Carbon Direct

Advanced Power Emission Accounting Methodologies for Large Electricity Loads

Using power data to optimize emissions, operations, and compliance

February 3, 2025

Patti Smith and Colin McCormick, PhD

Contents

Advanced power emission methodologies

As the global focus on decarbonization intensifies, understanding how greenhouse gas (GHG) emissions associated with power use are estimated is critical for businesses, policymakers, and regulators aiming to achieve sustainability goals. It is particularly crucial for large power consumers that are making decisions about how to source their power for today as well as tomorrow. The decisions they make will impact their businesses for decades to come.

As power grids rapidly transition to use greater amounts of clean energy while meeting amplified energy demands, emissions associated with power consumption increasingly matter. Most power consumers use grid-supplied electricity that comes from a combination of many different types of power generators, keeping track of exactly which power generators are providing electricity to exactly which facilities is impossible. To better account for the rapid changes to the power grid, the voluntary and compliance carbon markets are moving beyond the guidelines provided by the Greenhouse Gas Protocol (GHG Protocol) to develop and adopt more advanced power emission methodologies and estimates. Carbon Direct, following the science, has developed tools that can perform these advanced analyses including: (1) hourly power matching, (2) marginal carbon matching, and (3) average carbon matching. These tools help companies develop more comprehensive decarbonization strategies that optimize their power usage and procurement for cost, emissions, and regulatory compliance.

Below we explore the new reality of estimating emissions associated with power. These advanced power emission accounting methodologies better incorporate the physical realities of electricity grids, the differences in emissions during different time periods (annual versus hourly), different metrics for quantifying emissions (power versus carbon-matching), and different indicators for estimating changes in emissions as power demand changes (average versus marginal generators).

Electricity and greenhouse gas emissions

The electric power sector is one of the biggest sources of global greenhouse gas emissions. When power plants burn fossil fuels like coal and natural gas, GHG emissions are released from flue stacks (chimneys) into the atmosphere. Low-carbon power sources like solar, wind, hydroelectricity, and nuclear energy produce electric power without burning fossil fuels and do not release GHG emissions during power generation.

Estimating emissions associated with power consumption

Quantifying how much GHG an individual power plant emits when it generates one megawatt-hour (MWh) of electricity is fairly simple.[1] However, allocating those emissions to the specific entities that consume it is much more complicated. This is because most buildings, factories, data centers, and other facilities, or "power loads"[2] receive electricity from an electric grid. Grid-supplied electricity comes from a combination of many different types of power generators (which will include a combination of fossil fuel and renewable resources). The exact generator (marginal) or set of power generators (average) that are generating electricity and sending it into a grid

---

[1] United States Energy Information Administration (EIA). 2023. Frequently Asked Questions (FAQs). [accessed 2025 Jan 28]. https://www.eia.gov/tools/faqs/faq.php.

[2] A power load is the amount of electric power required at any specific point or points on a system.

changes from minute to minute and differs by region.[3][4] It is impossible to directly measure the emissions for a power load due to the physics of how electrons move across a grid so therefore keeping track of exactly which power generators are providing electricity to exactly which facilities is also impossible. Instead, approximations and assumptions are used to figure out the carbon intensity or "power emissions" of the electricity that is used by specific power loads.

Current state of calculating emissions for power consumption

For a long time, the method used to calculate the carbon intensity of electricity was not a significant concern. Power plants that generated electricity did not change often, so the amount of GHG emitted per MWh of electricity was fairly consistent from hour to hour and from day to day. The rules for carbon accounting, written a decade ago, reflect this. The GHG Protocol's scope 2 guidance says that emissions from consumed electricity should be calculated using an "emissions factor" that is a simple weighted average of the GHG emissions associated with power generation over a grid region (the location-based method).[5] The US Environmental Protection Agency publishes the weighted average datasets for 27 distinct regions, called eGRID.[6]

