Enhancing Carbon Reduction Estimation: A Time-Centric Analysis of Vermont's Clean Energy Programs

Efficiency Vermont R&D Project: GHG Reduction

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Executive Summary

Building on a long track record of reducing energy use statewide, Vermont's clean energy program efforts now include transitioning fossil fuel energy use onto an increasingly renewable electric grid and shifting energy time of use to periods where renewable sources represent a larger portion of grid generation. Quantifying the carbon reduction of these efforts might require greater consideration for the time component of energy use. Higher-frequency data sources for carbon emissions and program impact can enable a more granular accounting of program outcomes.

This project explores the value of higher frequency methods to better inform impact estimates for carbon reduction. Using hourly data for carbon emissions and program savings, two separate modeling exercises compare carbon reduction estimates for different impact summarization periods.

- Ex post: the first model reviews the annual emissions reductions for a historical project scenario, comparing different emissions reduction estimation methods to a ground truth based on actual emissions data from the Independent System Operator – New England (ISO-NE) grid.
- Ex ante: the second explores a program implementation context, comparing those same methods to current program impact estimation practices using long-run emissions data from the New England Avoided Energy Supply Cost study.

Recommendations

Generally, using an average emission factor to determine the emissions saved by a particular efficiency measure is nearly as accurate as using an actual, unique emission factor for every hour of the year. In rare cases when efficiency measures have very high use while the grid is especially clean or dirty, using an average emission factor can cause an emission savings overestimate error of 100% or an underestimate of 50%.

Introduction

The looming climate crisis has driven ambitious public policy goals to reduce carbon emissions through reductions in energy use and shifts to cleaner forms of energy. Demand-side clean energy programs have responded to that call, building on their track record of cost-effective energy efficiency and demand response programs to include efforts focused on decarbonization. An electric grid that continues to shift toward renewable energy sources and other lower-carbon alternatives complements these decarbonization efforts and necessitates the move towards more targeted clean energy programs that align energy use to periods of low carbon intensity on the grid. Informing these targeted efforts might require an advance in current methods for estimating avoided carbon, with a focus on higher frequency data for both program impacts and grid emissions.

Efficiency Vermont designed a research project to investigate updated estimation methods for avoided carbon impacts of current and future program efforts. The methods reviewed use higher-frequency data to characterize program impact and associated avoided emissions on the grid. The project seeks to understand whether these methods can provide more precise estimates for carbon reduction and if updated methods can provide valuable insights for program planning and deployment that balance increased cost and complexity.

The project consists of:

- A review of approaches to estimating avoided carbon from clean energy programs in other jurisdictions
- An inventory of data and methods that Efficiency Vermont can use in an updated approach
- An analysis comparing updated methods to current program practice
- A process review of the feasibility of shifting to updated methods

Background

Shifting toward a low-carbon future requires changes in both energy generation and energy use. Additional renewable energy resources move the grid toward lower carbon emissions, but the availability of these resources is time dependent, with differing levels of production depending on the time of day and year. Achieving clean energy goals is not as simple as totaling energy demand across a year and matching it with an equivalent amount of clean generation. This transition requires a balancing act where clean generation and energy use match more closely in real-time. Electrification efforts have the potential to move demand-side energy use onto a cleaner grid, but that transition will build load and shift current times of peak demand. Traditional energy efficiency and demand-response efforts have an ongoing role to play, reducing overall energy use and shifting that use toward times of day when the grid uses cleaner-generation sources. Additional recognition of the time dependence of impacts from clean-energy programs will allow for better coordination between the transition toward a lower-carbon grid and the deployment of complementary demand-side decarbonization efforts, including energy efficiency, flexible load management, and electrification.

Vermont has set legally binding targets for greenhouse gas reduction. The 2020 Global Warming Solutions act requires the state to reduce greenhouse gas emissions 26% by 2025 in comparison to 2005, 40% by 2030 in comparison to 1990, and 80% by 2050 in comparison to 1990.[1] Additional activities driven by legislative statute complement long-running Vermont Energy Efficiency Utility (EEU) program efforts by encouraging the transition of Vermont's grid to cleaner-energy sources and reducing fossil fuel–driven emissions through the electrification

[1] https://climatechange.vermont.gov/about

of heating, process, and transportation. The 2015 Vermont Renewable Energy Standard (RES) requires Vermont's Distribution Utilities (DUs) to adhere to three tiers regarding the acquisition and retirement of renewable energy attributes as well as the achievement of fossil fuel savings from energy transformation projects. Tiers I & II require the retirement of qualified renewable energy attributes or credits with a goal of total renewable energy and distributed renewable generation respectively at different thresholds. Tier III requires that DUs perform a variety of energy transformation projects that result in fossil fuel savings.[2] The recently passed Clean Heat Standard follows a similar path to the RES, seeking to drive a transition towards cleaner heating by requiring fossil-fuel wholesalers to support clean heating services such as weatherization, heating electrification, and lower-emissions fuels.[3]

Efficiency Vermont and the state's other EEU programs continue to support the state's clean energy goals through energy use reduction and transitions to clean energy sources. To incentivize Efficiency Vermont's carbon reduction efforts, the program's goals include a quantitative performance indicator for greenhouse gas reduction that accounts for 5% of the program's total performance award[4]. The accounting process to track progress towards that goal focuses on avoided marginal emissions on the ISO-NE grid for electricity; avoided emissions from direct burning of fossil fuels; and carbon reduction from non-energy sources, including efforts to reduce embodied carbon and usage of high-global-warming-potential refrigerants. This paper investigates more granular approaches for estimating avoided emissions for electricity.

Current practice for estimating the avoided emissions for electricity resulting from Efficiency Vermont's program activities already includes assumptions for time of use, but there may be value in developing more granular methods. The current approach accounts for carbon impacts from the grid over four periods: winter peak, winter off-peak, summer peak, and summer off-peak (see Appendix A). Four-period loadshapes allocate a proportion of each measure's total annual savings to each of these periods. If program decision-makers wish to tailor program efforts to better align with more granular marginal emissions, which can vary significantly throughout a day, estimating savings impacts at a higher frequency might be necessary. Updates to estimation methods could go so far as hourly impact estimates, but that level of granularity might not be necessary to provide more targeted insights.

Previous research here in Vermont has explored similar themes, investigating the potential for higher-frequency methods to inform more targeted deployment of energy efficiency and electrification programs. In 2021, Efficiency Vermont collaborated on a research project prepared for the Vermont Department of Public Service by an outside consultant that used Advanced Measurement &Verification methods to develop hourly estimates of energy savings and avoided carbon emissions for a subset of Efficiency Vermont program efforts. Comparing

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[2] https://publicservice.vermont.gov/renewables/renewable-energy-standard

[3] Clean Heat Standards: New Tools for Thermal Savings presented October 18,2023 for ACEEE – Energy Efficiency as a Resource by Richard Cowart, RAP & Chris Neme, EFG https://drive.google.com/file/d/1dQgqgP6o2wGieVj568qanfF3B61t5gOM/view

[4] Vermont Public Utility Commission order entered 9/26/2023 Case No. 22-2954-PET https://epuc.vermont.gov/?q=downloadfile/685871/171403

hourly impact estimates to Efficiency Vermont's four-period loadshapes, the study found that in cases where measures produce savings shapes that differ greatly from the ISO-NE system level load, more granular loadshapes may better capture program benefits for that subset of measures.[5]

The American Council for an Energy-Efficient Economy (ACEEE) has shown interest in exploring how GHG reduction goals are being considered and implemented at the national level. In 2021, ACEEE published "The Need for Climate-Forward Efficiency: Early Experience and Principles for Evolution,"[6] exploring the concept of aligning carbon accounting to a higher-granularity framework. ACEEE highlights the role of climate policy in driving advanced methods to better understand the impact that a given program or efficiency measure will have on the grid at a given period in time. Further work led by ACEEE explored the potential of energy efficiency to drive carbon reduction based on its "temporal, seasonal, and geographical impact," comparing emissions reductions for specific energy conservation measures using marginal emissions factors with levels of granularity ranging from 15-minute to annual. That study found that more granular emissions factors likely present value for grid regions with high levels of renewable generation and associated variability of the marginal generation source by time of day and season.[7]

This study further explores the value of more granular accounting of avoided carbon emissions in the Efficiency Vermont program context through examination of different summarization periods for avoided emissions. This examination is informed by peer energy efficiency programs that have developed program impact estimates using higher-frequency methods. The question of value goes beyond methodological questions to include the feasibility challenges for implementing new methods given available data, Efficiency Vermont's tracking infrastructure, and the Vermont regulatory environment. With a grid shifting towards more renewable forms of generation, the findings provide insights on alternative methods for estimating carbon reduction for potential use in targeting time-sensitive energy program implementation efforts.

