Marginal Emission Rates

The Needed metric of Carbon Displacement in an Increasinly Electrified World

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Climate Change, CO_2 Emissions and Pull of the Market

Corporate America is well ahead of Federal Policy on Responding to the Challenges of Climate Change

Google — "by 2030, Google intends to run on carbon-free energy everywhere, at all times."

amazon — "We want to reach net-zero carbon emissions by 2040, a decade ahead of the Paris Climate Agreement, and we are on a path to powering our operations with 100% renewable energy by 2025 as part of our goal to reach net-zero carbon."

Microsoft — "By 2030 Microsoft will be carbon negative, and by 2050 Microsoft will remove from the environment all the carbon the company has emitted either directly or by electrical consumption since it was founded in 1975."

Corporate America is, however, Spinning its wheeels

Net Zero is **NOT** being defined or calculated and / or communicated correctly by the Electric Power Industry

- Corporate America is trying to achieve net zero by calculating the "Average Emission Rate" of their ISO or possibly at their delivery node.
- Corporate America is trying to achieve net zero by matching "hour by hour" their Average Emissions (or incompletely or incorrectly calculated marginal emissions) to the paired hourly generation of the renewable assets they own or have under contract

Who and What is the Problem

I have identified the Enemy and WE ARE it

- Electric Power System "experts" writ large (me included) have failed Corporate America and it is costing these corporations and American consumers far more than it should to get electric power generated carbon out of the atmosphere.
- **FOCUS!!! It is Carbon we are trying to remove, not kWh**

The time for *“REDEMPTION”* in Now!

To provide Corporate America with what they need!!

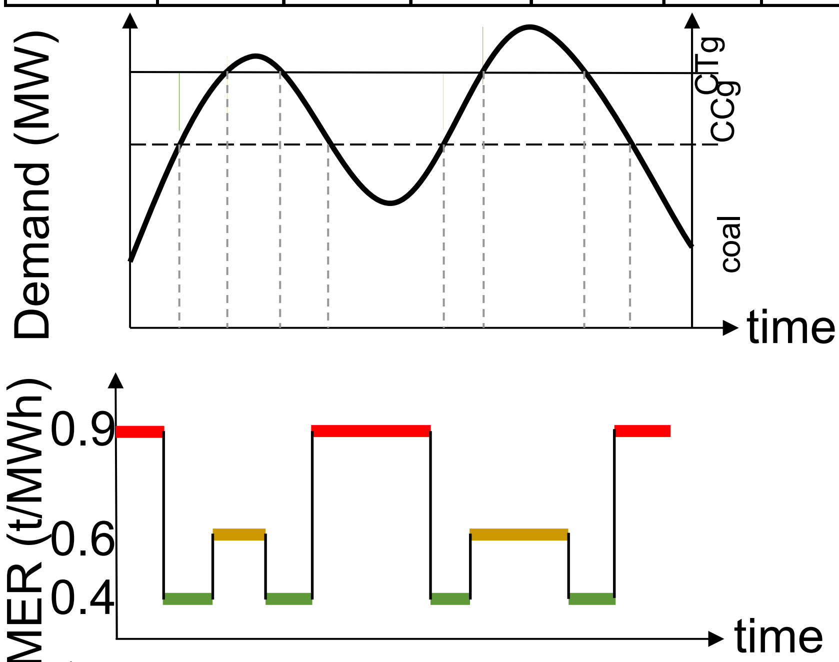
- Information upon which to base investment and operating decisions that is:
  - Based on the operational physics of the power system
  - Based on economic logic
  - Based on forecasts of system change
    - Climate Change and Extreme Events
    - Technology Development (Storage etc… through Scenario Analyses)
- Emissions are marginal not average, are calculable by the System Operator in real time and forecastable by sagacious use of a sophisticated production cost model

