Exploration of Methods for Determining Operational CO_2e Emissions

Steve Baden, RESNET
David B. Goldstein, David B. Goldstein and Associates, Inc.
Philip Fairey, Florida Solar Energy Center

ABSTRACT

RESNET® promulgated an ANSI Standard in 2022 specifying a methodology for determining the operational CO_2e emissions attributable to energy use in dwelling units. This methodology utilizes the NREL Cambium database for the Long-Run Marginal Emission Rates (LRMER) of combined pre-combustion and combustion CO2e emissions from 20 Generation and Emission Assessment (GEA) regions across the contiguous U.S. The levelized, month-hour, LRMER values, levelized over the 25-year period from 2025 through 2050, are used to determine the hourly CO_2e emissions resulting from the hourly energy use projections of accredited building simulation modeling. The legacy method of determining operational CO_2e emissions is based on the historical, empirical data published by the Environmental Protection Agency (EPA) in their eGRID database. The eGRID database is broken into multiple sub regions across the U.S. very similar to the GEA regions of the Cambium database. As such, it is reasonable to compare the two methods of determining operational carbon emissions. One of the principle reasons for determining operational carbon emissions in residences is to examine the consequences of design and construction decisions on the future emissions; thus the 25-year time frame. This paper examines these two basic methods of operational carbon emission determination using the RESNET-accredited EnergyGauge® USA v8 residential building energy simulation tool in 12 representative climates across the contiguous U.S. covering all IECC climate zones and a large variety of eGRID sub regions and Cambium GEA regions.

Introduction

The world has taken on increasingly ambitious carbon reduction goals over the past decade. These are expressed by national, regional, and international organizations such as the International Energy Agency (IEA) as societal carbon emission goals, which are in turn translated into organizational-level or building level policies (IEA 2023).

At a high level of aggregation, these policies call for fast and continuing reductions in emissions, primarily driven by energy efficiency, flexibility of demand in buildings, and expanded use of renewable energy. (DOE 2023). There is also general agreement among the IEA and U.S. agencies, including the Environmental Protection Agency (EPA) and the Department of Energy (DOE), not only on broad policy directions but also on what physical actions need to be taken to meet the broader goals.

Energy efficiency and some of renewable energy deployment is very distributed: it occurs in billions of buildings and millions of industrial plants. Each of them is likely to examine how each measure affects its own emissions and answer the question: "How do I know if specific recommendations apply in my individual case?"

To do this requires analytic tools that assign correct amounts of emissions from each direct emitter to each user. This is a Scope 2 calculation in terms of Life Cycle Analysis: while buildings and industrial plants are responsible for the overwhelming share of greenhouse gas emissions (referred to in this paper and broadly in the literature as "carbon emissions"), these are mostly indirect, as the physical emission is at the power plant or fuel production or distribution system.

The problem is that the high-level recommendations have evolved continually over the past decade, recognizing how the world's electricity grids have been shifting from primarily fossil fuel-based to heavily renewables-based. However, the facility-level metrics have not changed: they are still based implicitly on renewable energy being a small market whose effects are not seen in a significant way at the building level.

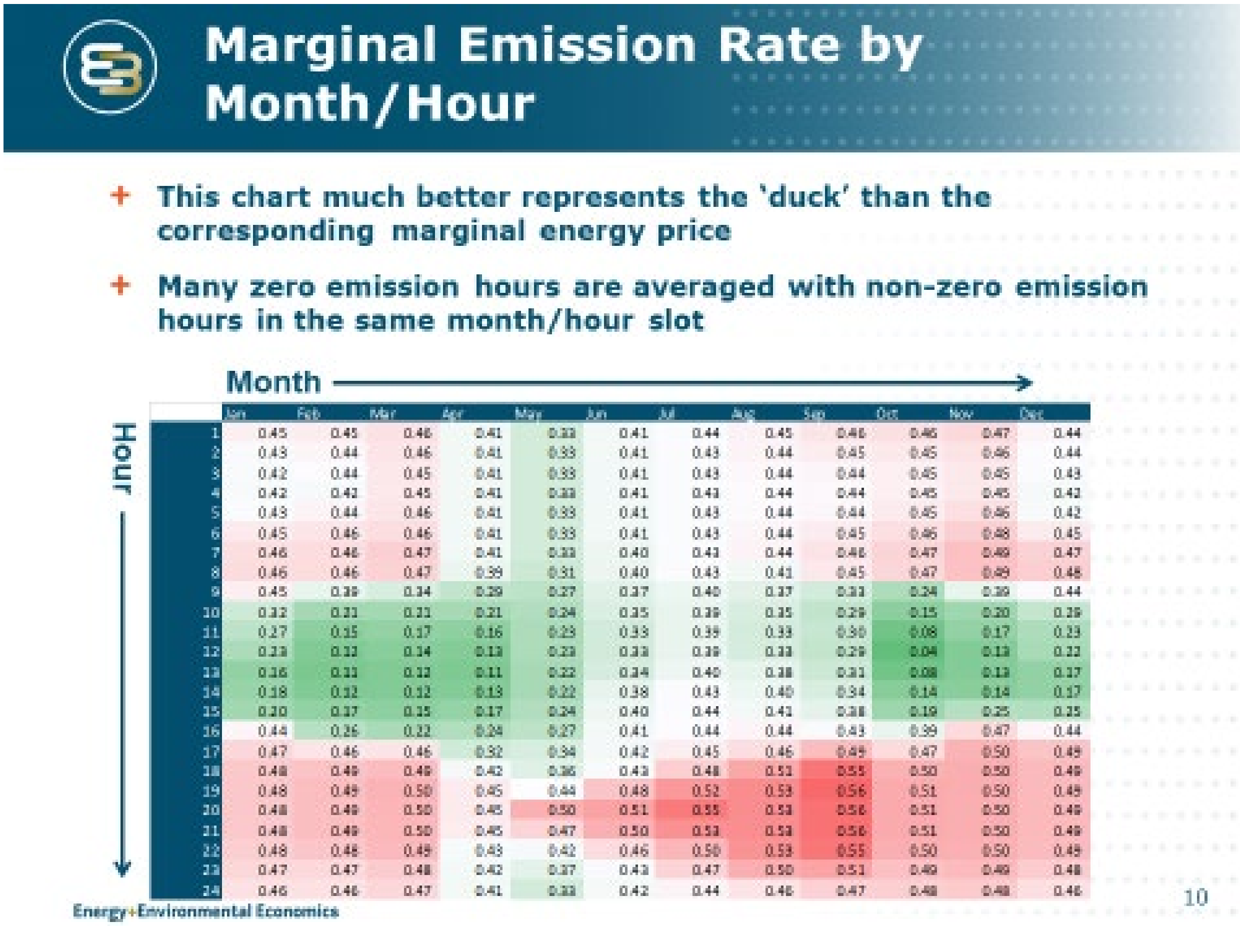
This disconnect presents major problems in implementation, in which trusted agencies, such as DOE and EPA and the IEA, advise building owners and operators to do one thing (e.g., electrify heating, electrify motor vehicles, and employ thermal storage for water heating and usually for space heating) while the building-level metrics often advise the reverse. Thus, the current metrics for carbon analysis undercut accepted global policy recommendations.