Peer Utility and Energy Efficiency Programs

A review of peer programs by the research team suggests that time-sensitive carbon analysis is at the cutting edge of carbon accounting practices. The team identified three programs that already use or are actively developing hourly carbon accounting methods: Sacramento Municipal Utility District (SMUD), Energy Trust of Oregon, and Maryland energy efficiency programs. These updates in methods have only occurred in the past few years.

[5] https://publicservice.vermont.gov/sites/dps/files/documents/VT%20PSD%20Hourly%20Impact%20of%20Efficiency%202021.pdf
[6] https://www.aceee.org/research-report/u2106
[7] https://aceee2022.conferencespot.org/event-data/pdf/catalyst_activity_32488/catalyst_activity_paper_20220810190543994_89962216_fe99_428b_9cc1_30adeef539c5

Energy Trust of Oregon lays out their methods and some motivators for higher-granularity carbon accounting in the Energy Trust of Oregon Carbon Emissions Avoidance Methodology Briefing Paper.[8] Beginning in 2022, Energy Trust transitioned to higher-granularity carbon accounting methods over an 8760[9] period considering marginal emissions, applied at the end-use level. This differs from their previous method of carbon accounting by applying an annual average across the portfolio. The Oregon Public Utilities Commission and the Northwest Power and Conservation Council motivated this change and provide the 8760 forecast data used in the analysis. Energy Trust is an important case study for Efficiency Vermont, as they are the most similar peer program that has considered a method shift of this kind.

The Sacramento Municipal Utilities Division (SMUD)'s 2030 Zero Carbon Plan[10] explains their case for using high-frequency generation mix data for carbon accounting. SMUD collects 8760 data from their opt-out time-of-day rates and applies them at the measure level. As a utility, SMUD benefits from collecting their own data for tracking purposes. Their desire to more closely track climate goal progress likely motivated their transition to time-of-day rates and updates to tracking methods.

Maryland's development and adoption of new carbon accounting methods occurred in 2023 alongside the drafting of an aggressive climate policy, the 2030 Greenhouse Gas Emissions Reduction Act (GGRA) Plan.[11] The state will measure lifetime GHG savings instead of its previous annual energy savings metric. Going forward, Maryland will track carbon impact of modeled generation mix at the hourly level to monitor progress toward their goals in more detail. The model considers both the emissions savings and costs associated with GHG emissions reduction measures included in the 2030 GGRA Plan.

All three programs outlined above that are now using higher-frequency data are doing so at the hourly 8760 level. Efficiency Vermont's four-period method employs broader assumptions across timeframes than would be necessary in an hourly carbon accounting scenario. Different temporal granularities offer programs options as they consider the best fit for carbon emissions accounting in their jurisdiction.

[8] https://www.energytrust.org/wp-content/uploads/2016/09/2022-Carbon-Avoidance-Methodology-Briefing-Paper.pdf
[9] 8760 represents the number of hours in one year.
[10] https://www.smud.org/-/media/Documents/Corporate/Environmental-Leadership/ZeroCarbon/2030-Zero-Carbon-Plan-Technical-Report.ashx
[11] https://mde.maryland.gov/programs/air/ClimateChange/Documents/2030%20GGRA%20Plan/THE%202030%20GGRA%20PLAN.pdf

Analysis Methods and Data Sources

Calculating Carbon Emissions

Modeling Focus

Peer research, data availability, the Efficiency Vermont measure portfolio, and Efficiency Vermont goals guided the modeling focus for this project. The research team compared two scenarios, both focused on the same energy efficiency upgrade package.

The first scenario presents an ex post analysis. It uses real-world, historical emissions data from energy usage on the New England grid to determine the accuracy of different carbon reduction estimates.

The second ex ante scenario provides a hypothetical lifetime carbon emissions comparison of those methods in a program context. How would the proposed methods compare to the existing Efficiency Vermont methods when estimating lifetime carbon reduction?

The Calculation

The calculation for carbon emissions is always the same: energy consumed multiplied by an "emission factor" that translates energy consumption into carbon emissions. For example, if one were to use 1.4 kWh of energy at a time when the emission factor is 0.49 kg CO_2e / kWh, the calculated emissions would be about 0.69 kg of CO_2e:

$$1.4\ kilowatt * hours * 0.49\ \frac{kilograms\ CO_2e}{kilowatt * hours} = 0.686\ kg\ CO_2e$$

The Emission Factor

Given that the measurement of consumed power is accurate, the resulting accuracy of any emission calculation will be determined by the accuracy of the "emission factor" that relates energy consumption to carbon emissions.

The primary aim of the following modeling is to find the calculation accuracy when using emission factors that are specific to different times of day and year. In this modeling, two sources were used for emission factors. For the ex post study that examines historical consumption, the research team used actual ISO-New England average fuel mix emissions data. For the ex ante lifetime emission projections, the research team used a projected ISO-New England emissions data set with projected values for every hour from January 1, 2021 through December 31, 2037[12].

[12] https://www.synapse-energy.com/sites/default/files/AESC%202021.pdf

Heatmaps of Emission Factors

The easiest approach to calculating a year of emissions is to find a single emission factor that is representative of that year—usually an average of all emission factors observed that year. A more accurate method would use a precise emission factor for every hour of the year. In what situation would the first method (a single average emission factor) be acceptably accurate? In what cases would the second method (hourly emission factors—8760 for the year) be necessary?

The following are heat maps of projected average fuel mix emission factors for 2026[13].

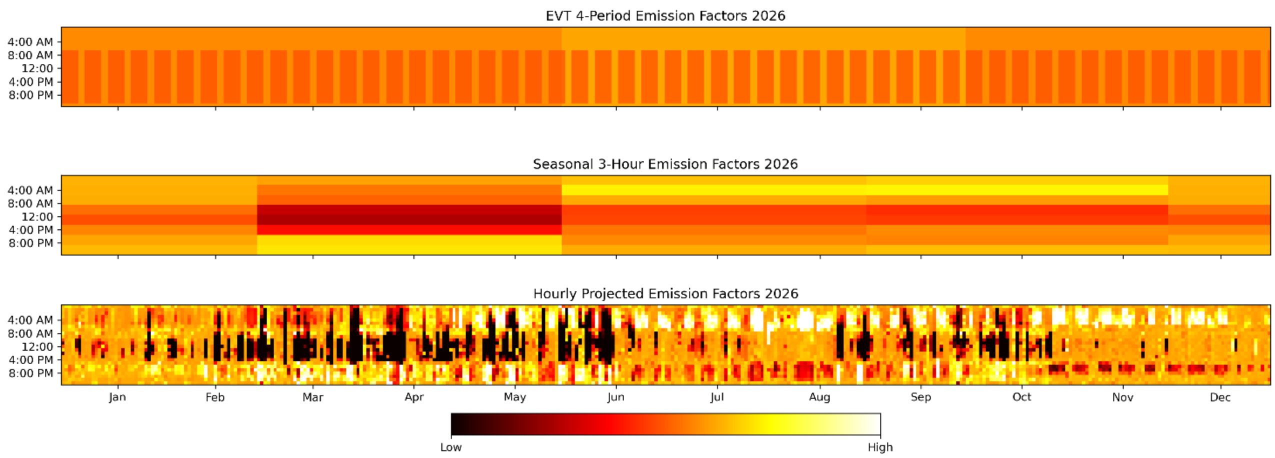

Figure 1. Projected emission factors for 2026 at three different granularities. The top heat map shows emission factors used in Efficiency Vermont's standard four-period calculation. The middle heat map shows emission factors using one of ACEEE's proposed emission factor summarizations (three-hour window, seasonal values). ACEEE summarization methods are described in greater detail in the "Emission Summarization Methods" section. The bottom heat map shows the projected emission factors at maximum resolution.

Assuming the emission factor projections in Figure 1 are accurate, a unique emissions calculation at every hour of the year yields the most accurate emissions results, but this level of detail might not always be necessary.

When the loadshape of the measure in question is relatively flat, for example, 8760 unique calculations of emissions values based on 8760 data for the entire year are not necessary to produce an accurate emissions value. If energy usage is close to the same over all periods of the year, using an average fuel mix emission factor introduces minimal inaccuracies.

Conversely, if a loadshape varies and is biased toward higher or lower than average emissions, using an average fuel mix emission factor introduces significant error. For example, referring to the 2026 projected emissions heat map, a measure that draws most heavily during the midday hours will have lower emissions than a measure that consumes the same electricity evenly over

[13] Data source: https://www.synapse-energy.com/sites/default/files/AESC%202021.pdf

all periods of the day, because often during the midday hours in 2026, the emission factor is projected to be 0 g CO_2e / kWh.