The Critical Metric: Tonnes of Carbon Displaced not kWh

The Challenge: Moving the Metric to the Margin of the system

- Reduction in kWh is the intermediary not the driver to reducing emissions of CO_2
- When a consumer increases their electric demand, the system increases the output of the marginal unit(s) which is the source of the added carbon emissions caused by the increase in consumer demand
- When a renewable generator produces clean kWh the impact on carbon emission is the quantity of emissions that would have produced BUT FOR the generation of the renewable resource
- For heavy electric consumers looking to go to zero carbon or for policy wonks, the need and by far the most cost effective, carbon reduction strategy for the electric sector is to focus on the Marginal Emission Rate (MER) and recognize the economic benefits of netting MER at the Point of Consumption against MER at the point of production.
    - Matching average values and claiming neutrality is neither accurate nor cost effective
    - Attempting to match hourly consumption to hourly renewable production is likely infeasible as well as neither accurate nor cost effective.

Technology	Heat Rate (Btu/kWh)	Fuel Price ($/MMbtu)	VO&M ($/MWh)	CO_2 rate (Ton/MWh)	CO_2 price ($/t)	Dispatch cost ($/MWh)
Coal	9500	2.0	1.0	0.9	10	29
CCg	7000	5.0	3.0	0.4	10	42
CTg	11000	5.0	5.0	0.6	10	66



- Marginal Emission Rate (MER) is the change in CO_2 emissions in the entire power system for a 1 MWh change in generation or load at a given location in a given moment in time, accounting for the re-dispatch needed to accommodate that load change

$$MER_{node} = \frac{\partial(CO_2)_{system}}{\partial(Demand)_{node}}$$

The Marginal Emission Rate (MER)

- In an interconnected power market, an incremental injection (generation) or withdrawal (load) of electricity at a given node will result in a systemwide change in the economic dispatch and in carbon emissions. The marginal emission rate (MER) measures the change in systemwide emissions in response to a marginal increase or decrease in demand at a given location, as shown in the equation below. The magnitude of this change will depend *on time and location*. MER is expressed in units of CO_2 per unit of electrical energy. If 1 MWh of increased demand at one node results in systemwide emissions rising by 1 tonne, then the MER at that node is 1 tonne/MWh.

- $$\boldsymbol{MER_{node\ A} = \frac{\Delta Systemwide\ Carbon\ Emissions}{\Delta Demand_{node\ A}}}$$

- The Marginal Emission Rate provides a mathematically sound and transparent way to quantify the carbon footprint of electricity consumption and production.

Carbon Footprint

Consumer

- The carbon footprint of electricity consumption at a specific location (e.g., node or area) at a particular time is calculated as quantity of electricity consumed multiplied by the MER at that location:
- $Carbon\ Footprint_{consumption} = MER_{Location} * Consumption$

Carbon Footprint

Traditional Fossil Generator

- The carbon footprint of generation at a specific node at a particular time is calculated as the amount of generation multiplied by the difference between the generator's emission rate and the MER at that node:
- $Carbon\ Footprint_{Generation} = (Emission\ Rate\ of\ Generator - MER_{Gen.\ Node}) * Generation$

