

INTERACTIONS BETWEEN DEMAND FLEXIBILITY AND ENERGY EFFICIENCY: The Opportunity Cost of Saved Energy

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ABSTRACT

This project explores the complex relationship between energy efficiency (EE), demand response (DR), and demand flexibility broadly. Demand response (DR) incentives can affect energy efficiency investments, though this impact is often overlooked when evaluating the economics of efficiency investments. As a customer becomes more efficient and reduces their demand for energy, their ability to respond to future demand response events decreases. As we move toward a future with greater dependence on variable renewable resources, the value of energy efficiency from an emissions perspective is less important, but demand flexibility will have greater value. However, both EE and DR are important resources to reduce peak demand, maintain reliability, and reduce emissions at lowest cost. This paper introduces the concept of “Opportunity Cost of Saved Energy” (OCSE). Given the possible diminished ability to reduce demand after an EE measure is installed, there is a “cost” of no longer having as much flexible demand “capacity.” The OCSE is conceptually illustrated through changes to loads with varying load factors and concretely illustrated by examining average load shapes of cooling of commercial buildings in California. The impact of accounting for the OCSE increases the payback period of EE measures related to cooling by about 25% on average in California. Accounting for the OCSE is a correction that will make EE financial savings estimates more accurate. Care must be taken to align incentives between DR and EE programs to achieve the outcomes that we desire.

Background

The purpose of this study is to better conceptualize and quantify how participation in demand response may impact the economics of energy efficiency investments. Demand response, as used by the Federal Energy Regulatory Commission (FERC), is “a reduction in the consumption of electric energy by customers from their expected consumption in response to an increase in the price of electric energy or to incentive payments designed to induce lower consumption of electric energy” (Federal Energy Regulatory Commission 2010). This paper will focus on the potential of incentive payments to reduce demand during certain times.

There has been little exploration of the complex relationship between DR and EE. York and Kushler (2005) have reviewed this topic but primarily came to the conclusion that the impact of DR on EE is not well understood. They suggest that there is some anecdotal evidence of spillover from DR to EE. They hypothesize that going through the process of identifying non-essential loads that could be shed during DR events also shows how energy could be reduced at all times. The higher level of awareness and understanding that comes from DR participation can inform consumers about energy savings opportunities. The energy monitoring and control systems that are needed for DR also can deliver EE savings by providing better information. Goldman et al. also explored the relationship between DR and EE and found that there was a greater need for coordination between programs (2010).

From a deployment point of view, research in California has shown that equipment used to enable demand shedding in commercial buildings is a subset of the equipment used to improve energy efficiency of buildings (Piette et al. 2005). The key piece of equipment that provides both EE and DR functions in commercial buildings is the energy management and control system (EMCS). The EMCS gives building operators the ability to centrally monitor, analyze, and control building systems which can make buildings more energy efficient and provide for peak load reduction (Kiliccote and Piette 2005).

The various types of demand response programs can be broadly separated into two types: incentive based and time based. Incentive-based programs may take many forms including direct load control, curtailable rates, emergency DR, capacity market programs, demand bidding, or peak time rebates. Time-based programs take the form of real time pricing or critical peak pricing (Federal Energy Regulatory Commission 2008).

Different DR program structures can have different impacts on customers' willingness to invest in energy efficiency measures. With either type of DR program, customers who are more willing and able to make reductions during periods of peak demand will be rewarded with lower spending on electricity. With flat retail rates, utilities deliver electricity at a given price which does not reflect the cost of generation at that specific time. Flat rates therefore must contain a risk premium, which time-based rates can reduce.

York and Kushler (2005) point out that EE and DR can conflict with each other with either time-based or incentive-based structures. In incentive-based DR programs, customers receive a payment based on the magnitude of their reduction (such as Emergency DR, Capacity Market Programs, Demand Bidding, and Ancillary Services Markets). It is therefore possible that energy efficiency, which reduces baseline energy use, will reduce the size of the demand reduction during a DR event. Therefore, the true cost of energy efficiency should include the DR opportunity cost—or the lost revenue from reduced DR participation. Doing so could affect the payback time for energy efficiency investments—or even make previously cost-effective measures no longer cost effective.