Emission Summarization Methods

There are 10 different emissions summarization methods used in these models. For the sake of being able to make a comparison ACEEE's previous work on this subject (Specian et. al.), the team duplicated the referenced study's nine summarization methods and added the summarization method currently used by Efficiency Vermont. The ACEEE summarization methods are generally accurate for many ISO regions in the United States, though less so in the California Independent System Operator region. This project presents the opportunity to compare the accuracy seen in other ISO regions to that seen in the ISO-NE region.

In Table 1 below are the average number of hours each calculated emission factor is used. Lower values imply a more specific and more accurate emission factor is being used at each hour.

Method Name	Average hours each calculated emission factor is used
Efficiency Vermont 4-Period	2190
Annual – Single Value	8760
Annual – Three Hour Window	1095
Annual – Hourly	365
Seasonal – Single Value	2190
Seasonal – Three Hour Window	273.75
Seasonal – Hourly	91.25
Monthly – Single Value	730
Monthly – Three Hour Window	91.25
Monthly – Hourly	30.4

Table 1. Summary of how many hours of a given year each calculated emission factor is used. Higher values indicate a less specific emission factor.

Here is an explanation of how each ACEEE method works:

Annual – Single Value: A single average emission factor is calculated for each entire year. In this method, all energy used during the entire year is assigned emissions with the average emission factor for that year.

Annual – Three-Hour Window: A set of eight unique emission factors are calculated by grouping neighboring hours of the day and finding an average emission factor for that three-hour period for the year. For example, the first window is from midnight to 3 AM. All of the exact emission factors over that period are averaged for the entire year, and then used to assign emissions for any energy used during that window over the year. For example, to calculate the emissions for a 7-8 PM period on July 13, one would find the emission factor for the 6 PM to 9 PM period and multiply it by the energy consumed to find emissions.

Annual – Hourly: Every hour of the day gets its own unique emission factor calculated by finding an average of that hour's emission factors over the entire year. Emissions are then calculated by multiplying energy consumption with the matching hourly emission factor. For example, if energy consumption on April 3 between 3 and 4 PM is 4.7 kWh, the emissions are 4.7 kWh multiplied by the emissions factor for the 3 to 4 PM hour.

Seasonal – Single Value: A single average emission factor is calculated for all hours of the day for an entire meteorological season. For example, to calculate emissions during the 10 AM hour of January 5, one multiplies the energy used during that hour by the average emissions factor calculated over the entire meteorological winter (December 1 through February 28/29).

Seasonal – Three-Hour Window: A set of eight unique emission factors are calculated for each three-hour window of the day and recalculated for each meteorological season. For example, to calculate the emissions for the hour of 12 AM to 1 AM on January 5, one uses an emission factor calculated by averaging all predicted emission factors between 12 AM and 3 AM for the entire meteorological winter.

Seasonal – Hourly: Same as the "Seasonal – Three-Hour Window" method, except that now the emission factor is an average of emission factors for a single individual hour of the day. In the January 5 midnight to 1 AM example, the Seasonal – Hourly emissions calculation uses an emission factor that is the average of all emission factors between midnight to 1 AM for the meteorological winter, rather than the midnight to 3 AM average used in the three-hour window method.

Monthly – Single Value: A single average emission value is calculated for each month of the year and used to calculate all emissions for that particular month, regardless of the time of day.

Monthly – Three-Hour Window: A new set of eight unique emission factors is calculated every month of the year. The eight unique emission factors come from three-hour windows throughout the day. For example, to calculate the emissions factor during the 4 PM to 5 PM hour for April 3, one would use the emission factor averaged from all emissions factors in the 3 PM to 6 PM window for the month of April.

Monthly – Hourly: Same as the "Monthly – Three Hour Window" method, except that there is a unique emission factor for each hour of the day. For the April 3 4 PM to 5 PM example, the emissions calculation uses an emission factor averaged only from the 4 PM to 5 PM hour for April, rather than the three-hour window from 3 PM to 6 PM.

Measure Focus

As a sample measure for investigation into different emission factor summarization methods, the team selected residential heat pump water heaters (HPWHs). The reasons for this selection include:

- Savings shape availability in NREL's ResStock[14] data set, specific to Vermont.
- Importance to the current and future Efficiency Vermont portfolio.
- The measure is used throughout the year, but has uneven usage intensity over the course of a day.

The average January and July savings shapes for a single-family residence employing a new HPWH are shown in Figure 2 below.

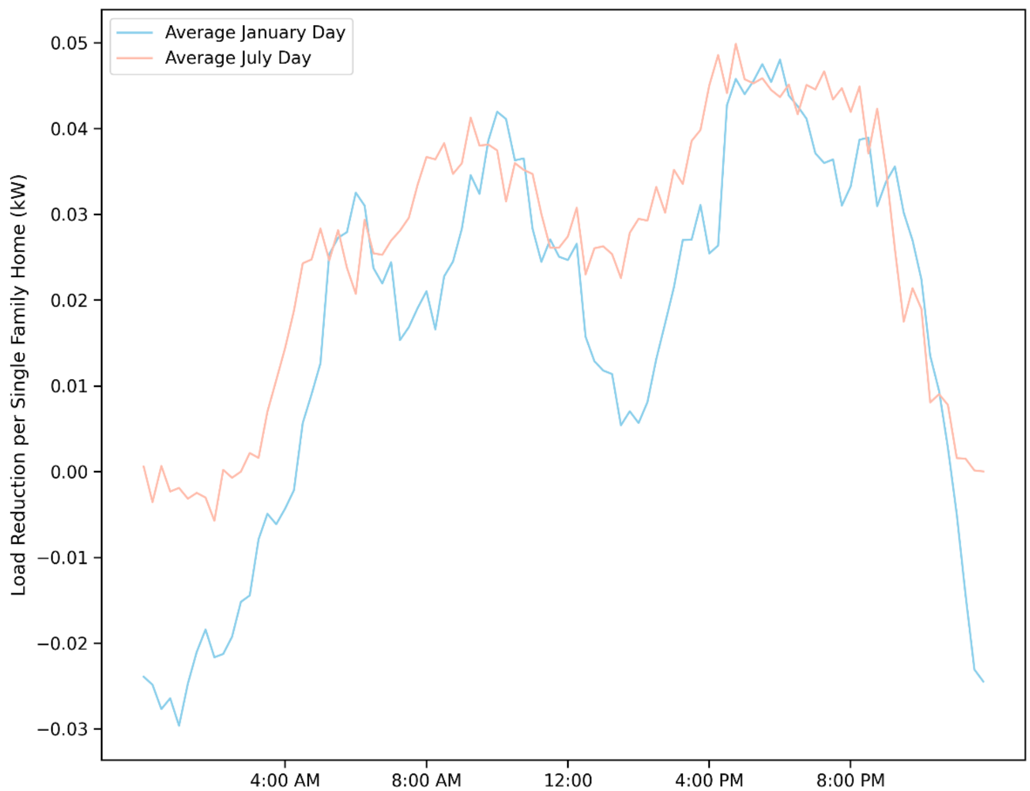

Figure 2. Savings shapes calculated by upgrading to a heat pump hot water heater in an average Vermont single-family dwelling by NREL in the ResStock dataset. These data are a summation of savings of all efficiency measures. Positive values indicate load that has been *conserved* by implementing efficiency measures. Negative values indicate load that has *increased.*

The savings shapes shown in Figure 2 may appear smaller in magnitude than expected. The NREL ResStock savings shape shows an annual decrease in electricity consumption of only

[14] The ComStock and ResStock datasets are publicly available datasets provided by NREL. They are a collection of partially disaggregated energy consumption and savings loadshapes for many kinds of commercial and residential buildings. The datasets are the result of combining energy modeling of building type and building stock along with real world AMI data from Vermont.

The datasets specific to Vermont were collected and built with assistance from Efficiency Vermont. In 2020 and 2021, Efficiency Vermont provided AMI electricity consumption data with a maximal amount of metadata (building type, behind-the-meter generation, zip code, etc.) while complying with requirements to preserve anonymity of Vermont ratepayers.

about 192 kWh—much smaller than the Efficiency Vermont calculation of roughly 1,150–2,000 kWh. This discrepancy results from NREL's calculation including households that are upgrading from oil, natural gas, or propane hot water heating. In these cases, there is an increase in electricity usage at all times of year, which lowers the average savings shape. If the calculation instead considers the median Vermont single-family household that has switched from conventional electric resistive hot-water heating, the NREL annual savings comes to 1152 kWh / year.