In addition to the location-based method, the GHG Protocol also allows for the purchase of renewable energy to cancel out emissions from a company's power consumption (the market-based method). With the market-based method, renewable energy purchases are measured in MWh and matched to the electricity consumed over the course of a year. In this method, any reference to the carbon intensity of a grid is removed. Instead, it simply measures the quantity of power consumed and generated over the course of a year. Purchased renewable energy can be generated at any time or location and applied to any power consumption at any time or location. While this method offers simplicity, it may result in carbon accounting discrepancies (as discussed below under the "Carbon matching methodology" section). With the rapid growth of solar power, wind power, and battery storage, power grids have changed significantly. This has created a need to develop new tools to better understand these new grid realities. For example, solar and wind generation ramp up and down during the day (and night), causing power plants that run on fossil fuels to ramp down and up in response. That means grid electricity can go from very clean (low-carbon intensity) to very dirty (high-carbon intensity) and back again within a single hour.

Types of advanced power emission accounting methodologies

Rapidly transitioning power grids, combined with the increasing availability of accurate, real-time, electricity-generation data,[7] have made it possible to optimize operations to reduce the GHG emissions associated with power consumption. Experts have proposed two broad categories of advanced power emission accounting methodologies for GHG emissions associated with electricity consumption. Broadly categorized into **power matching** and **carbon matching**

---

[3] California Independent System Operator. 2025. Today's Outlook | Supply. [accessed 2025 Jan 28]. https://www.caiso.com/todays-outlook/supply.
[4] See figure 3 for an example of the generators needed to meet the aggregate New York Independent System Operator NYISO power load.
[5] Greenhouse Gas Protocol. 2015. Scope 2 Guidance | GHG Protocol. [accessed 2025 Jan 28]. https://ghgprotocol.org/scope-2-guidance.
[6] United States Environmental Protection Agency. 2020. Emissions & Generation Resource Integrated Database (eGRID). [accessed 2025 Jan 28]. https://www.epa.gov/egrid.
[7] United States Energy Information Administration. 2025. Wholesale Electricity Market Portal. [accessed 2025 Jan 28]. https://www.eia.gov/electricity/wholesalemarkets/index.php.

approaches, these accounting methodology frameworks offer distinct strategies to align electricity consumption with low-carbon power generation in pursuit of reducing overall GHG emissions (**figure 1**). One of the challenges in using the different methodologies is that they are not easily comparable because they use different metrics. Power matching matches power consumed with power generated measured in MWh, whereas carbon matching is solving for GHGs emitted or avoided. This is one of the fundamental divides fueling the debate around which methodologies are most effective. The GHG Protocol is currently undergoing a rewrite which includes this topic as one of the areas of focus ("market-based accounting approaches").[8] As part of the rewrite process, the GHG Protocol solicited comments from market participants and received 343 responses pertaining to what methodology should be used to estimated these emissions.[9]

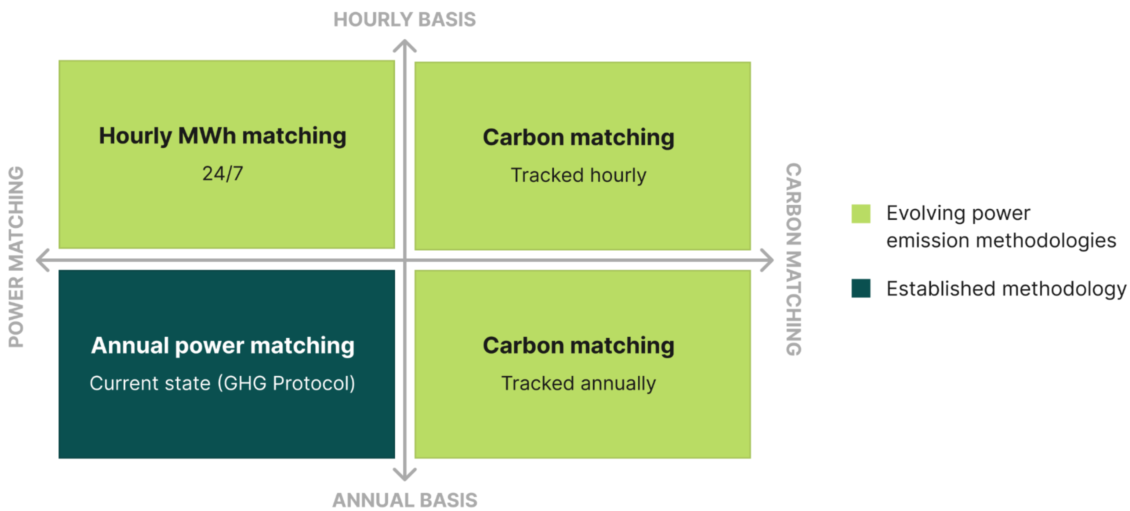

Figure 1: Power matching versus carbon matching methodologies for advanced power emission accounting, as applied to annual and hourly tracking. Source: Carbon Direct.

