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Time-Sensitive Value of Efficiency: Use Cases in Electricity Sector Planning and Programs

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Time-Sensitive Value of Efficiency:

Use Cases in Electricity Sector Planning and Programs

Natalie Mims Frick and Lisa Schwartz

November 2019

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Time-Sensitive Value of Efficiency: Use Cases in Electricity Sector Planning and Programs

Prepared for the
Building Technologies Office
U.S. Department of Energy

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Acronyms and Abbreviations

AESC	Avoided Energy Supply Costs for New England
AVERT	Avoided Emissions and Generation Tool
C&I	Commercial and Industrial
CPP	Critical Peak Pricing
CPUC	California Public Utilities Commission
DEER	Database for Energy Efficient Resources
DOER	Department of Energy Resources
DSM	Demand Side Management
DER	Distributed Energy Resource
DOE	U.S. Department of Energy
EE	Energy Efficiency
EIA	U.S. Energy Information Administration
EM&V	Evaluation, Measurement and Verification
FCM	Forward Capacity Market
HVAC	Heating, Ventilation and Air-Conditioning
IRP	Integrated Resource Planning
ISO	Independent System Operator
ISO-NE	New England Independent System Operator
LBNL	Lawrence Berkeley National Laboratory (Berkeley Lab)
LED	Light-emitting Diode
LMP	Locational Marginal Price
M&V	Measurement and Verification
NEEP	Northeast Energy Efficiency Partnership
NREL	National Renewable Energy Laboratory
NWA	Non-wires Alternatives
PG&E	Pacific Gas & Electric
PSE	Puget Sound Energy
PV	Photovoltaic (solar)
RPM	Reliability Pricing Model
RPS	Renewable Portfolio Standard
RTO	Regional Transmission Operator
RTP	Real Time Pricing
SCE	Southern California Edison
SMUD	Sacramento Municipal Utility District
RTO	Regional Transmission Operator
T&D	Transmission and Distribution
TECO	Tampa Electric Company
TOU	Time of Use
TSV-EE	Time-Sensitive Value of Energy Efficiency
VPP	Variable Peak Pricing

Executive Summary

Most energy efficiency measures produce energy savings that vary over the course of a year. The value of the hourly electricity savings also varies over the course of a year because the cost of generating, transmitting and distributing electricity during peak demand periods may be significantly higher than during off-peak, or lower load, hours. But many planning and program activities across the United States are missing this important element.

Furthermore, consideration of energy efficiency in electricity planning and programs has changed over time. A variety of trends are changing the electricity system, including increased adoption of other distributed energy resources, electrification of buildings and vehicles, and relative costs for natural gas-fired and renewable energy generation. Knowing *when* energy efficiency occurs and *the value* of the energy or demand savings to the electricity system—the time-sensitive value of efficiency[1]—provides public utility commissions, utilities and other decision makers with key information needed to procure the optimal amount of energy efficiency for their system. For example, in the United States, changes due to increased adoption of distributed energy resources, technology cost reductions and generation retirements make the time-sensitive value of efficiency critical to resource planning.

What is the time-sensitive value of efficiency?

For the purposes of this report, we define three values:
- Time-sensitive **demand** value (kilowatts, kW)
- Time-sensitive **energy** value (kilowatt-hours, kWh)
- Time-sensitive **economic** value ($)

Data must be at intervals that are more granular than annual (e.g., seasonal, monthly, weekly, daily, hourly or sub-hourly).

Previous studies by Lawrence Berkeley National Laboratory (Berkeley Lab) provide general guidance for capturing the time-sensitive economic value of electricity savings (Mims, Eckman, Goldman 2017; Mims, Eckman, Schwartz 2018). This report reviews specific use cases and examples by state, regional transmission operators, utility and program administrator to help advance their energy efficiency plans and programs and achieve their energy goals.

Specifically, this study:

- Identifies five use cases from the electricity system perspective for incorporating the time-sensitive economic value of efficiency: energy efficiency program planning and evaluation, electricity resource planning, distribution system planning, rate design and state activities.

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[1] In prior research, Berkeley Lab has used the term *time-varying value of efficiency.* Here, we use the term *time-sensitive value of efficiency.* These terms may be used interchangeably within our body of research.