Figure 2 also raises the question of why the savings are negative (indicating increased load) at any point during an average summer or winter day. The primary reason for this is the difference between the loadshapes of a conventional resistive hot water heater and a HPWH. When depleted, a resistive element water heater typically draws three or four kilowatts for 60 to 90 minutes, whereas a HPWH draws perhaps a tenth of the load, but for a few hours. This difference in loadshape leaves certain hours of the day when homes are likely to see negative savings, though the overall savings should be positive. For example, if one typically takes a hot shower and starts a laundry load at 11 PM, a resistive hot water tank might replenish the expended hot water by 1 AM and turn off. The HPWH may require until 3 AM to fully replenish the hot water tank, causing negative savings for 1 AM to 3 AM period, but saving more energy overall.

Ex Post Review

The exploration below reviews a year from the past and compares different methods for accuracy. As described in the previous sections, the HPWH savings are derived from the ResStock emissions data set. One difficulty associated with using NREL's ResStock and ComStock dataset savings curves is that the savings is calculated based on the *average* energy consumption reduction. That reduction depends not only on the efficiency measure, but also the equipment that home and business owners are upgrading from.

For example, upgrading to a cold-climate heat pump from resistive baseboard heating element will see enormous savings because the CCHP saves electricity relative to the baseboard electrical heating element at all hours. The converse scenario is that the CCHP upgrade displaces an oil furnace which used very little electricity. The electricity savings is negative, even if the emissions savings is large.

With NREL's datasets, each efficiency measure's savings curve is calculated as an improvement against a market average upgrade. In the case of CCHP upgrades in Vermont, this is an upgrade calculated from a mix of oil furnaces, natural gas, wood, and electric resistance. It may be a good representation of the portfolio savings, but it is not accurate for any single case (no one is upgrading from 45% oil, 30% natural gas, 15% wood and 10% electric resistance heating).

Efficiency Vermont claims site specific savings as program impacts rather than the market average upgrade, which complicates comparisons of measure impacts calculated using

ResStock and ComStock savings shapes. Comparisons may be informative, but they do not provide a direct comparison to current program savings claims.

Monthly Summarizations

Figure 3 summarizes the monthly emissions calculations using five different methods. The "ground truth" method uses the actual emission factor for each 15-minute period of the year to calculate avoided emissions. The other four methods are described earlier.

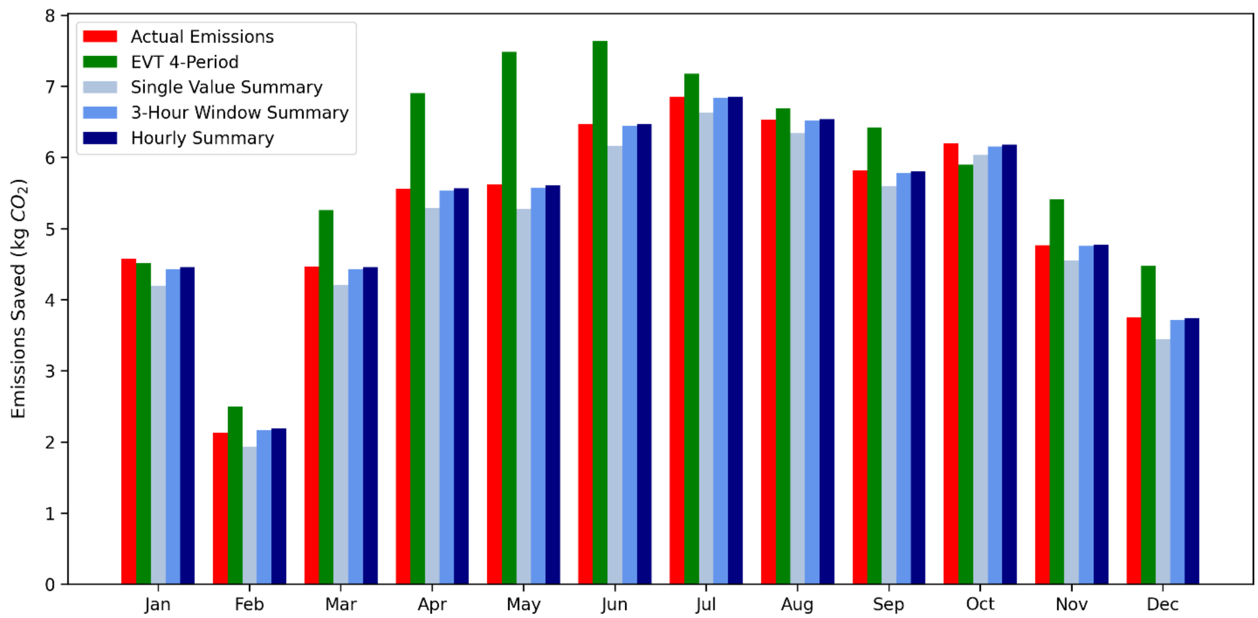

Figure 3. Monthly summary of the HPWH measure emission savings calculated using five different methods. The "Actual Emissions" bars are calculated from the actual ISO-New England emissions at 15-minute intervals over the year of 2018.

In a pattern that repeats itself in the upcoming calculations, the Efficiency Vermont four-period method tends to overestimate emissions savings for this measure (HPWH), especially in the late winter and spring, probably due to the HPWH's loadshape overlapping heavily with the very low emission factors observed during the midday hours at that time of year.

Seasonal Summarizations

The seasonal results for the same set of calculations are as follows.

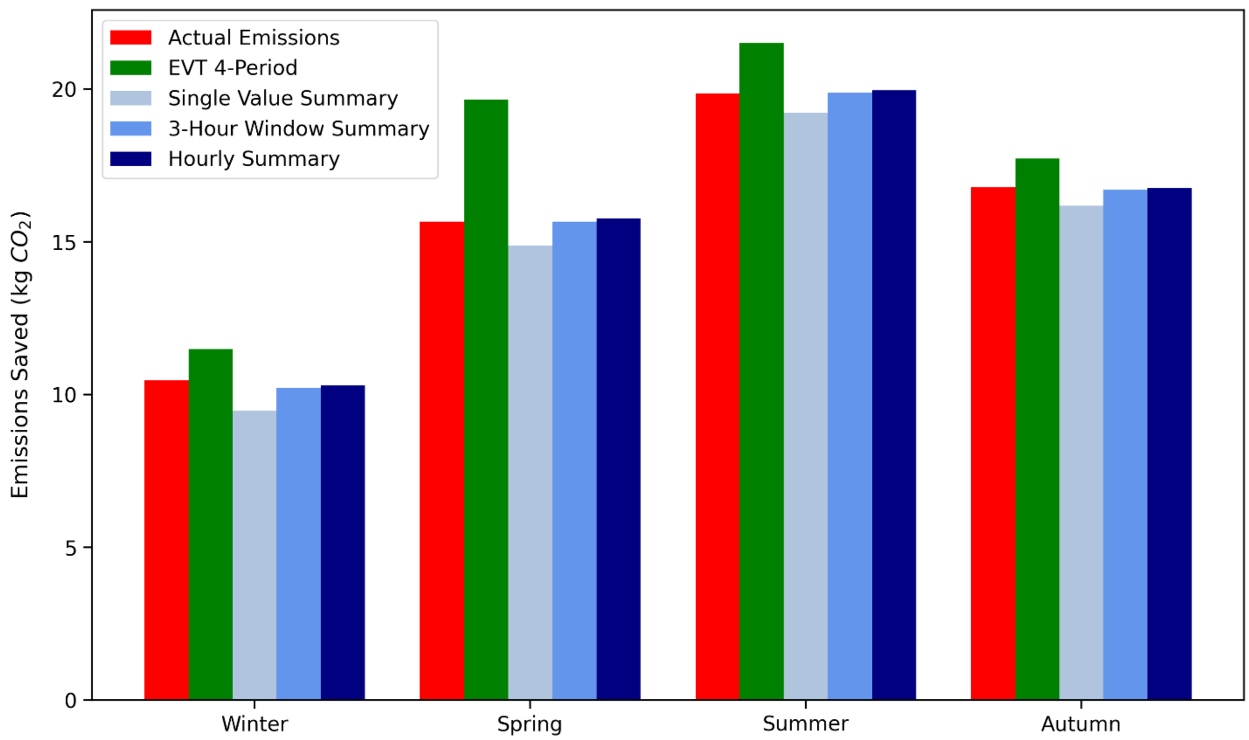

Figure 4. Seasonal summary of the HPWH measure emission savings calculated using five different methods. The "Actual Emissions" bars are calculated from the actual ISO-New England emissions at 15-minute intervals over the year of 2018. The summary methods are less accurate than in the monthly case because the summary emission factors are now used to summarize an entire season rather than a single month.

Again, the Efficiency Vermont four-period method tends to overestimate the emissions with the greatest error in the spring when it is using "peak winter" values on midday weekday hours, even though those are the cleanest hours of the entire year. The single-value summarization method consistently exhibits the largest underestimate. This results from the HPWH measure's loadshape slight bias toward hours when the grid is a bit dirtier than average.

