Assessing the Impact of Voluntary Actions on the Grid

A Consensus Paper from ZEROgrid's Impact Advisory Initiative

Impact Advisory Brief / May 2024

Authors and Acknowledgments

Authors

Charles Cannon
Pieter Gagnon, National Renewable Energy Laboratory
Gavin McCormick, WattTime
Wilson Ricks, Princeton University

Additional Contributors

Steve Abbott
Jesse Jenkins, Princeton University
David Luke Oates, Midcontinent Independent System Operator
Henry Richardson, WattTime
Lee Taylor, REsurety

Authors listed alphabetically. All authors from RMI unless otherwise noted.

Contacts

Charles Cannon, ccannon@rmi.org
Steve Abbott, sabbott@rmi.org

Copyrights and Citation

Charles Cannon, Pieter Gagnon, Gavin McCormick, Wilson Ricks, *Assessing the Impact of Voluntary Actions on the Grid: A Consensus Paper from ZEROgrid's Impact Advisory Initiative*, RMI, 2024, https://rmi.org/zerogrid-assessing-impact.

RMI values collaboration and aims to accelerate the energy transition through sharing knowledge and insights. We therefore allow interested parties to reference, share, and cite our work through the Creative Commons CC BY-SA 4.0 license. https://creativecommons.org/licenses/by-sa/4.0/.

All images used are from iStock.com unless otherwise noted.

About RMI

RMI is an independent nonprofit, founded in 1982 as Rocky Mountain Institute, that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and NGOs to identify and scale energy system interventions that will cut greenhouse gas emissions at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing.

About ZEROgrid

Through a first-of-its-kind collaboration among data providers, academics, corporations, and policymakers, ZEROgrid is accelerating actions that lead to a decarbonized and reliable grid. ZEROgrid's Impact Advisory Initiative includes expert practitioners from the National Renewable Energy Laboratory, Princeton University, REsurety, RMI, and WattTime.

Executive Summary

Over the past 10 years, voluntary procurement of clean energy by corporations has been a tremendous driver of renewable energy development. Since 2014, large companies have signed procurement contracts supporting the development of over 70 gigawatts of renewable energy in the United States,[1] in addition to purchasing renewable energy certificates (RECs), providing tax equity financing, and advocating regionally and nationally for more clean energy deployment. These voluntary procurement trends are continuing to scale and expand into other markets such as Japan, South Korea, and Taiwan.[2]

The urgency of the climate crisis is prompting many large energy consumers to consider how they can assess the impact of various actions on grid decarbonization and reliability. Such an assessment can be best made using consequential emissions impact analysis, which employs various approaches to estimate the difference between total global emissions in different possible states of the world.

Although many authors have published on consequential emissions impact analysis, there have been different views and until now no joint statement from differing authors on areas of consensus and how to resolve discrepant conclusions.

To provide greater clarity to corporate actors, ZEROgrid created the Impact Advisory Initiative, or IAI. The IAI comprises a group of expert practitioners from the National Renewable Energy Laboratory (NREL), Princeton University, REsurety, RMI, and WattTime who collectively identified key points of consensus as well as areas requiring further research.[i]

This paper provides an overview of the IAI's findings regarding emerging areas of consensus about consequential emissions impact analysis, its implications, and areas where further research is required.

Areas of Consensus:

1. **Defining impact.** The true impact of any voluntary corporate action (or any action) is the difference in total emissions between a world where the action was taken versus one in which it was not taken.

2. **Components of impact.** This impact is the sum of several different contributing effects, which must include the effects over the lifetime of the intervention — how an intervention changes the short-run operations of power plants, and structural change, i.e., how it changes the total supply of different power plants in the long run — to fully capture the impact of an action.

3. **Estimates versus true values.** The field has a number of ways to produce estimates of total emissions impact and its components. Although there is agreement regarding how changes to short-run operations can be quantified, the field currently lacks — and indeed may always lack — any generally accepted way to empirically verify estimates of structural change. Therefore, *any* approach that seeks to measure total impact has (potentially significant levels of) uncertainty.

---

i The ZEROgrid initiative brings together a group of corporate actors, including Akamai, General Motors, HASI, Meta, Prologis, Salesforce, and Walmart, seeking to drive deep decarbonization alongside increased power grid reliability and affordability, working in collaboration with emissions and reliability experts. Additional information is available at **https://zerogrid.org/**.