- Reviews methodologies used to incorporate the time-sensitive value of efficiency in these venues with illustrative examples.
- Explores practices and options that states, regional transmission operators or independent system operators, utilities and program administrators can consider adopting.

Berkeley Lab established a technical advisory group composed of representatives from utilities, state utility commissions, state energy offices, academic institutions and consulting firms to help guide the study and review the draft report.[2]

We also reviewed documents and data, including demand-side management plans; technical reference manuals; evaluation, measurement and verification reports; energy efficiency potential assessments; energy efficiency portfolio annual reports; distribution system plans; rate tariffs; integrated resource plans; and independent system operator and regional transmission operator rules. In addition, we reviewed publicly available reports on state and local building energy codes, state appliance and equipment standards, air emissions, and other guidance documents on the use of efficiency to meet state energy goals.

Among our findings:

- Each of the five use cases indicates that applying the time-sensitive value of efficiency can lead to planning or programs that more accurately values efficiency savings and identification of the most valuable energy savings.
- The purpose of the analysis will determine the necessary time interval for the data.
- Publicly available data on the time-sensitive value of efficiency are limited in several regions of the country: the Midwest, South and Southwest.

This study identifies outcomes that are enabled by using the time-sensitive value of efficiency for five use cases. Table ES-1 summarizes the outcomes.

Forthcoming research from Berkeley Lab will discuss the influence of time-sensitive value of efficiency in a utility's selection of its preferred portfolio in electricity resource planning. Ongoing research and modeling of residential and commercial end-use load profiles by the National Renewable Energy Lab (NREL), Berkeley Lab, Argonne Lab and others will provide a publicly available foundation for analyzing time-sensitive value of efficiency analysis.

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[2] Additional outreach included a public webinar on the time-varying value of efficiency. To listen to a recording, visit https://emp.lbl.gov/webinar/no-time-lose-recent-research-time.

Table ES-1. Summary of Outcomes Enabled by Using the Time-Sensitive Value of Efficiency

Use Case	Outcome
Energy Efficiency Program Planning and Evaluation	• Prioritize measures or programs that save energy during high or low demand periods • Inform new program design, or existing program and measure incentive or rebate levels, to achieve efficiency portfolio goals at least cost
Distribution System Planning	• Identify lower-cost non-wires alternatives to traditional distribution system expansion needs • Integrate distributed energy resources
Electricity Resource Planning	• Identify the optimal amount of energy efficiency for a reliable, electricity system at least cost (e.g., reduced reserve margins and system revenue requirements)
Electricity Rate Design	• Promote the efficient use of electricity • Create an increased value proposition for consumers to install efficiency that lowers energy use during periods of peak demand or high price
State and local government activities	• Achieve state goals at least cost (e.g., air pollutant emissions reductions) • Inform development of state standards to align with state energy goals (e.g., energy efficiency resource standards)

Other important areas of future research include:

- Development of energy efficiency savings profiles.[3]
- Regional transferability of end-use load profiles.
- Integration of energy efficiency and demand response technologies and programs.
- Opportunities for building owners and operators to use time-sensitive value of efficiency to meet grid needs.
- Opportunities to use energy efficiency program geotargeting to manage grid constraints.
- Time-sensitive electricity rate design impacts on customer adoption of energy efficiency measures and participation in energy efficiency programs.
- Considering time-sensitive value of efficiency to refine energy efficiency resource standards.
- Considering time-sensitive value of efficiency to align utility business models with state goals.
- Using time-sensitive value of efficiency to enable state and local building energy codes and other efficiency approaches to more precisely estimate cost-effectiveness of proposed requirements and prioritize measures.
- Case studies on using time-sensitive value of efficiency to improve energy efficiency program design and implementation (e.g., optimizing the mix of measure offerings to meet load priorities).

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[3] See the "Data Needs and Availablity" section for more information on energy efficiency savings profiles.

- Considering time-sensitive value of efficiency as electricity system load increases through electrification, and energy efficiency through fuel substitution. For example, electric vehicle charging patterns, or heat pump space and water heating in buildings.