Under time-based DR programs (like Critical Peak Pricing or Real Time Pricing), more responsive loads will shift their demand from peak to off-peak periods and, therefore, decrease the average price of electricity and the total energy spending. Energy efficiency that evenly affects load in all hours of the day (in percentage terms) has no impact on the average cost per kWh. Time-based rates could, as York and Kushler suggest, impact energy efficiency investments if they reduce the average cost of electricity saved through the efficiency measure to a level lower than the Cost of Saved Energy (CSE) for an energy efficiency measure, making the measure no longer cost effective. Or, rather than disincentivizing EE altogether, time-based DR for highly responsive loads could potentially lengthen the payback periods of energy efficiency measures by decreasing the average cost of electricity. The specific impacts of DR on EE also depend on the shape of the reduction of the efficiency measure. Efficiency measures that reduce load predominantly off-peak will be strongly disincentivized by switching to a time-based program. Efficiency measures on loads, such as air conditioning, which are higher during peak periods, may be even more cost effective under time-based DR programs.

Incentive-based DR programs are reliant on calculation of baseline level of consumption, but the administrator of the DR program cannot know as much as the customer about the true baseline. Bushnell et al. point out that it is impossible to know how much consumers would have demanded without the DR payment. This asymmetric information may allow customers to game the system and profit. Also, paying consumers for demand reductions may give them a perverse

incentive to use more energy and inflate their baseline demand in order to capture a larger DR payment. Dynamic pricing approaches to DR might be crowded out by incentive-based programs even though dynamic pricing approaches might achieve the same goals more effectively (Bushnell, Hobbs, and Wolak 2009).

The idea of DR opportunity cost applies in an abstract sense to time-based DR programs, but the interaction is much clearer with incentive-based programs. The rest of this paper applies only to incentive-based programs.

Methods

In order to see the interactions between EE and DR, the impacts were studied for generalized building load shapes. The metric that drives the interaction is the coincidence in time of savings from efficiency and hours of demand response participation. If there is no coincidence of efficiency savings and DR participation, then we can ignore this interaction.

If energy efficiency measures reduce demand during the system peak hour, and if the customer is compensated for reductions during that peak hour, then we can put a value on that potential lost revenue from DR participation. The value, in dollars per year, could be calculated by the following equation:

$$\begin{aligned} \text{DR Opportunity Cost} \\ &= EE\% \times \text{interaction effect} \times DR\% \times \text{Baseline Demand} \\ &\quad \times \text{Capacity Value of DR} \end{aligned}$$

The “EE%” is the percent reduction in load due to an energy efficiency measure. The “interaction effect” term is between zero and one and represents how much energy efficiency measures impact demand response actions. If a facility achieves a demand response reduction through dimming lighting, and more efficient lighting is the energy efficiency measure, then the interaction term would be close to one. If, however, a facility achieves DR through dimming lighting, but is considering installing a more efficient HVAC system, then this interaction term is close to zero—and there would be little or no DR opportunity cost. The opportunity cost is also based on the percentage of demand that can be shed during a DR event (DR% in equation above) and the baseline level of demand during time periods when a DR event is called. Lastly, the opportunity cost is also directly related to the capacity value of DR, which might be expressed in units of dollars per kW-year. This represents the avoided cost of generation capacity that would be passed on to the consumer. Peak generation capacity is typically provided by a combustion turbine, which has the lowest annualized fixed costs. According to data from the 2021 EIA Annual Energy Outlook, the annualized capital cost plus fixed costs of a combustion turbine is approximately \$61/kW-year (EIA 2021a). This assumption will be used in the results unless stated otherwise. DR energy payments are ignored.

By reducing energy use through energy efficiency measures, we reduce energy bills and may reduce load during peak hours. By reducing energy use, we also may reduce the amount by which we can further reduce load during a demand response event.

Traditionally, energy efficiency measures may be evaluated by calculating the Cost of Saved Energy (CSE). If the CSE is cheaper than the cost of buying energy, then the measure will pay back during the life of the measure:

$$\begin{aligned} \text{Cost of Saved Energy (CSE)} \\ &= \frac{\text{Annualized Incremental Cost of Energy Efficiency Measure}}{\text{Annual Energy Savings of the measure}} \end{aligned}$$

However, the CSE is an incomplete metric because it ignores the potential lost revenue (or savings) from DR participation. Here, I introduce a new term that may adjust the CSE—the Opportunity Cost of Saved Energy (OCSE). The OCSE shows the opportunity cost per saved kWh rather than the capital cost per saved kWh in the CSE.

$$\text{Opportunity Cost of Saved Energy (OCSE)} = \frac{\text{DR Opportunity Cost}}{\text{Energy Savings from EE}}$$

The true cost of saved energy should be the sum of the CSE and the OCSE.