This paper proposes a broad reform of protocols for how carbon emissions analysis is done, and focuses on a case study of what RESNET and others have done to implement a standard for correctly calculating operational building carbon impacts in the U.S.

Summary and Goals for Climate Change Mitigation

Most life cycle analysis is based on or consistent with the WRI Greenhouse Gas Protocols (WRI 2013), which were developed, reviewed and revised over several years beginning about 2001. Thus, they evaluate carbon emissions by simply multiplying energy consumption by an annual average conversion factor. These methods were written and standardized at a time before renewable energy became a large and often dominant contributor toward grid performance. Thus, they are based implicitly on the assumption that to a good enough approximation, energy consumption is proportional to carbon emissions.

This seemed a reasonable assumption at the time (~2009-13), but things were rapidly changing. This assumption is now shown to be much less predictive of observed emissions than those based on long-run hourly marginal analysis (Gagnon and Cole 2022): As grids became more dependent on renewable energy, the effect of time variability of renewable power output became more and more important. Figure 1 shows a 2018-vintage understanding of the problem, as presented by the California Energy Commission to RESNET members, which in retrospect is quite consistent with the more detailed analysis performed several years later by the National Renewable Energy Laboratory (NREL). See Gagnon and Cowiestoll 2023, for a description of the technical basis for NREL's Cambium database of hourly long-run marginal emission rates.



Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.45	0.45	0.46	0.41	0.33	0.41	0.44	0.45	0.46	0.46	0.47	0.44
2	0.43	0.44	0.46	0.41	0.33	0.41	0.43	0.44	0.45	0.45	0.46	0.44
3	0.42	0.44	0.45	0.41	0.33	0.41	0.43	0.44	0.44	0.45	0.45	0.43
4	0.42	0.42	0.45	0.41	0.33	0.41	0.43	0.44	0.44	0.45	0.45	0.42
5	0.43	0.44	0.46	0.41	0.33	0.41	0.43	0.44	0.44	0.45	0.46	0.42
6	0.45	0.46	0.46	0.41	0.33	0.41	0.43	0.44	0.45	0.46	0.48	0.45
7	0.46	0.46	0.47	0.41	0.33	0.40	0.43	0.44	0.46	0.47	0.49	0.47
8	0.46	0.46	0.47	0.39	0.31	0.40	0.43	0.41	0.45	0.47	0.49	0.48
9	0.45	0.39	0.34	0.29	0.27	0.37	0.40	0.37	0.33	0.24	0.39	0.44
10	0.32	0.21	0.21	0.21	0.24	0.35	0.39	0.35	0.29	0.15	0.20	0.29
11	0.27	0.15	0.17	0.16	0.23	0.33	0.39	0.33	0.30	0.08	0.17	0.23
12	0.23	0.12	0.14	0.13	0.23	0.33	0.39	0.33	0.29	0.04	0.13	0.22
13	0.16	0.11	0.12	0.11	0.22	0.34	0.40	0.38	0.31	0.08	0.13	0.17
14	0.18	0.12	0.12	0.13	0.22	0.38	0.43	0.40	0.34	0.14	0.14	0.17
15	0.20	0.17	0.15	0.17	0.24	0.40	0.44	0.41	0.38	0.19	0.25	0.25
16	0.44	0.26	0.22	0.24	0.27	0.41	0.44	0.44	0.43	0.39	0.47	0.44
17	0.47	0.46	0.46	0.32	0.34	0.42	0.45	0.46	0.49	0.47	0.50	0.49
18	0.48	0.49	0.49	0.42	0.36	0.43	0.48	0.51	0.55	0.50	0.50	0.49
19	0.48	0.49	0.50	0.45	0.44	0.48	0.52	0.53	0.56	0.51	0.50	0.49
20	0.48	0.49	0.50	0.45	0.50	0.51	0.55	0.53	0.56	0.51	0.50	0.49
21	0.48	0.49	0.50	0.45	0.47	0.50	0.53	0.53	0.56	0.51	0.50	0.49
22	0.48	0.48	0.49	0.43	0.42	0.46	0.50	0.53	0.55	0.50	0.50	0.49
23	0.47	0.47	0.48	0.42	0.37	0.43	0.47	0.50	0.51	0.49	0.49	0.48
24	0.46	0.46	0.47	0.41	0.33	0.42	0.44	0.46	0.47	0.48	0.48	0.46

Figure 1. Marginal emission rates for the California grid, as presented to RESNET in February 2018.

In the light of accelerating commitment to renewables everywhere, this trend toward time-dependent emission factors will spread globally and accelerate.

Coupled with this observation are the policy choices that have spurred renewable energy development. Grid operators increasingly will dispatch renewables preferentially; and in many jurisdictions an additional kWh of consumption must be offset by some fraction of a kWh of newly constructed renewables, so the capital stock of renewable generation will also increase with electricity sales and electricity sales will increase with electrification.

Thus, if one is concerned about calculating the effect on societal carbon emissions of an action that an individual facility or organization takes, one must take into account the marginal source of generation both from dispatch and from construction, and differentiate by time of use.

This is not a surprising result in 2024: The International Energy Agency (IEA) has identified three widely accepted pillars of decarbonization that rely implicitly on this type of analysis. They are

- Electrification of low- and moderate-temperature heat by replacing fossil fired boilers and heaters with heat pumps
- Use of thermal and battery storage and other methods that can transfer electricity consumption from the red hours on Figure 1 to the green hours, and

- Electrification of motor vehicles.

These recommendations are made almost universally.

The problem is that for many grids around the world, some of which are in the United States, traditional methods of analysis using annual energy use data will show these three actions to be losers on emissions. For example, adding energy storage to a facility to offset grid emissions during high emission periods will increase energy use for the facility. If carbon emissions are based on this annual energy use increase, the exact wrong message will be sent for energy storage.

This means that implementation of the accepted measures for decarbonization will be undercut by calculations that will show that they do not appear to cut carbon emissions.