Power matching methodology

The power matching methodology matches the MWh consumed to the MWh generated over a defined time period. While the time period can be defined in several ways, the two most common are annual power matching and hourly power matching:

1. **Annual power matching** allows the power load to sum up all electricity consumption over the course of a year in MWh and then match it to the sum of all low-carbon power generation over the year, regardless of the time of consumption and generation. Currently, the GHG Protocol's market-based method uses the annual power matching methodology.[10]

---

[8] Huckins S. 2025 Jan 16. 2024 Reflections and Looking Ahead: Letter from GHG Protocol Steering Committee Chair and Vice Chair. [accessed 2025 Jan 30]. https://ghgprotocol.org/blog/2024-reflections-and-looking-ahead-letter-ghg-protocol-steering-committee-chair-and-vice-chair?apcid=0066e472beeaa43ffb902704&utm_campaign=cli-ghgp-2025-update-to-su&utm_content=cli-ghgp-2025-update-to-su&utm_medium=email&utm_source=ortto.

[9] Huckins S. 2024 Apr 8. GHG Protocol Releases Market-based Accounting Approaches Survey Draft Summary Report. [accessed 2025 Jan 31]. https://ghgprotocol.org/blog/ghg-protocol-releases-market-based-accounting-approaches-survey-draft-summary-report-0

[10] Greenhouse Gas Protocol. 2015. Scope 2 Guidance | GHG Protocol. [accessed 2025 Jan 28]. https://ghgprotocol.org/scope-2-guidance.

As a result of the on-going GHG Protocol rewrite, the annual power matching methodology is expected to change to reflect one of the advanced power emissions methodologies.

2. **Hourly power matching** (sometimes called "24/7") requires all electricity consumption within an hour to be matched against low-carbon power generated for the corresponding hour. Results are often reported as a percentage of energy matched.[11]

Annual power matching versus hourly power matching (24/7)
For a simplified example of annual versus hourly power matching, **figure 2** shows how much traditional renewable power generation would be needed to meet a 75% annual power matching target versus the amount that would be needed to meet the same percentage using hourly matching. Using a typical solar and wind capacity factor, you would have to contract for more than twice as much solar and five times as much wind.

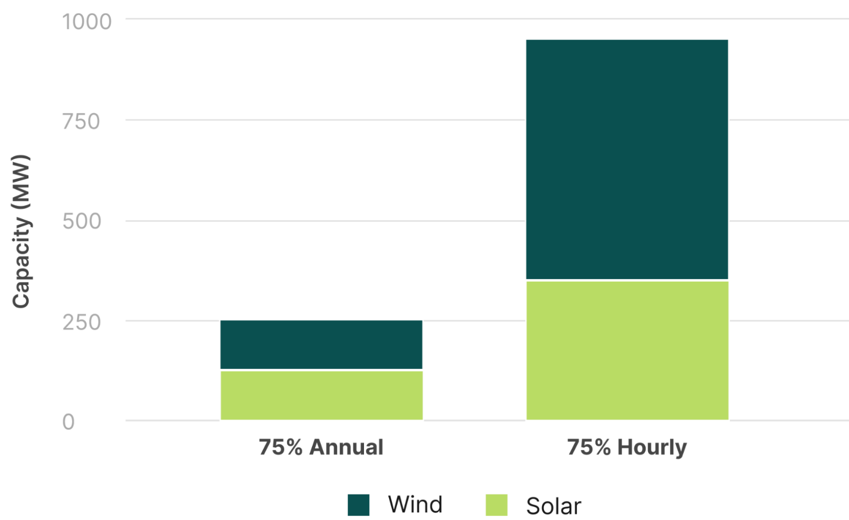

Figure 2: Renewable power generation required to hit a 75% target using annual power matching versus hourly power matching. Source: Carbon Direct.