Results

Depending on the shape of the load reduction and how it coincides with the system peak, the OCSE will vary. To begin, a range of scenarios are investigated that span from a load factor of 100% (constantly on) to a load that is on only one hour per day (load factor of 4.2%). The intermediate cases have a constant load that is on anywhere between 2-23 hours per day. It is assumed that a DR event is called during an hour that the load is operating in all cases. For the case with a high load factor, you would save a lot of energy (and money) with an energy efficiency investment, relative to the DR capacity that is available. On the other hand, a load that is coincident with the system peak but does not use much energy in other hours, would not save very much energy relative to the DR capacity. This is illustrated in Figure 1. We can see that there is a very high OCSE for loads that are not on much overall but that are on during DR events. For the DR opportunity cost calculation, the capacity value of \$61/kW-year was used, which is based on the annualized capital and fixed O&M cost of a natural gas combustion turbine (EIA 2021a).

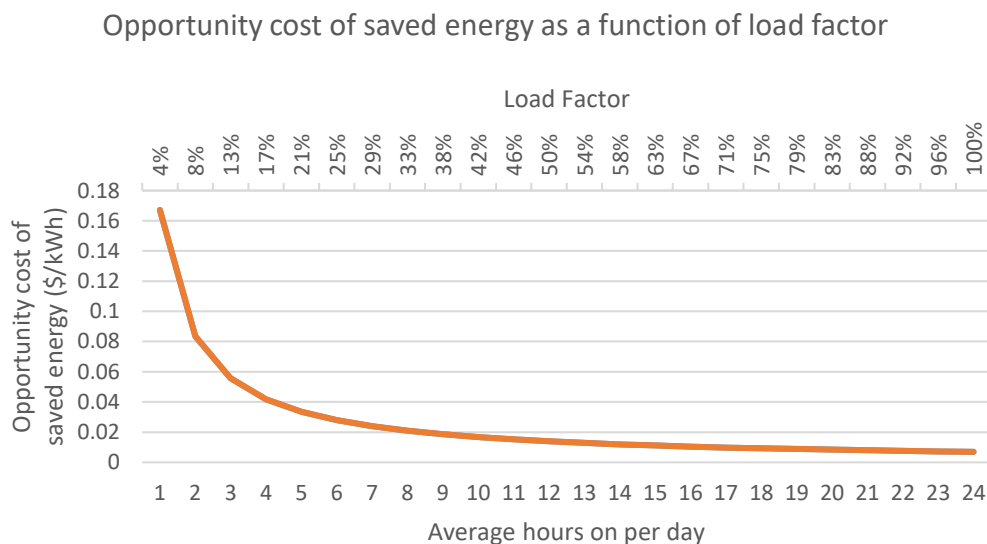


Figure 1. Opportunity cost of saved energy as a function of load factor. Very low load factors that operate during peaks correspond to high OCSE.