1 Introduction

Historically, most quantification of energy efficiency's benefits has focused largely on the economic value of annual energy reduction. However, because the value of energy and the shape of energy savings varies over time, annual assessments can overlook these important variations and can result in under or over valuation of energy efficiency (EE). The time-sensitive value of energy efficiency (TSV-EE) is a calculation that considers *when* energy efficiency occurs, and *the value* of the energy and demand savings to the electricity system at that time.[4] Quantifying the TSV-EE is necessary to properly account for all of the costs and benefits of energy efficiency, and to identify, prioritize and implement efficiency resources that contribute to a low-cost, reliable electric system (Mims, Eckman, Goldman 2017; U.S. EPA 2006; Boomhower and Davis 2016).

Time-sensitive *demand* or *energy* value of efficiency can be revealed with end-use or savings load profiles. End-use profiles show the energy consumed during each hour of the year, and savings profiles show the reduction in energy consumed, as measured against a designated baseline.

The time-sensitive *economic* value of efficiency is typically determined using system avoided costs, or integrated resource planning (IRP) models for regulated utilities. In centrally organized markets, locational marginal prices and transmission and distribution capacity values may be used.

Previous studies by Berkeley Lab have discussed two approaches for capturing TSV-EE (Mims, Eckman, Goldman 2017; Mims, Eckman, Schwartz 2018). One approach uses daily or seasonal load profile data, or both, to allocate energy savings by peak periods and off-peak periods, and coincidence factors[5] to estimate peak impacts. The second option uses annual hourly data (8,760 hours) for both energy savings and avoided costs. Both approaches require (1) data on the load profile of the efficiency measure savings, (2) electricity system load profiles, and (3) the economic value of the efficiency savings to the electricity system. All data sets must be available at the same level of granularity (e.g., hourly, daily). The primary differences between the two methods are the fidelity of the data requirements and the method used to determine peak reduction impacts of efficiency measures. Annual hourly data are chronological and are therefore more suited to evaluation of dispatchable resources such as dynamic thermostats or energy storage devices.

The report begins with a discussion of our approach to determining use cases and examples, and then examines the need for time-sensitive efficiency data. Next, it examines five use cases

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[4] For the purpose of this study, we define *time-sensitive* as intervals more granular than annual (e.g., seasonal, monthly, weekly, daily, hourly or sub-hourly).

[5] A *coincidence factor* is a metric that represents the fraction of peak demand reduction from a particular type of efficiency measure, across all installations in the utility's service area that occurs at the time of the utility system's peak.

in which states, independent system operators/regional transmission operators (ISOs/RTOs), utilities, and efficiency program administrators consider the TSV-EE:

1. Energy efficiency program planning and evaluation
2. Distribution system planning
3. Electricity resource planning
4. Electricity rate design
5. State and local government activities

The report concludes with areas for future research on the time-sensitive value of efficiency.

1.1 Using this Study

The primary audiences for this study are public utility commissions, electric utilities and ISOs/RTOs, efficiency program administrators and implementers, state energy offices, and state decision makers that are interested in *when* energy efficiency occurs and *the value* it has to the electricity system. Other stakeholders include consumer representatives, energy evaluators and product providers and researchers.

This study identifies and describes use cases and specific examples of implementing the TSV-EE. The examples are organized to provide relevant information, but approaches, tools and data may not transfer from one jurisdiction to the next. Thus, we have provided the following questions that readers can ask themselves as they utilize this study for the use cases and examples within their jurisdiction:

- In what ways is the TSV-EE—*energy, demand and economic value*—considered for planning and programs in the electric utility sector?
- How might time-sensitive value of efficiency affect efficiency resources or program screening and cost-effectiveness?
- Are these time-sensitive values considered *consistently* across the range of planning processes and programs?
- Does the granularity and accuracy of data used support a reliable, least-cost electricity system and other state energy goals?
- Are data transparent and accessible to interested stakeholders?
- If additional or updated data are needed, can multiple utilities leverage economies of scale for collection and use the same information?
- How will forecasted shifts in electricity consumption (e.g., due to distributed energy resources or changes in end-use loads) affect the value of efficiency throughout the day and year, as well as the need for time-based data?
- How will beneficial electrification and transportation electrification change the TSV-EE?

- How can the use cases in this report—and other research on the TSV-EE—be used to improve planning and programs (e.g., how programs are prioritized, designed and evaluated or how risk can be mitigated in electricity resource planning and procurement)?

The conclusion section of this study offers guidance that utilities and states can consider to advance applications of TSV-EE.