This error is potentially a bigger problem than it looks. Economic theory says that organizations attempt to maximize profits, but profitability is not predictable going forward. So typical behavior for an organization is to establish Key Performance Indicators (KPIs) and optimize the value of these parameters.

For carbon, the calculation method is the definition of the KPI for climate. If the variability of the KPI—its response to a given proposed change in facility design and operation—goes in the opposite direction of what the true effect on global emissions is, this will thwart climate mitigation until it is corrected.

Thus, the urgency of the recommendations of this paper.

Attributional versus Consequential Calculations

The traditional methods of averaging emission factors are using what is called "attributional" accounting measures. This use is appropriate under some conditions. But it is inappropriate for decarbonization planning. For such cases, which are dominant under a climate mitigation solution, "consequential" accounting methods are more appropriate because they address what the consequences are of taking a new action. In economics language, attributional accounting looks at average outcomes, whereas consequential accounting looks at marginal differences in outcomes. Only the use of marginal accounting produces optimal results, especially if life-cycle assessment is the desired outcome.

Therefore, consequential accounting methods are recommended for action such as climate mitigation by consensus standards such as ISO 14044, ISO 14049, and ISO 50010.

How Should the Future be Treated in this Calculation?

As noted, the grids of the world are changing rapidly, in large part in response to the newly tightened[1] climate stabilization goals. So the grids last year will be measured as a lot dirtier than the grids in 5 or 10 years. Which year(s) should the KPI look at?

It makes sense to match the carbon calculation period to the period of effectiveness of the mitigation measure in question. For a long lived measure such as improving the efficiency of a

[1] Tightened because the 2 degree goal was replaced with the goal of "well under 2 degrees" with an additional goal of less than 1.5, followed by a public shift in emphasis to the 1.5 degree goal. Also the definition of degrees changed to provide a greater protection against uncertainty by referring to a 70th percentile calculation of the limit not being exceeded int the climate models compared to the previous 50th percentile.

.

house, RESNET chose to use a levelized hourly emission rates from 2025 to 2050. See Kruis 2022 for a more detailed rationale statement. For shorter-lived interventions the more appropriate time period will be shorter. RESNET is developing a new ANSI candidate standard based on hourly metering data that is considering using a much shorter look-ahead period.

Writing and Adopting Standards

RESNET's Decision to Address the Issue of Carbon Accounting

The question of changing carbon accounting began to be raised at RESNET meetings in the mid-2010s in response to analyses that were being performed by the California Energy Commission, the National Renewable Energy Laboratory (NREL), and others.

Previously RESNET used the EPA's eGRID for modeling carbon reductions in RESNET's HERS® Index rated homes.

This was judged inadequate. Several speakers at RESNET conferences, and in particular Dave Roberts of NREL, gave an influential presentation at the 2018 RESNET® Conference showing that *when* energy is used is as important to utilities as *how much* is used. This generated significant interest among the RESNET community and may have helped NREL obtain support for the analytical work that was published a few years later as Cambium.

This evolution paralleled growing interest in the homebuilding industry. Increasingly builders are having their homes HERS rated and the HERS Index Scores, energy savings and carbon reduction reported in their Environmental, Society and Governance (ESG) reporting. Financial decisions are being made based on these reports. It was therefore critical that RESNET employ a more accurate method of modeling carbon emissions.

The RESNET Board recognized that action needed to be taken and in 2019 constituted a Board Working Group on Incorporating When Energy is Used or Load Flexibility in HERS® Index Scores This led the Board to approve the development of an ANSI standard for a Carbon Rating Index. The new standard was approved through the ANSI process and is contained in RESNET/ICC ANSI Standard 301, Addendum B, published in 2022.

ASHRAE Actions

The ASHRAE committee charged with its residential energy standard 90.2 decided overwhelmingly in 2020 to continue to expand its presence as a leadership standard, defining leadership to include explicit responsibility for environmental quality issues including both indoor environmental quality and greenhouse gas emissions. Thus, the path was cleared to use carbon emissions calculated in accordance with RESNET 301 as a regulated parameter. In 2023, 90.2 published an Addendum that set a maximum limit on the CO_2e Rating Index as calculated in accordance with the RESNET 301 Standard. This requirement was an additional requirement rather than a replacement for the Energy Rating Index (ERI) to assure survivability under extreme conditions as well as limiting carbon emissions.

The required value for this parameter was reduced in 2024 in parallel with reductions in ERI.

ISO Activities

The International Organization for Standardization (ISO) took on the question of carbon accounting by an indirect or evolutionary process. ISO's Technical Committee on Energy Management began a process of writing a standard for Net Zero Energy in 2016. As the working group in charge of the Net Zero standard began its work, it started recognizing that there were several different levels of zero in the world literature and in conferences, levels with different scopes and boundaries. Two of the most commonly used levels were net zero Energy and net zero Carbon.

The ISO Working Group analysis recognized that these goals were different—Net Zero Carbon is much more ambitious—but that the calculational methods used by most jurisdictions failed to make this distinction. Or worse, they made the distinction in words but the equations undercut the language. This conflict is obvious in retrospect: if carbon is calculated by multiplying energy by an annual conversion factor, then net zero carbon will be identical to net zero energy because zero energy times ANY POSSIBLE CHOICE of emissions rate must always equal zero carbon.

The results of this effort were the publication of ISO/PAS 50010: 2023 (ISO 2023), as discussed in Goldstein and Park, 2023. This standard establishes at least six nested levels of net zero and strongly recommends the use of hourly long-run marginal emission rates, citing RESNET 301 as an example of how to do so.

ISO 50010 notes that the Cambium-style data on which RESNET 301 relies may be unavailable except in the lower 48 U.S. states. In this case it asks the user to request such data of its government or energy supplier. Long run marginal hourly emission factors are expensive to generate and authorities will predictably be loath to spend the money unless they see a commercial use for it. This can be a vicious cycle, but the recommendation in the standard is a positive sign that the data will be used when available. This may have been part of the dynamic behind the U.S. Department of Energy's funding of NREL to produce Cambium: the promise that an organization like RESNET would use the results in Home Energy Ratings if the data existed.

Absent such data, 50010 suggests relying on data from a similar grid elsewhere, but permits using annual factors.

Analysis of the Difference that hourly LRMER data make

Housing

This paper has discussed how and why carbon calculations were done very simply in the past and on an ongoing basis. But this simple method assures that a net zero energy home is automatically a net zero carbon home. This section discusses the analysis that demonstrates and quantifies the difference between net zero energy and net zero carbon. It shows that the difference matters in almost all cases, and using LRMER makes a big difference in many grids.