Defining Impact

The IAI advisors unanimously agree that the emissions impact, whether avoided or induced emissions, of any intervention is the difference between total emissions if the action is taken and the total emissions in a counterfactual scenario where it *is not* taken. An intervention could be a corporate project, a policy, or anything else that affects emissions.

Emissions impact can be articulated in an equation as follows. An intervention works by changing some variable to be $X + \Delta X$ instead of just being X. The grid emissions impact, ΔE, of that change is the difference in the resulting total grid emissions, which can be written as:

$$\text{Impact } \Delta E = E(X + \Delta X) - E(X)$$

If the intervention is measured in megawatt-hours (MWh), the total impact on a per-MWh basis is therefore $\Delta E/\Delta X$.

Components of Impact

This change in emissions can happen via a variety of different phenomena. Any given intervention could, intentionally or unintentionally, change:

- The supply or demand for power (either briefly or permanently)
- The cost of some power plant or energy storage technology type
- The rate at which renewable energy projects clear the interconnection queue
- The cost of capital for renewable energy power plant developers

The sum of all these and any other phenomena is the total impact of a project or intervention. As a result, many different factors can influence an intervention's impact on grid emissions.

One useful mental framework to reason through this complexity is to note that in nearly every case, all of these different effects ultimately only change emissions in one of two ways: (1) effects that change how much different power plants get *used* or (2) effects that change what power plants do or do not get *built*. Total impact is the sum of these two effects.

Components of Total Emissions

Consider that the total emissions (*E*) from any given power plant in a given time period is the product of its capacity (*C*) in megawatts (MW), the utilization (*U*) of that capacity (to generate MWh), and the emissions factor (*EF*) of that power plant at that time (pollution per MWh). The total emissions of the grid over time are the sum of this product across all regions (*r*), times (*t*), and power plants (*p*). Or in an equation:

$$E = \sum_{r,t,p} C_{rtp} U_{rtp} EF_{rtp}$$

For example, consider a grid that consists of just one region, measured over one hour, powered by two coal plants. If each plant has 100 MW capacity and always operates at 50% utilization, emitting 2,000 pounds of CO_2 per MWh, the grid's total annual emissions would be (100+100)(0.5)(2,000).[ii]

Based on the equation above, there are three variables for each electric generator that can impact its emissions: capacity, utilization, and emissions factors. Companies can seek to reduce emissions by influencing one or more of these variables. As such, the impact previously denoted by Δ*X* can also be more specifically articulated as changes in capacity (Δ*C*), utilization (Δ*U*), or emissions factors (Δ*EF*).

The emissions factors of power plants can change due to actions like plant retrofits or changes in operations, but voluntary corporate actions most often materially affect changes in the capacity and utilization of power plants. Given this, emissions impact will be considered primarily through the predominant changes to capacity and utilization.

---

ii Note that this equation is not a model of how to estimate any of these values, but rather just a description of the components of the total emissions from any group of power plants.

Components of Emissions Impact

A notable feature of power grids is that in response to an intervention, utilization often changes quickly (i.e., in minutes or seconds) but capacity usually changes more slowly (i.e., in years or decades).

A common convention in economics is therefore to distinguish between **short-run** impact (reflecting only changes in utilization) and **long-run** impact (reflecting changes in both utilization and capacity). However, this terminology can sometimes be confusing to corporations for which the phrases "short run" and "long run" have different meanings in other contexts.

To make sure this important concept is not lost in translation between different fields, it can be helpful to use rigorous language spelled out precisely in equations. One such useful distinction is similar to the approach laid out in the Greenhouse Gas Protocol's *Guidelines for Quantifying GHG Reductions from Grid-Connected Electricity Projects* (GHGP).[3]

Let us first define the **operating change** of an intervention as the change in any variable that an intervention would cause if the grid did not respond by changing the capacity of any of its power plants. **Operating impact**, ΔE^{op}, is the operating change in emissions.

Of course, in practice, grids *do* respond to market adjustments (e.g., persistent electricity supply and demand shifts) by changing the capacity of their power plants, just more slowly. So let induced structural change, also known as **build change**, to any variable be the difference between the *total* consequential changes in that variable and the operating change. **Build impact**, ΔE^{bu}, is the build change in emissions.