The yearly results, below, resemble the monthly and seasonal results.

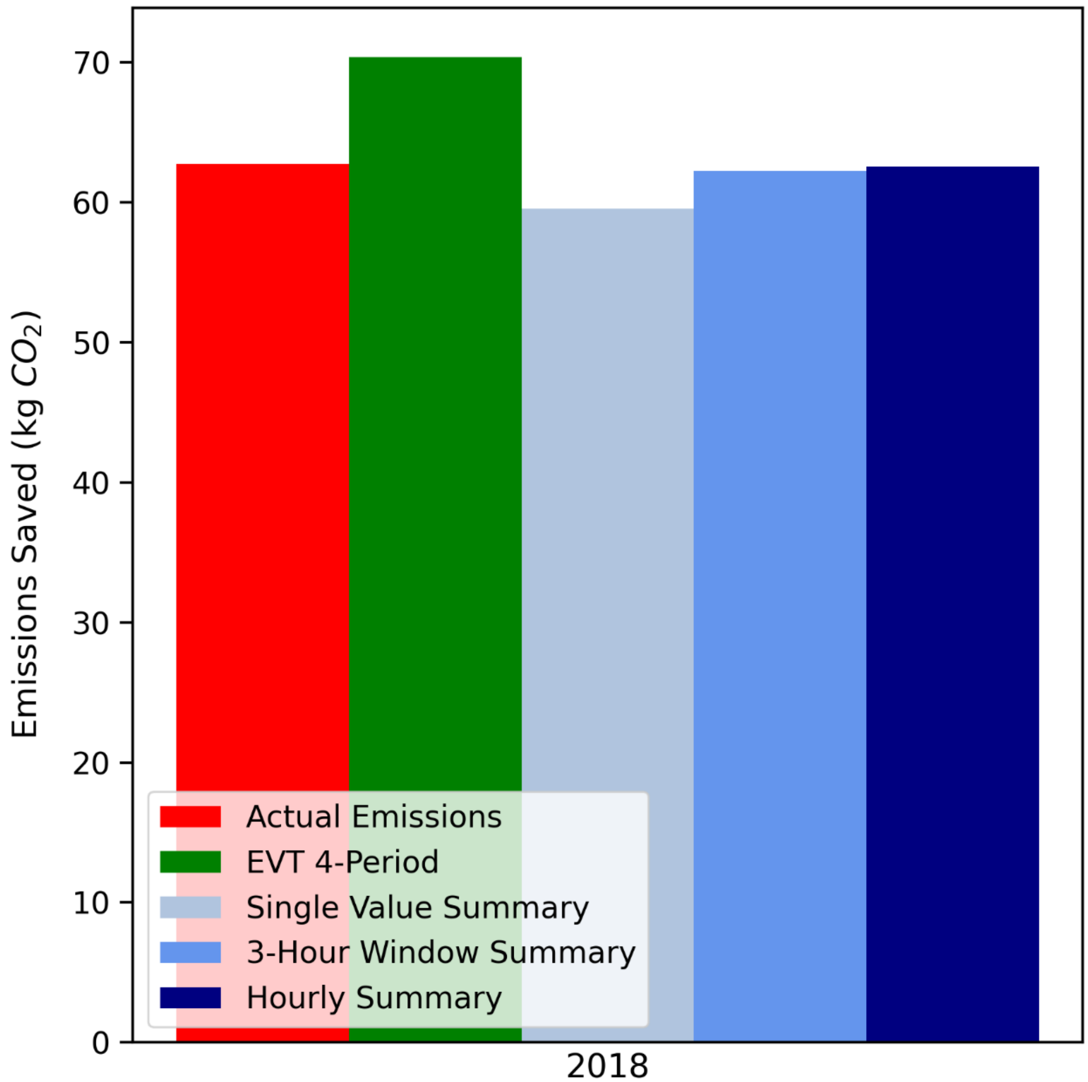

Figure 5. Annual results of emission savings calculations for 2018 for the HPWH measure.

The annual results for the same emissions calculation are expected to show increased inaccuracy for the summary methods because the same number of summary emission factors are now being used for an entire year rather than a single month. However, the summary methods all appear to be quite close to the actual saved emissions value. A probable explanation for this is that although the summarized emission factor is incorrect for many hours of the year, the error is not systematic; in the case of the HPWH measure, the times of overestimates almost exactly balance out the times of underestimates.

The Efficiency Vermont four-period method again finds a small but significant excess of saved emissions relative to the other methods.

Ex Ante Comparison

To explore the impact of differing approaches in a program implementation context, the team examined lifetime savings estimates using AESC projected emission factors for the HPWH measure. In all cases, the examined 12-year lifetime was from 2021 through 2032. Again, the hourly savings shapes and loadshapes from NREL's ResStock were used to find energy savings and emissions savings for the HPWH measure in Vermont single-family homes.

The results are as follows.

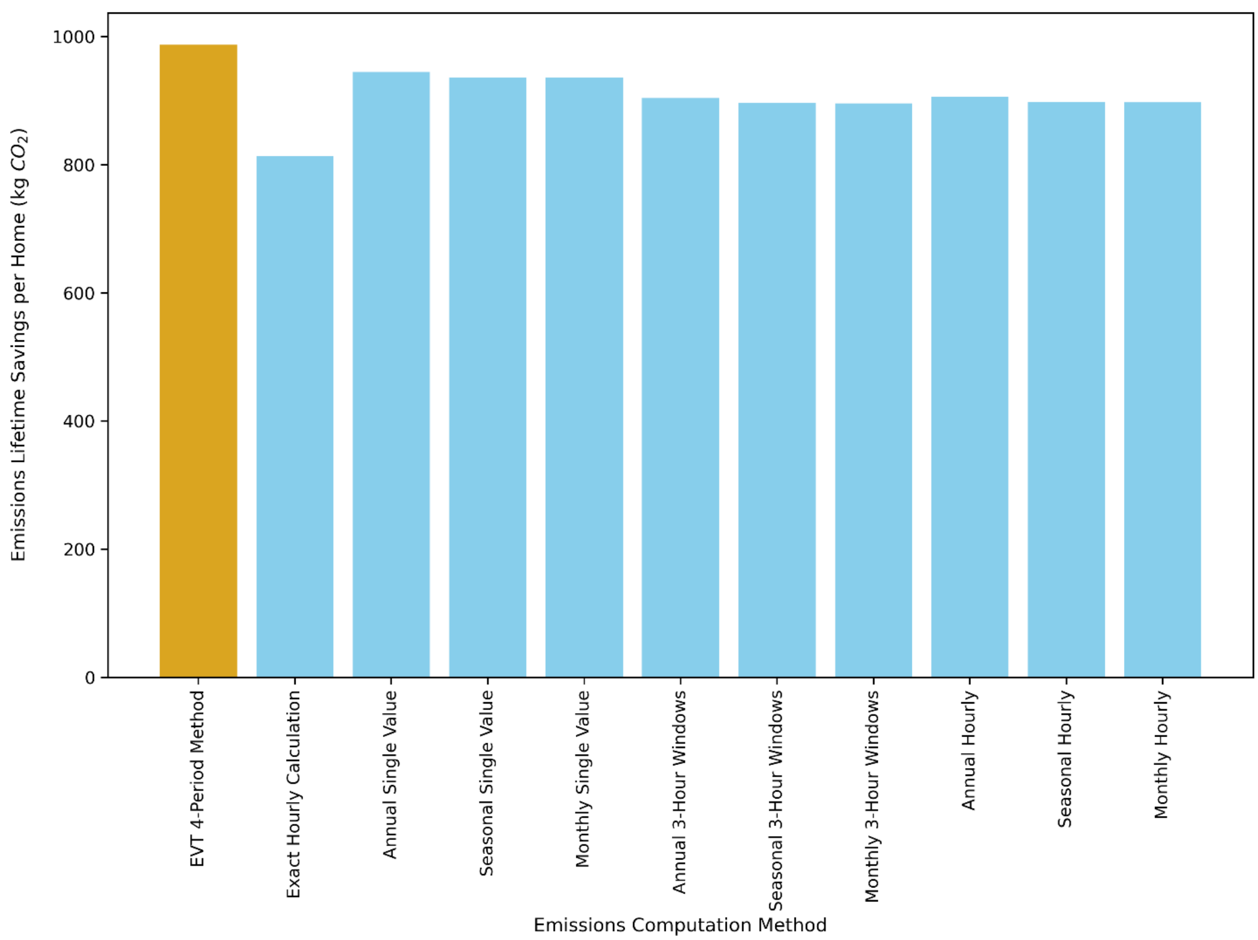

Figure 6. Lifetime (12-year) emissions savings for HPWH measure using ResStock savings shape as calculated by different methods.