Carbon matching methodology

The carbon matching methodology estimates the GHG emissions caused by a large power load and matches this estimate to the estimated emissions that are avoided by using low-carbon power generators. As described previously, within a region, a power grid is constantly balancing power generation with power load. With the increase in intermittent renewable power generation, such as solar and wind, a grid can go from very clean to very dirty many times throughout the day. In this context, how can the carbon intensity of a power load be reliably estimated? Experts have approached this problem using two different indicators:

1. The "marginal generator," which is the **last** dispatched generator needed to meet the power load, or
2. The "average generation," which looks at **all** the dispatched generation that is running to meet the power load.

[11] Google Data Centers. 2024. 24/7 Clean Energy – Data Centers – Google. [accessed 2025 Jan 28]. https://www.google.com/about/datacenters/cleanenergy/.

Figure 3 shows an illustrative market supply curve for the New York Independent System Operator (NYISO) grid,[12] which represents the following:

- the available generation to meet load in New York (x-axis)
- the price that the generators are willing to be turned on for or “dispatched” (y-axis)
- the total load in New York at a particular point in time (vertical red lines)

Relative to the place where the total load intersects the market supply curve, all generators to the left need to be turned on or “dispatched” to meet the load.

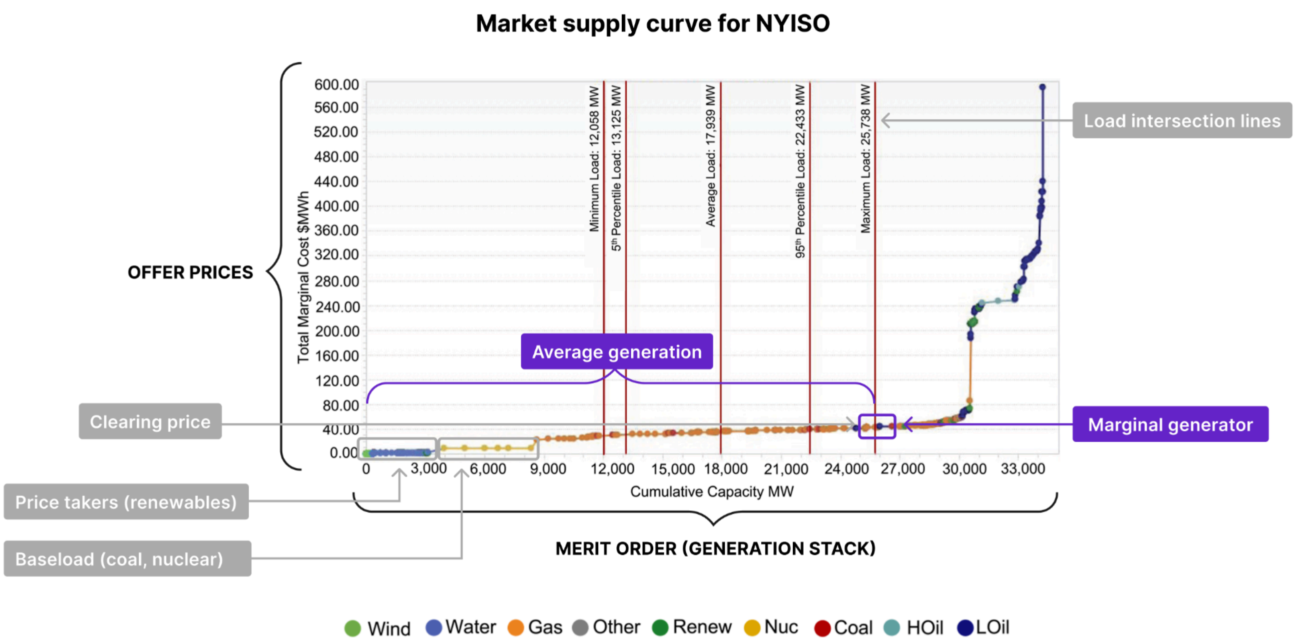

Figure 3: Estimating the carbon intensity of a power load using average generation versus the marginal generator. Source: adapted from Federal Energy Regulatory Commission, 2020.

Emissions factors, or carbon intensities for power generation technologies by type, are generated for either: (1) the marginal generator called the “marginal emission factor,” or (2) the mix of all generators on a grid through averaging called the “average emission factor.” These two methods, marginal carbon matching and average carbon matching, are used to communicate different information about the impact of power loads.

Marginal carbon matching estimates the emission impact of the marginal generator (the last to be turned on or off) trying to more closely represent the direct carbon impact of a power load. It is attempting to show the direct impact of the power load causing the last power generator to have to turn on or be “dispatched’ to meet the increased load.

[12] Federal Energy Regulatory Commission. 2020. Energy Primer: A Handbook for Energy Market Basics. [accessed 2025 Jan 28]. https://www.ferc.gov/sites/default/files/2020-06/energy-primer-2020_0.pdf.

In contrast, using the **average carbon matching** which looks at all generators needed to meet the load at that particular moment in time represents the impact of a power load on the power system as a whole. Using these two carbon matching methodologies, using the same renewable portfolio, different outcomes result depending on if the average emissions factor or the marginal emission factors is applied (**figure 4**). There is currently an active discussion within the expert community regarding which approach is best suited for certain situations.[13, 14, 15, 16]

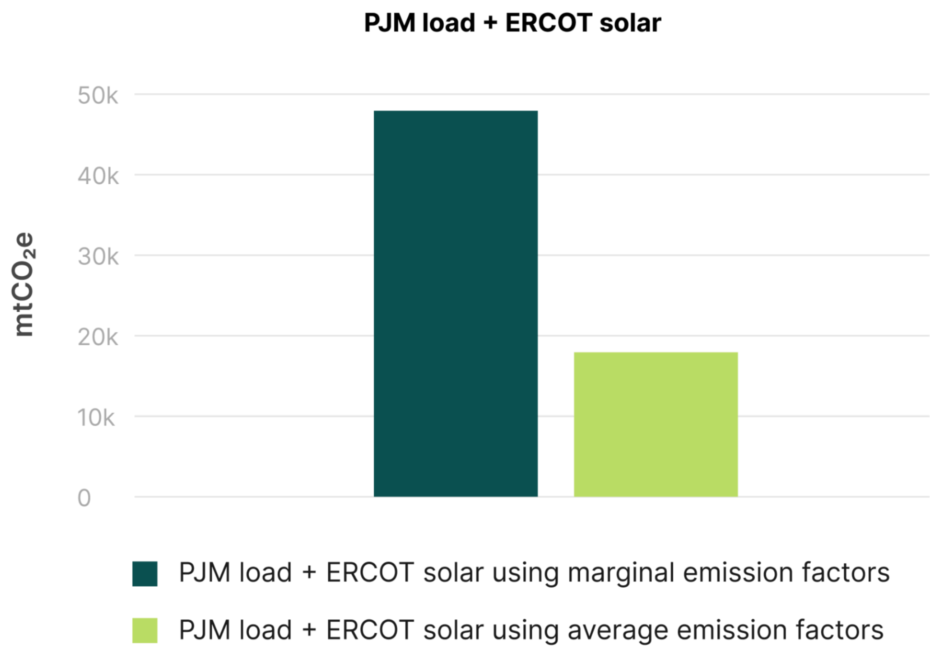

Figure 4: Results of using the marginal emissions factor versus the average emissions factor for the same renewable power generation portfolio (PJM load + ERCOT solar) under the carbon matching methodology. Note: EF = emissions factor, ERCOT = Electric Reliability Council of Texas, $mtCO_2e$ = metric tonnes of carbon dioxide equivalent, PJM = Pennsylvania-New Jersey-Maryland regional transmission operator. Source: Carbon Direct, based on data from https://watttime.org/ and https://electricitymaps.com/.