It is important to note that despite the name, build impact includes plants built because of the intervention, plants retired because of the intervention, plants *not* built because of the intervention, and plants *not* retired because of the intervention. Some of these are relatively easy to observe and others can be more subtle, but all of these effects are still important.

The above formulation can be used to understand the total impact of an intervention on the grid. Using these terms, the total impact of an intervention is the sum of operating impact plus build impact. Thus, any analysis of consequential impact that neglects either operating impact or build impact is incomplete. That is:

$$\Delta E = \Delta E^{op} + \Delta E^{bu}$$

This is similar to the formulation for avoided emissions as laid out in the GHGP.

Components of Operating Impact and Build Impact

Operating impact and build impact can themselves be further broken down into components, as follows:

In this formulation, operating impact (ΔE^{op}) is the change in emissions that occurs solely due to changes in the utilization of power plants. For any intervention that does not change emissions factors, this can be expressed mathematically as:

$$\Delta E^{op} = \sum_{r,t,p} C_{rtp} \Delta U^{op}_{rtp} EF_{rtp}$$

where ΔU^{op} equals the operating change in utilization.

Build impact (ΔE^{bu}) represents all impacts not included in ΔE^{op}, which is the sum of the changes in emissions that occur from direct or induced changes to plant capacities across the system as a result of an action, plus the resulting changes to the utilization of existing power plants. This can be expressed mathematically as:

$$\Delta E^{bu} = \Delta E - \Delta E^{op} = \sum_{r,t,p} (\Delta C_{rtp}(U_{rtp} + \Delta U_{rtp}) EF_{rtp} + C_{rtp} \Delta U^{bu}_{rtp} EF_{rtp})$$

where ΔU equals the total change in utilization, and ΔU^{bu} equals the build change in utilization.

For those interested in where these equations come from, a more detailed explanation and formal proof are available in the *Technical Appendix*.

Additionality

Additionality is the sense in which an intervention's emissions reductions are additive. Breaking additionality into two components can help clarify a common area in which different practitioners may misunderstand each other.

- First, actions can have **direct** impacts on grid emissions by influencing the capacity, utilization, or emissions factors of specific generators. For example, purchasing RECs, engaging in power purchase agreements or green tariffs, and undertaking other actions may each drive different amounts of new clean energy capacity.
- Second, the overall grid emissions impacts of these actions can vary depending on the total **induced** structural changes to the system. For example, if a company's actions directly enable the construction of a new solar plant, the addition of that new solar resource could in turn induce the retirement of a coal plant, the abandonment of a different renewable energy project in the development queue, or the development of additional energy storage.

As such, the additionality or non-additionality of an action depends on both components. An action might be non-additional if it simply had no impact on capacity, utilization, or emissions factors. Alternatively, even if an action did directly enable new capacity, it might still be non-additional if it also induced an equal and opposite indirect change in capacity.

Estimates Versus True Values

The practice of estimating this total impact is known as consequential emissions impact analysis. The *theory* of consequential emissions impact analysis, as stated above, is relatively simple. The practice of it, however, has many difficult challenges and unquantified uncertainties. If an actor wishes to estimate the impact of an action it is considering (or has already taken), it needs to estimate the total difference in global emissions *with and without* the action.

But a well-known problem in any kind of impact analysis — whether about emissions, economics, medicine, or policy — is that it is inherently difficult to validate any estimates of *impact*. This is because one can never both take a specific action *and* not take it. As with almost any variable, one can only observe the emissions that occur if one takes an action — that is, $E(X + \Delta X)$ — or if one does not take an action — that is, $E(X)$ — but never both.[iii]

Therefore, as in any type of impact analysis, it is important to distinguish between true consequential impact (which is unobservable) and estimates of it (which are observable). A common convention is to use ^ above a letter to indicate an estimation. For example, if the true impact of a change ΔX *is* $\Delta \hat{E}(\Delta X)$, one can only measure (ΔX), or the *estimate* of that true impact.

