Research & Development 2019-2020 Final Report for PowerShift

EFFICIENCY VERMONT R&D PROJECT: DEMAND RESPONSE CAPABILITY AND EFFECTIVENESS ASSESSMENT

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Efficiency Vermont

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Introduction

Changing energy systems—from the fuels that generate electricity and the ways in which utilities interact with customers, to the role of increasingly mature energy efficiency programs—require all energy industry players to think differently about what they offer to their customers. Ever since 2000, when the first statewide energy efficiency utility, Efficiency Vermont, began delivering demand-side management (DSM) services, the primary objective of most of its energy efficiency initiatives has been to provide *least-cost* electric energy supply for Vermonters.

This objective has historically been met by traditional, "passive" energy efficiency measures. That is, these measures do not operate with controls, and they are deemed cost-effective for installation on the basis of the annual energy savings (kWh) they can produce. Historically, Efficiency Vermont has not delivered demand response (DR) measures, which reduce demand (kW) during a utility's and the regional grid's defined peak periods. Nevertheless, influencing electricity grid load through energy efficiency and demand response measures has been conceptually evolving throughout the past two decades.

And now, Efficiency Vermont has investigated the practical strategies for achieving grid benefits from flexible load management, through its Project PowerShift. This report describes that work.

Background and Significance

Three years ago, Efficiency Vermont produced a report, 2018 Assessment of Demand Response Capability and Effectiveness, that provided a foundation for understanding how efficiency program activity could complement DR services offered through the state's distribution utilities. Since the release of that report, Efficiency Vermont and Washington Electric Co-op (WEC) have partnered on Project PowerShift, a two-year demonstration of the potential for water heaters and electric vehicle chargers to function as "virtual batteries" within the territory of this low-density, largely rural residential Vermont utility. Conceptually, this 2019 – 2020 project went beyond traditional energy efficiency or demand response and considered how WEC could use DSM to shape member loads to optimize both utility and member benefits. Vermont has adopted the term, *flexible load management,* to define this now-burgeoning DSM activity.[1]

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[1] Case No. 19-2956-INV; see definitions on page 5 of Department of Public Service second set of comments regarding proceeding; October 18, 2019. https://epuc.vermont.gov/?q=node/64/143416/FV-ALLOTDOX-PTL,

A grant to WEC from the Vermont Low Income Trust for Electricity (VLITE) and support from Efficiency Vermont R&D funds made Project PowerShift possible. Efficiency Vermont published an interim report[2] in April 2020, describing first-year findings. This final report presents the project's costs and benefits and considers how these concepts might be made accessible for more WEC members and Efficiency Vermont customers. The report thus also offers a model for other jurisdictions that are considering how to integrate energy efficiency and DR programs into comprehensive DSM solutions—in the form of flexible load management.

As more renewables with very low marginal operating costs come online and as winter peaks constrain the supply of natural gas regionally, the timing of all energy use becomes more important. Utility costs associated with peak times have been rising in recent years, which is causing upward pressure on utility rates. WEC, for example, has over $4 million in peak-related expenses. Pre-loading storage devices and deploying other demand response controls can reduce power demand during peak events. This strategy results in lower costs, while ensuring adequate grid performance and member-customer satisfaction.

Electro-chemical batteries provide stored energy during peak demand periods, but the upfront cost of either a grid-scale or individual-home electric batteries can be prohibitive. Most homes in Vermont have a "battery" in the basement, already: an electric water heater storage tank. By safely raising the temperature of hot water before it is needed (pre-loading), an insulated water heater tank can store hot water until the customer needs it. This strategy means the customer does not have to draw power from the grid during expensive peak times. Electric vehicles, although not yet widely adopted, are gaining in popularity. As a practical matter, the timing around vehicle charging—which puts a disproportionately high electric load on the system—is not necessarily fixed. That is, experience shows that customers can be flexible in adhering to charging schedules when capacity is less constrained than during peak hours. To determine how much peak demand can be reduced through residential water heater and electric vehicle charging controls, Project PowerShift has used advanced controls on existing water heaters and new electric vehicle chargers to create a "virtual battery" that can help WEC save costs (for members) and reduce capacity (for the utility and grid) during peak times.

Specific Aims

PowerShift used WiFi-enabled sequencing controls to demonstrate that shifting electricity demand for up to 200 units of two types of residential water heaters and up to 36 electric vehicle chargers could be accomplished remotely. The project's technology could thus shift energy use away from peak times to times that avoid peak capacity periods (and their attendant costs) for WEC, while ensuring that WEC's members' hot water supply and electric vehicle needs would not be disrupted.

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[2] Vandette, JJ, 2020. *Research & Development2019 Year-End, Interim Report for PowerShift.* Winooski, VT: VEIC (Efficiency Vermont). https://www.efficiencyvermont.com/news-blog/whitepapers/interim-report-for-powershift

Efficiency Vermont has brought program and technological expertise to support WEC in meeting the Project PowerShift goals to:

- Prove the concept that advanced, remote controls can be used to optimize the time at which water heaters and electric vehicles use energy
- Quantify the value of flexible energy use in reducing WEC's peak-related capacity and transmission costs, and derive the costs and benefits associated with scaling up the demonstration
- Bring higher customer value to WEC's members by making existing water heaters and new electric vehicle chargers grid interactive; these devices will help members access new and meaningful information about their devices and energy use

Given the importance to Efficiency Vermont of learning from Project PowerShift, so that the energy efficiency utility could continue to deliver higher value to customers statewide, Efficiency Vermont laid out the following learning tasks:

- Understand areas for potential collaboration in supporting flexible load management with distribution utilities
- Understand different WiFi-enabled options for controlling connected devices
- Gain practical experience with controls protocols, generally.
- Gain expertise with data transfer options (cellular [lower frequency] vs. WiFi [LAN / radio]).
- Fully understand the function of a load aggregator and the value proposition the aggregator brings to flexible load management programs.
- Gain expertise in projection algorithms and how loads respond to time-shift events.
- Gain a comprehensive understanding, behind the meter, of how a connected home product can have greater potential impact on the home—viewing the home as a system.
- Understand the barriers that constrain scaling of the FLM model.

Research Activity

PowerShift has put the following assumptions to the test, and tested both stand-alone hypotheses and hypotheses that relate to the learning tasks:

- Efficiency Vermont and WEC can collaborate effectively on flexible load management projects for WEC's members.
- Connected devices, when specified and installed correctly, can reduce utility cost of service with no negative impact on building occupants.
- Total benefits associated with flexible load management of residential water heaters and electric vehicle chargers are greater than the costs.
- Efficiency Vermont's measurement and verification capabilities are sufficiently comprehensive to prove the net value of flexible load management.

- PowerShift lessons are transferrable to other Efficiency Vermont program designs and are relevant to other Vermont distribution utility programs.
- Project PowerShift will result in sufficient information to replicate the model to the benefit of Vermont ratepayers, and to enable other organizations to scope and design a scalable, Vermont-associated flexible load management model for the residential market throughout the region and possibly nationally.

Project Components

Efficiency Vermont and WEC jointly created a PowerShift project scope that incorporated planning, design, deployment, and evaluation.

Planning

In the first year of PowerShift, 2019, WEC sought to shift residential water heater loads during peak events. It began with a goal of enrolling 100 customers (WEC members) with electric resistance water heaters (ERWHs) and 100 customers (WEC members) with heat pump water heaters (HPWHs). Project PowerShift added electric vehicle chargers (electric vehicle supply equipment, or EVSE) to the enrollment scope in June 2020, with a goal of enrolling 36 customers with EVSE. For all technologies, Efficiency Vermont used publicly available data to estimate the potential impact of shifting loads.

The dark gray line in

Figure 1 shows the average load of an ERWH from a reliable residential baseline load shape study,[3] across 24 hours. The orange dotted line shows the project team's original estimated average demand

[3] The study was conducted in Massachusetts, which has similar weather and types of energy supply needs, thus enabling valid comparisons to Vermont load shapes. Electric and Gas Program

(0.40 kW) that could be avoided during the typical 5:00 p.m. – 9:00 p.m. peak period of the local grid. During the course of the demonstration, the project team was able to collect and analyze ERWH data from the enrolled units in the field; the blue line reflects those data. There are clear differences in the load shapes in this graph. However, the contours of the baseline load shape and the Vermont ERWH load shape are sufficiently similar to give WEC and Efficiency Vermont confidence that future FLM planning can leverage existing baselines to project FLM outcomes.

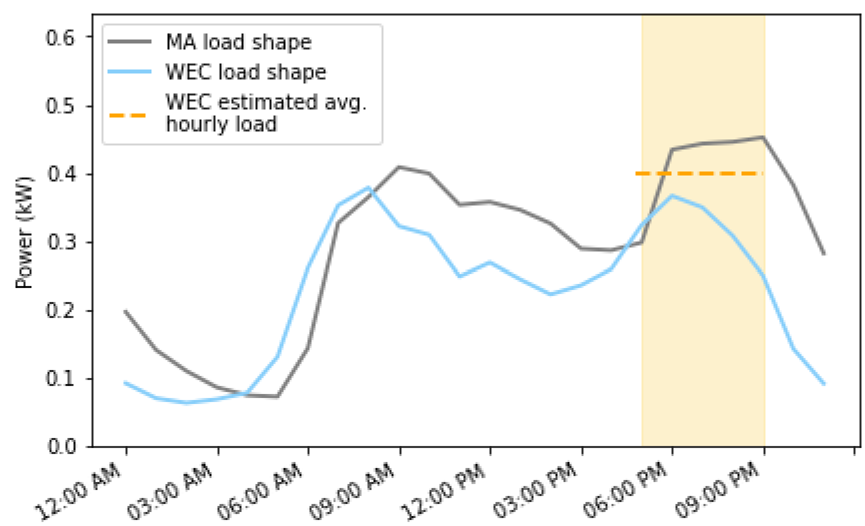

Figure 1. Comparison between Massachusetts water heating load shape for ERWH (dark gray line) and PowerShift average ERWH consumption (blue line), and the assumed potential for load reduction in peak hours (orange dotted line).

Source of gray line data: RES 1 Baseline Load Shape Study (see Footnote 3, Figure 42, p. 60)

The project team estimated the potential impact from shifting the load of HPWHs; for this estimate, the team used the same baseline load shape data set. **Figure** 22 shows the HPWH load shape in the dark gray line, and the orange line (0.18 kW) indicates the project team's original estimated demand that

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Administrators of Massachusetts, n.d. RES 1 Baseline Load Shape Study, Prepared by Navigant. Boston: Massachusetts Energy Efficiency Advisory Council. http://ma-eeac.org/wordpress/wp-content/uploads/RES-1-FINAL-Comprehensive-Report-2018-07-27.pdf.

could have been avoided during the typical 5:00 p.m. – 9:00 p.m. peak period of the local grid. The blue line reflects the field data collected throughout Project PowerShift.

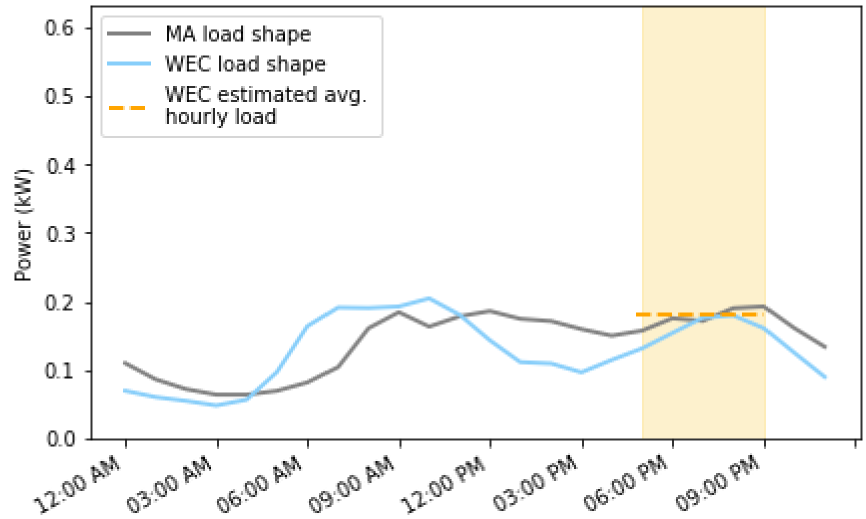

Figure 2. Comparison between baseline average water heater load shape for HPWH (dark gray line) and WEC average HPWH consumption (blue line), and the assumed potential for load reduction in peak hours (orange dotted line).

Source of gray line data: RES 1 Baseline Load Shape Study (see Footnote 3, Figure 42, p. 60)

With regard to EVSE, the dark gray line in **Figure** 23 shows the average load shape from EVSE use. Unlike the source for the dark gray lines in Figures 1 and 2, the project team adapted the data in **Figure 3** from a Green Mountain Power data set.[4] The orange dotted line represents the project team's original estimated average demand (0.50 kW) that could be avoided by an EVSE charging station during the typical 5:00 p.m. -9:00 p.m. peak period for the local grid. Unlike the water heater load shapes above, an insufficient amount of EVSE project data was available at the time of writing this report, and therefore, a comparison of a WEC EVSE data is not available alongside the GMP EVSE load shape.

[4] Exhibit AND-3: EV Charging Data Used to Establish Proposed Rates: Anderson, Scott, 2020. "GMP/electric vehicle charging rates tariff filing." Vermont Public Utility Commission Case 19-3586-TF: https://epuc.vermont.gov/?q=node/64/144640/FV-PFEXAFF-PTL.

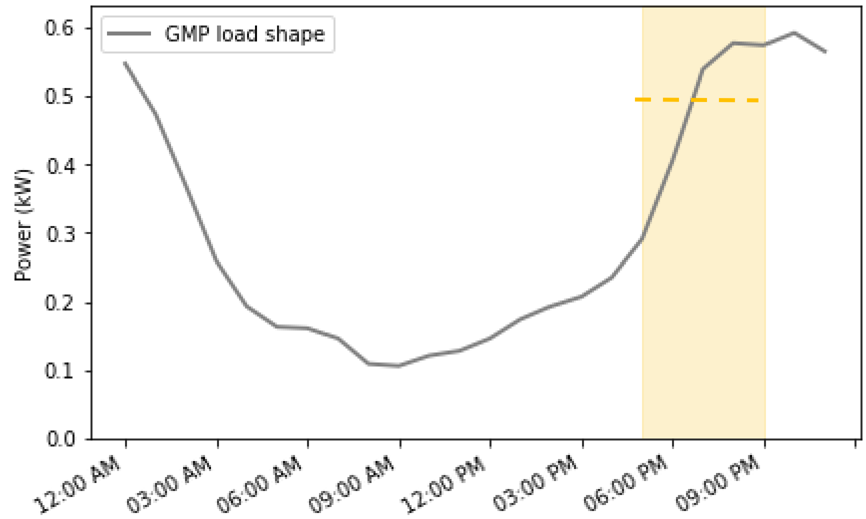

Figure 3. Baseline average EVSE load shape (dark gray line) and the assumed potential for load reduction in peak hours (orange dotted line).
Source of gray line data: GMP Case 19-3586-TF

WEC estimates the financial value of shifting demand during the 13 hours of the year that comprise peak energy times will result in cost reductions of approximately $250 per kW.[5] These peak hours were assumed to take place between 5:00 p.m. and 9:00 p.m. The project team used average load during this yellow-shaded timeframe in the figures above to estimate the kilowatts that could be avoided for each measure controlled, as shown in **Table 1**.

Table 1. Summary of estimated annual impacts from peak demand load shifting for WEC

	Measure controlled			
	ERWH	HPWH	EVSE	Annual total
Estimated kW / unit	0.40	0.18	0.50	n/a
Number of units	100	100	36	n/a
Total kW	40	18	18	76
Total annual value @ $253 / kW savings	$10,000	$4,500	$4,500	$19,000
Annual peak value / unit	$100	$45	$125	n/a

[5] This value is an approximation of the value over the course of the 2-year project. It considered: 2019 regional network service (RNS) charges of $112 / kW-year; 2020 RNS charges of $129 / kW-year; and the following charges for participation in ISO New England's Forward Capacity Market: 2019, $7.03 / kW-month (or $84 / kW-year); 2020, $5.30 / kW-month (or $63.6 / kW-year). Other local transmission charges approximated $52 / kW-year.

Prior to the time Efficiency Vermont co-created Project PowerShift, WEC had built relationships with software companies that could provide device controls. Efficiency Vermont and WEC together reviewed the separate contracts, sharing technical information that could help PowerShift optimize program costs and WEC member benefits. WEC ultimately signed contracts that gave it access to three separate software platforms:

- Packetized Energy Technologies (PET) Mello™ controls for ERWH with the Nimble™ dashboard software to manage the load (PET is based in Vermont)
- Virtual Peaker (VP) for HPWH, with a distributed energy platform to remotely control the HPWHs
- ChargePoint (CP), with a dashboard that is specific to its EVSE technologies

Program design

Efficiency Vermont and WEC coordinated their work in determining roles and responsibilities for:

- Program requirements
- Member engagement and outreach
- Gaining access to data from software companies
- Onboarding and scheduling contractors, where necessary
- Calling and scheduling peak events
- WEC member support
- Measurement and evaluation of the program impacts

Program deployment

WEC and Efficiency Vermont conducted outreach to enroll members in PowerShift, using marketing materials inserted into WEC member utility bills, articles in WEC's *Co-op Currents* periodical, notices on Front Porch Forum (a free online community-building platform for sharing information and creating connections), and direct mail and email to WEC members.

WEC member enrollment

Member requirements for pre-qualification:

- Own the home (to simplify participation agreements)
- Live in the home year-round (to ensure savings will accrue)
- Have a smart phone or tablet (to enable connection to devices)
- Have WiFi available 24 / 7 (to enable consistent connection to devices)
- Have at least 2 bars of WiFi strength at device (to ensure adequate communication)

Each HPWH also needed to have a mixing valve[6] to allow for shifting / storing energy safely,[7] and EVSE had to be paired with an all-electric vehicle.[8]

Forecasting and controls sequencing for events

The peak-related costs that PowerShift intended to avoid were FCM costs,[9] RNS costs,[10] and local transmission costs. The controls strategies enabled water heaters and electric vehicle chargers to avoid using energy during the forecasted peak times—without disrupting the hot water service or, in the case of EVSE, participating members' driving schedules. To avoid using energy at peak times, WEC and Efficiency Vermont used peaking forecasting services supplied by Utopus Insights to "call" peak events 1-5 times per month during the course of 2019.[11] In the middle of 2020, the Vermont Public Power Supply Authority (VPPSA) was the source for peak event forecasts. As noted in the recommendations of the 2019 Interim Report for this project, the team began to call three events within each 10-day period, to increase the likelihood of calling the correct peak time.

ERWH peaks were avoided by using PET's "Peak Crusher" algorithm to reduce kW during called events. HPWH peaks were avoided by preheating tanks to 140°F, starting 3 hours before a forecasted peak; during events, the HPWH temperatures were turned down to 120°F. The peak event windows were 2 hours for both types of water heaters for most events. However, the project team tested and confirmed that both HPWHs and ERWHs could withstand longer event periods without negatively impacting WEC members' hot water service. This observation allowed for a greater ability to match load shifting to more difficult-to-predict peak hours. To further ensure the ability to match power reduction to peak hours, a participating WEC member could schedule an EVSE to delay the start of charging when plugged in between 3:00 p.m. and 10:00 p.m. This daily shifting of energy patterns alleviated the need for peak EVSE forecasting.

Evaluation

To verify program impacts for both WEC and its participating members, access to device-level data was a critical element of the program. Efficiency Vermont's Data and Technical Services team, WEC, and the software providers established practices in the early phases of the project to ensure access to device-

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[6] Mixing valves had to be installed on all water heaters, per Vermont building code.

[7] The specific controls approach that PET uses for ERWHs does not require a mixing valve.

[8] Plug-in hybrid electric vehicles did not qualify.

[9] FCM rates from the corresponding Forward Capacity Auctions for the project periods: ISO New England, 2020. "Forward Capacity Market (FCA 10) Result Report," and "Forward Capacity Market (FCA 11) Result Report." Holyoke, MA: ISO New England. https://www.iso-ne.com/static-assets/documents/2018/05/fca-results-report.pdf.

[10] RNS rates for the study period: NEPOOL Reliability Committee, 2018. "RNS Rate – Effective June 1, 2018." DayPitney, Hartford, CT: https://www.iso-ne.com/static-assets/documents/2018/08/a2.0_2018_08_07_08_rc_tc_ptoac_rates.pptx

[11] The Utopus Insights forecasting tool was no longer available as of Q1 2020. The unavailability directly affected the program in 2020. VPPSA made the forecasting available to WEC per an existing relationship.

level data, thus allowing for monthly evaluation of the project impact, and for verification at the end of the project.

Evaluation of the PowerShift program addressed WEC's peak impact and participating members' energy and bill impacts. To calculate these impacts, Efficiency Vermont quantified the load reduction from the devices under the control and monitoring of Virtual Peaker, PET, and ChargePoint for WEC during peak hours, as well as total energy consumption for participants. The evaluation of the water heaters determined how the devices affected members' electricity bills, ensuring that pre-heating the water did not increase total energy costs for members.

The next two sections review the methods used for the evaluation of water heaters. Due to the delayed enrollment of the WEC members' EVSE, a full evaluation of this measure type was not possible, although the project team expects to provide an update to this report in the coming months, once it completes data collection and analysis.

Utility Peak Impact

Efficiency Vermont's goal was to create an accurate and scalable baseline that measured water heater load over time, without the effects of the controllable devices. Using the baseline, Efficiency Vermont measured the change in load during the monitored flexible load event. To understand the typical impact on load from these devices, the team averaged the load for all participating water heaters in each cohort. The cohorts corresponded to water heater type: HPWH or ERWH.[12] Aggregation across cohorts helped the team understand the average impact for a typical household device, as well as the total impact for a peak hour with the entire population of participating devices. In this study, the water heaters showed some hour-of-day and hour-of-week patterns from hot water use, but human behavior in the home caused variability that was very difficult to predict. Baseline models at the device level are very inaccurate for homes with irregular schedules. However, aggregating devices by cohort allowed the team to capture the average water heater usage pattern, which is more predictable.[13]

In 2019, Efficiency Vermont evaluated two models to create a baseline for the event period of interest: (1) an ISO New England model,[14] and a time series model based on the literature.[15] When the frequency of scheduled events increased in 2020, the team moved to a simpler evaluation model to allow for more complicated controls. Using experience from 2019, the team modified ISO New England's

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[12] Efficiency Vermont separated water heaters by type because of differences in how they perform. Heat pumps are far more efficient than electric resistance water heaters.

[13] When more devices enroll in future PowerShift activity, the results will be more representative of the behavior of the WEC population and the current baseline error will likely decrease.

[14] ISO New England model: Smith, Doug, 2017. "Price-Responsive Demand (PRD) Overview." Customer training webinar. Holyoke, MA: ISO New England, November 7. https://www.iso-ne.com/static-assets/documents/2017/11/20171107-webinar-prd-overview.pdf.

[15] Time-series model: Gelažanskas, Linas, and Kelum A. A. Gamage, 2015. "Forecasting Hot Water Consumption in Residential Houses." *Energies 8* (11): 12702-17. https://www.mdpi.com/1996-1073/8/11/12336/htm.

unadjusted baseline model to contain data from 15 days before or after the event.[16] The baseline used a 10-day average from the most recent 30 non-holiday weekdays to predict a weekday baseline. The team extended it for weekends or holidays by taking a 5-day average of Saturday, Sunday and holidays.

This baseline model assumed that there were recent historical data that were not influenced by the flexible load behavior. Second, if a member participated in an FLM event every day or almost every day, there was not enough evidence to build a model of the counterfactual. Third, these models predicted the expected or on-average behavior of the cohort. They have been unable to predict unusual or one-off load changes, such as when the electric resistance mode comes on in a heat pump water heater, if there has been no prior evidence that (or the extent to which) the electric resistance element turns on under those conditions.

Peak Impact Model Evaluation

To evaluate the uncertainty of the water heater baseline model, Efficiency Vermont predicted 15 randomly selected non-event days per month and evaluated the accuracy of the model between the hours of 3:00 p.m. and 9:00 p.m. These hours are the most likely hours for RNS and FCM peaks to occur. Efficiency Vermont measured the coefficient of variation of root mean squared error [CV(RMSE)] when the members were not following flexible load events. The goal was to have a lower CV(RMSE). CalTRACK, a national, open-source platform for calculating avoided energy use, recommends a CV(RMSE) threshold of 100 percent as a default for portfolio-level (or in this case, cohort-level) model performance.[17]

Figure shows the monthly CV(RMSE) during 2020 with the average number of participating devices. With the increase in sample size in 2020 (especially for electric resistance water heaters), the project team saw a lower error rate, compared to 2019.

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[16] Using data before and after the event allowed the team to use the most recent days, relative to the event day, to build the baseline—even as events became more frequent. Using the simple averaging technique of the ISO-NE baseline allowed more advanced scheduling of the event, without biasing baseline. Real-time evaluation was not necessary for this pilot, so using post-event data was possible.

[17] CalTRACK Methods, n.d. "CalTRACK Methods, Version 2.0." http://docs.caltrack.org/en/latest/methods.html

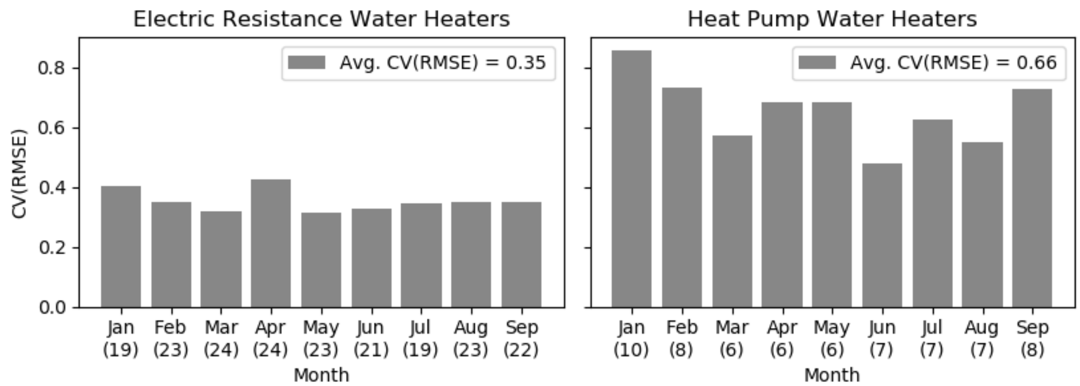

Figure 4: Model error for two cohorts of water heater participants, by month, in 2020.

Participant Member Impact

To estimate the impact of peak events on member energy bills, Efficiency Vermont modeled the daily energy use for all days within the month of interest. It should be noted that there are no expected effects for WEC members with EVSE, for the load-shifting strategies are simply to delay charging to later in the day; there is no time-of-day rate available to WEC members. To isolate the effects of the event days on total energy use for ERHWs and HPWHs, Efficiency Vermont built a mixed-effects model controlling for differences between devices, time of week, and temperature. The model yielded an estimate of the average effect of an event day on the energy per day, controlling for time of week and temperature. The project team did not need the granularity of an hourly model to evaluate the impact on energy bills. The mixed model enabled an estimate of the effect of events on daily energy while controlling for each device's schedule. More details on model parameters and evaluation are in

Appendix A: Technical Supplement.

Results & Findings

Two years have passed since project planning kicked off. Nevertheless, the PowerShift results are still considered "preliminary," because of the small number of enrolled devices. This gives the project team relatively low confidence in the accuracy of the findings. However, as more water heaters and EVSEs are enrolled, the team will be able to derive a more accurate estimate for the impacts from all device types. The team has categorized the results according to program deployment, utility impact, participant member impacts, program costs and benefits, project roles, and measures of success.

Program deployment

The team further categorized program deployment results by member enrollment, forecasting and controls, and technology performance.

Member enrollment

The PowerShift team aimed to enroll 100 electric resistance water heaters, 100 heat pump water heaters, and 36 electric vehicle chargers within the 24-month pilot. Program planning and design took longer than anticipated, and 6 months passed before the team could deploy the pilot and initiate outreach. From July through December 2020, 225 WEC members consulted with Efficiency Vermont's Customer Support Team about PowerShift. Of those total inquiries, 156 (70%) WEC members did not qualify for the program; the team referred them to other energy savings programs offered by Efficiency Vermont and WEC. Table 2 contains the reasons these members did not qualify for the PowerShift pilot. The factors below impacted some WEC member's abilities to participate and thereby prevented the project team from having a representative sample across WEC's membership, the expectation of this limited scale demonstration was never to have a representative sample.

Table 2. WEC member reasons for non-participation

WEC member reasons for non-participation	Count	Percent of total
No response / opted out	63	40%
Disqualified water heater types (gas, oil, storage only)	19	12%
HPWH without a mixing valve	13	8%
HPWH model not WiFi enabled	17	11%
Technology limitations (no Internet, no smartphone, no WiFi, "too complicated")	9	6%
WiFi signal too weak	8	5%

WEC member reasons for non-participation	Count	Percent of total
Technical issues with existing water heater	5	3%
Seasonal property	4	3%
Plug-in hybrid or standard hybrid vehicle	6	4%
Existing EVSE and did not want to switch	4	3%
Other	8	5%
Total unqualified participants	156	100%

By the end of 2020, the pilot had enrolled 16 HPWH, 29 ERWH, and 12 EVSE participants.[18] COVID-19 affected the project team's ability to continue business as usual. The enrollment momentum in late 2019, for example, stopped entirely in the first half of 2020. The team experienced a delay in rolling out the EVSE offering during this same time, affecting the total number of installations completed by the end of 2020.

Member education was an important element of the PowerShift project. WEC members understand the concept of *energy efficiency* reasonably well, but most members were new to the idea of *flexible load management*. A video on the PowerShift website[19] was a key component for helping members understand the project's purpose. A few members were concerned about the data sharing, however.

The ease with which WiFi controllers were installed varied widely by site. The most challenging example involved re-routing plumbing (PowerShift did not recommended this step to members) to make space for the controller on top of an ERWH; in that example, the member noted that the installer had to make a second trip to wire in the controller. The ease with which EVSEs were installed also varied by location. The easiest enrollments involved members who already had in place the built-in WiFi controls of an existing HPWH, and through an e-mailed link, could connect to the WEC dashboard to complete the enrollment process.

Forecasting

Forecasting the monthly Vermont grid peaks and the annual ISO New England peak has become more difficult with the increase in installed renewable resources behind the meter (for example, net-metered PV). The forecasting has also been made more difficult with the installation of flexible load devices that are controlled by the many distribution utilities in Vermont. From July through December 2020, 2 FCM peaks and 18 RNS peaks took place. The project team correctly scheduled events for 13 of the 20 peak

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[18] By the end of the first 12 months of the pilot, 15 HPWH and 18 ERWH were fully enrolled in PowerShift, and 27 additional members were in various stages of the prequalification or enrollment process.

[19] The site is www.EfficiencyVermont.com/PowerShift.

events, indicating that the project team was able to accurately forecast 65% of the peaks during the project period.

Forecasting challenges are not unique to the PowerShift program or to WEC. The 2019 Interim Report described how the project team deployed strategies that might mitigate the uncertainty related to peak forecasting for future FLM efforts. This work involved calling events more frequently for water heaters and requiring that EVSE program participants shift their charger use every day.

Month	Event called correctly?
July 2019, FCM	YES
July 2019	**NO**
August 2019	YES
September 2019	YES
October 2019	**NO**
November 2019	YES
December 2019	**NO**
January 2020	YES
February 2020	**NO**
March 2020	**NO**
April 2020	YES
May 2020	YES
June 2020	YES
July 2020, FCM	YES
July 2020	YES
August 2020	**NO**
September 2020	YES
October 2020	YES
November 2020	YES
December 2020	**NO**

Technology performance

To complicate the forecasting challenges, the project team encountered technology challenges. For example, the PET Mello WiFi controller for ERWHs could be retrofitted onto nearly any existing electric resistance water heater and controlled via PET's Nimble software dashboard; however, in the first few months, the team had difficulty with mode settings and the continuity of data flow. Therefore, the team could not validate ERWH results until after October 2019. But thereafter, the team was able to obtain the data and process the results without incident. Further, several installations were not done correctly, which meant temporary disruptions to members' hot water service. Such issues have been resolved, and the project team has made program changes to ensure they do not recur. And in another example, a few ERWHs had only one of the two electric resistance elements in working order, which limited the amount of flexibility in the water heater. As with all WiFi-connected devices, continuity of connection—and the flow of data—were also a challenge, although PET applied further checks and balances in the fourth quarter of 2020 to try to eliminate the number of hours that ERWHs were offline.

For HPWHs, the two WiFi controllers that were used to connect to the VP software were EcoNet (Rheem) and ConnectPlus (GE). Both Rheem and GE support the hardware and the back-end application programming interfaces for remotely connecting to the devices. At the time of the pilot, these two HPWH manufacturers were the only ones supporting commercially available hardware and software for FLM. VP's dashboard controlled the water heaters. The team had some initial difficulty in understanding the manufacturer settings that govern the controls, but that has since been resolved. For a few devices, the continuity of power data was an issue, making their evaluation impossible. The biggest setback for HPWHs was in the number of units that did not meet project participation criteria because mixing valves were not available.

Evaluation

Utility Impacts

Peak event tracking started in July 2019 and continued through December 2020. **Table 3** and **Table 4** show the change in kW demand (impact) during the RNS or FCM peak hours on water heater consumption and WEC's associated avoided costs for ERWHs and HPWHs. The team based the RNS and other local transmission peak costs on an approximate avoided cost of $15 / kW during peak hours in both 2019 and 2020. For the FCM peak in July 2019, the rate was $84.36 / kW, and in July 2020 the rate was $63.6 / kW. Any positive impact indicates a reduction in the load during the peak hour compared to the baseline, and similarly, any positive avoided cost indicates lower peak demand charges for WEC relative to the baseline. Negative impacts indicate an increase in the load during the peak hour compared to baseline, and similarly, any negative avoided cost indicates higher peak demand charges for WEC relative to the baseline.

Due to data quality issues and peak forecasting inaccuracies, the ERWH results were not valid for 6 events in 2019. The PowerShift team has not expected to see significant change in demand (impact) in the PET devices until the sample size approximates 50 devices because, at small numbers, and given the quality of service guarantee, one or two large usage events could trigger power consumption that would outweigh the impact of any energy saved.

Table 3. July - December 2020 ERWH demand impacts and avoided costs

	Electric resistance water heaters (controlled via Packetized Energy Technologies software)					
	Number of devices	Devices participating	Impact per device (kW)	Avoided cost per device ($)	Total impact (kW)	Total avoided cost ($)
2019 RNS						
July*	6	N/A	N/A	N/A	N/A	N/A
August**	11	0	N/A	N/A	N/A	N/A
September**	9	0	N/A	N/A	N/A	N/A
October*	14	N/A	N/A	N/A	N/A	N/A
November**	22	0	N/A	N/A	N/A	N/A
December*	23	N/A	N/A	N/A	N/A	N/A
2020 RNS						
January	27	17	0.31	4.55	5.22	77.38
February*	29	N/A	N/A	N/A	N/A	N/A
March	30	24	(0.11)	(1.63)	(2.63)	(39.00)
April	31	23	0.44	6.60	10.23	151.72
May	31	21	0.10	1.52	2.15	31.91
June	31	22	0.29	4.23	6.28	93.18
July	29	18	0.07	1.07	0.07	1.30
August	29	24	(0.15)	(2.23)	(3.60)	(53.46)
September	29	23	0.27	3.97	6.15	91.26
October	29	23	0.22	3.26	4.05	60.10
November	29	23	0.36	5.31	8.23	122.05
December*	29	N/A	N/A	N/A	N/A	N/A
Total RNS		-	-	-	40.06	536.44
2019 FCM**	6	0	N/A	N/A	N/A	N/A
2020 FCM	31	18	0.22	13.79	3.91	248.25

*No events called on these RNS peaks. ** Results not validated due to errors in device modes.

The team drew some insight about HPWH performance using VP software, although sample sizes were small.

Table 4. July - December 2020 HPWH demand impacts and avoided costs

	Heat pump water heaters (controlled with Virtual Peaker software)					
	No. of devices enrolled	No. of devices participating	Impact per device (kW)	Avoided cost per device ($)	Total impact (kW)	Total avoided cost ($)
2019 RNS						
July*	4	N/A	N/A	N/A	N/A	N/A
August	4	3	0.05	0.67	0.14	2.01
September	7	4	0.04	0.69	0.19	2.77
October*	10	N/A	N/A	N/A	N/A	N/A
November	10	5	0.20	2.89	1.01	14.44
December*	13	N/A	N/A	N/A	N/A	N/A
2020 RNS						
January	14	11	0.07	1.05	0.78	11.58
February*	15	N/A	N/A	N/A	N/A	N/A
March	15	7	(0.12)	(1.83)	(0.86)	(12.82)
April	16	6	0.20	2.89	1.17	17.35
May	16	3	0.05	0.72	0.15	2.17
June	16	9	0.01	0.19	0.11	1.73
July	16	9	0.18	2.67	0.18	1.62
August	16	8	(0.00)	(0.02)	(0.01)	(0.18)
September	16	8	0.14	2.02	1.09	16.17
October	16	9	0.03	0.44	0.27	3.99
November	16	10	0.14	2.05	1.38	20.48
December*	16	N/A	N/A	N/A	N/A	N/A
Total RNS	-	-	-	-	5.59	81.30
FCM 2019	4	3	0.03	2.42	0.09	7.26
FCM 2020	16	9	0.09	6.02	0.85	54.17

* No event called on these RNS peaks.

A similar project in the Pacific Northwest demonstrated that ERWHs could shift approximately 0.32 to 0.33 kW, and HPWHs could shift 0.09 to 0.20 kW, depending on the season and using different controls strategies.[20] In months where the peak hour was called correctly by the project team, this order of magnitude of impact has been observed for PowerShift, as well.

Again, peak forecasting accuracy is important for controlling water heaters, so that they can help the utility avoid peak demand costs and to create value for WEC members. **Figure 1** shows power use during an event that was called for ERWH on August 11, 2020. The pre-event period was 6:00 p.m. to 7:00 p.m.; the blue line indicates an increase in power leading up the forecasted peak period of 7:00 p.m. to 9:00 p.m. During this forecasted peak period, WEC drew a smaller amount of power from the water heaters, which again indicates a successful load-shifting event. However, because the actual peak occurred earlier than forecasted—during the pre-event period—the water heaters used more power than indicated by the baseline during this time. This is a worst-case example of how an inaccurate forecast can lead to the opposite of the intended results. The negative results shown in Table 3 and Table 4 were caused by this type of forecasting error.

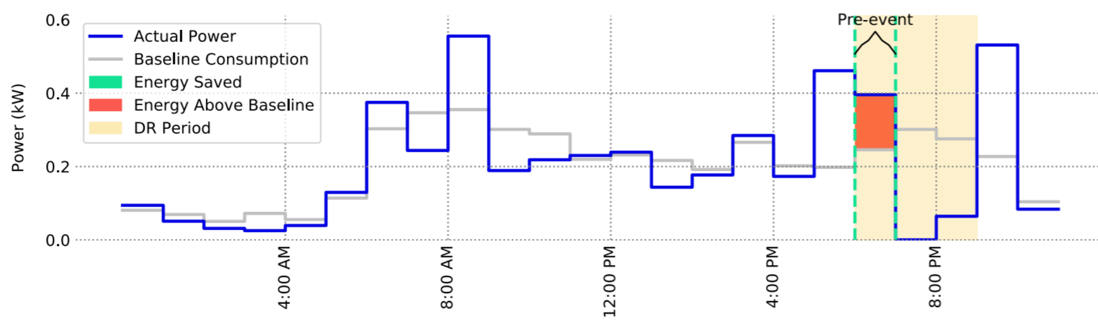

Figure 1. ERWH (PET controlled) aggregate load shape for August 11, 2020, RNS event.

Figure 2 presents results for HPWHs during the same event that was called on August 11, 2020. The pre-event period was 4:00 p.m. to 7:00 p.m., and the blue line indicates an increase in power during this time. The period of 7:00 p.m. to 9:00 p.m. was the forecasted peak. Very little power was drawn from the water heaters in those hours, which indicates a successful load-shifting event. However, after the month ended, the peak was determined to have occurred during 6:00 p.m. to 7:00 p.m. on August 11. Therefore, the shift in energy had no impact on the RNS peak hour. In this instance, the pre-loading of the HPWHs was completed before the peak hour, and although the peak was missed, no harm was done.

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[20] Metzger, Cheryn, Travis Ashley, Sadie Bender, Scott Morris, Conrad Eustis, Phillip Kelsven, Eva Urbatsch, and Nathan Kelly, 2018. "Load Shifting Using Storage Water Heaters in the Pacfic Northwest." In *CTA-2045 Water Heater Demonstration Report, Including a Business Case for CTA-2045 Market Transformation.* BPA Technology Innovation Project 336. Appendix E. Portland, OR: Bonneville Power Administration: 169-89. https://www.bpa.gov/EE/Technology/demand-response/Documents/20181118_CTA-2045_Final_Report.pdf.

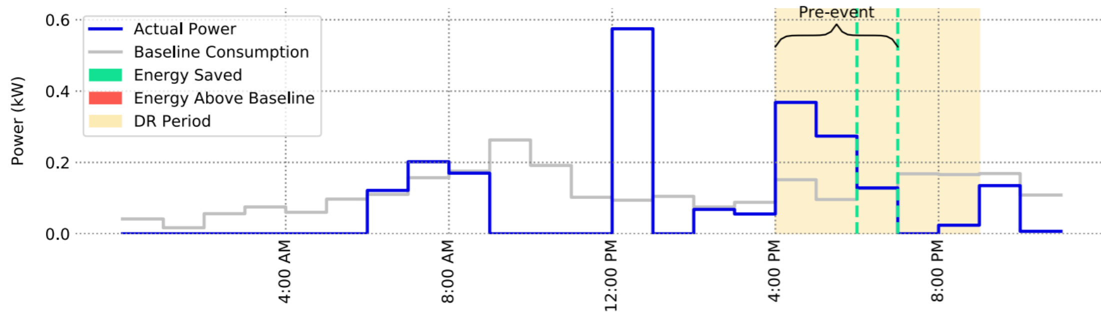

Figure 2. HPWH (VP controlled) aggregated cohort load shape for August 11, 2020, RNS event.

Because the EVSE units were installed late in the demonstration project, a full analysis of the impact of these measures for WEC is not yet available. However, the team presents preliminary data in **Figure 3**, which depicts average EVSE use for WEC PowerShift participants (blue line) and baseline data (dark gray line). The difference between the two lines during the expected peak hours of 5 p.m. to 9 p.m. demonstrates the expected average demand savings from participants to date.

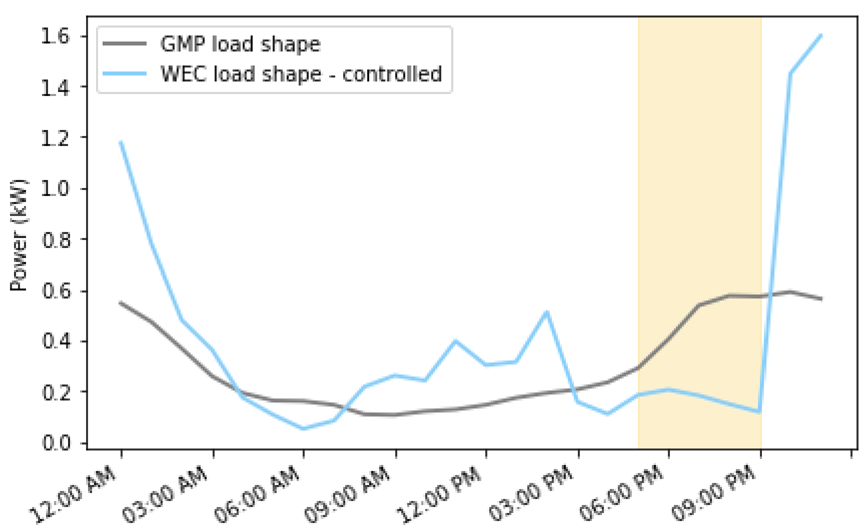

Figure 3. Preliminary results showing the PowerShift average kW per EVSE charger (blue line), relative to baseline (dark gray line).

Participant member impacts

The team found that event days did not have a significant effect on the amount of energy the participant members' water heaters used each day. **Table 5** and **Table 6** show the average effect of the event day on the total energy used per day. The change in bill calculation assumed a residential rate of $0.23 / kWh. Positive changes in bill amounts per event day indicate that the event days increased the total energy consumed, whereas negative bill amounts per event day indicate that the event days decreased total energy consumed. The net member impact was based on the effects of the called events, excluding the monthly credit of $5.00 for participating members. The project team has not seen significant effects from event days on water heater energy use (kWh), with some months showing minor increases in usage over baseline and other months showing minor increases in usage compared to baseline. In summary, the most significant impact on the participating members' bills has been the $5.00 monthly bill credit for participation.

Table 5. ERWH member impacts (PET software)

	Electric resistance water heaters			
	Number of events	Change in use per event day (kWh)	Change in bill per event day ($)	Avg net member impact / month ($)
2019				
July	3	(0.15)	(0.04)	(0.11)
August**	4	N/A	N/A	(0.00)
September**	8	N/A	N/A	(0.00)
October	2	(1.05)	(0.24)	(0.48)
November**	1	(2.46)	(0.57)	(0.57)
December	1	(0.24)	(0.06)	(0.06)
2020				
January	6	(0.10)	(0.02)	(0.13)
February	1	1.39	0.32	0.32
March	4	0.96	0.22	0.88
April	7	(0.14)	(0.03)	(0.22)
May	10	0.24	0.06	0.56
June	9	0.55	0.13	1.14
July	8	(0.72)	(0.17)	1.32
August	6	0.63	0.14	0.87
September	8	0.16	0.04	0.30
October	9	0.37	0.09	0.77
November	6	(1.25)	(0.29)	(1.73)
December	6	0.83	0.19	1.14
Average all months	6	(0.06)	(0.01)	0.18

** Results not validated because of errors in device modes.

Table 6. HPWH member impacts (VP software)

	Heat pump water heaters			
	Number of events	Change in use per event day (kWh)	Change in bill per event day ($)	Avg net member impact / month ($)
2019				
July	4	0.00	0.00	(0.00)
August	5	0.00	0.00	(0.00)
September	6	(0.47)	(0.11)	(0.64)
October	2	(0.10)	(0.02)	(0.05)
November	2	(0.32)	(0.07)	(0.15)
December	1	0.28	0.07	(0.07)
2020				
January	6	(0.23)	(0.05)	(0.32)
February	1	(0.34)	(0.08)	(0.08)
March	4	(0.05)	(0.01)	(0.04)
April	7	(0.52)	(0.12)	(0.84)
May	10	0.35	0.08	0.80
June	9	0.32	0.07	0.65
July	8	0.45	0.10	0.82
August	5	0.11	0.02	0.12
September	8	(0.21	(0.05)	(0.40)
October	9	0.05	0.01	0.10
November	6	(0.21)	(0.05)	(0.29)
December	6	0.25	0.06	0.35
Average all months	6	(0.03)	(0.01)	(0.00)

For the members with EVSE, the project team has anticipated no changes to kWh because the energy use patterns are not changed—the timing of the energy use is simply delayed each day during the peak time.

Project costs and benefits

TABLE 7 contains the PowerShift project's costs.

Table 7. PowerShift costs, 2019-2020

	2019	2020	Total	Funding
Program administration				
Project Management	$5,000	$5,000	$10,000	WEC: VLITE grant
Data Analytics	$37,800	$16,873	$54,673	EVT: DSS R&D
Customer Support	$4,500	$3,078	$7,578	EVT: DSS R&D
Marketing	$6,300	$1,044	$7,344	EVT: DSS R&D
Software	$18,650	$18,650	$37,300	WEC: VLITE grant
Subtotal	$72,250	$44,645	$116,895	
Variable costs, HPWH				
Hardware	$1,666	$95	$1,761	EVT: DSS R&D
Contractor	$0	$0	$0	N/A (none)
Member incentives	$140	$765	$905	WEC
Subtotal	$1,806	$860	$2,666	
Variable costs, ERWH				
Hardware	$5,467	$0	$5,467	EVT: DSS R&D
Contractor	$2,213	$610	$2,823	EVT: DSS R&D
Member incentives	$140	$1,525	$1,665	WEC
Subtotal	$7,820	$2,135	$9,955	
EVSE, Variable costs				
Hardware	n/a	$22,667	$22,667	WEC: VLITE grant
Contractor	n/a	$0	$0	N/A (member)
Member incentives	n/a	$0	$0	WEC
Subtotal	$0	$22,667	$22,667	
Total	$81,876	$70,307	$152,183	

This project's quantifiable benefits were less than originally forecasted. As noted in Technology Performance, the software controls for the electric resistance water heaters were not operational until November 2019, and the peak hour was missed entirely during 7 of the 20 peak events. For ERWHs, a maximum of 24 units performed during an event during the course of the program—far lower than originally forecasted. The total avoided costs realized for ERWHs were $0 in 2019 and $785 in 2020, amounting to a total of $785 for the project. For heat pump water heaters, a maximum of 11 water heaters performed in any monthly peak hour during the project—also far lower than originally forecasted. The total impact for WEC from July through December 2019 for each heat pump water heater was estimated to result in peak cost savings of approximately $19, and in 2020, the total avoided costs were $62, resulting in a total of $81 of avoided costs. By the end of 2020, the EVSE impact was not large enough to warrant the same level of analysis that had been applied to the water heaters. As a result, the project team has not estimated avoided costs for EVSE.

At face value, the avoided costs did not cover the total cost of approximately $150,000. However, more and more customer devices will be enabled with WiFi controls from the original equipment manufacturer. This will mean that future total costs to run programs resulting from this project could be driven mostly by software costs. The up-front investment costs in data analytics tools have already been made, and the hardware used for the demonstration will soon be commonplace in most devices. These observations notwithstanding, scaling this work will be critical for any future cost-effective FLM-related program, if only to cover software costs.

Project Roles and Measures of Success

A memorandum of understanding (MOU) created the PowerShift partnership between WEC and Efficiency Vermont. Through that agreement, this project has allowed both organizations to learn together about FLM. Early planning was necessary to ensure each party took on tasks for which it was better suited, in terms of skills, expertise, and capacity. Efficiency Vermont, for example, applied its experience in customer-facing programs to inform the project design phase. The program design itself incorporated Efficiency Vermont data analysts' experience in evaluation and WEC's goals to create a single voice for discussions with software providers. Efficiency Vermont's marketing team supported WEC's member outreach group in deploying member-friendly monthly utility bills inserts, newsletters, and additional media context. For event days, WEC provided Efficiency Vermont access to forecasting services, whereas Efficiency Vermont optimized the control schedules to meet those forecasts. Efficiency Vermont led project intake and evaluation, and WEC supplemented participant lead generation through its member engagement channels.

Efficiency Vermont identified several metrics that would indicate a successful project. Table 8 provides the status of the success metrics.

Table 8. PowerShift success metrics at the end of 2020

Success metric	Results
1. Explore Efficiency Vermont's role in supporting distribution utilities (DUs) with FLM—within the bounds of the Vermont Public Utility Commission's Order of Appointment and existing Quality Performance Indicators	Achieved
2. Strong partnership with DUs to explore FLM programming	Achieved
3. Demonstration of FLM without adversely impacting the member	Achieved
4. Quantification of all value streams of FLM	Work in progress

5.	Understand any potential paths forward for Efficiency Vermont to support future FLM programs	Achieved

The team achieved the exploration and partnership measures of success by building on a relationship between WEC and Efficiency Vermont. The member survey results in Appendix B and the preliminary results noted in **Results & Findings** -- **Member Impacts** support the achievement of the third success metric. An assessment of the fourth success metric will be possible only after more devices are in the field. Regarding the fifth success metric, the Public Utility Commission has ordered Efficiency Vermont to support Vermont DUs with FLM programs in the 2021-2023 performance period.

Recommendations

WEC and Efficiency Vermont have agreed to continue the FLM project as a program in 2021, funded by Efficiency Vermont's resource acquisition budget with the State, and with WEC's 2021 operating budget. Both entities now understand the mechanics and promise of an FLM program and are committed to scaling such programs.

The project team is confident that program cost effectiveness can be demonstrated with EVSEs relatively easily and in a straightforward manner in the short term. Both parties agree that future program planning must consider:

(1) the coincidence of the measures (load / end use)
(2) the "flexibility" of the load (for example, how easy it is to shift load without disrupting customers)
(3) the total number of anticipated devices that can be connected during the program period
(4) the ease with which controls can be accessed (for example, whether they are built in, or conform to open standards)

Although WEC members and the utility itself are not installing a significant amount of EVSEs, this technology aligns well with the other three program planning considerations: coincidence with peaks, "flexibility" of the load, and ease with which controls can be accessed.

WEC will still have to consider whether FLM will lend itself to a formal tariff offer to members; this consideration will become increasingly important when more EVSEs are brought online. PowerShift currently relies on WEC members' good will for effective load shifting. Turning good will into regular behavior can result from incentives such as a time-of-day (TOD) rate or an EV-specific rate.

Still to be considered are the peak forecasting and controls scheduling challenges posed by elusive monthly peak events. Although scheduling load-shifting events more frequently yielded better results in the pilot, the daily load shifting approach for EVSE essentially guaranteed that load shifting could match the peak time—thus eliminating the complexity of forecasting and scheduling device use. Because the team has not yet seen any negative peak event-related impacts to members (e.g. no significant increase in kWh or costs), the team is inclined to consider a daily load shift for water heaters.

Beyond the term of this pilot, WEC could also consider how additional avoided costs could be realized beyond RNS and FCM peaks. Energy supply arbitrage is an additional value stream that might be relatively easy to monetize. Another potential value stream for load shifting relates to emissions. WEC's annual energy generation mix is 100 percent renewable, but the carbon intensity of the ISO New England grid varies hourly, daily, and seasonally. Efficiency Vermont and Packetized Energy conducted an experiment in September 2020 to understand the mechanics of energy arbitrage with ERWHs, using Packetized's LoadShaper™ controls. Appendix B contains the preliminary results. Although the individual effects at the device level are not significant with such a small number of devices, this value stream, along with the others noted above, could result in meaningful impacts when an FLM program scales.

As with any demand side management effort, scaling is of utmost importance. Its success depends on the ability of Vermonters' bringing relevant technology to a load management program. This concept, known as *bring your own device* (BYOD or BYO-technology), might necessitate greater attention to "open standards" for device communication and controls. The growing national conversation about such standards could eventually help FLM programs scale enough to demonstrate significant grid value.

A final consideration that can affect scaling relates to the software that interfaces with these FLM devices. PowerShift uses three different dashboards; a single interface will not only likely evolve, but also simplify operations and decrease overhead costs. In the PowerShift context, WEC will ultimately be responsible for this role, with methods and other partners still to be determined.

Clearly defining roles and building strong partnerships should be the central activity for FLM program development in Vermont. Efficiency Vermont and WEC collaborated successfully on program planning, program design, and implementation. This was possible only with a deep level of trust and mutual respect between the parties. The lessons learned from PowerShift should inform how Efficiency Vermont engages with other DUs during the 2021-2023 performance period.

Thus, the short term requires FLM programs to be co-developed between Efficiency Vermont and other distribution utilities if Vermont ratepayers are to benefit from multi-faceted collaboration on program planning and design. As with other efficiency program objectives, market transformation needs to be the goal. FLM is highly promising as an effective tool for grid stability and utility cost containment, but the success of future BYOD FLM programs in Vermont relies on good coordination to bring FLM to scale—and thus bring benefits to Vermont utility customers.

Appendix A: Technical Supplement

Evaluation Interval

The project team evaluated flexible load performance from July 2019 through December 2020. The team evaluated performance during the hour of each monthly RNS, and the hours of the yearly FCM peak. The team calculated power reduction on the mean 5-minute reading within the peak hour, compared to the forecast for that hour.

Calculation Method and Analysis Procedure

WEC Peak Impact 2020 Calculation Method

Using experience from 2019, the team modified the ISO New England unadjusted baseline model to include data within 15 days before and after the event. Using data before and after the event built the baseline, even as events became more frequent. Using the simple averaging technique of the ISO New England baseline allowed advanced scheduling or event scheduling without biasing baseline. This allowed multiple events per day and multiple event days in a row. The baseline used a 10-day average from the most recent 30 non-holiday weekdays to predict a weekday baseline. It is extended for weekends or holidays by taking a 5-day average of Saturday, Sunday, and holidays. For more information on the ISO New England unadjusted baseline, see this appendix's **ISO New England Unadjusted and Adjusted Baseline.** Other water heater evaluations used similar averaging methods.[21]

WEC Peak Impact 2019 Calculation Method

In 2019 Efficiency Vermont implemented an auto-regressive integrated moving average model (ARIMA). The model is trained on the 30 days prior to the peak event and forecasts from 3 hours prior to the peak event through the end of the peak event. The project team removed from the training data any peak events that occurred in the previous 30 days. Efficiency Vermont included into the aggregation only the devices that had at least 30 days of historical data. This model assumed that there were enough days in the training data that were not demand response (DR) event days, so that the model had evidence to learn the typical power consumption behavior of each site. The model predicted the average behavior and cannot predict one-off or uncommon load changes. This made predicting changes in household schedules nearly impossible without other variables to predict schedule.

Dependent variables: y_t = *load* at time t, where the time series frequency is hourly

Independent variables: Time series configuration ARIMA (2,1,1) with exogenous variables

Model parameters: Model is trained before each evaluation period, and parameter values are stored in a database.

$$\hat{y}_t = y_{t-1} + \phi_1(y_{t-1} - y_{t-2}) + \phi_2(y_{t-2} - y_{t-3}) + \delta_1 y_{t-24} + \delta_2 y_{t-48} - \theta_1 \epsilon_1 + \beta_w x_{w_t} + \beta_T x_{T_t} +$$

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[21] Metzger, Cheryn, et al. "Load Shifting," 2018.

$$\sum_{n=1}^{40}\left(a_n \cos\frac{n\pi h_t}{168} + b_n \sin\frac{n\pi h_t}{168}\right)$$

y_t	Load at time t
ϕ_i	Parameter for the i^{th} lag term, i = 1, 2
δ_i	Parameter for 24-hour seasonal lag terms, i = 1, 2
θ_i	Parameter for the i^{th} moving average term, i = 1
ϵ_i	The i^{th} moving average term (lagged forecast error), i = 1
β_w	Parameter for the indicator of weekend or holiday
x_{w_t}	Indicator variable for weekend or holiday at time t
β_T	Parameter for temperature
x_{T_t}	Temperature in degrees F at time t
a_n, b_n	Parameters for Fourier series for 168-hour of week seasonality
h_t	Indicator of hour of week (ranges from 0, ..., 167)

Member Impact

Efficiency Vermont modeled the effect of event days on total kWh using a mixed-effects model. For each month, Efficiency Vermont re-fit the model on the data for that month. The data team included a random intercept for each device to account for the variability in hot-water consumption among households. The team also included random slopes for the effect of weekends versus weekdays on daily kWh. This meant that each device could have a different effect for the type of day. The data team also included a fixed effect for temperature. The team chose the model based on lowest Akaike information criterion (AIC) value and best coefficient of variation of the root mean squared error [CV(RMSE)]. Due to the small sample sizes Efficiency Vermont could not include many variables or fit a very complicated model to account for confounding variables.

Expected Accuracy

To assess model error, Efficiency Vermont trained the model on 15 random non-event days, and then measured the CV(RMSE) of the predicted values compared to the actual values. The CV(RMSE) values were on the higher side, since PowerShift was trying to predict schedule of hot-water use, which can be very difficult without other data.

ISO New England Unadjusted and Adjusted Baseline

Efficiency Vermont used ISO New England's unadjusted baseline from the Price-Responsive Demand programs as a reference for modeling. The unadjusted baseline uses a 10-day average from the past 30 non-holiday weekdays to predict a weekday baseline. The baseline is extended for weekends or holidays by taking a 5-day average of Saturday, Sunday, and holidays. The maximum lookback is 42 days. This adjustment procedure is not designed for device-level data and is mostly for large or aggregated assets. Therefor this adjustment was not effective in this pilot. **Figure 4** shows the procedure for adjustment.

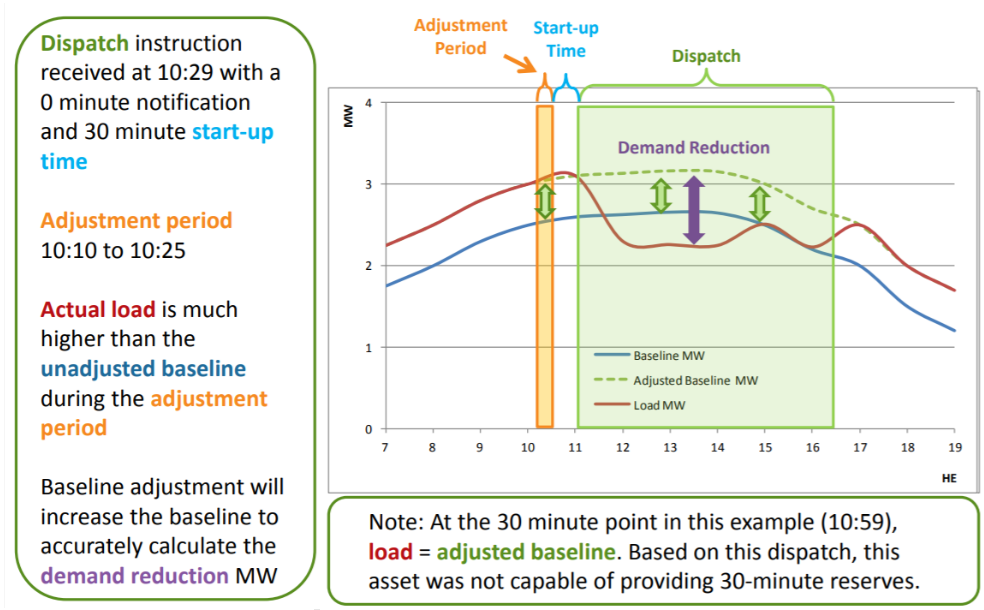


Figure 4. ISO New England adjustment procedure.

Appendix B: PET LoadShaper Results

From September 21 to September 26, the project team set ERWHs to be controlled by Packetized Energy Technology's LoadShaper™. These controls optimize the ERWHs for the locational marginal price (LMP). **Figure 5** shows the baseline compared to actual load, the impact of the controls, and the corresponding LMP, all averaged across the week. The ERWHs used less energy during times with higher LMPs, whereas energy use increased during times with low LMP. The total avoided LMP costs for the 6 days that the ERWHs were in LoadShaper™ mode was $-0.32 across the 23 participating devices. This was approximately $-0.01 per device. PET claims that device fleets with at least 100 connected devices consistently demonstrate over $10 per device in annual savings, but energy arbitrage is not recommended with fleets that involve fewer than 100 devices. That is, the randomness of energy prices and consumption patterns do not lead to predictable results in such a small sample size. Simulations suggest that devices could unlock $30 per device per year in large and fully optimized fleets of devices.

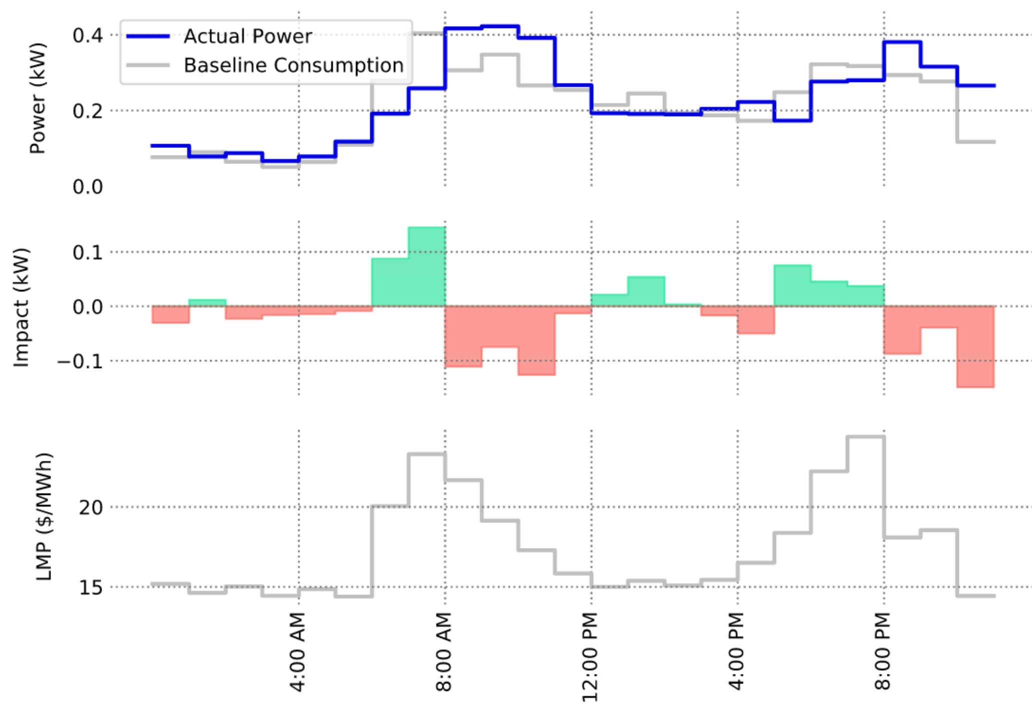
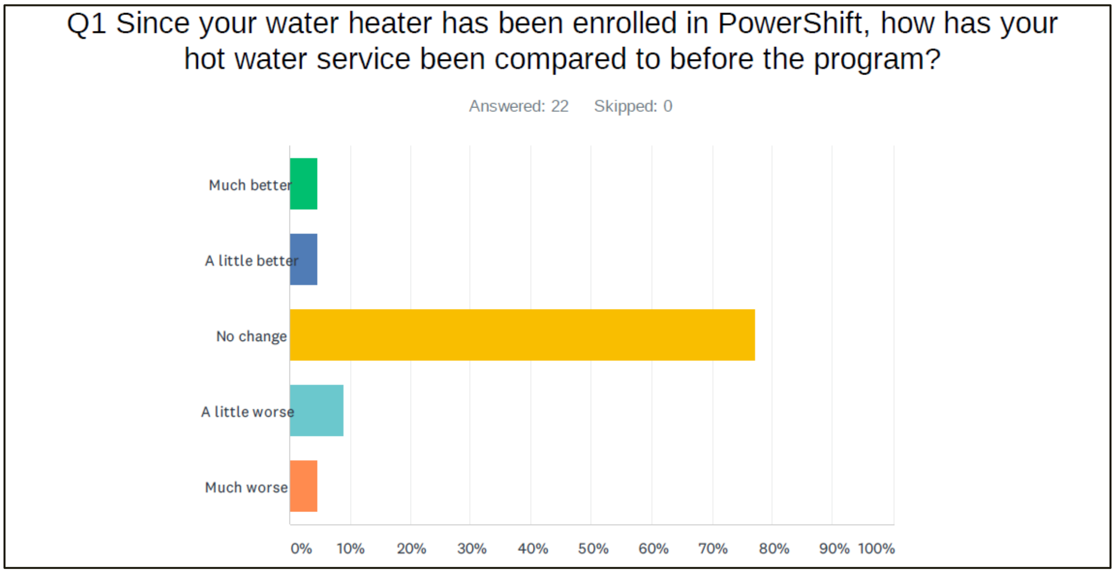


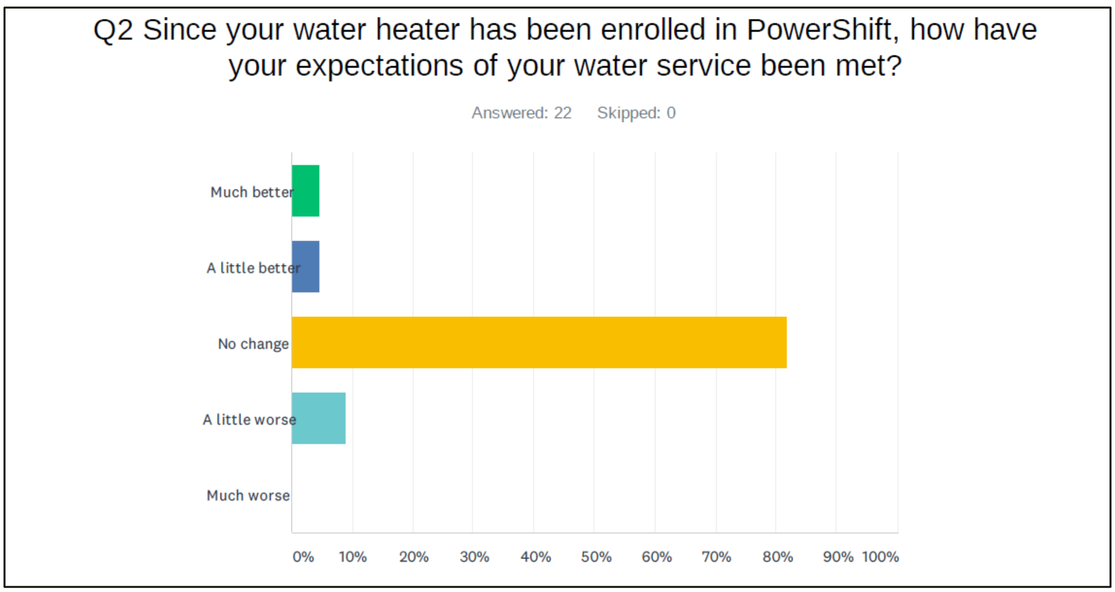
Figure 5. Weekly impact of LoadShaper controls and LMP.

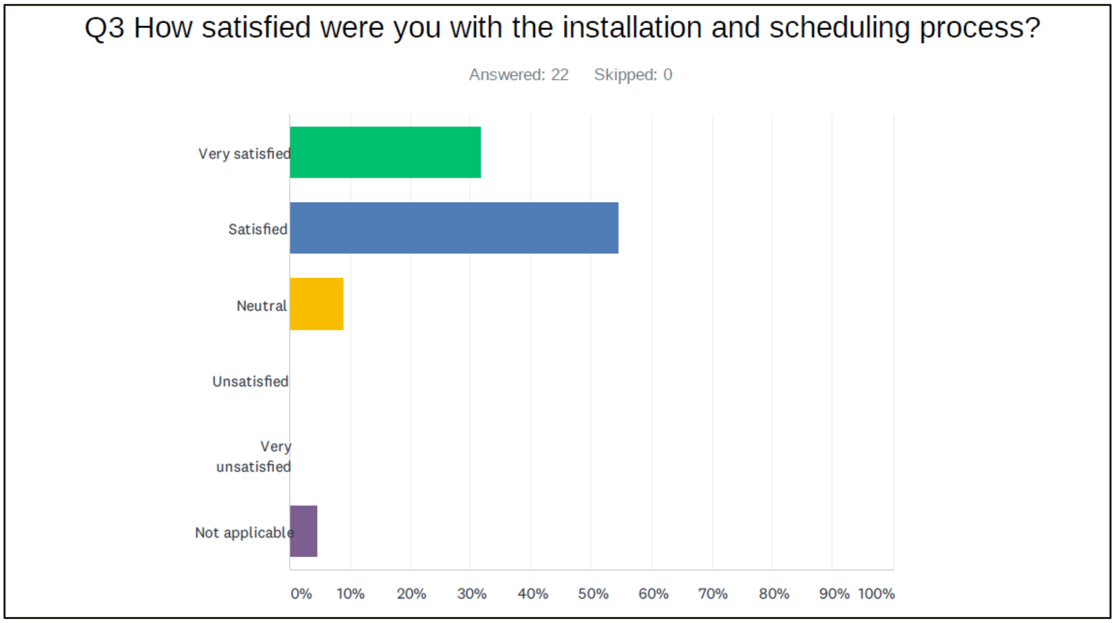
Appendix C: Member Survey Results

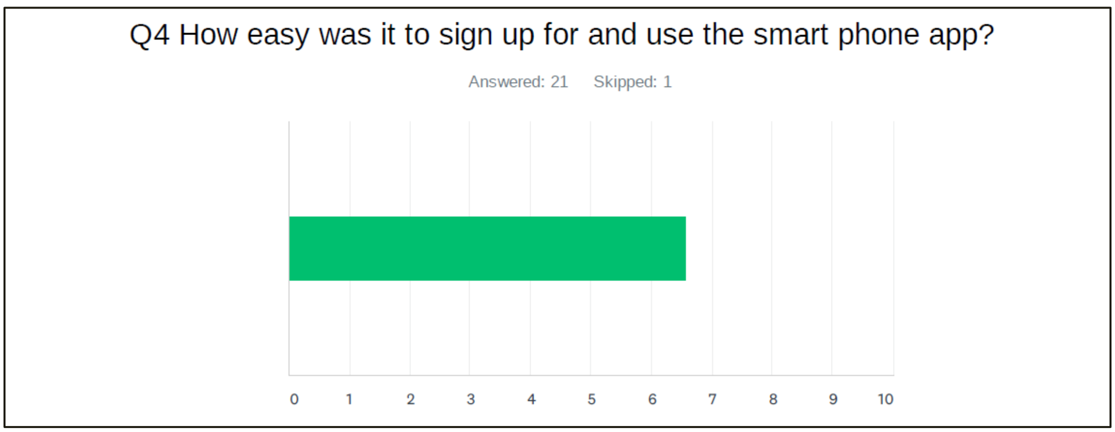
The following survey questions were given to PowerShift participants six weeks after enrollment. In total, 22 water heater participants and 2 EVSE participants responded to the survey over the course of the project period.

Water heater survey responses

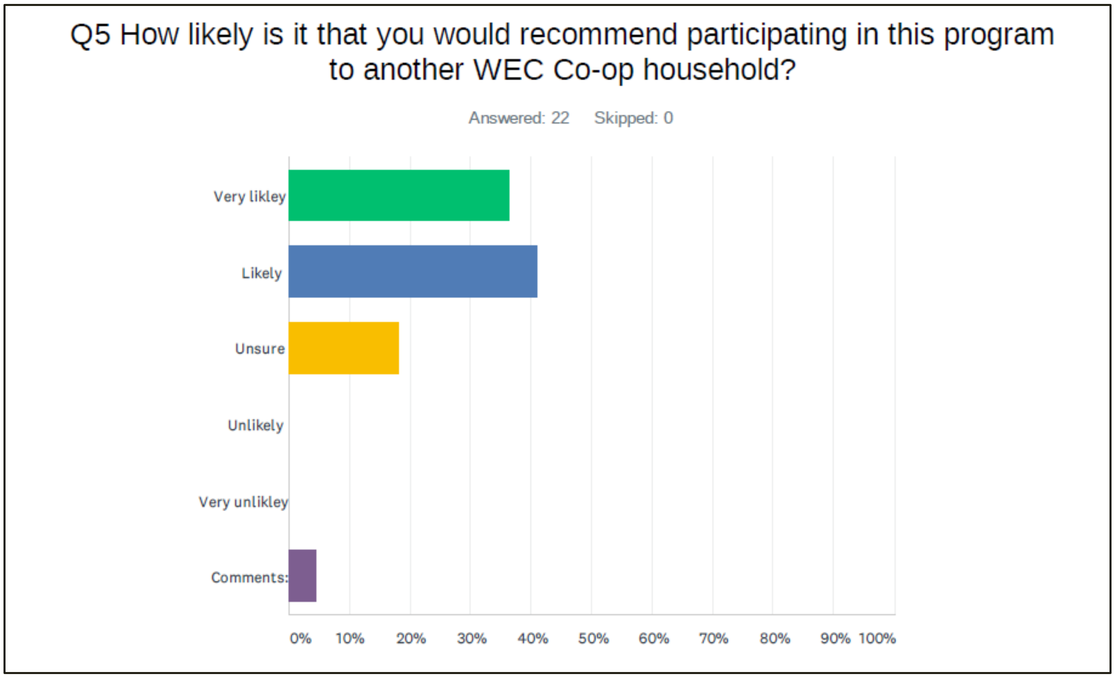


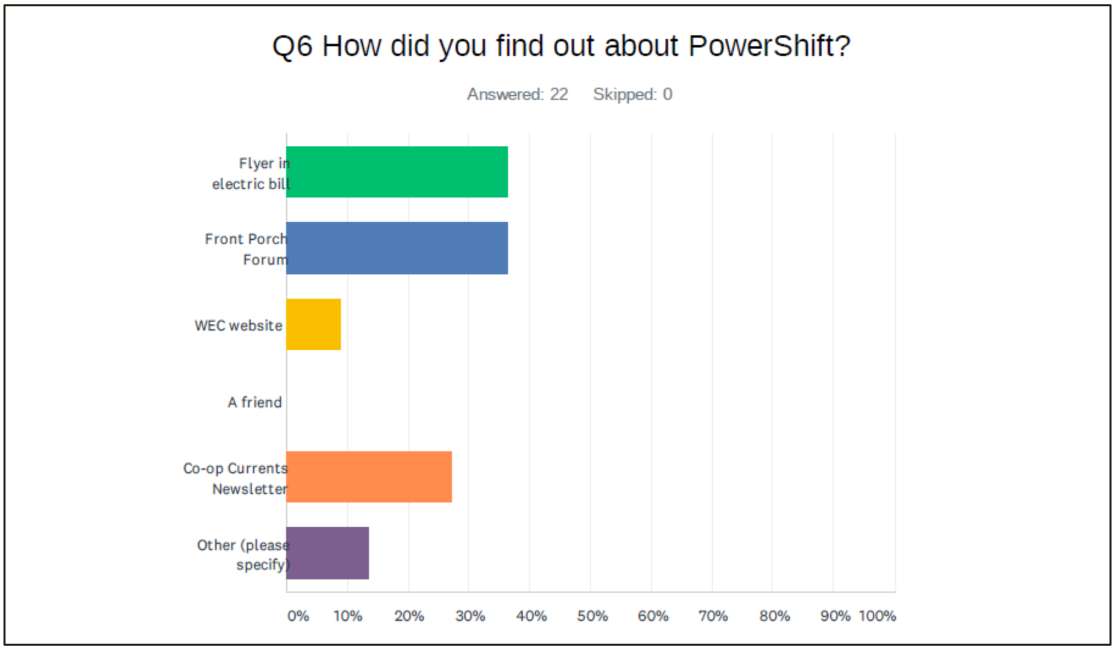




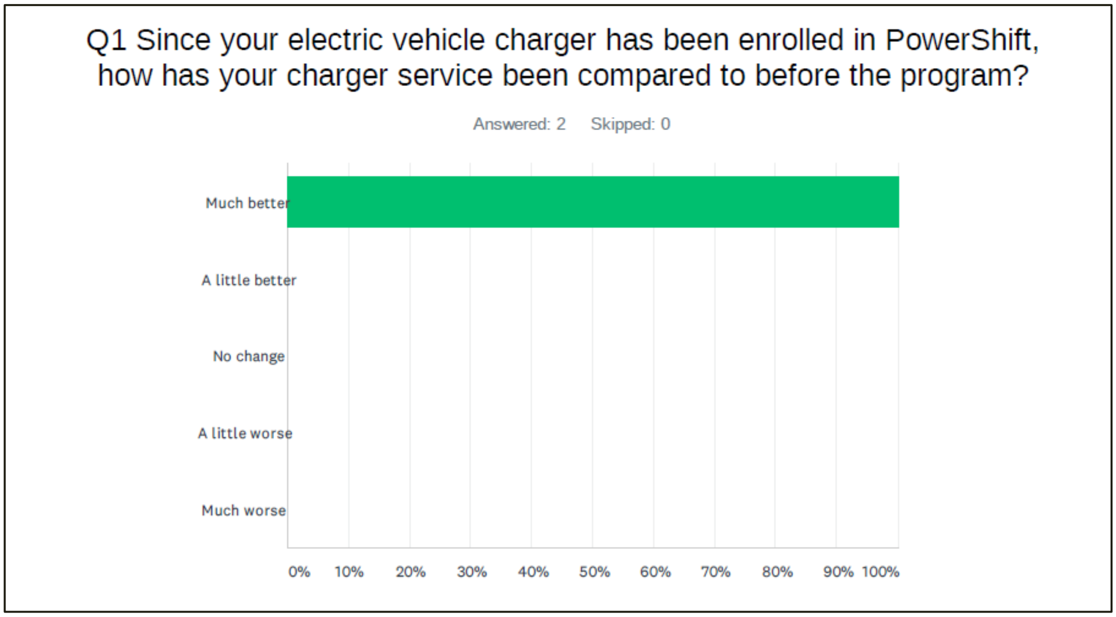


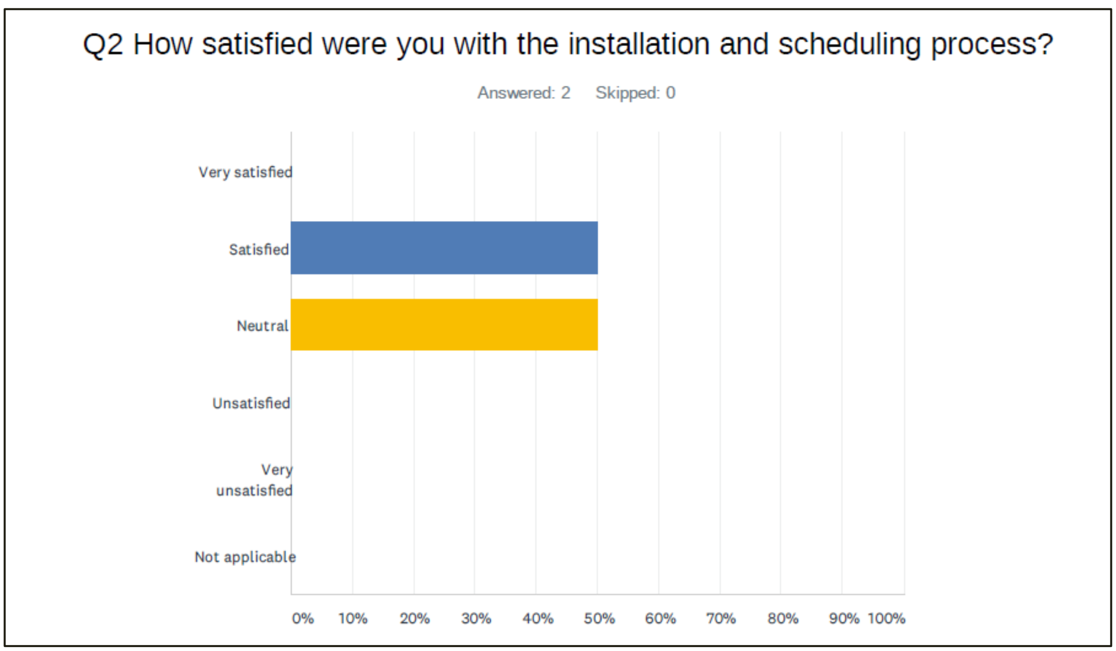
**on a scale of 0-10, with 0 being difficult and 10 being easy*

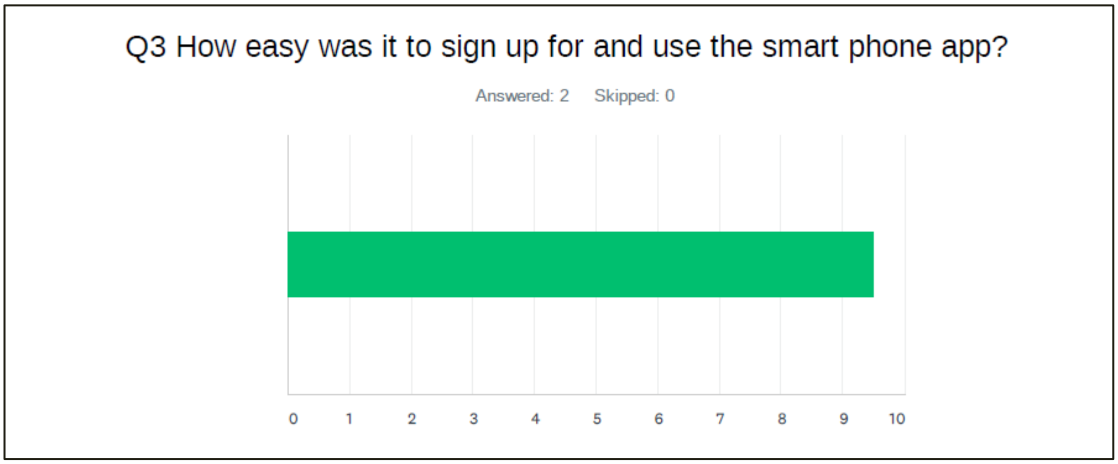

Q5 How likely is it that you would recommend participating in this program to another WEC Co-op household?
Answered: 22 Skipped: 0
Very likley
Likely
Unsure
Unlikely
Very unlikley
Comments:
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

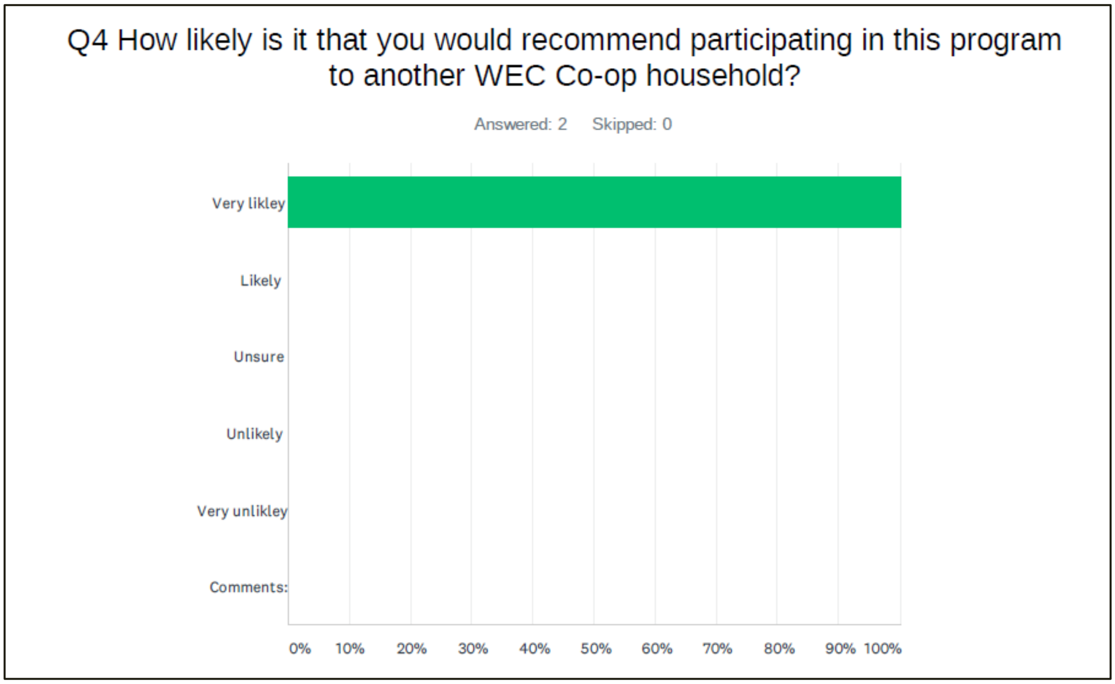

Q6 How did you find out about PowerShift?
Answered: 22 Skipped: 0
Flyer in electric bill
Front Porch Forum
WEC website
A friend
Co-op Currents Newsletter
Other (please specify)
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

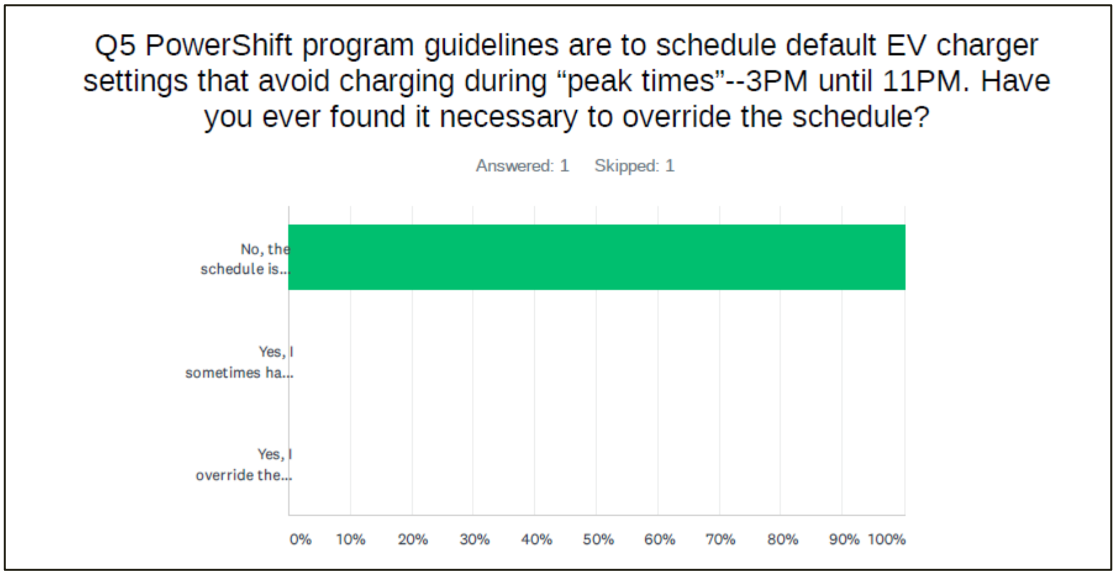
Electric vehicle supply equipment survey responses

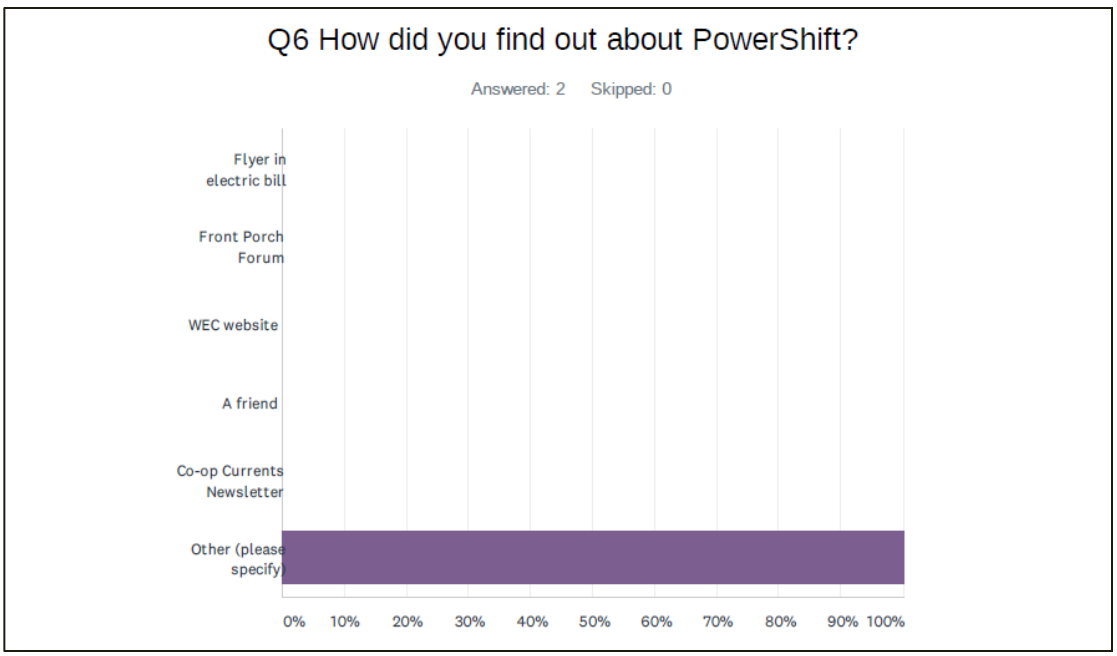





Q3 How easy was it to sign up for and use the smart phone app?
Answered: 2 Skipped: 0
0 1 2 3 4 5 6 7 8 9 10


Q4 How likely is it that you would recommend participating in this program to another WEC Co-op household?
Answered: 2 Skipped: 0
Very likley
Likely
Unsure
Unlikely
Very unlikley
Comments:
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%


Q5 PowerShift program guidelines are to schedule default EV charger settings that avoid charging during "peak times"--3PM until 11PM. Have you ever found it necessary to override the schedule?
Answered: 1 Skipped: 1
No, the schedule is...
Yes, I sometimes ha...
Yes, I override the...
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%


Q6 How did you find out about PowerShift?
Answered: 2 Skipped: 0
Flyer in electric bill
Front Porch Forum
WEC website
A friend
Co-op Currents Newsletter
Other (please specify)
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%