This issue was perhaps noticed first in California, where aggressive renewable policies led to renewable power generation large enough to affect the overall shape of the diurnal load curve for the Independent Systems Operator. In Figure 2, the "duck curve" shows how predicted net generation required after renewables dips more and more precipitously during the day as time progresses.

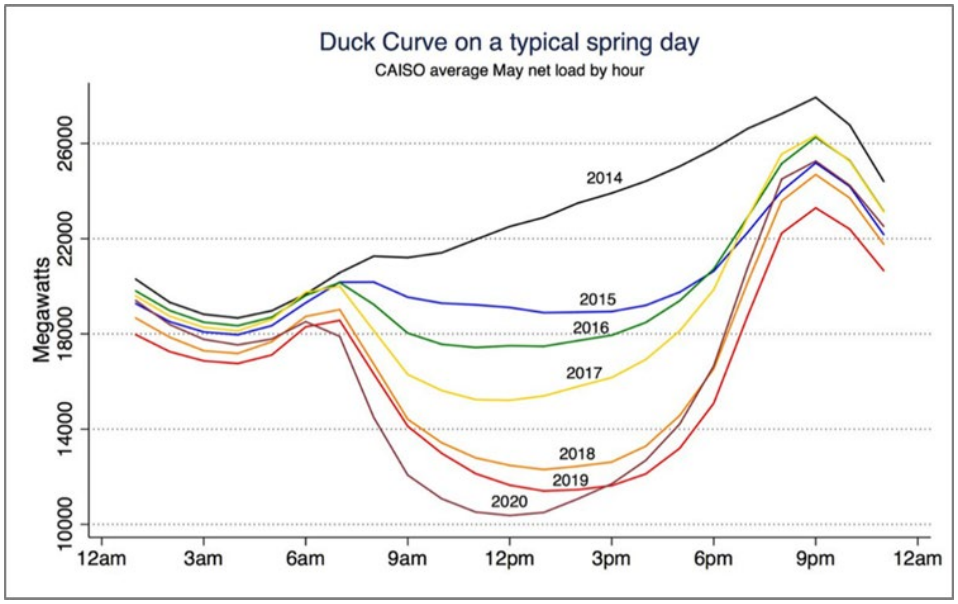


Figure 2. So called "duck curve" showing how typical spring day utility power demand changed substantially between 2014 and 2020.

Gagnon and Cole (2022) have demonstrated that, of the available carbon metrics, long-run marginal emission rate (LRMER) is better correlated to observed changes in utility emission rates than either short-run marginal emission rates (SRMER) or average emission rates (AER). This section shows how substantially the results differ.

LRMER methods have been incorporated into the Carbon Rating Index (CRI) prescribed in ANSI/RESNET/ICC Standard 301. This standard provides a repeatable methodology for calculating emissions using long-run marginal emissions, which vary by time of day and month of the year. The rationale is discussed in Fairey, et al. (2022) and Kruis (2022).

The concept of net zero energy homes is rooted in research on residential energy efficiency. When renewable energy is expensive, buildings employ efficiency first and then renewable energy. That is the original concept behind net zero energy homes and it still is. Russel (2010) provides a synopsis on how the concept matured over time and Parker and Dunlop (1994) discuss the first efforts toward achieving the goal of net zero energy in the field.

The definition of NZE homes is based on an ANSI Standard.[2] A NZE home is capable of producing all of its annual energy needs using renewable energy resources. Using traditional annual emission factors, this definition will produce similar results (net zero) for carbon.

But the energy demand does not need to match the renewable generation. During the day PV produces more power than is needed by the home which is returned to the home during periods when the PV is not producing energy. This process of net metering is assumed by default in NZE home projections.

Figure 3 presents an example (Fairey, et al., 2023).

[2] ANSI/RESNET/ICC 301, *Standard for the Calculation and Labeling of Dwelling and Sleeping Units Using an Energy Rating Index.*

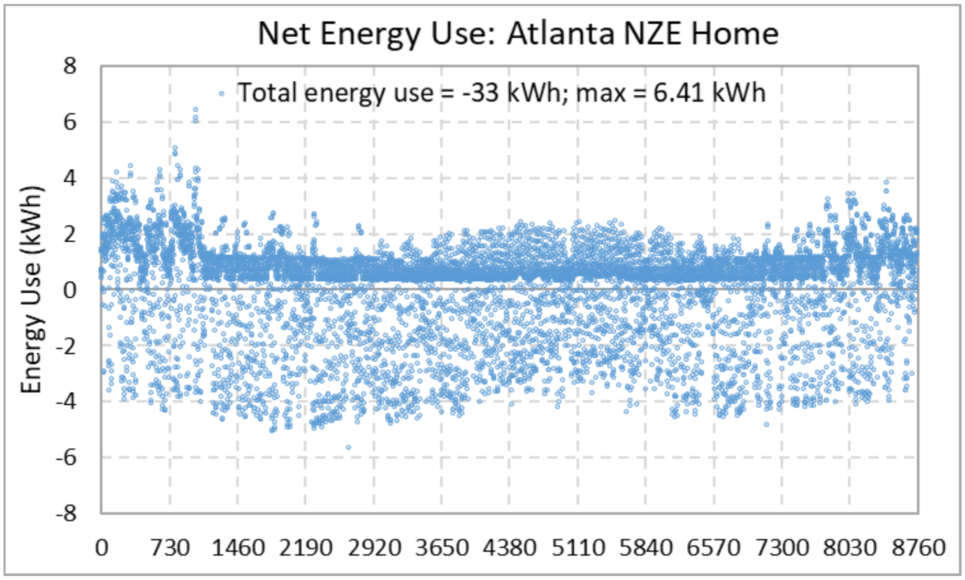


Figure 3. Hourly energy use for highly efficient NZE home in Atlanta, GA.

This NZE home is not a net zero carbon home because it matters when that kWh of electricity is generated. Grid emissions are heavily dependent on time of day and month of the year. Emissions are significantly smaller during periods when utility generation is using renewable resources and larger during periods when utility generation is using conventional fuels.

The National Renewable Energy Laboratory (NREL) developed an extensive database of utility generation and emission assessments based on a publically available utility capacity expansion model (Cohen, et al. 2019) that projects the evolution and operation of the electric sector in the contiguous U.S.[3] This database, named *Cambium*, contains forward-looking generation and emission data based on different metrics and economic scenarios across 134 balancing areas. The data are also presented as Generation and Emission Assessment (GEA) regions that mimic the U.S. EPA eGRID sub regions.[4] Figure 4 illustrates how the Cambium regions are virtually identical to the eGRID sub regions.