As with the single year calculation, the Efficiency Vermont four-Period calculation finds the highest avoided emissions with the HPWH measure, while the "exact" hourly measurement that uses a new projected emission factor every hour finds the lowest savings.

The "exact" measurement, upon closer inspection, reveals a lot of projected values of no carbon emissions, especially during midday periods (refer to the bottom heat map in Figure 1). This midday period is overrepresented on the HPWH loadshape (refer to the loadshapes in Figure 2). Even though these projected periods of zero emissions are included in some fashion in the summaries, they are not weighted as heavily as with the “exact hourly calculation” due to the HPWH loadshape.

The Efficiency Vermont four period method suggests the largest avoided emissions, though not by a large margin. The discrepancy between the Efficiency Vermont four-period result and the other results is probably due to the large number of ‘zero emission periods’ that occur frequently in the projected 12-year emission factor dataset. It is likely that those periods are emphasized by the “exact hourly calculation” and underrepresented in the EVT four-Period method.

When Summaries Cause Inaccuracies

With any summarization of data, there is loss of information. For any given emission factor summarization, one could concoct a fictional loadshape whose savings would be inaccurately calculated using that specific summarization. If an efficiency measure’s saved electricity usage occurs disproportionately toward the grid’s very cleanest periods, that efficiency measure’s emissions reduction impact will be overestimated. Conversely, if an efficiency measure saves electricity disproportionately when the grid is especially dirty, the summarization method will underestimate that efficiency measure’s carbon emission reduction.

To discover if any existing efficiency measures have carbon impacts that are not accurately described by the summarization methods, the team ran all lifetime emissions calculations for all 19 of Efficiency Vermont’s measures for which there is a yearly projected savings shape available from the Vermont-specific dataset included in the Demand Side Analytics report commissioned by the Vermont Department of Public Service in 2021[15]. In 16 of those 19 cases, the currently used four-period summarization and all the investigated ACEEE summarizations led to emission calculations that were in agreement (+/- 20%). Below are two examples when all the tested summarization methods missed the “exact” emission calculation badly.

Four-Period Method Overestimates Emission Savings

Interior LED prescriptive lighting is an example of when the four-period method of summarizing emission factors overestimates the lifetime emission savings by about 100%. The following figure (Figure 7) summarizes the lifetime emission savings using each summarization method for prescriptive LED interior lighting.

[15] These loadshapes can be found here: https://demand.files.com/f/3b91d830cf01b64f .
They are a product of a Vermont-specific study that uses advanced measurement and verification procedures by applying LBNL’s time-of-week temperature model to real energy consumption data observed at Vermont rate-payer servicepoints. The full report can be found here: https://publicservice.vermont.gov/sites/dps/files/documents/VT%20PSD%20Hourly%20Impact%20of%20Efficiency%202021.pdf

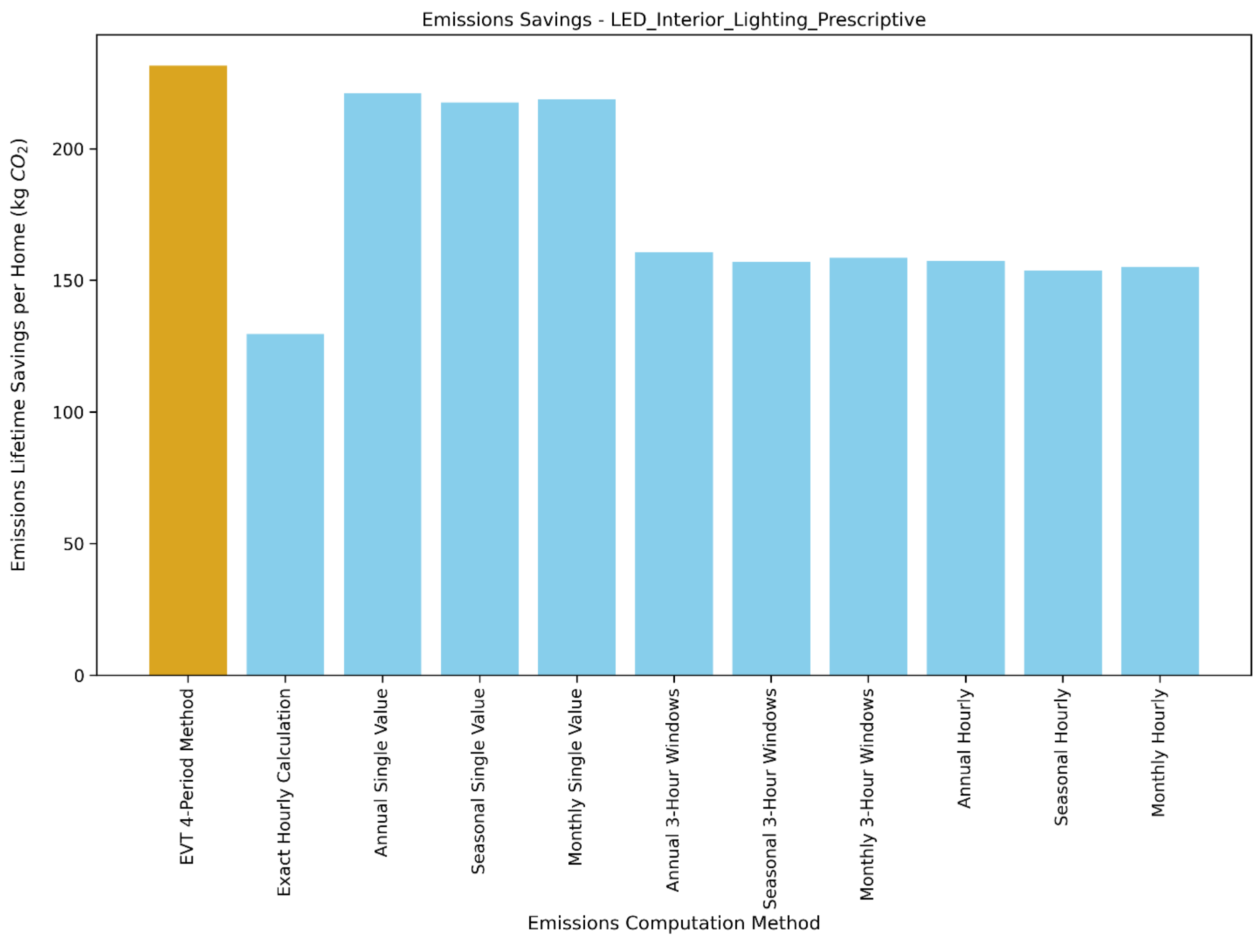

Figure 7. Emissions savings calculated for prescriptive interior LED lighting by all summarization methods. The current EVT method of calculating emissions is highlighted in yellow.

Prescriptive interior lighting shows an interesting pattern in calculated emissions among the different summarization methods. The methods that have the lowest time-of-day resolution of emission factors (single value summarizations and the Efficiency Vermont four-period summarization) all calculate emissions savings at twice the value of the highest resolution method ("exact hourly calculation"). The reason for this can be explained by looking at the savings heat map for this measure (below, Figure 8).

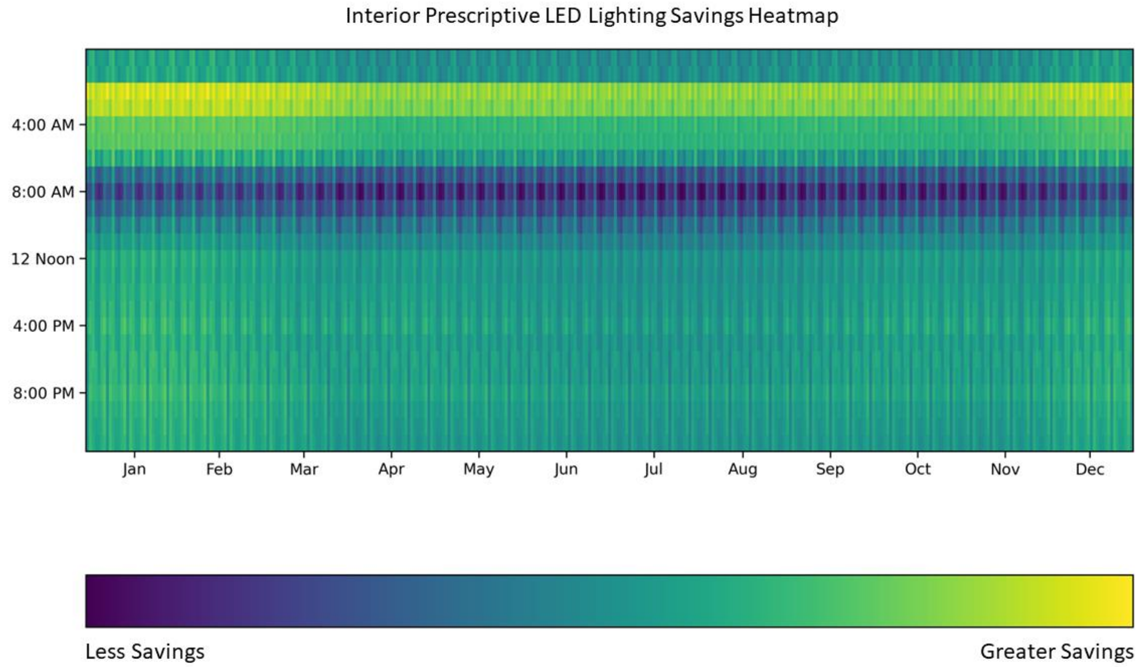

Figure 8. Savings heat map for interior prescriptive LED lighting.

The heat map of the savings for interior prescriptive LED lighting reveals the cause of the drastic overestimation of emissions savings by the four-period method. Clearly visible in the heatmap are a streak of high energy savings in the midnight to 4 AM period—typically a very low emissions period for the ISO-New England grid. Compounding the problem is that very little savings happen in the 7 AM to 11 AM period, which is typically dirtier than average. This particular energy savings shape (high at night, low during the morning peak) is a perfect storm for overestimation of emission savings by nearly any summarization method.

Four-Period Method Underestimates Emission Savings

If a way exists to overestimate savings with any summarization method, it is probable that the same summarization method with different savings shapes can underestimate savings. The underestimation of emission savings is the case seen with the advanced thermostats measure (Figure 9).

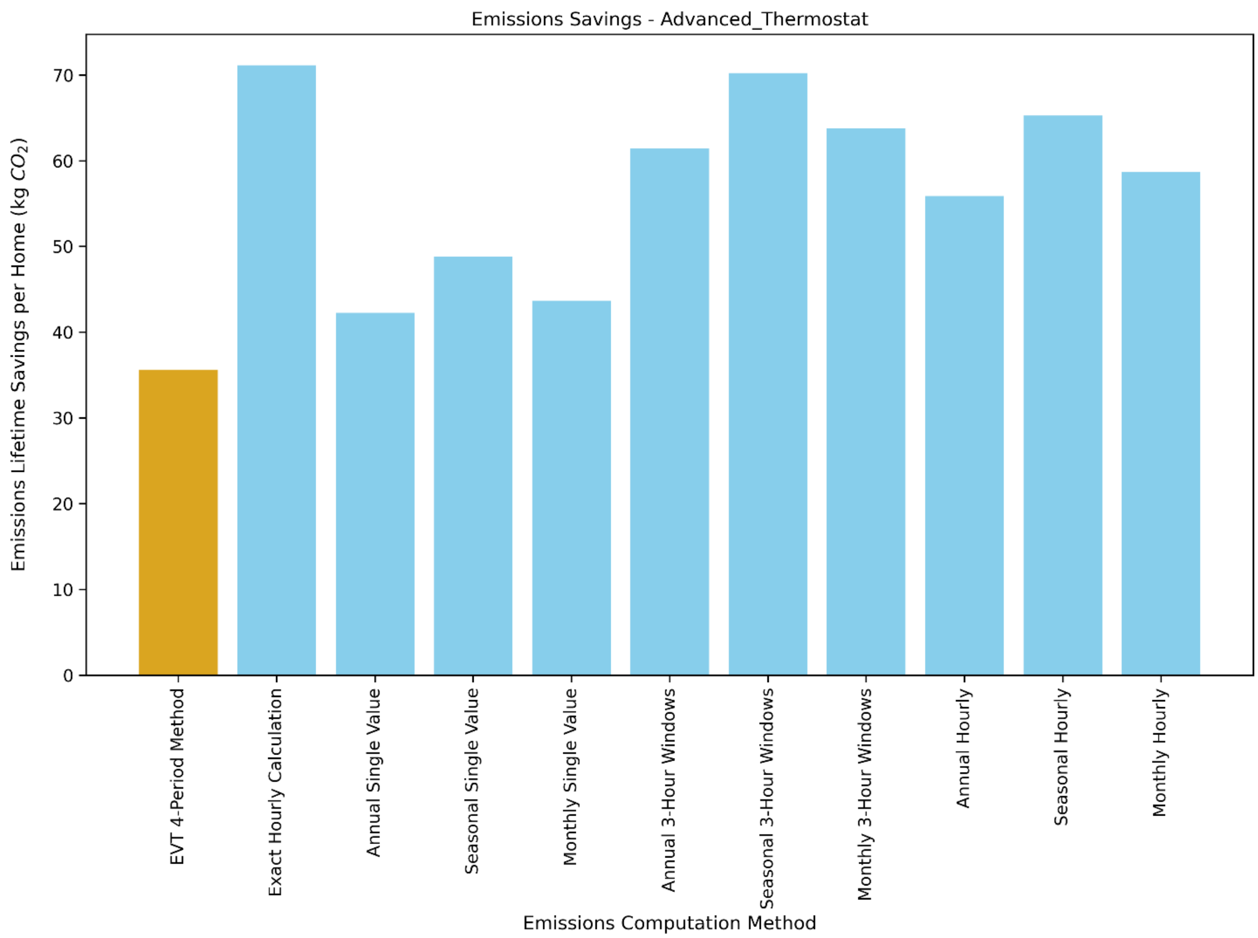

Figure 9. Emission savings calculated through all summarization methods.

Advanced thermostats show the exact opposite relationship in calculated savings between the Efficiency Vermont four-period method and the "exact hourly method": the actual emissions savings is almost exactly double the savings calculated by the Efficiency Vermont method. As in the savings overestimation case, this can be explained by looking at the energy savings heat map for the advanced thermostat.

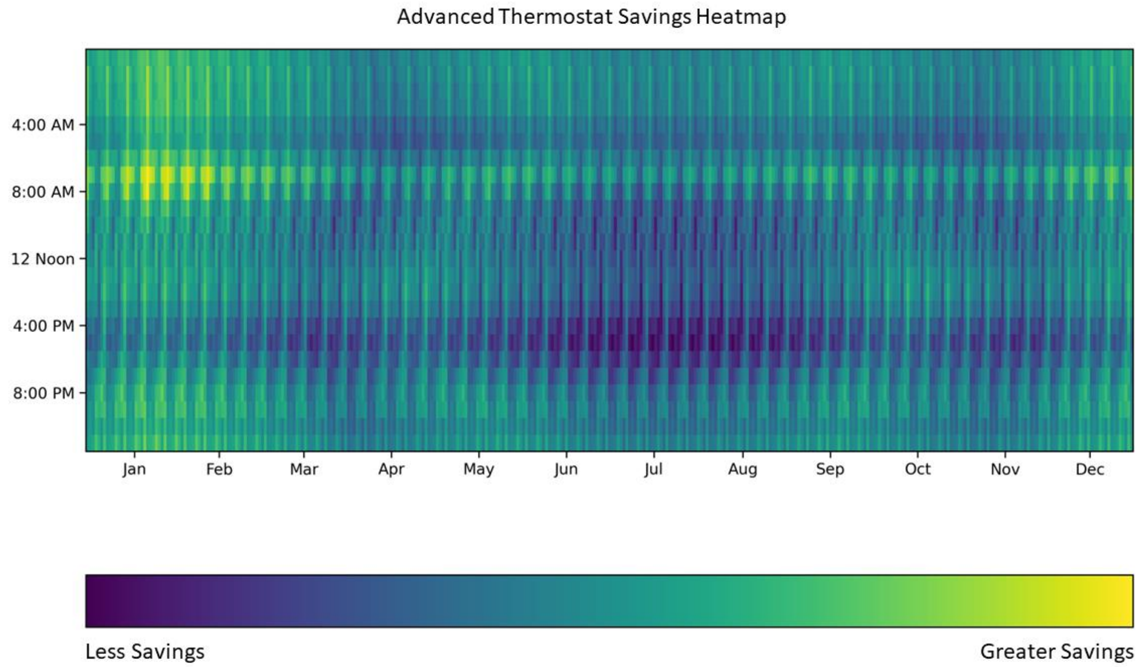

Figure 10. Energy savings heat map for the advanced thermostat measure used by EVT.

The energy savings heat map reveals that the greatest savings occur during the morning peak hours in the coldest part of winter. This corresponds to the dirtiest time of year for the ISO-New England production fleet. Often during this coldest time of year, natural gas is curtailed for use in electricity production while oil and coal make up for natural gas's absence. The matching of the greatest energy savings with the time of the dirtiest electricity production is the perfect combination for the summarizations to underestimate the actual savings.

An interesting note on this: the seasonal three-hour and seasonal hourly summarizations accurately approximate the emissions savings, probably because their resolution is fine enough to capture the inflated emissions factors during the morning peaks in the winter, when the advanced thermostat is exhibiting its greatest savings.

Implementation Feasibility

Investigating alternative temporal approaches to Efficiency Vermont's current carbon impact estimation approach reveals that increasing the time frequency of our methods is not without challenges. Data availability presents as a limiting factor, more so for high frequency estimates of measure impact than corresponding carbon emissions. Counterparts from peer programs also noted the cost and complexity of more advanced methods, a perspective the authors share after completing the comparative modeling exercise using different time frequencies and summarization periods. Despite these challenges, estimating carbon impacts from a more granular time perspective can provide a more accurate and valuable result for a subset of program efforts. The confluence of these factors provides a potential pathway for implementing these methods for Efficiency Vermont in the future.

Data Opportunities and Limitations

Deploying higher-frequency estimates of carbon impact requires emissions data and program impact data, both at the same time interval. High-frequency emissions data has been identified from reliable and acceptable sources, while program impact data presents a potential constraining factor to the application of new approaches.

Emissions Data

Comparative modeling identified several sources of emissions data at higher frequencies. The study that serves as the source for Efficiency Vermont's current four-period approach, the Avoided Energy Supply Cost (AESC) in New England study, also includes long-run hourly avoided emissions estimates that could serve as a basis for higher frequency estimation in the future. The AESC study is updated on a three-year recurring basis through a stakeholder driven process, including input from program administrators and regulators from across New England. Efficiency Vermont updates assumptions for avoided costs and emissions on the same three-year basis through a regulatory proceeding that follows the completion of each study update. Since AESC values underlie Efficiency Vermont's current carbon reduction estimates, there might be an opportunity to employ the higher-frequency avoided carbon emissions data without any large regulatory hurdles. The hourly avoided emissions data from the AESC study could enable updated approaches to avoided carbon estimation at different frequencies, including hourly estimates or other summarization periods as covered in the modeling section of this paper.

Program Impact Data

Insufficient examples of program impact data exist to apply the methods explored in this paper to all program activities in Efficiency Vermont's portfolio; however, savings impact shapes have been identified for a subset of measures that could prove the value proposition of high-frequency data. Existing research on the time value of efficiency has produced savings shapes that tend to focus on measure impacts that have a high level of time dependence and might provide additional carbon reduction for program efforts focused on time of use and load shifting.

Using historical data on measure deployments through Efficiency Vermont's program efforts, the previously referenced *Hourly Impact of Energy Efficiency Evaluation Pilot* included the development of a base set of savings shapes spanning 19 different measures, including thermostats, appliances, heat pumps, and lighting. The authors of that study noted challenges in applying hourly impact estimates to market opportunity measures, as well as custom projects. Expanding this set of savings shapes beyond the pilot list would require additional research, likely involving modeling for non-retrofit measures.

A large-scale study that used such modeling efforts to develop savings shape data is the End-Use Load Profile project led by the National Renewable Energy Laboratory (NREL). Efficiency Vermont provided aggregated AMI utility data to NREL and their partners that helped to calibrate the results of that study, including end-use and savings shape data specific to Vermont. The end-use data set is extensive, but the savings shape profiles are limited to specific energy upgrades and packages. For the residential sector, savings shapes are available for ten measures including home weatherization, electrification of heating and hot water end uses, and packages of measures that combine shell upgrades with fuel-switching. For the commercial sector, 28 technology savings shapes are available for 14 different building types.

Implementation Process

Updates to Efficiency Vermont's avoided carbon estimation methods would require process-related work to substantiate new methods and secure regulatory approval, along with significant refactoring of existing analysis and tracking infrastructure.

It is not expected that process requirements would be a showstopper, as these methods are technically robust and the required data can come from well-established third-party sources that have already been accepted by Vermont regulators. An update in approach, however, would likely require approval by the Vermont PUC in the next avoided-cost hearing and a technical review in the Vermont EEU Technical Advisory Group to finalize and approve methodological updates and data sources.

On the infrastructure side, changes to the existing state screening tool, which serves as the basis for avoided carbon estimates, and the VEIC Screening API, which enables avoided carbon calculations in Efficiency Vermont's tracking system, would be required.

Potential Approach

Given limitations on the data necessary to implement a high-frequency estimation approach across Efficiency Vermont's portfolio, and the associated complexity and cost, a more targeted approach might be necessary. This approach would apply these new methods only in cases where a high-frequency estimate provides additional insight and value to program stakeholders. Efficiency Vermont currently uses a targeted approach to estimate non-energy greenhouse gas impacts for a subset of program efforts that encourage the use of low-global-warming-potential refrigerants, calculating and tracking these impacts separately from avoided emissions from electricity and fuel reductions. That process could not be directly leveraged, as a high-frequency approach is still estimating avoided emissions related to energy use, but precedents do exist for targeted application of impact estimates for certain program efforts. The research team recommends piloting a similar approach for new methods and expanding the approach as new data becomes available, program offerings shift, and internal resources allow.

Conclusion

Shifting how and when we use energy will be necessary to reach current public policy and clean energy decarbonization goals. Transitioning fossil fuel end uses to electricity and shifting the time of use for existing electric loads can reduce carbon emissions by moving that use onto a cleaner grid and aligning it to times when marginal generation mix uses low carbon sources.

High-frequency estimates of program impact and grid emissions have the potential to better recognize the decarbonization impact of targeted program efforts, but updating and evolving methods for estimating program impacts has significant complexity. Currently available savings shapes to characterize program impact do not represent the breadth of efforts within Efficiency Vermont's program portfolio, and in cases where savings impacts do not align with periods of low carbon emissions, updated methods do not provide improved impact estimates. The study team recommends limiting high-frequency estimation methods to a subset of the portfolio where those conditions apply and pausing further exploration until more applicable savings shape data become available. Three measures worthy of high-frequency emissions calculation because of their unusual loadshapes causing large errors are clothes washers, smart thermostats, and interior prescriptive LED lighting.

Future Work

There are many possible areas to expand on this work, most notably the following.

- Investigate efficiency measures with different savings shapes.
- Revisit the calculations with updated projections of more realistic or different projected emission factors. Existing 15-year emission factor predictions contain emission factors of 0 g / kWh CO_2e for hours-long stretches during many days in the spring and late summer as soon as 2026. As of April 2024, ISO-New England has *never* recorded a single hour with an emission factor of 0 g / kWh CO_2e.
- Examine summarization methods that incorporate both time of day (like the ACEEE summarizations) and normal grid peak and non-peak times (like the EVT four-Period method).
- Further leverage high-frequency data to explore location-based considerations. Incorporating more granular location information could address geo-equity and program participation concerns. There is also a potential to consider the impacts of generation at its source, where nearby communities are likely to be lower-income communities.

Appendix A – Loadshape Overview

The current approach to estimating carbon impacts for Efficiency Vermont relies on a four-period loadshape method. Loadshapes identify when the savings for a given measure occur, and do not convey the timing of measure usage. Savings that occur during the day are worth more in screening than those that occur at night. Additionally, savings that occur during seasonal system peaking are valued the highest.

Each loadshape is made up of six percentage values; four energy periods (totaling 100%) that are multiplied by the first-year electric energy savings and applied to a unique set of avoided costs (for winter peak, winter off-peak, summer peak and summer off-peak), and two coincidence factors (winter and summer) corresponding to the percent of kW savings that is concurrent with ISO-NE's defined coincident peak periods. Loadshapes also include assumed hours of use, which is used in determining the loadshape but might be different from the hours used in a measure's savings calculation.

As of January 1, 2016, Efficiency Vermont is using the following avoided-costs energy periods based on the Avoided Energy Supply Costs in New England: 2015 Report prepared for the Avoided-Energy-Supply-Component (AESC) Study. The coincident peak periods are based on ISO New England performance hours for the forward capacity market.

- Winter Peak Energy:
    - 7AM - 11PM, weekdays, October to May
- Winter Off-Peak Energy:
    - 11PM - 7AM, weekdays, all weekend hours, October to May
- Summer Peak Energy:
    - 7AM - 11PM, weekdays, June to September
- Summer Off-Peak Energy:
    - 11PM - 7AM weekdays, all weekend hours, June to September
- Summer Gen. Capacity:
    - 1PM-5PM, weekday, non-holiday, June-August
- Winter Gen. Capacity:
    - 5PM-7PM, weekday, non-holiday, December-January

There is a different avoided-cost value for each of the four periods. The range of these avoided costs is not large. There are not currently specific goals for energy savings in each period, and this is not typically considered in the evaluation process. The current aim is to get the avoided costs in the right ballpark to represent reasonably what is happening in the real world.