Validating different *operating* impact estimates is an active and ongoing area of research, focusing on the confidence level with which estimates will match observable values.[iv] To date, no method for estimating the build emissions impact of electricity sector interventions has been rigorously verified. This is largely because of the lack of observable counterfactual scenarios and difficulty in performing gold-standard empirical experiments to establish causality (e.g., randomized controlled trials). Even if a model for estimating build impact were to be rigorously validated, the *predictive* accuracy of this model would always be fundamentally constrained by deep uncertainties in its input parameters (e.g., future trends in energy demand, policy, and techno-economics).

A variety of models, produced by the authors of this paper and others, can be used to estimate these impacts or components in the United States and elsewhere with varying degrees of uncertainty, including:

- Capacity expansion models with economic dispatch (e.g., NREL's Cambium, Princeton University's GenX)
- Regression models (e.g., REsurety, WattTime, Stanford University, and United Nations Framework Convention on Climate Change)
- ISO dispatch models (e.g., PJM's model)
- Pure capacity expansion models (e.g., Transition Zero's Future Energy Outlook)

---

iii This is often referred to as the Fundamental Problem of Causal Inference and is the statistical underpinning for why fields such as medicine conduct randomized controlled trials. See Paul W. Holland, "Statistics and Causal Inference," *Journal of the American Statistical Association*, vol. 81, no. 396, 1986, pp. 945–960, **https://doi.org/10.2307/2289064**.

iv See, for example, Sam Koebrich et al., "Towards Objective Evaluation of the Accuracy of Marginal Emissions Factors," available at SSRN **https://ssrn.com/abstract=4631565** or **http://dx.doi.org/10.2139/ssrn.4631565**, and other papers at **VERACI-T.org**.

- Monte Carlo models (e.g., the Environmental Protection Agency's AVERT model)
- Heat rate models (e.g., the Self-Generation Incentive Program and New York ISO models)
- Machine learning models (e.g., Carnegie Mellon)
- Various proxy metrics (e.g., average emissions, locational marginal pricing, recently built generation, renewable fraction, and non-baseload generation)

By using the concepts described above in *Components of Impact*, it is possible to check whether any given model is estimating all or just some of the different components of impact, and to compare differing estimates of similar phenomena (such as operating impact or build impact, or impact in a particular region or year) in an apples-to-apples fashion.

Conclusions and Future Research

This paper has articulated a mathematical framework in an effort to help companies, policymakers, and others better interpret and understand the results of various consequential impact assessment models. Despite the inherent limitations and uncertainty of the existing models and literature, the IAI experts continue to recommend these approaches as powerful tools to estimate the emissions impact of different possible actions and policies.[4]

In order to build on this work and continue to provide further actionable insights to companies and policymakers, IAI members intend to continue to explore questions such as:

- How can the outputs of various models be compared using the framework presented here, and what are their respective strengths and limitations (e.g., accessibility, uncertainty, and ability to estimate total and/or components of impact)?
- What insights can consequential impact assessments provide to inform and improve attributional frameworks such as annual matching, time-based procurement, and emissions-based procurement?
- Which actions are consistently higher impact and which ones are not?
- Across a range of different actions, models, methods, and authors, which statements are consistently supported and which vary based on the model or method?
- Even if it is not possible to fully quantify the uncertainty in these estimates, is it possible to at least bound that uncertainty so policymakers can have some idea of what is known and unknown?

Technical Appendix

Definitions 1 (Related to Total Emissions)

Let

r = a region, from 1 to R, which may be a balancing authority, state, node, etc.
t = a time step, from 1 to T, which may be measured in years, hours, five-minute periods, etc.
p = a power plant, from 1 to P, representing a power plant or group of similar power plants within a given region (e.g., coal plants)

E_{rtp} = total grid emissions in a given region, time, and group of plants, in tons or pounds
C_{rtp} = installed capacity in the same, in MW
G_{rtp} = generation in the same, in MWh
U_{rtp} = weighted average capacity utilization in the same, in MWh per MW, i.e., G_{rtp}/C_{rtp}
EF_{rtp} = weighted average emissions factor in the same, in tons per MWh, i.e., E_{rtp}/G_{rtp}

So total grid emissions are the sum of the emissions factor of each MWh generated over all regions, times, and fuel types, where each MWh is the product of that capacity times the utilization rate:

$$E = \sum_{r,t,p} G_{rtp} EF_{rtp} = \sum_{r,t,p} C_{rtp} U_{rtp} EF_{rtp}$$

Definitions 2 (Related to Consequential Impact)

To discuss the effect on emissions of an **intervention** — which is any project, policy, or other action that causes some variable to be X^1 instead of a counterfactual base case in which it was instead just X — let $\Delta X = X^1 - X$ be the difference from the counterfactual scenario. Note that by this definition, ΔX is a "change" not in the sense of a change over time, but rather of a change relative to a counterfactual scenario in which the intervention did not occur.