[3] http://www.nrel.gov/analysis/cambium.html
[4] https://www.epa.gov/egrid

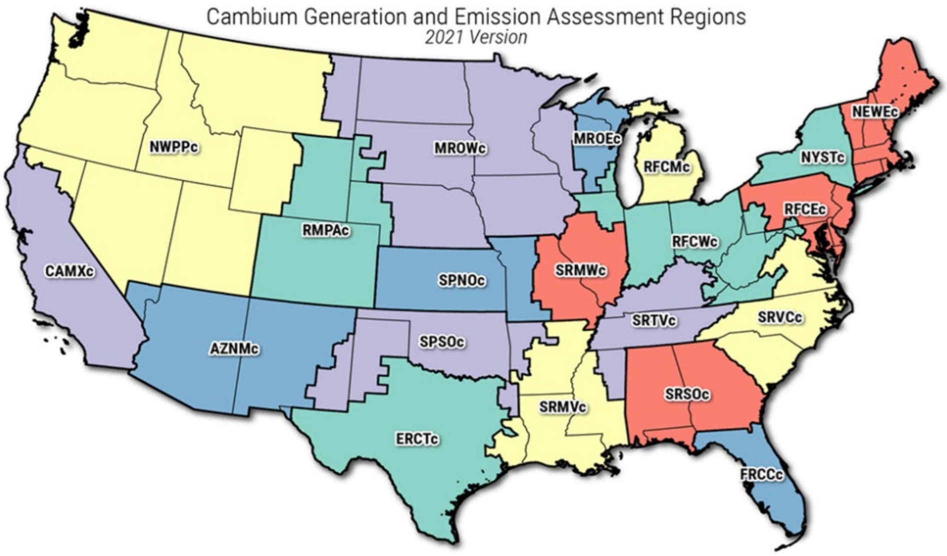


Figure 4. Map of 20 Cambium Generation and Emission Assessment Regions

The very large difference between the two data sets is that eGRID data are historical data that do not reflect how the grid will change in response to changes in demand for electricity, either in real time over the course of the day and the seasons of the year or in the future.

Economists call these marginal emissions and distinguish them from average emissions. The whole foundation of economics is based on the recognition that for the economy to produce optimal results, not just for energy but for everything, decisions on current and future actions must be based on marginal calculations.

The Cambium data used in the analysis presented here are based on long-run marginal emission rates (LRMER). They include projections of how the grid is likely to change in response to demand, both immediately and in the future. The Cambium data are presented for two year periods from 2022 through 2050. The results presented in this article use the levelized 2021 Cambium LRMER data for the 25-year period from 2025 to 2050 with a 3% social discount rate.[5]

Use of Cambium's LRMER data to make emission projections over the next 25 years yields substantially different results than use of eGRID (EPA 2022) data to make projections over the same time period. Fairey et al. (2023) evaluated very efficient homes that comply with ASHRAE Standard 90.2 in twelve U.S. climate locations. Figure 5 presents results from this analysis.

[5] https://data.nrel.gov/submissions/183

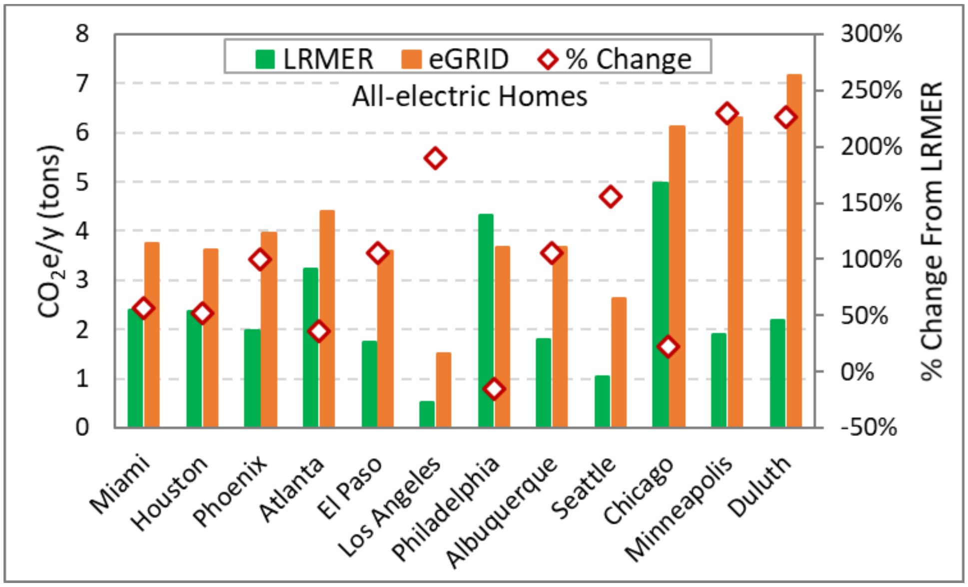


Figure 5. Projected annual CO_2e emissions in twelve U.S. climates showing the difference between LRMER and eGRID-2022 emission projections.

These result show that where eGRID data are used to project CO_2e emissions, the result is more than two times greater than the LRMER result in some cases (Minnesota cities).

These results also illustrate a basic difference between carbon accounting techniques. The eGRID technique assumes there will be no change from past data. This method of carbon accounting is called attributional accounting. The levelized, LRMER carbon accounting technique is referred to as consequential accounting, because it measures the consequences of specific actions to decarbonize the grid.

In consequential accounting the fact that policy and cost decisions are driving increasing electrification and a cleaner grid over time changes the value of the metric being used to assess the carbon emissions.

Why is a net zero energy home not a net zero carbon home? Figure 6 provides a heat map of the CO_2e emission rates from the Cambium LRMER database for the levelized emissions in the region containing Atlanta, GA (SRSOc).

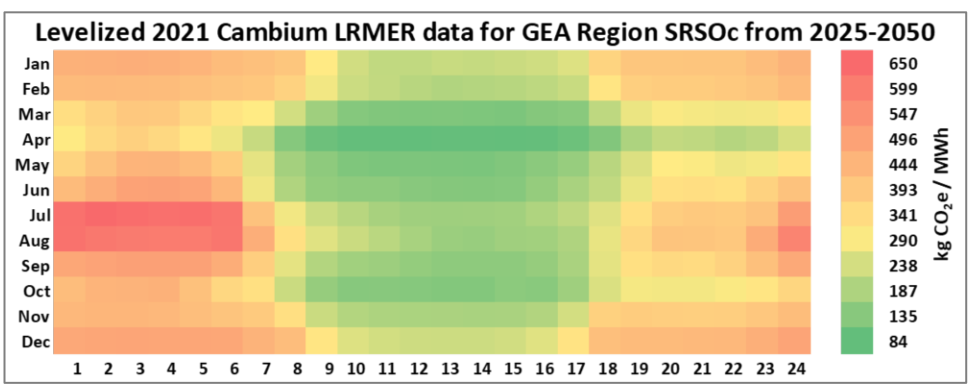


Figure 6. Levelized LRMER data for Atlanta's Cambium GEA region.

