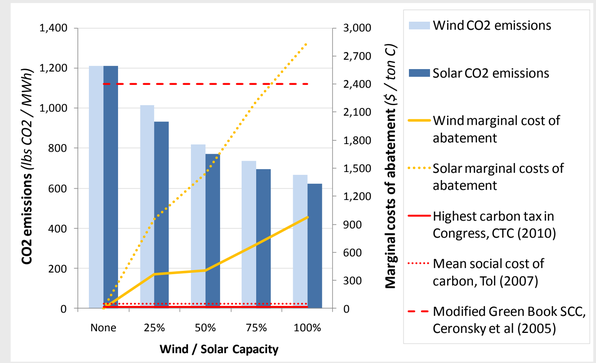

Figure – The marginal cost of abatement rapidly increases as more renewables capacity is added to the grid.

Conclusions

• In spite of their variability, wind and solar have potential to **moderately reduce CO_2 emissions** from electricity generation

• However, the maximum practical reduction in CO_2 from a very large expansion in either is estimated to be **50%**

• Integrating mixes of wind and solar **does not extend this limit**, but a modest expansion in nuclear power increases it to **72%**

• Ultimately, this only represents a **50% reduction relative to 1990 levels**, which is short of the commonly held **80% goal**. To reach this, a grid will likely have to add more nuclear capacity, energy storage or demand reduction as **even very large expansions in wind and solar cannot practically do it alone.**