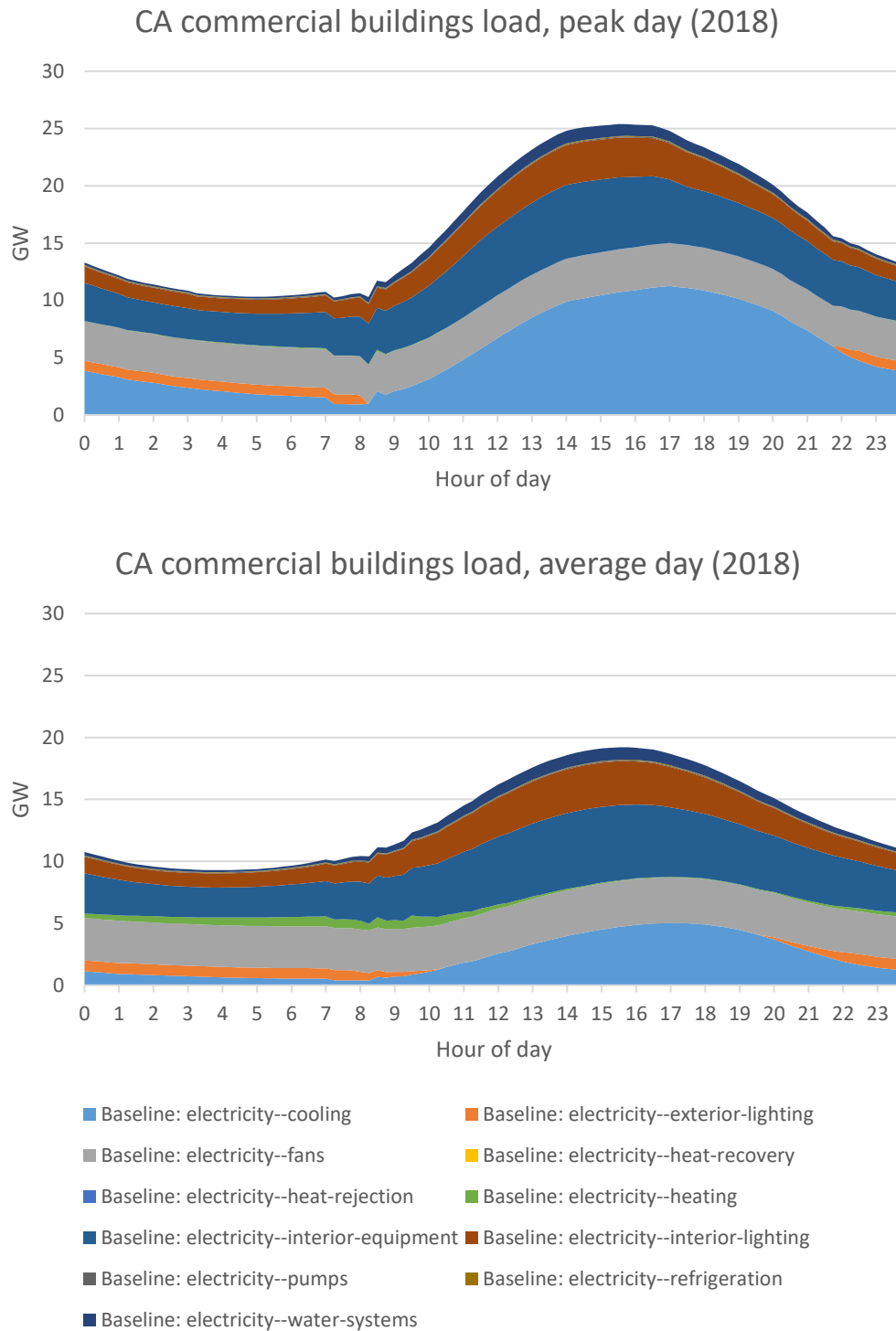


Figure 2. Load shapes of average and peak day for all commercial buildings in CA (Wilson et al. 2021).

The impact of the OCSE across all commercial buildings in California was also modeled. Using data from ComStock, a DOE-funded research program to build validated load profiles of commercial buildings across the United States, the impact of energy efficiency of cooling systems on energy and capacity savings was estimated (Wilson et al. 2021). The 2018 estimate

of all commercial buildings cooling energy use in California was 19.4 TWh per year. The peak cooling load is 11.3 GW. Given the annual cooling load shapes for commercial buildings in California, the estimated OCSE is \$0.035/kWh. Using an average retail price of \$0.18/kWh in California (EIA 2021b) we can determine that the gross financial savings (not accounting for incremental capital cost of the efficiency measure) from energy efficiency related to cooling would be 20% lower after accounting for the OCSE. If we apply the same capacity value but with national average retail rates of \$0.1059/kWh (EIA 2021b), then the gross financial savings would be 33% lower after accounting for the OCSE. As a result of this potential lost “revenue” from DR, the payback periods of cooling energy efficiency measures would increase by 24% in California or 50% when using national average retail rates (but commercial building models in CA). It is a well-documented phenomenon that high discount rates are already applied to savings from energy efficiency measures, and investors demand very short payback periods from energy efficiency investments (Anderson and Newell 2004; DeCanio 1993; Gillingham and Palmer 2014; Jaffe and Stavins 1994). Accounting for lost capacity value included in the OCSE further exacerbates this challenge.

The analysis assumes that energy efficiency measures impact all hours on an equal percentage basis and that the DR potential of a load is 100% reliable and captures the full capacity value (avoided cost) of new generation. In practice, utility planners may not assume that load reductions are 100% reliable, and therefore DR participants would not be compensated at the full avoided cost of peaking generation capacity. Even if half of that value is passed on to customers, the OCSE is significant and could impact energy efficiency investments, particularly related to cooling.

Conclusion

It is well known that different energy efficiency resources can provide varying capacity values and contributions to resource adequacy depending on how they impact peak electricity consumption. This can impact the incentives that a utility would be willing to provide for various measures. If DR incentive programs are in place, greater incentives for on-peak energy efficiency reductions are necessary from the perspective of the customer because a greater opportunity cost exists. The inclusion of the OCSE will lead to more accurate financial analysis when the customer is participating in EE programs and DR programs simultaneously. This more accurate analysis should also be taken into account during program design.

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