Figure 6 shows that emissions during the hours of 9 through 16 will be significantly smaller during most of the year than emissions during the night and evening. The differences in emission rates in the Atlanta GEA vary by almost an order of magnitude, from 84 kg/MWh to 650 kg/MWh.

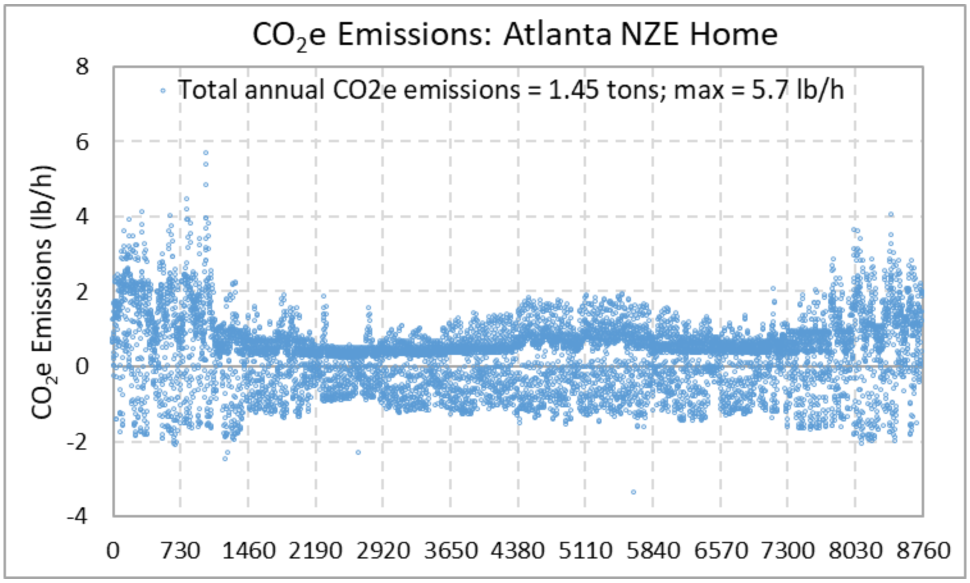


Figure 7. Hourly CO_2e emissions for Atlanta NZE home showing that total annual carbon emissions remain at 1.45 tons for this NZE home.

According to Figure 7, 1.45 tons of CO_2e emissions remain for this Atlanta NZE home. This is a good deal more than net zero. Can we simply add battery storage to offset the remaining 1.45 tons of carbon from this home? The answer to this question is no. The PV system that makes this Atlanta home a NZE home has a 6.75 kWdc capacity. It produces sufficient power to achieve net zero energy but it produces that energy at the exact same times of the day when the electric grid is the cleanest (see Figure 6). Battery storage will not get the home all the way to net zero carbon because the PV system is not large enough, regardless of battery storage capacity.

Figure 8 shows the PV production, the net energy use after accounting for the PV production and the Atlanta grid emission rate for the first week of the year. The first week of the year is selected because it represents one of the periods during which CO_2e emissions are larger than normal (see Figure 7). These emission rates vary from a low of about 0.45 lb/kWh at around noon to a high of about 1.0 lb/kWh around 3 a.m. in the morning.

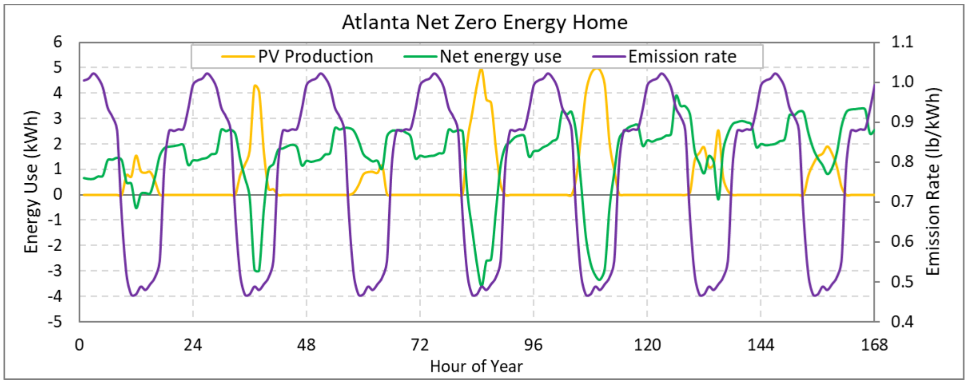


Figure 8. PV production, net energy use and the grid emission rates for the Atlanta NZE home for the first week of the year.

Where a 21 kWh battery storage system with a very simple charge and discharge control algorithm is added to this home, it reduces total annual emissions from 1.45 tons to 0.61 tons. For this simplified control algorithm, the battery is charged whenever PV production is greater than the home energy demand and the battery capacity has not been reached. Where the battery capacity is exceeded, the excess power is returned to the grid. The battery is then discharged whenever the house energy demand is greater than the PV production until the battery has been fully discharged.

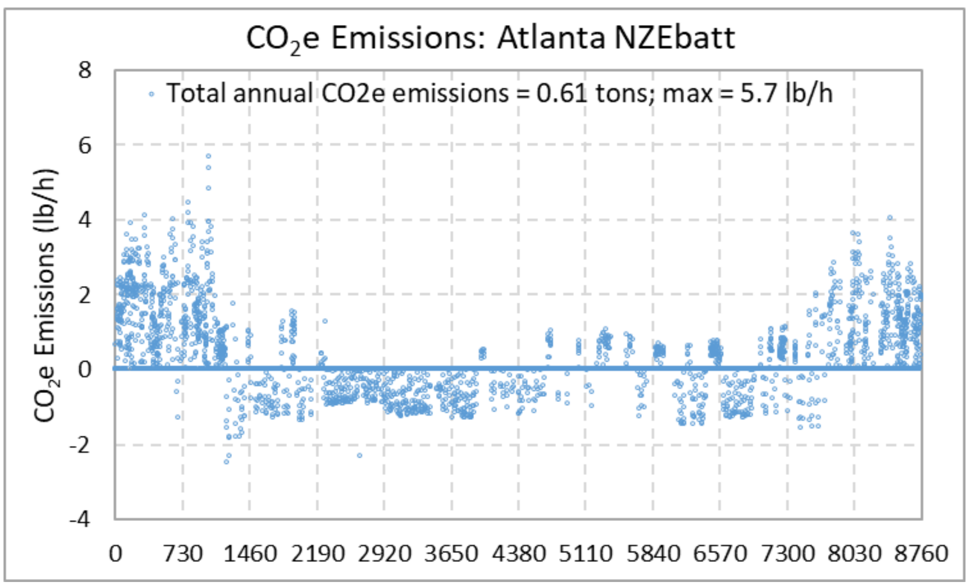


Figure 9. Carbon emissions for Atlanta NZE home with 21 kWh battery system.