In theory, ΔX could be anything: a project to build a wind farm, a purchase of RECs, load shifting by an electric vehicle, a government policy, a change of accounting practices, or any other intervention. But *most often*, the focus is on interventions that change something at one or more regions, times, and/or power plants. Thus, like the other variables above, ΔX can often be viewed as a matrix of different values ΔX_{rtp} (potentially with many values equal to zero).

Similarly let ΔC, ΔU, ΔG, ΔEF, and ΔE be the change in C, U, G, EF, and E that results from this intervention, respectively; and let C^1, U^1, G^1, EF^1, and E^1 be the values of each variable after this change.

Let Y be all *other* exogenous variables that influence these parameters (e.g., weather conditions). Thus, the causal effect of changing X to X^1 is $\Delta E(\Delta X) = E(X^1 \mid Y) - E(X \mid Y)$.

The notation $\mid Y$ means that everything on the left side of the bar is true, holding variable Y constant at value Y. It is a way of acknowledging that many things obviously affect emissions besides just X, but by holding those things constant, it is possible to examine how changing X changes emissions.

Definitions 3 (Related to Dividing Effects)

Let the **long run** be defined as the values that occur if the intervention happens. And let the **short run** be defined as the effects that *would* instead occur *if* X changed to X^1, but C was not able to respond. Let X^{SR}, C^{SR}, U^{SR}, G^{SR}, EF^{SR}, and E^{SR} be the values of X, C, U, G, EF, and E that would occur in this hypothetical situation.

Let the **operating change** be the change in any variable that would result from the intervention in this definition of the short run, and be represented with the superscript ^{op}. Specifically, let ΔX^{op} be defined as $X^{SR} - X$ and define ΔC^{op}, ΔU^{op}, ΔG^{op}, ΔEF^{op}, and ΔE^{op} the same way for their respective variables. Note that by definition, ΔC^{op} will always be zero.

Let **structural change** be equal to **build change**, which is the difference between total change and the operating change, and be represented with the superscript ^{bu}. Specifically, let ΔX^{bu} be defined as $X^1 - X^{SR}$ and define ΔC^{bu}, ΔU^{bu}, ΔG^{bu}, ΔEF^{bu}, and ΔE^{bu} the same way for their respective variables.

Here is the derivation of the formulas for operating change and build change for interventions that do not change EF.

$$
\begin{aligned}
\Delta E^{op} &= E^{SR} - E \mid Y \\
&= \sum_{r,t,p} C^{SR}_{rtp} U^{SR}_{rtp} EF^{SR}_{rtp} - \sum_{r,t,p} C_{rtp} U_{rtp} EF_{rtp} \mid Y \\
&= \sum_{r,t,p} C_{rtp} U^{SR}_{rtp} EF_{rtp} - \sum_{r,t,p} C_{rtp} U_{rtp} EF_{rtp} \mid Y \\
&= \sum_{r,t,p} C_{rtp} (U^{SR}_{rtp} - U_{rtp}) EF_{rtp} \mid Y \\
&= \sum_{r,t,p} C_{rtp} \Delta U^{SR}_{rtp} EF_{rtp} \mid Y
\end{aligned}
$$