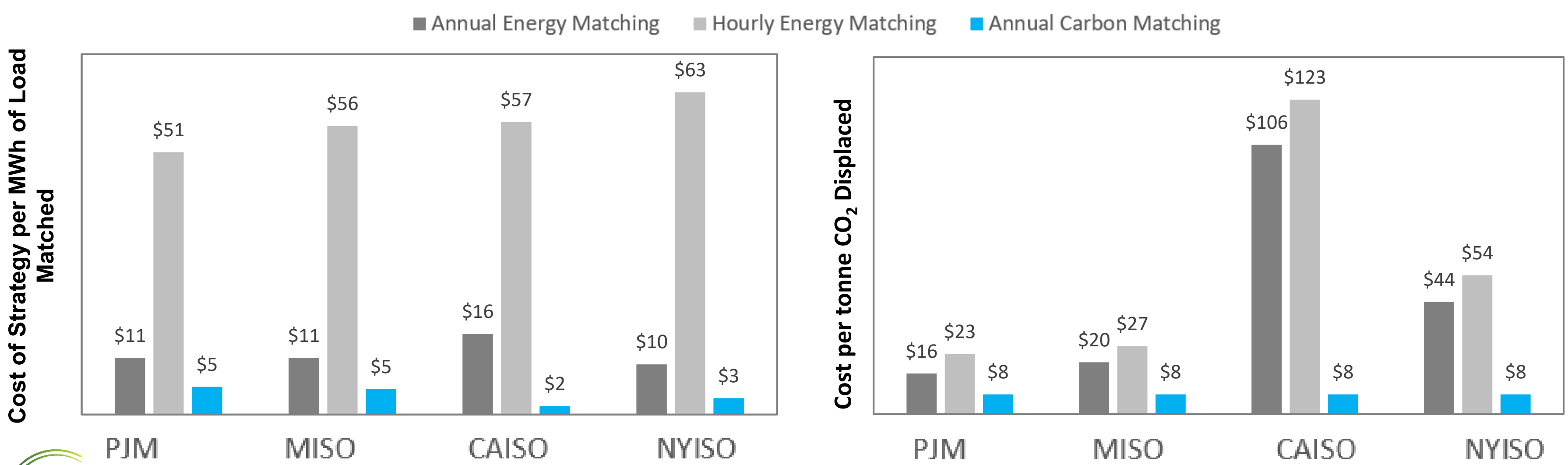
Carbon Footprint

Renewable (wind, Solar, Nuclear and … Demand Response)

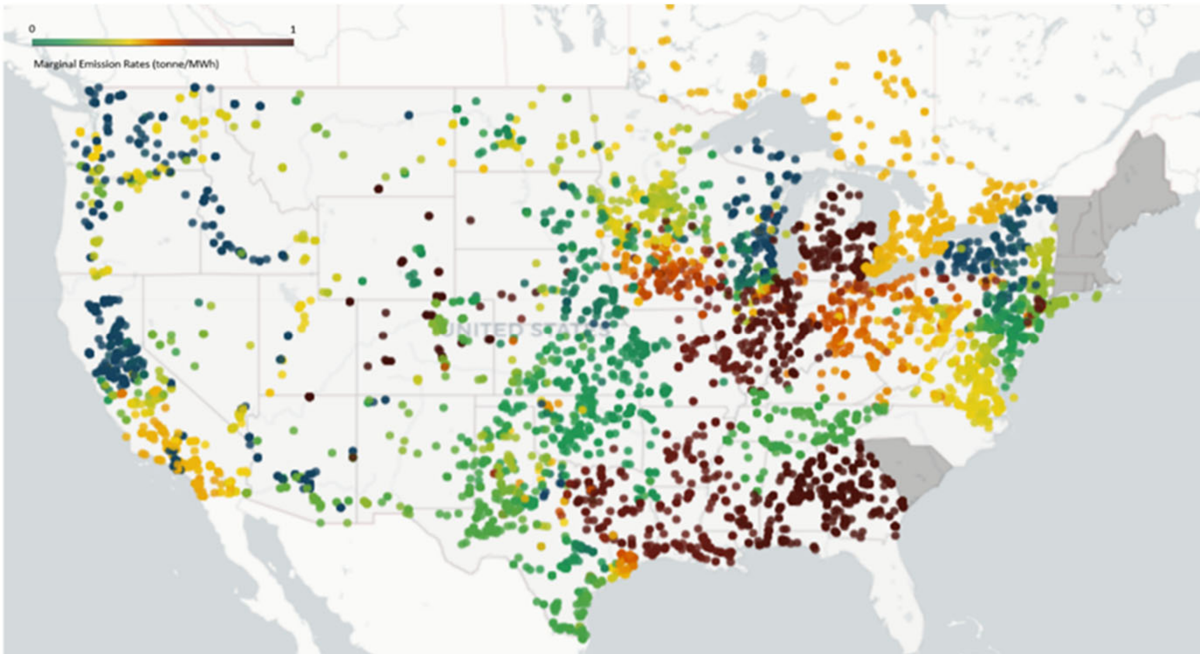
- For renewable resources, the emission rate is 0, so the equation becomes:
- $Carbon\ Footprint_{RenewGen} = -\ (MER_{Gen.Node} *\ Generation)$

- Displacing the most carbon per dollar of investment
- Identifying optimal generation sites requires detailed knowledge of the US power markets- both marginal fuel sources at each node, as well as transmission capabilities & constraints.