Figure 8 shows the hourly CO_2e emissions for this home after the 21 kWh battery storage system is adde9. Much of the CO_2e emissions during the middle of the year are reduced but the winter emissions of the home are not altered very much. In fact, the maximum emission rate does not change. This is likely due to high weighting of night time heating requirements when emission rates are large (see Figure 7 for comparison).

For simple battery charge and discharge control, if we add more battery storage than 21 kWh, the emissions are not reduced accordingly. The impact of battery capacity for this home is shown in Figure 10.

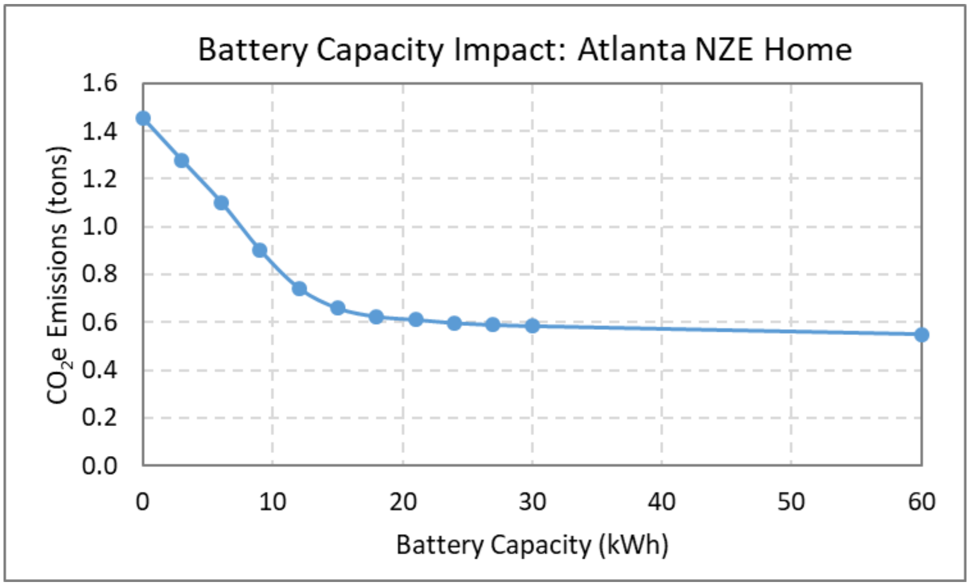


Figure 10. Impact of battery storage capacity on CO_2e emissions with simple battery storage controls

The net energy used to charge the battery storage for the home is not sufficient to overcome the full 24 hour energy demand of the home. Second, the PV power production is offsetting home energy use during the time of the day when the CO_2e emission rate is at its smallest.

Figure 11 presents battery storage results from the most productive solar energy day during the first week of the year (see also Figure 8). The integrated battery energy storage (highlighted in green) offsets the integrated home energy demand (highlighted in orange) for less than seven hours on this day. Battery charging is occurring during the period when CO_2e emissions are the smallest while battery discharge is occurring during periods when CO_2e emissions are almost twice as large.

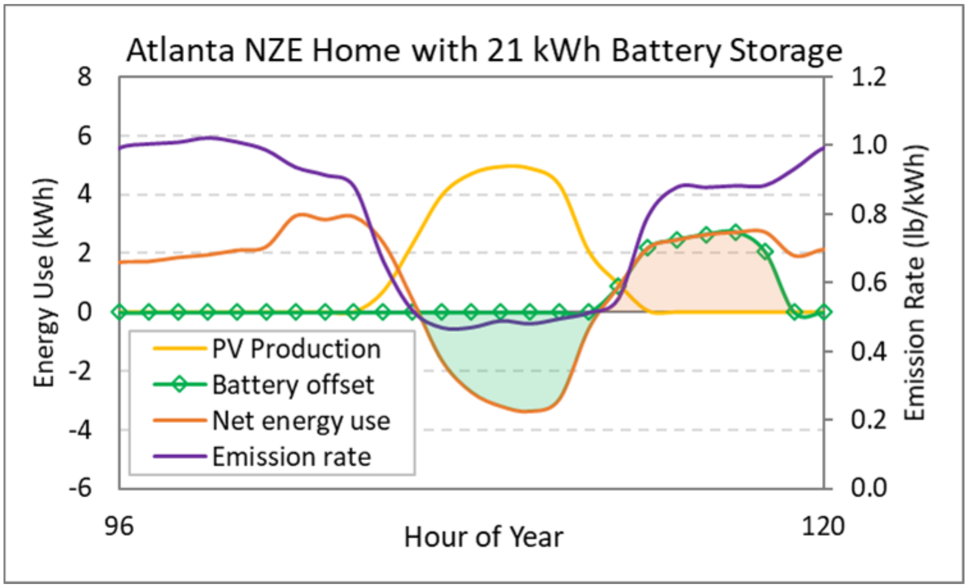


Figure 11. Battery energy charge and discharge integrals for Atlanta NZE home with 21 kWh battery storage system with simple charge and discharge controls.

Figure 11 shows that simplified battery control algorithms may not be the optimum solution for building decarbonization. If all of the PV production shown if Figure 11 is used solely for battery charging when emissions rates are small, total battery storage would be larger and a larger portion of the periods with large emission rates could be offset by the battery.

ASHRAE Standard 90.2 for high performance homes requires that homes in Atlanta, GA achieve an ERI less than or equal to 47. Standard 90.2 also requires that homes achieve a Carbon Rating Index (CRI) less than or equal to 55. Simulation analysis (Fairey et al. 2023) shows that the 90.2 compliant Atlanta home shown in Figure 3 without PV achieves an ERI of 45 and a CRI of 47. With the addition of 6.75 kWdc PV, this home achieves the hourly energy use results shown in Figure 3 – an ERI of 0 but a CRI of 21.

