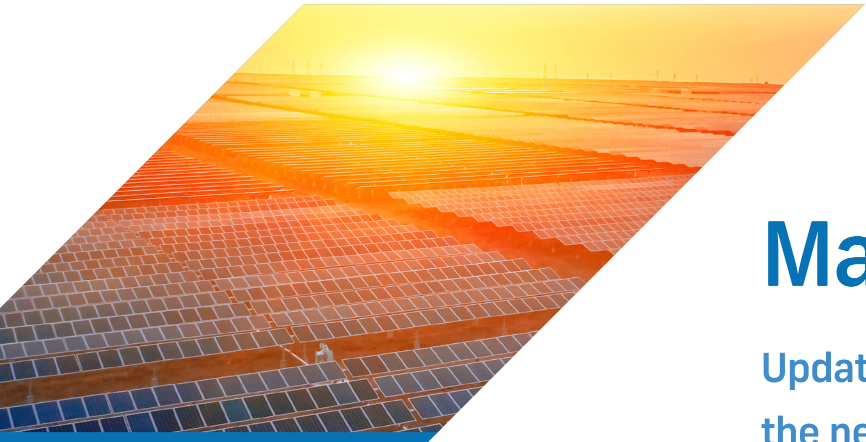

Making It Count

Updating Scope 2 accounting to drive the next phase of decarbonization

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Overview

Corporations are increasingly focused on reducing their carbon footprints by decarbonizing the electric grid. While solar and wind energy development have rightly been a mainstay of these efforts, there is growing consensus that producing more clean energy alone isn't enough. To maximize grid decarbonization, clean generation needs to occur at times and locations where its output displaces the highest-emitting resources. Consumption timing and location should be adjusted to minimize its carbon emissions via siting decisions, demand flexibility measures, and energy efficiency. And energy storage is needed to manage grid congestion and mismatches between clean supply and demand.

Effective carbon accounting frameworks can help coordinate these complex mitigation strategies by allocating emissions among the entities responsible for producing them. These accounting frameworks attempt to ensure that activities with more impact on *actual* emissions have more impact on carbon *accounts*. Given the large and increasing interest of investors, customers, regulators, and governments in corporate decarbonization initiatives, effective carbon accounting frameworks can encourage corporations to maximize their actual carbon reductions.[1]

The Greenhouse Gas (GHG) Protocol Scope 2 Guidance is currently the bedrock framework for carbon accounting for the electric power sector. It has been used extensively for voluntary emissions disclosures, incorporated into modern frameworks for climate-related financial disclosures and used as a basis for science-based climate targets. It has been an accessory to the recent rapid growth in corporate-funded clean energy purchases. In short, the framework has in many ways been an enormous success.

Unfortunately, current Scope 2 carbon accounting rules suffer from a number of material drawbacks. The Location-Based mechanism doesn't provide any way for buyers or owners of clean energy to claim the resulting carbon benefits. Both Location-Based and Market-Based methods lack a means of accurately attributing the carbon benefits of energy storage to owners or operators. And–most importantly–under the Market-Based mechanism, carbon *accounts* are disconnected from *actual* emissions impacts, a problem that is not addressed through an hourly accounting framework.

Ideally, decision makers managing their *private* carbon footprints should be incentivized to make the same decisions they would if they were managing *system-wide* total emissions. In the remainder of this document, we describe and evaluate a revised Scope 2 accounting rule that achieves this alignment of incentives better than the status quo. The proposed rule effectively differentiates between clean energy investment opportunities with higher and lower carbon reduction potential. It aligns more closely with consequential carbon impact. And it works both with small-scale and large-scale clean energy investments. We believe that adoption of this accounting framework would enable faster grid decarbonization at a lower cost.

1 For an example of the wide-ranging interest in this area, see the U.S. Security and Exchange Commission's proposed rule on climate disclosure and the large number of public comments received by the Commission on the proposed rule.

Proposed Scope 2 accounting rule

Current Scope 2 rules require reporting entities to apply the rule described in Equation 1 to calculate their Market-Based Scope 2 carbon footprint. The entity's carbon footprint is determined by multiplying the average emissions of the grid where it is consuming power by its *net* consumption.[2] Net consumption is determined by subtracting REC purchases from power consumption. Average emissions rates, consumption, and REC[3] purchases are determined at the annual level, and the location of REC purchases are not taken into account.[4]

[1] ***Scope 2 Footprint = Average Emissions Rate @Load × (Consumption - RECs)***

There has been significant recent discussion on the importance of timing in accurately calculating carbon footprints.[5] This discussion correctly highlights that grid conditions vary from hour to hour and these differences can materially impact emissions. Equation 2 shows a modified Scope 2 accounting rule based on these insights. In the calculation shown in Equation 2, average emissions rates, consumption, and RECs are combined at the hourly level (as indicated by the subscript "t") to determine an hourly Scope 2 footprint. This hourly footprint is then summed over all the hours in the reporting period to determine the entity's Scope 2 footprint.[6]

[2] $\text{Hourly Scope 2 Footprint}_t = \text{Average Emissions Rate @Load}_t \times (\text{Consumption}_t - \text{RECs}_t)$

$\text{Scope 2 Footprint} = \text{sum}_t\,(\text{Hourly Scope 2 Footprint}_t)$

Despite the obvious improvements in accuracy associated with the use of hourly data, we believe the accounting rule shown in Equation 2 needs further refinement. This rule still does not explicitly take into account the location of REC purchases and it still does not align incentives towards grid-wide decarbonization.

We propose two refinements, shown in Equation 3. First, the emissions rates applied to consumption and generation should reflect the specific conditions at the location where power is consumed or produced. This means that different emissions rates should be applied to power consumption and REC generation. Second, the emissions rates applied to both consumption and clean generation should be marginal rather than average.[7] We will show below that these changes ensure that reporting entities are incentivized to maximize carbon abatement associated with their procurement decisions.

[3] $\text{Hourly Scope 2 Footprint}_t = \text{Marginal Emissions Rate @Load}_t \times \text{Consumption}_t - \text{Marginal Emissions Rate @Generator}_t \times \text{RECs}_t$

We are not the first to propose this accounting rule. To the best of our knowledge, it was initially proposed by Ruiz and Rudkevitch in a series of papers more than a decade ago.[8] Ruiz and Rudkevitch demonstrated, among other things, how to calculate nodal marginal emissions rates based on a system operator's power system model. They also showed how the proposed accounting rule in equation 3, if applied sufficiently broadly, results in total Scope 2 allocations matching total Scope 1 emissions.

[2] Current Scope 2 guidance suggests applying a "residual mix emissions rate" in place of an average emissions rate when such an emissions rate is available. A residual mix emissions rate is an average emissions rate that has been adjusted to account for RECs claimed in any reporting entity's Market-Based Scope 2 account. Residual mix emissions rates are intended to ensure that total Scope 2 allocated emissions match total Scope 1 emissions. In practice, reporting entities use both types of emissions rates due to challenges with residual emissions rate data availability and latency. The use of residual mix rather than average emissions rates does not affect the arguments made in this whitepaper.

[3] We use Renewable Energy Certificate (REC) here to refer to any type of non-emitting energy attribute certificate, including certificates associated with net generation from storage resources, and including both unbundled RECs and RECs bundled with energy.

[4] In response to this shortcoming, many reporting entities have adopted self-imposed limits on the source of the RECs they deduct from their consumption. These limits often require RECs to be produced within the same market (or transmission zone or country) as consumption, or to be produced within nearby areas.

[5] See, for example, Google's 24/7 initiative

[6] We use hours as a granular time increment throughout this document. However, there isn't anything special about hours. Carbon impact and generation could be measured at the highest time granularity for which data are available.

[7] REsurety offers a nodal marginal emissions rate data product which we refer to as "Locational Marginal Emissions". While we believe that more geographically granular emissions data has significant value, the arguments in this whitepaper are not limited to nodal marginal emissions data or to our Locational Marginal Emissions data set. Many of the benefits of using marginal data can be achieved using marginal emissions rate data at more aggregated geographic granularity.

[8] See Rudkevich, A. and Ruiz, P.A. Locational Carbon Footprint of the Power Industry: Implications for Operations, Planning and Policy Making, January 2012, Chapter in: Handbook of CO2 in Power Systems, Springer

Example system

We introduce a simplified power system to illustrate the value of the hourly marginal accounting rule described in Equation 3. The system includes two zones, as shown in Figure 1. Zone 1 contains 90% of the demand. It is a net importer of power, though it also has significant generating capacity. Zone 2 has a small amount of demand and is dominated by wind energy production. Zone 2 has an export limit of 150 MW that restricts the output of local generation.

Figure 1: Example System Zonal Peak Load, Generation Capacity, and Transmission Limits

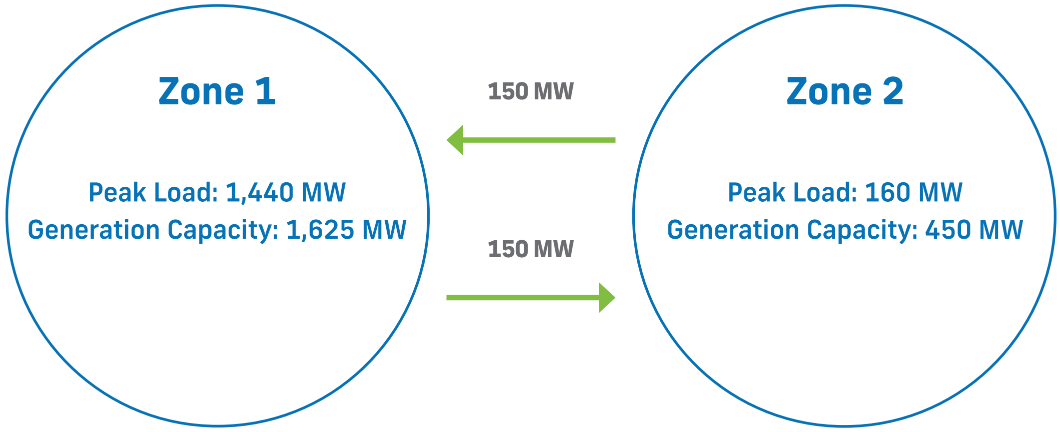
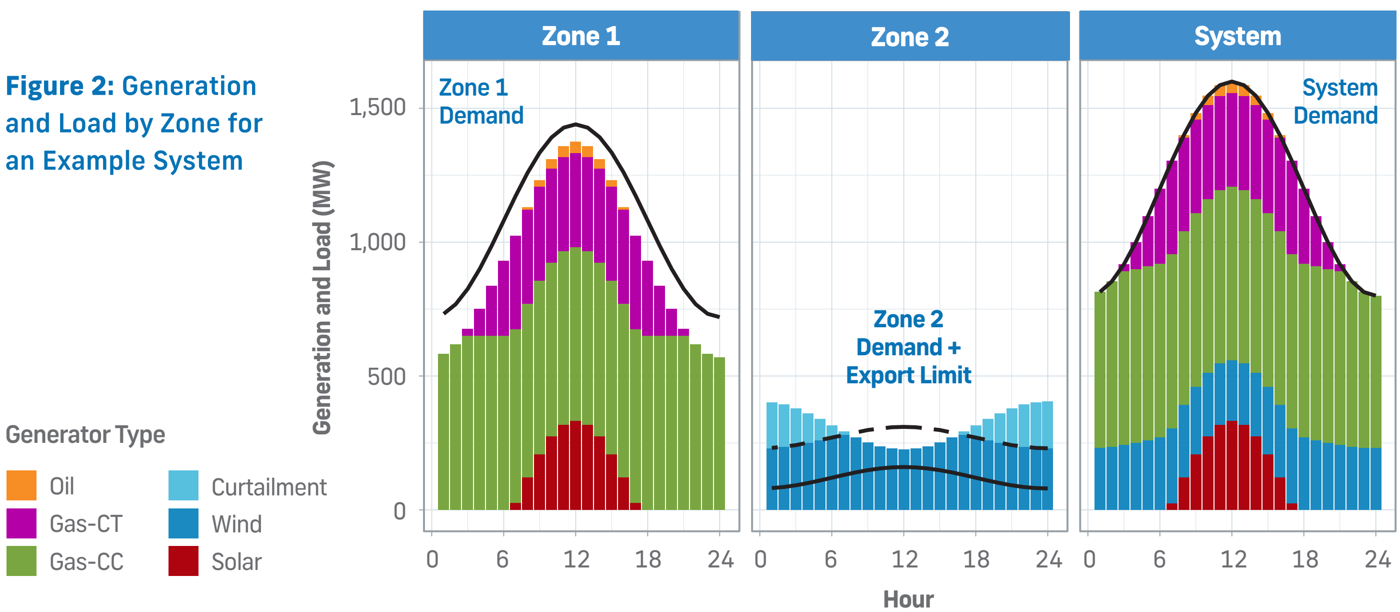


Figure 2 shows generation and load from this system over the course of an illustrative day, based on least-cost economic dispatch of the generators and accounting for the transmission constraint.[9] Table 1 shows the generators in this system. During the overnight hours, a mix of relatively clean natural gas combined cycle (Gas-CC) resources in Zone 1 and wind generation in Zone 2 meet demand. Zone 2 wind output is high and Zone 2 demand is low overnight, leading to a binding export constraint and wind curtailment. As demand rises in the morning, higher-cost and higher-emitting Gas-CTs enter the fuel mix. Overall wind output drops, but curtailment also drops, leaving delivered wind output relatively constant. In the middle of the day, a combination of solar and oil generation meet peak demand. The cycle reverses in the latter part of the day.

Figure 2: Generation and Load by Zone for an Example System



Note: *Solid black lines indicate hourly demand. Dashed black line shows hourly demand plus the 150 MW export limit from Zone 2. Gas-CT denotes a simple-cycle natural gas turbine generator. Gas-CC denotes a more efficient combined-cycle natural gas turbine generator.*

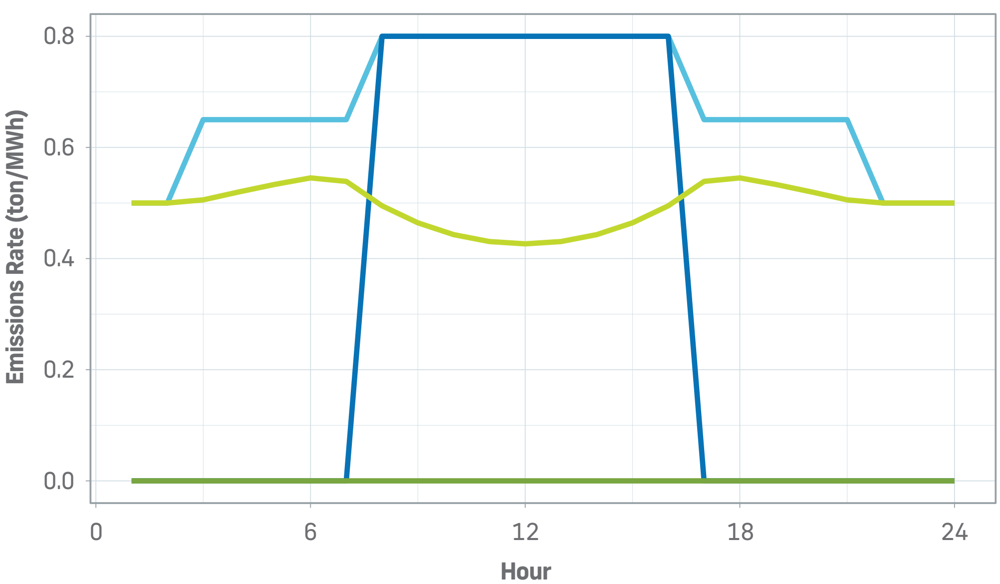
[9] Note that demand, wind, and solar follow stylized profiles, as shown in the figure.

Table 1: Generating resources in the example system

Unit	Zone	Type	Capacity (MW)	Marginal Cost ($/MWh)	Emissions Rate (ton/MWh)
CC 1	Zone 1	Gas-CC	650	25	0.5
CT 1	Zone 1	Gas-CT	350	30	0.65
Oil 1	Zone 1	Oil	250	35	0.8
Solar 1	Zone 1	Solar	350	0	0
Wind 2	Zone 2	Wind	450	-10	0

Figure 3 shows hourly average emissions rates for the system as well as hourly marginal emissions rates for each zone. The average emissions rate in Zone 2 is always zero, as it contains no carbon-emitting generation. The average emissions rate in Zone 1 varies slightly throughout the day as a function of changes in the generation mix as described above. Marginal emissions rates vary more significantly over the course of the day, and by location. In Zone 1, the pattern reflects the emissions rates of the Gas-CC, Gas-CT, and Oil generators that are marginal at various points throughout the day. Zone 2 marginal emissions rates track Zone 1 in the middle of the day when transmission is unconstrained. However, during the overnight hours when transmission is constrained and wind is being locally curtailed, Zone 2 marginal emissions rates fall to zero. During these hours, incremental clean generation in Zone 2 does not reduce system-wide carbon emissions.

Figure 3: Marginal Emissions Rates and Average Emissions Rates by Zone and Hour



Emissions Rate

- Zone 1 Marginal
- Zone 2 Marginal
- Zone 1 Average
- Zone 2 Average

Benefits of the hourly marginal accounting rule

Consider a firm that consumes 120 MWh of energy over the course of the example day. This firm is interested in making an investment in clean energy with the aim of reducing its carbon footprint. Our firm has two candidate clean energy resources to choose from: a wind farm located in Zone 2 and a solar facility located in Zone 1. We assume both resources have the same PPA cost incremental to their energy value. Our firm has a limited budget and can only afford to purchase 120 MWh of clean power. This means it must choose between the solar and wind resources.

As might be evident from the preceding discussion, investing in the solar facility will reduce system-wide carbon emissions by more than investing in the wind facility. For a significant number of hours of the day, incremental wind output in Zone 2 will only serve to increase curtailment and will have no effect on system-wide emissions. Furthermore, the output profile of the solar facility is better aligned with periods of high marginal emissions intensity. Our goal for the remainder of this section is to explore how the three accounting rules align the firm's incentives towards selecting the solar facility.

Table 2 shows how the firm's Scope 2 carbon footprint would change if it developed the solar or the wind facility under the Annual Average @Load approach (Equation 1), the Hourly Average @Load approach (Equation 2) or the proposed Hourly Marginal approach (Equation 3). The table compares the Accounting Carbon Displacement (the reduction in the firm's Scope 2 footprint associated with clean generation) to the Actual Emissions Reduction, system-wide, associated with developing each resource.[10] The table also shows the central role of emissions rates in aligning the firm's incentive to reduce its Scope 2 footprint with actual carbon emissions reductions.

Table 2 highlights two important challenges with both the Annual Average @Load and Hourly Average @Load approaches. First, average emissions rates, even when based on hourly data, provide a poor indication of the relative carbon abatement value of the two projects. The effective emissions rates[11] of the solar and wind facilities are identical under the Annual Average @Load approach, providing no differentiation between the projects. Under the Hourly Average @Load approach, the emissions rates of the projects are very similar, with the wind facility actually showing a slightly higher value of 0.5 ton/MWh, compared to 0.44 ton/MWh for the solar facility. Accounting Carbon Displacement (and therefore the firm's Scope 2 carbon footprint) is essentially the same between projects.

Second, there is a significant discrepancy between Accounting Carbon Displacement and Actual Emissions Reduction for both projects under the average emissions approaches. When selecting the wind facility, the entity's carbon footprint drops by 59 or 60 tons (depending on whether the firm employs Annual or Hourly accounting), whereas actual carbon emissions only drop by 27 tons. This means the firm, even when correctly applying the Scope 2 guidance, has claimed about double the emissions reductions that actually occurred. When selecting the solar facility, the entity's carbon footprint drops by 53-59 ton, whereas actual carbon emissions drop by 96 tons. This means the firm has nowhere near the right level of incentive to pursue the solar project.

[10] Actual Emissions Reduction is calculated by 1) running two versions of a production cost-minimizing scheduling model for the example system: a version excluding the resource under study and a version including that resource and 2) taking the difference in total system-wide carbon emissions between the two model runs.

[11] Effective emissions rates are simply generation-weighted average emissions rates, reflecting the time-varying output profile of each facility.

Table 2: Carbon footprint and actual emissions impact of solar or wind investment

	Load		Clean Generation		Carbon Impact of Clean Generation		
	Effective Emissions Rate (ton/MWh)	Consumption (MWh)	Effective Emissions Rate (ton/MWh)	Generation (MWh)	Accounting Carbon Displacement (ton)	Actual Emissions Reduction (ton/MWh)	Error in Accounting Displacement (%)
Annual Average @Load							
Solar	0.49	120	0.49	120	59	96	-38%
Wind	0.49	120	0.49	120	59	27	120%
Hourly Average @Load							
Solar	0.49	120	0.44	120	53	96	-45%
Wind	0.49	120	0.50	120	60	27	122%
Hourly Marginal							
Solar	0.70	120	0.80	120	96	96	0%
Wind	0.70	120	0.22	120	27	27	0%

Note: *Effective Emissions Rate columns pertaining to Load and Clean Generation reflect the load-weighted and generation-weighted averages of hourly emissions rates, respectively. Generation-weighted average emissions rates differ between the solar and wind scenarios under Hourly Average@Load accounting primarily due to the difference in hourly generation profiles between the solar and wind resources. Accounting Carbon Displacement represents the change in Scope 2 footprint associated with the clean energy purchase. Actual Emissions Reduction represents the reduction in system-wide carbon emissions associated with each project.*

While the above discussion is based on our small-scale example system, the misalignment between Accounting Carbon Displacement and Actual Emissions Reduction has significant impact in real power systems. In a previous whitepaper, we calculated marginal emissions rates for wind and solar resources in Texas in 2018-19, finding a factor of two difference between the best- and worst-performing projects from a carbon perspective. The results of this study show that about 65% of solar and wind energy projects have better carbon abatement potential than the mean, by an average incremental amount of 70 lb/MWh. Scaling this value up to the U.S. and applying a social cost of carbon, we estimate that at least $600 million of wind and solar carbon abatement potential is undervalued each year and the same amount is overvalued.[12]

The proposed Hourly Marginal accounting rule improves on both of the issues identified above. Marginal emissions rates are materially different between the two projects, reflecting the very real difference in their carbon impact. With the Hourly Marginal accounting rule, our firm is strongly encouraged to pursue the solar project that achieves materially more emissions reductions. In this example, Actual Emissions Reductions match Accounting Carbon Displacement exactly, though we will show in the next section that this will not always be the case. We should expect, however, that the Hourly Marginal approach provides a better indicator of Actual Emissions Reduction.

[12] Social Cost of Carbon ($/ton) x Average Carbon Abatement Incremental to Mean (lb/MWh)/2000 x Percentage of Solar and Wind Projects Abating More Than Mean (%) x U.S. 2021 Solar Generation (MWh) = $51 x 70/2000 x 65% x 540,779,000 = $627,000,000. Social Cost of Carbon from U.S. Interagency Working Group on Social Cost of GHGs. Average Carbon Abatement Incremental to Mean and Percentage of Solar Projects Abating More Than Mean based on Figure 2 from Spees, K. and, Oates, D.L. Locational Marginal Emissions: A Force Multiplier for the Carbon Impact of Clean Energy Programs, 2021. U.S. 2021 Solar and Wind Generation from EIA Electric Power Monthly.

Marginal accounting for large investments

In the example above, the size of the project developed by our firm was small. As a result, the generators on the margin in each hour, and therefore marginal emissions rates, remained constant after either the wind or the solar project came online. This feature ensured that Actual Emissions Reduction exactly matched Accounting Carbon Displacement using the Hourly Marginal accounting rule. While most wind and solar facilities are small compared to the power systems in which they operate, we can't rely on marginal emissions rates remaining constant after an investment decision. Fortunately, the Hourly Marginal accounting rule still works well under non-marginal changes to the system.

Figure 4 illustrates the emissions rates after either a 1,200 MWh investment in solar or wind. Comparing Figure 4 to the pre-investment emissions rates in Figure 3 shows that solar investment reduces marginal emissions rates in both zones and average emissions rates in Zone 1 in the middle of the day when solar output is high. Wind investment has less of an impact on emissions rates, reducing marginal emissions rates during some but not all daytime hours and having a less noticeable impact on average emissions rates.

Table 3 shows the carbon footprint impacts of this larger scale investment in solar or wind. As with the small-scale investment, both methods for average emissions accounting fail to encourage our firm to invest in the solar farm. The generation-weighted average emissions rate of the wind facility is in fact higher than the solar facility in the two average accounting cases, encouraging investment in the wrong facility. Average marginal emissions rates for the solar facility are lower in this higher investment scenario than they are after the smaller investment shown in Table 2, due to the changes in emissions rates shown in Figure 4. However, the stronger carbon abatement value of the solar facility remains clear. Due to the changes in emissions rates pre- and post-investment, Actual Emissions Reductions don't match Accounting Carbon Displacement under the Hourly Marginal accounting rule. However, this rule is a much better indicator of Actual Emissions Reduction than rules based on average emissions rates.

Figure 4: Emissions Rates after a 10x (1,200 MWh) investment (Left: Solar, Right: Wind)

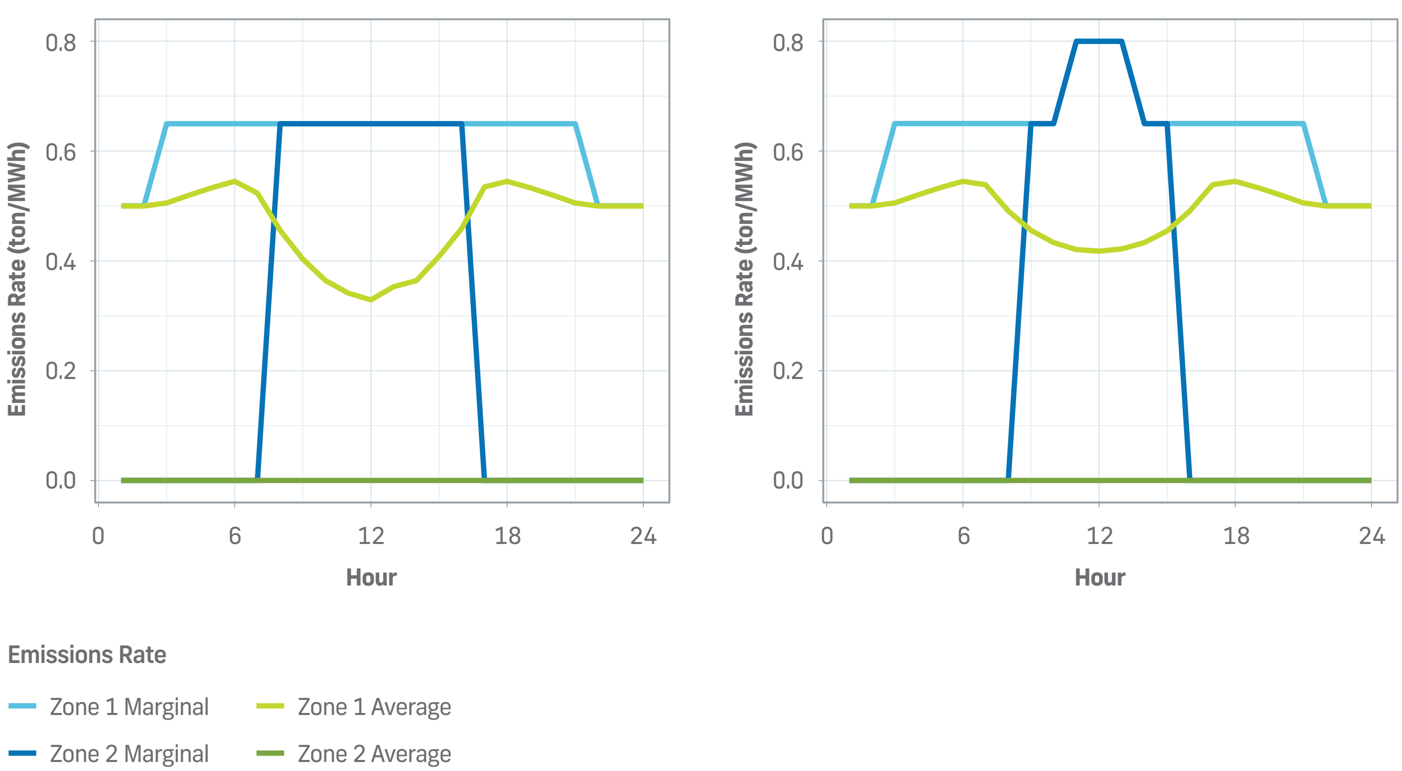


Table 3: Carbon impacts of 10x (1,200 MWh) solar or wind investment

	Load		Clean Generation		Carbon Impact of Clean Generation		
	Effective Emissions Rate (ton/MWh)	Consumption (MWh)	Effective Emissions Rate (ton/MWh)	Generation (MWh)	Accounting Carbon Displacement (ton)	Actual Emissions Reduction (ton/MWh)	Error in Accounting Displacement (%)
Annual Average @Load							
Solar	0.47	1,200	0.47	1,200	562	819	-31%
Wind	0.49	1,200	0.49	1,200	590	229	158%
Hourly Average @Load							
Solar	0.46	1,200	0.37	1,200	450	819	-45%
Wind	0.49	1,200	0.50	1,200	597	229	161%
Hourly Marginal							
Solar	0.63	1,200	0.65	1,200	780	819	-5%
Wind	0.65	1,200	0.15	1,200	183	229	-20%

Note: *Effective Emissions Rate columns pertaining to Load and Clean Generation reflect the load-weighted and generation-weighted averages of hourly emissions rates, respectively.*

Marginal emissions and the carbon abatement cost curve

Figure 4 and Table 3 show that effective emissions rates can change if substantial clean energy is added to a system. As clean energy is added, fossil generator dispatch patterns change, altering marginal emissions rates and the incremental carbon benefits of further investment. This means Accounting Carbon Displacement will not necessarily match Actual Emissions Reductions under any of the carbon accounting mechanisms described above, including the Hourly Marginal approach.

However, the Hourly Marginal accounting rule retains an important feature even when investment magnitudes are large enough to affect marginal emissions rates. Even under these conditions, investments that minimize *system-wide carbon emissions* also minimize *individual* Hourly Marginal Scope 2 footprints. Entities are therefore incentivized to select from among the available and affordable investment opportunities those that abate carbon at the lowest cost, as measured by their post-construction effective marginal emissions rate.

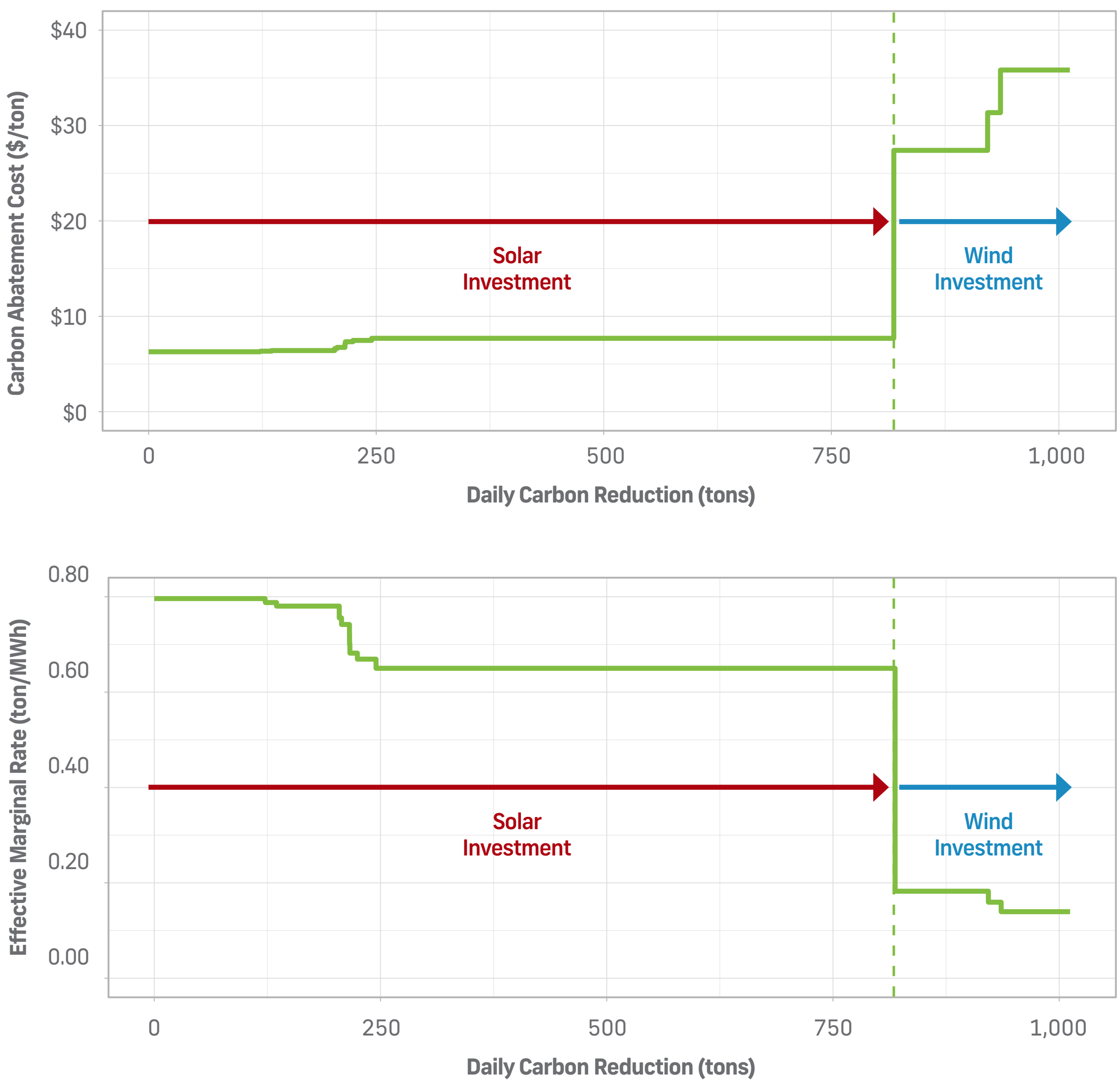
To help illustrate this, we evaluate the most cost-effective decarbonization pathway available to the entity we have been considering. As in the discussion above, the entity has access to two projects: the 1,200 MWh/day solar project in Zone 1 and the 1,200 MWh/day wind project in Zone 2, both at the same incremental cost of $5/MWh. For illustrative purposes, we consider both investments to be divisible into many small steps and allow the possibility of investing in both the wind and solar facility.

[Figure 5](#) shows a $/ton carbon abatement cost curve (top) and a ton/MWh effective marginal emissions rate curve (bottom) for this scenario. Both values are plotted against cumulative carbon reductions, which increase from left to right as additional MWh of solar or wind are developed. The left part of the figure represents the lowest-cost decarbonization options - solar in our scenario.

As the amount of carbon abatement increases, effective marginal emissions rates drop and abatement costs correspondingly increase. The maximum amount of carbon that can be abated by the 1,200 MWh of available solar is about 820 tons. Beyond that point, marginal abatement costs increase substantially, as further abatement must be accomplished by investing in the wind resource.

The $/ton carbon abatement cost at each level of carbon abatement in Figure 5 is easily calculable based on effective (i.e. generation-weighted) marginal emissions rates. It is simply equal to the cost of the clean energy resource ($/MWh) divided by the (post-construction) effective marginal emissions rate of the resource (ton/MWh). In other words, at any point in the curve, the lowest cost way to reduce system wide carbon emissions is to make the feasible investment that has the greatest effective marginal emissions rate per dollar.[13]

Figure 5: Marginal carbon abatement cost curve (top) and clean resource effective marginal emissions rate curve (bottom) for the large investment scenario



[13] There are already entities who make use of marginal emissions rate information to guide private investment decisions of this kind. For example, Hannon Armstrong's Carbon Count system signals the cost-effectiveness of investment decisions and is in the process of being updated to use marginal emissions rate data to do so.

Conclusions

Effective carbon accounting frameworks for electric power are an important component of efforts to mitigate climate change. Accounting should incentivize impact. Ideally, decision makers managing their *private* carbon footprints should be incentivized to make the same decision they would if they were managing *system-wide* total emissions. Current Scope 2 rules, which are based on annual average emissions rates at load, don't accomplish this objective. Simply moving to hourly emissions rates also doesn't properly align incentives.

An accounting rule based on hourly marginal emissions rates, applied to consumption and generation at their respective locations, does a better job of aligning incentives to reduce carbon emissions. The hourly marginal accounting rule effectively distinguishes between projects with high and low carbon abatement value. It allows the carbon impact of energy storage to be accounted for in a straightforward manner. For small projects, the hourly marginal rule closely matches the consequential emissions impact. For larger projects, the quality of this match is lower, but still better than under current accounting rules.

The hourly marginal accounting rule is not perfect and additional effort is needed to build confidence in its performance in practice. In particular, further work is needed to address unevenness in access to granular data, illustrate alignment between total Scope 1 and Scope 2 emissions in practice, characterize performance in full-scale power systems, and potentially account for participation in capacity and ancillary services markets as well as the markets for electric energy shown in this paper.

However, we believe the hourly marginal accounting rule shows clear advantages relative to the status quo. It should be seriously considered in discussions to update GHG Protocol Scope 2 guidance in the coming months and years. In the shorter term, entities interested in clean energy technology selection and siting, consumption siting and shaping, and storage operations should consider this rule when evaluating decisions. There is a tremendous amount of work to be done to mitigate the worst effects of climate change. Better aligning incentives towards decarbonization is a small, but meaningful and achievable piece of the puzzle.

If you would like to speak with the REsurety team about how the hourly marginal accounting rule can be used in practice today, contact us at: carbon@resurety.com.

To learn about high-resolution Locational Marginal Emissions, please download the white paper.

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