Marginal CO_2 Rates of US Electricity Generation

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1. BACKGROUND

Numerous strategies exist for reducing emissions from electricity generation. Renewable energy resources, such as wind and solar generation, are commonly suggested as supply-side solutions. Renewables reduce emissions by displacing conventional power plants. Similarly, demand-side solutions such as efficiency measures would reduce demand for electricity, thus displacing both energy and emissions that would have otherwise been produced.

Knowing the marginal emissions rate of the system, we can quantify the displaced emissions from various supply- and demand-side interventions.

2. RESEARCH OBJECTIVE

This work presents the first systematic calculation of marginal emissions rates for the US electricity system.

3. DATA

Hourly emissions and generation data are from the Continuous Emissions Monitoring System (CEMS), a database maintained by the US Environmental Protection Agency (EPA, 2010). CEMS provides hourly SO_2, NO_x, and CO_2 emissions and gross electrical output for all fossil-fueled plants larger than 25 MW. CEMS data from 2007 were aggregated by NERC region. As shown in Table 1, the generation mix varies widely from region to region.

Table 1: Regional generation mix

NERC Region		Total (TWh)	Coal	Gas	Oil	Nuclear	Hydro
FRCC	(Florida)	218	27%	47%	9%	13%	0%
MRO	(Midwest)	215	70%	5%	1%	15%	3%
NPCC	(Northeast)	282	15%	37%	5%	28%	11%
RFC	(Mid-Atlantic)	1005	64%	7%	1%	26%	1%
SERC	(South)	1133	57%	14%	1%	24%	2%
SPP	(South)	212	62%	26%	0%	5%	3%
TRE	(Texas)	342	34%	49%	0%	12%	0%
WECC	(West)	735	30%	31%	0%	10%	23%

Source: EPA eGRID 2010

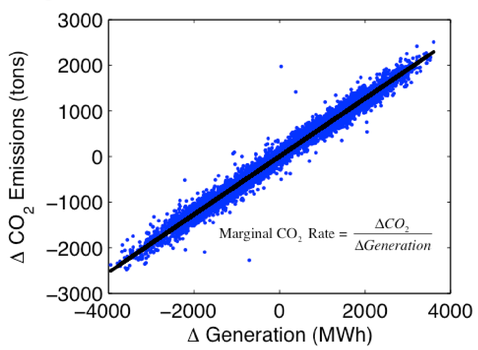
METHOD

For each region, we calculate the change in generation and change in emissions between one hour and the next:

$$\Delta G = G_t - G_{t+1} \qquad \Delta E = E_t - E_{t+1}$$

This gives 8760-1 observed changes in generation, and the corresponding change in emissions. The figure below shows the change in CO_2 emissions (ΔE) plotted against the change in total generation (ΔG), where the slope of a linear regression gives the marginal emissions rate of the system. This method was originally demonstrated by Hawkes (2010) and used to calculate marginal emissions rates of the UK electricity system[1].

Calculating Marginal CO_2 Emissions



[1] Hawkes, A. (2010). Estimating marginal CO2 emissions rates for national electricity systems. Energy Policy.

5. RESULTS

Marginal emissions rates for eight NERC regions are shown in Table 2. The West (WECC) and Northeast (NPCC) have the lowest marginal emissions rates, around 0.5 tons of CO_2 per MWh. The Midwest (MRO) and mid-Atlantic (RFC) — both coal-heavy regions—have marginal emissions rates of 0.87 and 0.8, respectively. This suggests that an energy efficiency measure in the Midwest would avoided 70% more CO_2 than a comparable measure in California.

5.1 Comparison of marginal and average emissions rates

Table 2 shows a comparison of marginal emissions rates and average emissions factors (AEF), which are the ratio of annual emissions to annual generation. AEFs are commonly used in place of marginal emissions rates. Compared to marginal emissions rates, the AEF is 25% lower in the Northeast (NPCC), 35% higher in the South (SERC), and within ±15% in the remaining six regions.

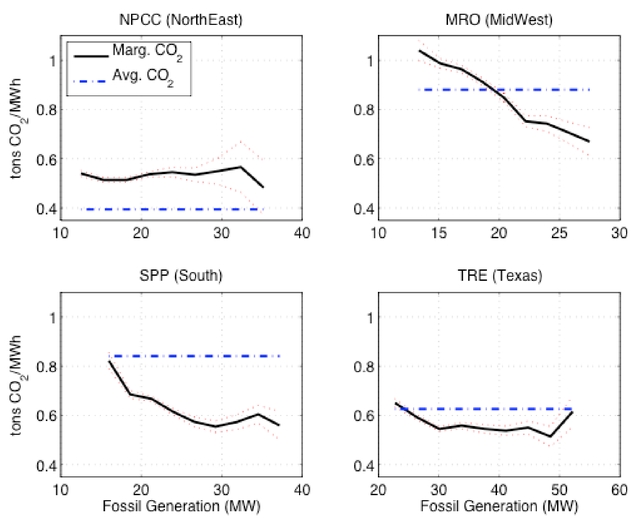
Table 2: Comparison of marginal and average CO_2 rates

NERC Region	Marginal (tons/MWh)	Average (tons/MWh)	Difference
FRCC	0.64	0.61	-4%
MRO	0.87	0.88	2%
NPCC	0.53	0.39	-25%
RFC	0.80	0.71	-11%
SERC	0.72	0.68	-6%
SPP	0.62	0.84	35%
TRE	0.56	0.63	12%
WECC	0.51	0.51	0%

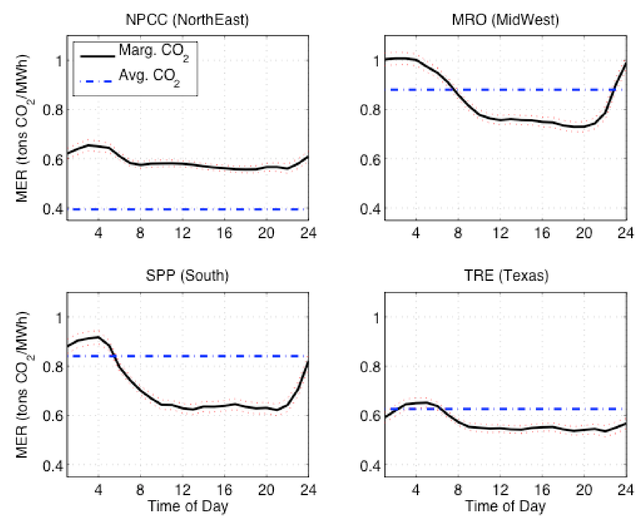
5.2 Variations in marginal emissions rates

As the characteristics of the electricity system change, the marginal emissions rate also changes. The figures below illustrate trends in marginal emissions rates with respect to (1) total fossil generation and (2) time of day. Total fossil generation is a proxy for total system demand, which was unavailable for most regions.

Marginal CO_2 Rates v.s. System Generation



Marginal CO_2 Rates v.s. Time of Day



6. CONCLUSIONS

This work presents the first systematic calculation of marginal emissions rates of the US electricity system, which are necessary to understand the emissions benefits from supply- and demand-side interventions. We find that:

- Regional differences are significant. Avoiding one MWh of electricity in the Midwest (MRO) avoids 0.87 tons of CO_2—70% more than a comparable intervention in the West (WECC).
- Compared to marginal emissions rates, the average emissions factor is 25% lower in the Northeast (NPCC), 35% higher in the South (SERC), and within ±15% in the remaining six regions.
- The marginal emissions rates, in some regions, varies with system load or time of day.

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