Carbon matching allows the buyer to invest in Carbon Displacement where the value is the highest / cost is the lowest

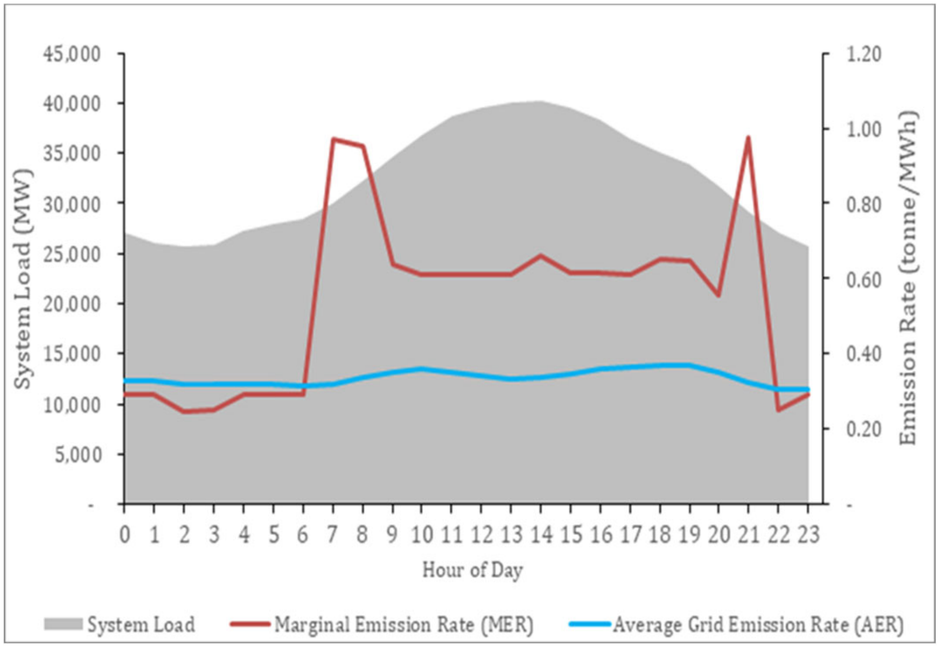


One-hour locational MERs based on TCR simulations



A sample hour locational distribution of MERs across three interconnections (New England, FL, NC, SC not covered) for a simulated future year scenario

Source: Tabors Caramanis Rudkevich. Simulations using ENELYTIX



MERs provide precise signals on the efficiency of carbon displacement over time

A typical intra-day dynamics of carbon emissions within a system dominated by nuclear, coal and gas-fired generation technologies.

Source: Tabors Caramanis Rudkevich. Simulations using ENELYTIX

MER is related to the calculation of Locational Marginal Price (LMP)

Like LMP and system lambda, MER can be calculated for each node in an interconnected power grid, and is a function of two variables:

- ***Time***. The marginal emission rate depends on the time of energy consumption. Net demand changes from hour to hour. Different generation with significantly different MER is economically dispatched to balance the system.
- ***Location***. Between power markets, difference in generation mix causes large differences in MER. Within a single market, transmission constraints and losses can cause marginal emissions in one area to be higher than another.

The Missing Pieces

Real Time calculation by System Operators

- New York ISO has developed the capability of providing Nodal MER (based on the Rudkevich Ruiz developed analytic methodology)
- PJM States that they have developed but not fully implemented the capability
- The FERC has the power to make it happen in Real TIme
- TCR has the ability to forecast hourly nodal MER

For Further Reference on Marginal Emission Rates

References

- Ruiz P, Rudkevich A (2010) Analysis of marginal carbon intensities in constrained power networks. *Proceedings of the 43rd Hawaii international conference on systems science, Koloa. HI.*
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