2 Study Approach

Our approach for this study drew upon the experience and expertise of a diverse technical advisory group and a comprehensive literature review. We convened a technical advisory group composed of representatives from utilities, state public utility commissions, state energy offices, academic institutions, and consulting firms to help identify data gaps, guide the study and review the draft report.

We began by identifying use cases that implement the time-sensitive value of efficiency. After vetting our use cases with members of the technical advisory group, we began to identify robust examples of efficiency program administrators, utilities and regional transmission operators using TSV-EE. We leveraged prior Berkeley Lab research on the cost of saving electricity (Hoffman et al. 2018; Frick et al. 2019) and the future of ratepayer funded efficiency (Goldman et al. 2018). For this report, we reviewed:

- Demand-side management plans.
- Technical reference manuals.
- Evaluation, measurement and verification reports.
- Energy efficiency potential assessments.
- Energy efficiency portfolio annual reports.
- Distribution system plans.
- Rate tariffs.
- Integrated resource plans, legislation and statutes.
- Regulations for each state in the country.

We also built on our distribution system planning research (Schneider et al. 2019) to identify time-sensitive value of efficiency examples, and our energy efficiency in resource planning (Frick et al. forthcoming) for information on competitive wholesale markets and TSV-EE examples. Finally, we reviewed publicly available reports on codes and standards, air emissions, and other guidance documents on the use of efficiency to meet state energy goals.

The selected examples are intended to represent a range of opportunities in geographically diverse locations for applying the TSV-EE to planning and programs. These examples are not a comprehensive list of all examples of using TSV-EE, but are meant to be representative of the ways in which TSV-EE is being used.

3 Data Needs and Availability

In this section, we discuss *why* these time-sensitive demand, energy and economic data are needed, and *where* the data are commonly found.

Time-sensitive demand and energy value of efficiency require data on what devices (e.g., appliances, equipment, lights) are consuming electricity and the hourly and seasonal pattern of their consumption. These data are obtained through end-use load research, which involves measuring electricity consumption of an individual appliance or piece of equipment to obtain information on its demand on a sub-hourly, hourly, daily, weekly, monthly, seasonal or annual basis.

End-use load research is used for a variety of other electricity planning functions, including: load forecasting, demand-side management and evaluation, capacity planning and demand response, IRP, renewable energy integration, smart grid investments, rates and pricing and customer service. End-use load research data also can serve as critical input to state and federal appliance and equipment standard development processes by providing actual field usage information that can inform both testing procedures and economic analysis.

Understanding the difference between end-use load profiles and energy savings load profiles is critical to accurately quantifying the value of energy efficiency. In short, the time pattern of savings from substitution of a more efficient technology does not always mimic the end-use load shape.

End-use load shape: Hourly consumption of an end use (e.g., residential lighting, commercial HVAC) over the course of one year.

Energy savings shape: The difference between the hourly use of electricity in the baseline condition and the hourly use after installing the energy efficiency measure (e.g., the difference between the hourly consumption of an electric resistance water heater and a heat pump water heater, or the difference between the hourly lighting use in a commercial building pre- and post-installation of daylighting controls or occupancy sensors) over the course of one year.

Figure 1 shows the potential inaccuracy introduced in the calculation of the time-sensitive value of an efficiency measure if an end-use load shape, rather than the energy savings shape, is used. It shows the end-use load shape for an electric resistance residential water heater and the shape of the savings resulting from its conversion to a heat pump water heater. The red line represents the electric resistance load shape, and the green line represents the saving shape of a heat pump water heater. Figure 1 illustrates that both the “peak” and “off-peak” savings from the conversion to a heat pump water heater do not follow the load shape of electric resistance water heating. Peak savings occur three hours earlier in the morning and nearly three hours earlier in the evening than would be estimated using the resistance water heating load shape.