[13] WattTime. 2022. Accounting for Impact. [accessed 2025 Jan 30]. https://watttime.org/wp-content/uploads/2023/12/WattTime-AccountingForImpact-202209-vFinal2.pdf.
[14] Andlinger Center for Energy and the Environment. 2025. Princeton University Zero Lab. [accessed 2025 Jan 30]. https://acee.princeton.edu/24-7/.
[15] Google Data Centers. 2025. Electricity Maps. [accessed 2025 Jan 30]. https://www.electricitymaps.com/client-stories/google-data-centers.
[16] Greenhouse Gas Protocol. 2023 Dec 20. Inventory and Project Accounting: A Comparative Review. [accessed 2025 Jan 30]. https://ghgprotocol.org/blog/inventory-and-project-accounting.

Using new tools to solve new problems

Following the latest science, Carbon Direct has developed tools to help companies with large power loads quantify the impacts of these methods on their operations and help develop strategies to understand and plan for their future load growth. These tools allow for a better understanding of the changing carbon intensity of a grid and create opportunities for decarbonization and power optimization, such as:

- Time of Use Optimization: Companies can adjust their power consumption to try to line up with cleaner times and reduce their overall emissions impact.[17][18]
- Location Optimization: Companies consider the emission impact of where they locate their new large power loads and whether cleaner or dirtier power plants run more often as a result.[19]
- Demand Response Optimization: During times of high load on a grid, which often correspond to periods of high carbon intensity, data centers or other large power loads can help support utility partners and alleviate grid stress by shifting power load to different grids or moving power loads that are not time sensitive to a lower load portion of the day.[20]

Understanding your power emissions to meet sustainability goals

During this time of rapid power grid transition, and increasing scrutiny on emission growth, the need to understand what is happening beyond standard power contract terms is critical for businesses whose operations depend on securing large power supply. Understanding the developing area of advanced power emissions accounting and using sophisticated analytical tools developed by Carbon Direct helps provide this deeper insight into the impacts of a company's growth plans, on-going operations across multiple metrics which will allow companies to develop actionable strategies to optimize across different sustainability and operational goals.

[17] Microsoft Switzerland. 2023 Jan 10. Carbon-aware computing: Measuring and reducing the carbon footprint associated with software in execution. Microsoft Switzerland News Center. [accessed 2025 Jan 29]. https://news.microsoft.com/de-ch/2023/01/10/carbon-aware-computing-whitepaper/.

[18] Cozzi L, Goodson T. 2020 Jan 15. Empowering electricity consumers to lower their carbon footprint – Analysis. International Energy Agency. [accessed 2025 Jan 28]. https://www.iea.org/commentaries/empowering-electricity-consumers-to-lower-their-carbon-footprint.

[19] Sang Y, Santiago I. 2023. Locational Marginal Emission Evaluation for Electric Vehicle Charging Facility Planning. Center for Advancing Research in Transportation Emissions E and Health (CARTEEH) Tier-1 University Transportation Center (UTC), University of Texas at El Paso. [accessed 2025 Jan 28]. https://rosap.ntl.bts.gov/view/dot/74513.

[20] Mehra V, Hasegawa R. 2023 Oct 3. Using demand response to reduce data center power consumption. Google Cloud Blog. [accessed 2025 Jan 28]. https://cloud.google.com/blog/products/infrastructure/using-demand-response-to-reduce-data-center-power-consumption.

Appendix: Examples of applied power emission methodologies

Power matching and carbon matching approaches are currently being applied in a number of ways (**table 1**). The specific applications have significant variations in how they are being implemented, including different regional boundaries, additionality requirements, and tracking obligations. These variations can critically impact the cost and compliance of a company's power portfolio strategy. Specific interpretations and applications of the methodologies, beyond the general categorization shown here, require in-depth analysis of the rules and how they have been applied.

Table 1. Current applications of advanced power emission methodologies

Application	Methodology	Time scale
45V Tax Credit	Power matching	Hourly (starting in 2030)
Google, 24/7	Power matching	Hourly
Emissions First Partnership (Meta, Amazon, Salesforce, etc.)	Carbon matching	Variable
GHG Protocol Scope 2 Guidance	Power matching	Annual
GHG Protocol Project Accounting	Carbon matching	Variable
Carbon Border Adjustment Mechanism (CBAM)	Carbon matching	Annual
Clean Development Mechanism	Carbon matching	Variable