$$
\begin{aligned}
\Delta E^{bu} &= E^{1} - E^{SR} \mid Y \\
&= \sum_{r,t,p} C^{1}_{rtp} U^{1}_{rtp} EF^{1}_{rtp} - \sum_{r,t,p} C^{SR}_{rtp} U^{SR}_{rtp} EF^{SR}_{rtp} \mid Y \\
&= \sum_{r,t,p} C^{1}_{rtp} U^{1}_{rtp} EF_{rtp} - \sum_{r,t,p} C^{SR}_{rtp} U^{SR}_{rtp} EF_{rtp} \mid Y \\
&= \sum_{r,t,p} C^{1}_{rtp} U^{1}_{rtp} EF_{rtp} - \sum_{r,t,p} C_{rtp} U^{SR}_{rtp} EF_{rtp} \mid Y \\
&= \sum_{r,t,p} (C^{1}_{rtp} U^{1}_{rtp} - C_{rtp} U^{SR}_{rtp}) EF_{rtp} \mid Y \\
&= \sum_{r,t,p} (C^{1}_{rtp} U^{1}_{rtp} + C_{rtp} U^{1}_{rtp} - C_{rtp} U^{1}_{rtp} - C_{rtp} U^{SR}_{rtp}) EF_{rtp} \mid Y \\
&= \sum_{r,t,p} (\left(C^{1}_{rtp} - C_{rtp}\right) U^{1}_{rtp} + C_{rtp} (U^{1}_{rtp} - U^{SR}_{rtp})) EF_{rtp} \mid Y \\
&= \sum_{r,t,p} (\Delta C_{rtp} (U_{rtp} + \Delta U_{rtp}) EF_{rtp} + C_{rtp} \Delta U^{bu}_{rtp} EF_{rtp}) \mid Y
\end{aligned}
$$

In this paper, the $\mid Y$ term is not used but is still present.

Models Versus Reality

For any variable, let the true value of that variable (whether or not it is in practice knowable) be represented with its normal notation and let a ^ above that variable refer to estimates of it. For example, let estimates of counterfactual emissions that would have occurred if the intervention does not occur be represented by $\hat{E}(\Delta X)$.

Relationship to the Greenhouse Gas Protocol

Note the equations laid out in this appendix are similar to the formula to calculate consequential impact in the Greenhouse Gas Protocol's *Guidelines for Quantifying GHG Reductions from Grid-Connected Electricity Projects*. According to the Greenhouse Gas Protocol, the total consequential impact of a project per MWh of an intervention, if and only if that project is additional, is the weighted average (w) of operating margin (OM) and build margin (BM), or:

Impact per MWh of an additional project according to the GHGP = w BM + (1 − w) OM

It is possible to derive the Greenhouse Gas Protocol's formula from the formulas in this appendix. Doing so may also provide insights into the meaning of additionality and how to think about the consequential impact of projects that are not fully additional. ZEROgrid is pursuing the development of such derivations in a future report.

Endnotes

1 CEBA Deal Tracker, Clean Energy Buyers Association, May 2, 2024, **https://cebuyers.org/deal-tracker/**.

2 You-Jie Cai, "A Deep Dive Into PPAs and VPPAs in East Asia," APALA GROUP, October 17, 2023, **https://www.apalagroup.com/angles/wudgp1hcm054ccvow9mhu3waen8yl1**.

3 Derik Broekhoff, *Guidelines for Quantifying GHG Reductions from Grid-Connected Electricity Projects*, World Resources Institute, July 1, 2007, **https://www.wri.org/research/guidelines-quantifying-ghg-reductions-grid-connected-electricity-projects**.

4 Wilson Ricks, Qingyu Xu, and Jesse D Jenkins. "Minimizing Emissions from Grid-Based Hydrogen Production in the United States," *Environmental Research Letters*, Volume 18, Number 1, January 6, 2023, **https://doi.org/10.1088/1748-9326/acacb5**.

Charles Cannon, Pieter Gagnon, Gavin McCormick, Wilson Ricks, *Assessing the Impact of Voluntary Actions on the Grid: A Consensus Paper from ZEROgrid's Impact Advisory Initiative*, RMI, 2024, **https://rmi.org/zerogrid-assessing-impact**.

RMI values collaboration and aims to accelerate the energy transition through sharing knowledge and insights. We therefore allow interested parties to reference, share, and cite our work through the Creative Commons CC BY-SA 4.0 license. **https://creativecommons.org/licenses/by-sa/4.0/**.

All images used are from iStock.com unless otherwise noted.

RMI Innovation Center
22830 Two Rivers Road
Basalt, CO 81621

www.rmi.org

© May 2024 RMI. All rights reserved.
Rocky Mountain Institute® and RMI® are registered trademarks.