Net zero carbon can be achieved in two ways: by increasing PV capacity without battery storage or by increasing PV capacity plus battery storage. Achieving a CRI of 0 with only PV capacity will require a 12.225 kWdc PV system. Increasing the PV system size to 9.6 kWdc coupled with a 19 kWh battery storage system will also achieve a CRI of zero.

Table 1 shows that net zero energy is not net zero carbon – by 21 points in this case. It illustrates the fact that adding energy storage increases energy use, resulting an increase in ERI – so net zero energy is no longer NZE. Finally, it shows that there are multiple ways to achieve net zero carbon.

Table 1. Getting to net zero carbon with the Standard 90.2 home in Atlanta, GA.

ASHRAE Standard 90.2 Atlanta Home Cases	ERI	CRI
Minimally compliant home	45	47
NZE home with 6.75 kWdc PV	0	21
Home with 6.75 kWdc PV and 21 kWh battery storage	2	10
Home with 9.6 kWdc PV	-19	10

Home with 9.6 kWdc PV and 19 kWh battery storage	-17	0
Home with 12.225 kWdc PV	-37	0

The results shown here are determined using the energy and carbon calculation methods specified by ANSI/RESNET/ICC 301. These results illustrate the critical importance of using hourly energy use and emission rate data in the evaluation of building decarbonization. As illustrated in Table 1, where demand control strategies like battery storage are used, annual carbon emissions are reduced, as indicated by the change in CRI score. However, annual energy use is increased as indicated by the increase in ERI score for the homes with battery storage. On the other hand, the use of annual energy use data to estimate carbon emissions would say that the carbon emissions for battery storage are increased rather than decreased because annual energy use is increased as shown in Table 1. Additionally, where annual energy use is used to calculate carbon emissions the NZE home would always show zero carbon emissions because zero times any emission rate will always be zero. Such a zero carbon result would clearly not be in line with the reality of time of use electricity grid emissions – even today, much less into the future when the grid will become even cleaner.

Conclusion

RESNET has published standards that allow the use of levelized, hourly long run marginal emission rates (LRMER) for greenhouse gases from electricity consumption to be modeled and regulated in energy codes and specifications. This paper argues for their widespread use. These RESNET standards have been used in ASHRAE 90.2 to set normative limits on Scope 2 and Scope 1 emissions in dwelling units. A reasonable skeptical question is: how much difference does LRMER make?

This paper looks at data from simulations performed to estimate differences in prototypical homes as compared with eGRID emission data. Up to 250% difference is observed. There are substantial differences from the reference case, where ERI and CRI are not very different, to options that include solar PV and battery storage. They show that time of day is critically important and validate what practitioner experience has also found: that net zero carbon is a different and much more ambitious goal than net zero energy. These differences are highly visible in Atlanta, which has one of the dirtier grids in the US; thus they are predictably larger in regions more dependent on utility-level renewable energy.

Thus, the recommended use of levelized hourly LRMER emission data enhances the accuracy of carbon emission calculation enough to make a significant difference.

References

Cohen, S., J. Becker, D. Bielen, M. Brown, W. Cole, K. Eurek, A. Frazier, B. Frew, P. Gagnon, J. Ho, P. Jadun, T. Mai, M. Mowers, C. Murphy, A. Reimers, J. Richards, N. Ryan, E. Spyrou, D. Steinberg, Y. Sun, N. Vincent, and M. Zwerling (2019). "Regional Energy Deployment System (ReEDS) Model Documentation: Version 2018." United States. https://doi.org/10.2172/1505935

EPA, (2022) "eGRID 2022 Summary Tables." Released 1/30/2024, accessed 2/2/2024.

Fairey, P., D. Goldstein, C. Eley and P. Gagnon (2022) "Evaluating Long Term Greenhouse Gas Emissions in Buildings." *Proceedings of ASHRAE International Building Decarbonization 2022 Conference, pp 9-16*. American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA.

Fairey, P., R. Vieira and K. Fenaughty (2023) "Market Driven Residential Energy Codes: Getting to Zero." Contract Report FSEC-CR-2123-23, Florida Solar Energy Center, Cocoa, FL https://publications.energyresearch.ucf.edu/wp-content/uploads/2023/11/FSEC-CR-2123-23_GettingToZero.pdf

Gagnon, Pieter, Cowiestoll, Brady and Schwarz, Marty. NREL 2023. Cambium 2022 Scenario Descriptions and Documentation. https://www.nrel.gov/docs/fy23osti/84916.pdf.

Gagnon, Pieter and Cole, Wesley. Planning for the evolution of the electric grid with a long-run marginal emission rate. iScience Article, 2022.

Goldstein, D. and Park, J, 2023. "Approaches to Net Zero Carbon in Industry: ISO/PAS 50010", Proceedings of the 2023 ACEEE Summer Study on Energy Efficiency in Industry. Washington, D.C.: American Council for an Energy-Efficient Economy,

ISO (International Organization for Standardization). 2023. *Energy management and energy savings — Guidance for net zero energy in operations using an ISO 50001 energy management system.* ISO/DPAS 50010:2023(E)

IEA (2023), Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach, IEA, Paris https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach, Licence: CC BY 4.0

Kruis, Neal 2022. "*RESNET Load Flexibility Task Group: Developing Ratings that Incentivize Demand Responsive Buildings and a Cleaner Grid.",* Proceedings of the 2022 ACEEE Summer Study on Energy Efficiency in Buildings. Washington D.C.: American Council for an Energy-Efficient Economy, 2022.

Parker, D. S. and J.P. Dunlop (1994) "Solar Photovoltaic Air Conditioning of Residential Buildings." *Proceedings of ACEEE 1994 Summer Study, Panel 3, Paper 21, pp 3.189 – 3.198*. American Council for an Energy-Efficient Economy, Washington, DC.

Russel, S. (2010) "Evolution of the American Zero Energy House." *International Journal of Sustainable Construction Engineering & Technology*. WIT Transactions on Ecology and the Environment, Vol 128, pp. 471-481. http://dx.doi.org/10.2495/ARC100401

Rangnathan, Janet et.al, The Greenhouse Gas Protocol. World Resources Institute, 2013.

DOE (2023) U.S. Department of Energy. *Decarbonizing the U.S. Economy by 2050: A National Blueprint for the Buildings Sector.* https://www.energy.gov/eere/decarbonizing-us-economy-2050-national-blueprint-buildings-sector.

WRI (World Resources Institute) 2013. Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard.