UCLA Luskin Center for Innovation

BRIEFING PAPER
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Electricity Conservation During Critical Times

Identifying and Shaping Effective Demand Response Programs for Residential Customers

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Introduction

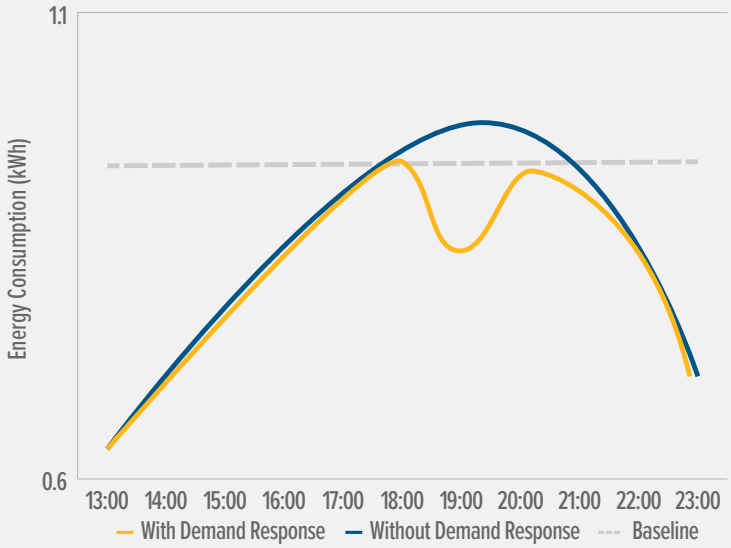
Many Californians can enroll in programs that pay customers to use less electricity during heat waves and other times the electrical grid may need help to avoid blackouts. If properly designed, these demand response programs can result in a variety of economic, health, and environmental benefits for Californians.

Demand response encourages electricity customers to reduce their energy consumption at times of high stress on the electrical grid. Customers are notified during these critical periods, called demand response events, and then their consumption is measured relative to their estimated counterfactual consumption, called a baseline. These notifications can also be accompanied by different types of messages and financial incentives that reward users for reducing their electricity consumption during demand response events.

Demand response programs reduce electricity consumption during critical times when electricity is often generated by the most expensive and polluting power plants. Energy consumption reductions lessen emissions of greenhouse gases and air pollution, resulting in environmental and health benefits. Furthermore, demand response is an important tool to support a flexible electrical grid that can better support more renewable energy.

Figure 1

Reduction in Electricity Use During Peak Times With Demand Response Programs



Objectives

Conducted by the UCLA Luskin Center for Innovation and supported by the California Energy Commission, this study evaluated the effectiveness of demand response program designs. The results of this study can be used to design more effective programs that result in greater environmental and economic benefits for Californians. To date, empirical studies that evaluate the effectiveness of residential demand response program designs have been limited.

This study assessed energy savings that resulted in over $1 million in rewards for over 20,000 study participants. The resulting research can inform decision-makers about the role of demand response programs in supporting grid reliability during the clean energy transition. The study can also help managers of residential demand response programs maximize participation, energy consumption reductions, and cost-efficiency to enhance benefits for Californians.

This briefing paper provides an overview of the research approach, key findings, and policy recommendations. For more details, see the study's full technical report, titled "Identifying Effective Demand Response Program Designs for Residential Customers."

Approach

Researchers tested the effectiveness of different program designs through partnerships with two demand response providers, Chai Energy and OhmConnect Inc.

Chai Energy communicates to its users through a smartphone application. This application alerts users to critical periods and encourages them to shift or reduce consumption. With Chai Energy, researchers performed a randomized control trial to test the effectiveness of demand response program incentives and messages. Incentives ranged from $0 to $5 per unit of electricity saved and were accompanied by messages emphasizing the economic benefits of participation or the health and environmental benefits of participation.

OhmConnect is an Internet-based demand response provider with more than 100,000 users in California. OhmConnect challenges users to reduce consumption during critical periods, called #OhmHours. Researchers analyzed existing energy consumption data from these customers. These analyses examined (1) programs that reward users for consistent behavior, (2) the accuracy of user baseline estimations and customer responsiveness to baseline levels, and (3) the ways consumption varied by demographics, which can help inform understanding of the effect of time-of-use rates.

Researchers estimate the effect of a demand response event on electricity consumption for different types of users. The effect is defined as the amount a user consumes beneath what he or she would have consumed in the absence of the demand response event. It is important to highlight that this is a different definition from those traditionally used to evaluate demand response programs, which estimate savings beneath the California Independent System Operator (CAISO)-defined baseline. In this analysis, researchers do not use that baseline because the accuracy of the CAISO-defined baseline differs across groups, which would lead to bias in the project team's estimations of differing responsiveness. Instead, researchers measure reductions against a counterfactual group, constructed using difference-in-difference analysis.

The goal of this project is to identify the most effective message content, timing and format, as well as incentive level, depending on the socioeconomic and energy use characteristics of customers. Alternative demand response program designs were tested on subsets of customers within Pacific Gas and Electric (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E) service territories. This study is not a performance evaluation of these demand response providers.

Findings

Demand Response Is Effective at Reducing Consumption

Researchers found that demand response events are effective at reducing consumption, but reductions vary

Figure 2

Comparison of Reductions in Users' Demand Response Events Over Time

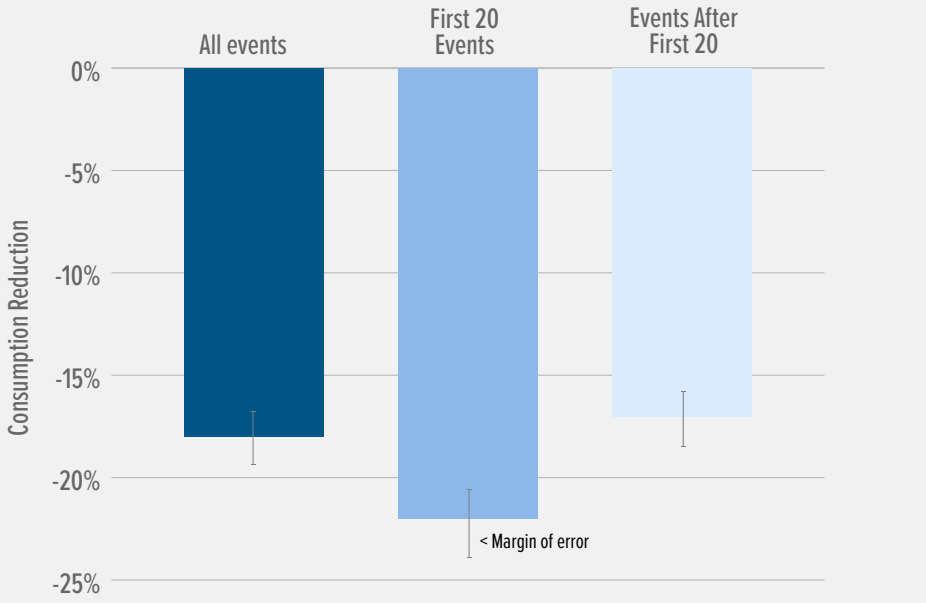


Figure 3

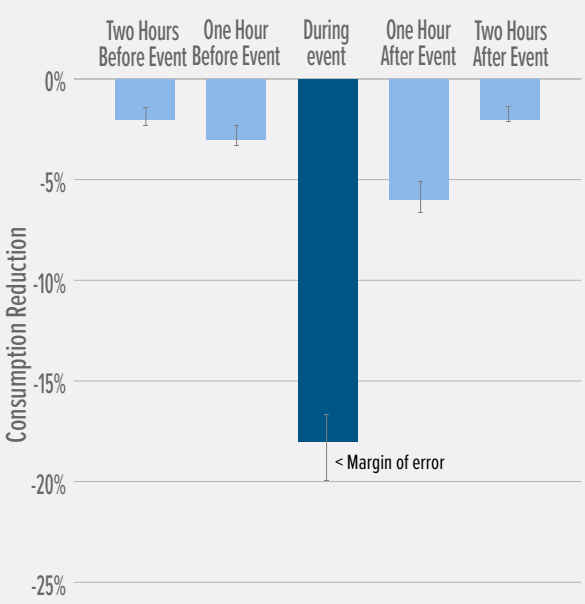
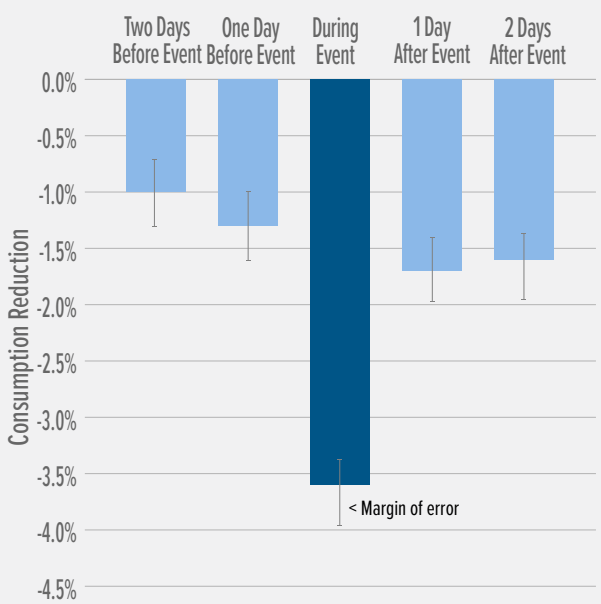


Figure 4



by user characteristics and other factors. Across all users, researchers found that energy consumption is reduced by 18% (0.15 kilowatt-hours [kWh]) on average during an OhmConnect demand response event relative to what a user would have consumed without an event. Users reduced consumption by similar amounts even when they received demand response events two days in a row, an indication that energy use was not simply delayed to the next day but instead was an absolute reduction.

Users have larger reductions in energy consumption during demand response events when they first begin participating. Researchers found that users reduced consumption about 30% more during their first 20 demand response events relative to later events. This finding suggests that user engagement falls over time.

Although users reduced consumption during demand response events throughout the year, the greatest reductions occurred in the spring and summer, and especially on hotter days. This conclusion suggests that it is easier for customers to reduce consumption when they have a greater capacity to do so; that is, when they can turn off or reduce use of their air conditioners. On average, customers reduced electricity consumption during demand response events by 21% on days hotter than 90 degrees Fahrenheit and only 15% on cooler days. Similarly, energy conservation during demand response events is about 1.8 times and 3.5 times greater in absolute terms during spring and summer, respectively, compared to the rest of the year.

Demand Response Results in Overall Consumption Reduction, Not Shifting

Users' consumption actually decreased slightly in the hours and days surrounding a demand response event. These results suggest that demand response results in overall consumption reductions, not shifting energy consumption to other times.

Demand Response Varies by Energy Use, But Not Social, Characteristics

Surprisingly, there were not large absolute or proportional differences across most social subgroups. Differences in consumption reductions ranged from about 2 to 4 percentage points (0.01 to 0.08 kWh) between users living in zip codes above versus below the median for income, percentage white population, and home ownership. The largest absolute difference was seen when comparing users living in zip codes above the median for single-family homes: those above the median reduced by 0.08 kWh more, although this is only a 2-percentage point difference. The largest proportional difference was between users who receive discounts on their energy bills through enrollment in the California Alternative Rates of Energy (CARE) program and those who do not. The study found non-CARE users reduce their consumption by 7 percentage points more, although this difference was driven largely by differences in solar, plug-in electric vehicle (PEV), and automation device ownership between those two customer classes.

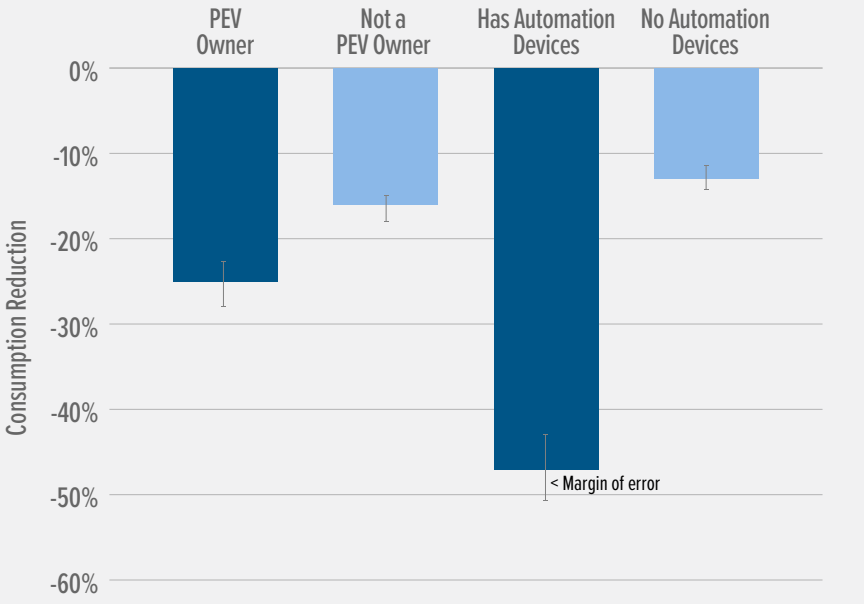
Researchers measured larger differences depending on users' energy use characteristics. Users with above median energy consumption and "energy engaged users," or those with solar panels, PEVs, or automation devices (i.e., technology that can automatically alter its energy usage as needed, such as smart thermostats and other smart appliances) or a combination, are more likely to reduce consumption during demand response events. Specifically, PEV owners reduced their consumption by 25% during demand response events, while non-PEV owners reduced consumption by only 16%. The most noticeable difference was seen between users with and without automation devices. Users who have automation devices used 47% less energy during an event relative to 13% reductions for those who do not.

Electricity Rate Structures and Automation Devices Matter

There are important behavioral differences among users with different electricity rates. Researchers compared how users on a time-of-use (TOU) rate performed during demand response events to users on other rates. TOU rates charge users different

Figure 5

Reduction Differences for Users With and Without Technologies



electricity rates per kWh depending on what time of day the electricity is consumed. Typically, TOU rates are most expensive at the same time that demand response events occur. This means TOU users are already incentivized to consume less during these times.

When looking at "non-energy engaged users" (those without solar, PEV, or automation devices), customers on TOU rates reduce less than users on other rate schedules. However, "energy engaged" TOU users reduce energy consumption by *more* than non-TOU users. Favoring energy technologies such as automation seems essential to maintain high demand response efficiency, especially as California transitions more customers to TOU rates, so that consumption reductions can be maintained.

Lower Energy Conservation Targets Can Induce Larger Savings

Demand response providers typically reward users during a demand response event based on their conservation relative to an assigned baseline. The baseline represents a user's energy consumption in the absence of a demand response event. Baselines are set based on the average of consumption in the same hour as the demand response event during the previous 10 nonevent, nonholiday weekdays. Demand response providers have traditionally calculated baselines based on historical usage rather than forecasts. A better understanding of how baselines influence event participation and energy consumption reduction is essential to designing more cost-effective demand response events. In this analysis, researchers examined how the baseline set by demand response providers affects users' conservation behavior.[1]

Researchers found that customers reduce their energy consumption more when their baseline is set lower, all other factors held constant. In other words, lower baselines induce greater conservation: A 0.1 kWh decrease in the baseline level leads to an additional 0.017 kWh conservation. Researchers found suggestive evidence that customers use their baseline as a reference point for how much conservation is needed, which drives this response. Customer responsiveness to baseline changes varied by demographics. Notably,

Figure 6

Comparison of Reductions Throughout the Year

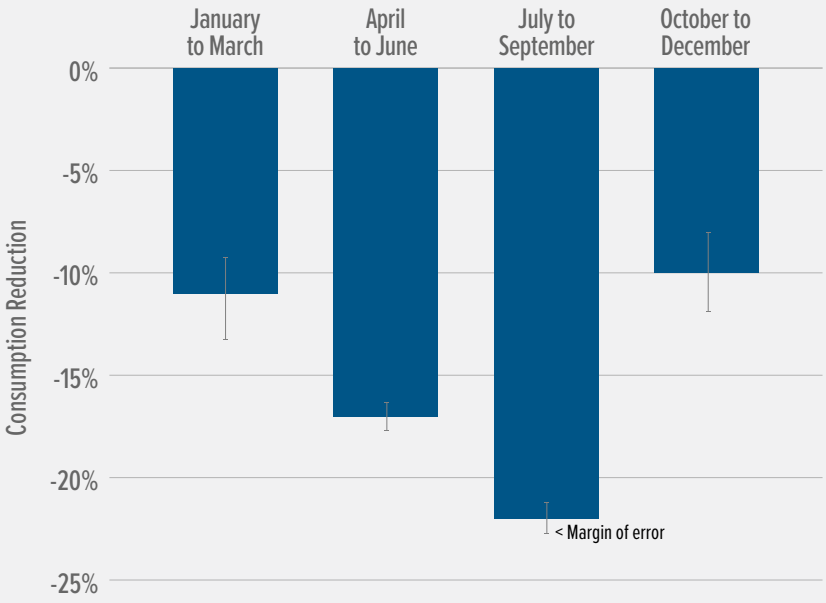


Table 1

Testing Message Effectiveness

Messaging Treatment Group	With Any Financial Incentive	Without Financial Incentive
Economic Benefits	"Utilities struggle to generate enough power during PrimeTime. Earn cash rewards by cutting your electricity use!"	"Utilities struggle to generate enough power during PrimeTime. Lower your utility bill by cutting your electricity use!"
Moral Subsidy	"PrimeTime electricity produces pollution that causes childhood asthma and cancer. Save lives and reduce pollution by cutting your electricity use. Be a PrimeTime Hero and earn cash rewards!"	"PrimeTime electricity produces pollution that causes childhood asthma and cancer. Save lives and reduce pollution by cutting your electricity use. Be a PrimeTime Hero!"
Moral Tax	"PrimeTime electricity produces pollution that causes childhood asthma and cancer. Don't endanger lives and increase pollution in your community by wasting energy. Earn rewards by not being a PrimeTime Waster!"	"PrimeTime electricity produces pollution that causes childhood asthma and cancer. Don't endanger lives and increase pollution in your community by wasting energy. Don't be a PrimeTime Waster!"

customers in low-income zip codes responded the most to changes in baseline.

Economic Benefits Messages Are Most Effective

Demand response events that included messages emphasizing personal economic benefits were more effective than those that included messages about health and the environment. For this analysis, researchers tested three types of messages (Table 1) that were randomly assigned to nearly 3,000 Chai Energy users. The economic benefits message emphasized the cost-savings or the financial rewards, if applicable. Another message emphasized the positive environmental and health benefits of reducing consumption during critical times, while the third message emphasized the negative health and environmental consequences of not reducing consumption during critical times. The messages customers received are summarized below.

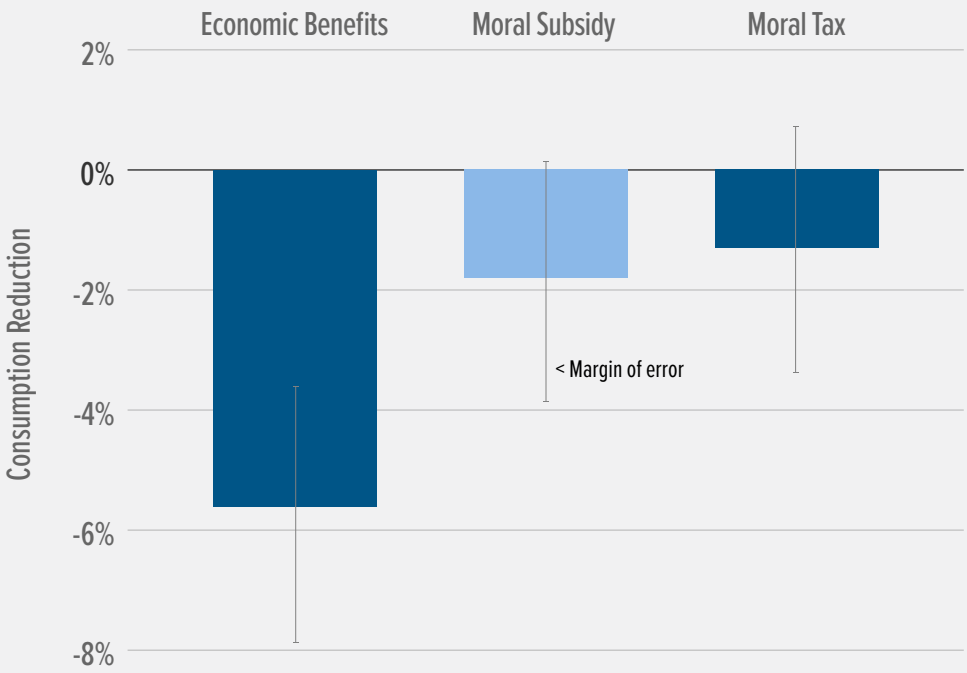
On days hotter than 90° Fahrenheit, the economic benefits messaging emphasizing cost savings was the most effective framing for demand response events. Messages emphasizing how health and the environment are affected reduced consumption by only 1% to 2% compared to the economic benefits message, which reduced consumption 6%. Economic benefits messaging was more effective than health and environmental messaging regardless of whether it was accompanied with a financial incentive. On days cooler than 90° Fahrenheit, no messages were strongly effective.

Financial Incentives, at Any Level, Matter

Offering a financial incentive for participation was critical to inducing consumption reductions, although the level of the incentive is less important. In the

Figure 7

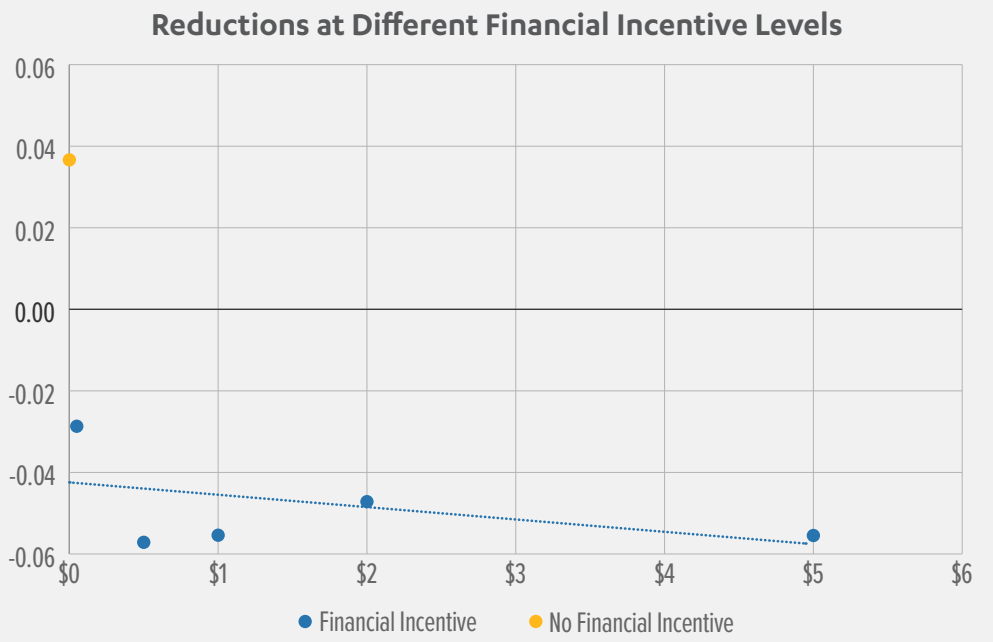
Effect of Different Messages on Days Hotter Than 90° Fahrenheit



randomized experiment with Chai Energy, researchers uncovered how different types of financial incentives affected consumers' willingness to reduce energy consumption during critical periods. Researchers offered financial incentives of 5 cents to $5 per kWh, and a control group received no financial incentive. Without a financial incentive, customers did not have statistically significant consumption reductions. There were not large differences in consumption reductions between the different levels of financial incentive. For example, the $5 incentive is 100 times larger than the 5-cent incentive, but only increased consumption reductions by two times. Although differences in consumption reductions between financial levels were larger on days above 90 degrees Fahrenheit, reductions still did not scale with the size of the incentive.

Researchers found similar results when looking at differences in the level of incentive with OhmConnect users. In this analysis, researchers looked at two of OhmConnect's performance-based rewards programs: streak and status. Users can build streaks by consuming less than their baseline in consecutive demand response events. For every event an individual successfully consumes less than their baseline, they maintain any existing streak and extend it by one. Each extension of the streak is rewarded with bonus points. OhmConnect participants can earn different statuses (silver, gold, or platinum) based on the percentage of energy saved relative to the baseline over their past 10 events. To qualify as an Ohm gold member, a customer must save 15% beneath baseline on average for the previous 10 events. To qualify as a platinum member, the customer must save 40% beneath baseline over the same period. Ohm gold members receive 1.5 times more points per #OhmHour and Ohm platinum members receive two times more points. In this analysis, researchers examined how extending a streak or increasing status affected consumption reductions in subsequent events.[2]

Figure 8



Generally, the nonlinear increase in incentive level did not lead to greater consumption reductions. Researchers found no effect of extending the status or streak when compared to users who lost the status or streak, despite differences in marginal financial incentives. However, there were two minor exceptions. During the first 20 events, when users have a streak longer than five, they reduce 0.09 kWh more during the next demand response event when they maintain their streak compared to those who lost their streak. Similarly, users who moved from silver to gold status reduced by 0.04 kWh more than those who did not achieve gold status. Gaining gold status also increased the likelihood that a user would invest in automation technology. These effects were not seen for platinum status. Researchers also found that streak length and status level decline over time, suggesting lower user engagement over time. Importantly, users with automation devices and non-CARE customers tend to have longer streaks and higher statuses. This finding is consistent with the results from the Chai Energy analysis in this report and in a previous study (Gillan 2017) that found very low additional responsiveness to higher marginal rewards.

These results do not mean that streak and status programs are ineffective, but rather that users do not respond strongly to changes in their incentive levels. It could be that the presence of streak or status rewards induces all users to try harder, whether they have an active streak or status. Streak and status programs could improve customer engagement or encourage customers to reduce more consistently. Given data limitations, the research team could not test this hypothesis, but it is an important area of potential future research.

Timing and Frequency of Events Is Less Important Than Other Factors

The effectiveness of event timing and frequency varied by context, making it difficult to draw universal conclusions. Other factors such as message framing and financial incentives appear to be more important to demand response effectiveness than timing, and especially frequency.

Policy Recommendations

1 Support automation device adoption.

Automation devices helped customers achieve larger reductions in energy consumption during demand response events. These technologies, such as smart thermostats and other appliances, can automatically alter their energy usage as needed, which allows customers to automatically have their electricity use reduced. Importantly, automation devices may assist with a central challenge of all demand response providers: not only attracting customers but also ensuring that they remain active conservers in the long term. Because the effort of reducing consumption is reduced, these devices help with long-term customer engagement and could alleviate attrition-related issues, thus assisting with demand response event predictability and reliability.

Automation devices can also help to ensure the success of demand response programs as more customers switch to TOU rates. As researchers found some evidence that income differences were driven by differential adoption rates of technology like automation devices, supporting automation device adoption in low-income households can help demand response programs achieve more equitable benefits.

2 Offer financial incentives and emphasize economic benefits to participants.

To ensure the greatest consumption reductions, demand response programs should include simple messaging that emphasizes incentives and bill savings. While offering an incentive is important to inducing consumption reduction, users do not respond proportionally to greater financial incentives and do not respond strongly to changes in marginal price. The results from this study suggest that using flat and lower incentives could lead to more cost-effective programs.

3 Refine baseline calculation and its communication to users.

The baseline calculation is crucial for event forecasting and accurate rewards for participants. Furthermore, customers modify the magnitude of their conservation depending on their baseline level. Changing the way baselines are communicated to customers could induce greater conservation. Users were responsive to changes in their baseline level, likely because they use it as a reference point for how much to reduce their energy consumption. Setting consumption targets lower than baselines could induce greater conservation behavior. Alternatively, demand response providers could provide users with additional information to help them target consumption reductions, such as estimates for how much energy could be saved by making different behavioral changes.

Authorship

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Acknowledgments

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Endnotes

[1] This analysis quantified whether user baselines have a causal effect on energy consumption during events using an econometric approach called an instrumental variables strategy.
[2] Researchers nonexperimentally evaluated the effect of qualifying for OhmConnect's streak and status programs by using regression discontinuity design methods. That is, comparing the performance of individuals whose performance on their last #OhmHour was either just above or below the threshold value necessary for inclusion into the program.

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