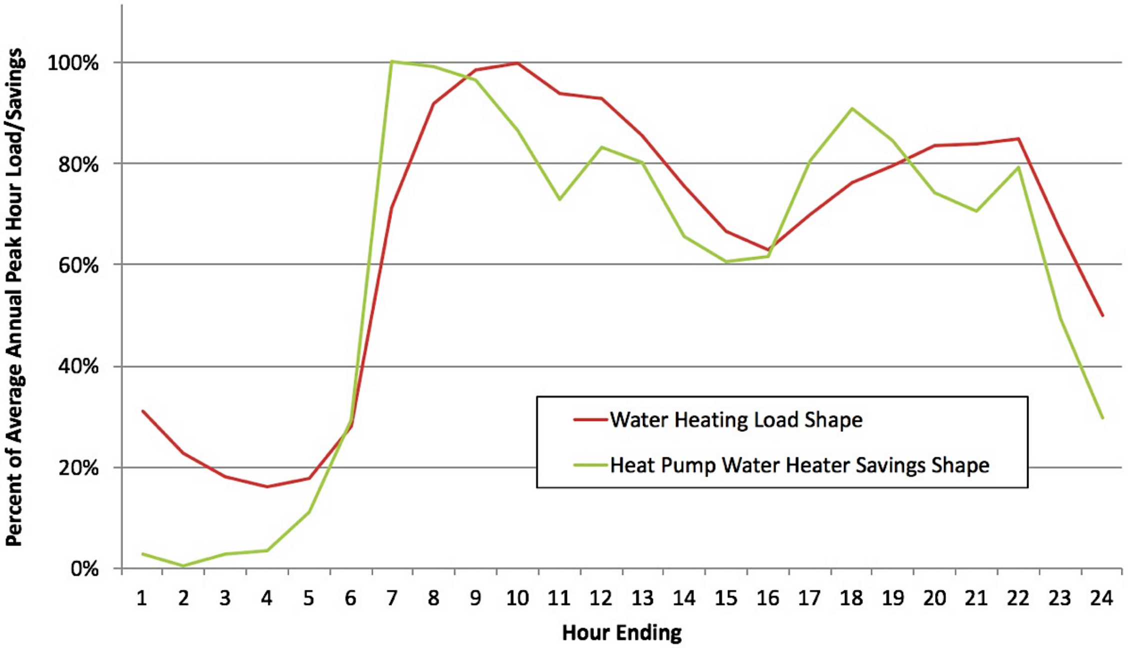

Figure 1. Comparison of a Residential Water Heating Load Shape with a Heat Pump Water Heating Savings Load Shape (Eckman 2014)

To further illustrate the difference between end-use load profiles and electric savings load profiles, it is useful to consider the three ways that energy efficiency measures can reduce energy and peak demands: improved efficiency of end-use technology, controls, or a combination of improved end-use technology and controls.

- **Improved Efficiency of End-Use Technology:** These are energy efficiency measures that reduce the energy needed to accomplish a given task (e.g., use of light-emitting diode [LED] lamps that require 12 watts to produce the same lumen output as 75-watt incandescent lamps). The savings from technology that reduces the energy required to accomplish a specific end-use task typically have the same shape as the end-use load shape. Higher efficacy lighting and high efficiency motors are examples of efficiency measures that produce savings that follow their end-use load shape.
- **Improved Efficiency of Controls:** Controls often reduce the hours of operation of equipment (e.g., use of occupancy sensors to switch off lights in unoccupied spaces). The shape of the savings from controls are typically different than the underlying end-use because the savings result from modifying the duty cycle (i.e., changing the hours of operation)—not simply reducing the wattage used to perform the desired task.
- **Improved Efficiency of End-Use Technology and Controls:** These are efficiency measures that apply a combination of both energy reduction and reduced hours of operation (e.g., use of daylighting controls to reduce wattage and to switch off lighting when natural lighting is adequate, or adding sensors and software to power down computers or televisions to standby mode when not in use). As with controls, the

energy savings occur from modifying the end-use duty-cycle (i.e., hours of use) so the savings load shape is not typically the same as the end-use load shape.

3.1 Geographic gaps in public availability and use of data

End-use load profiles are publicly available through sources such as the Electric Power Research Institute's Load Shape Library, the Northwest Power and Conservation Council, the Database for Energy Efficient Resources (DEER), and the Northeast Energy Efficiency Partnerships (NEEP) Load Shape Catalog. However, many of the end-use load profiles are dated, and savings load profiles are sparse. In particular, the Midwest and South regions lack robust publicly available end-use load profiles (Figure 2). Ongoing U.S. Department of Energy (DOE)-funded research by NREL, Berkeley Lab and Argonne Lab will produce metered or simulated end-use load profiles that will be publicly available in the next three to five years.[6]

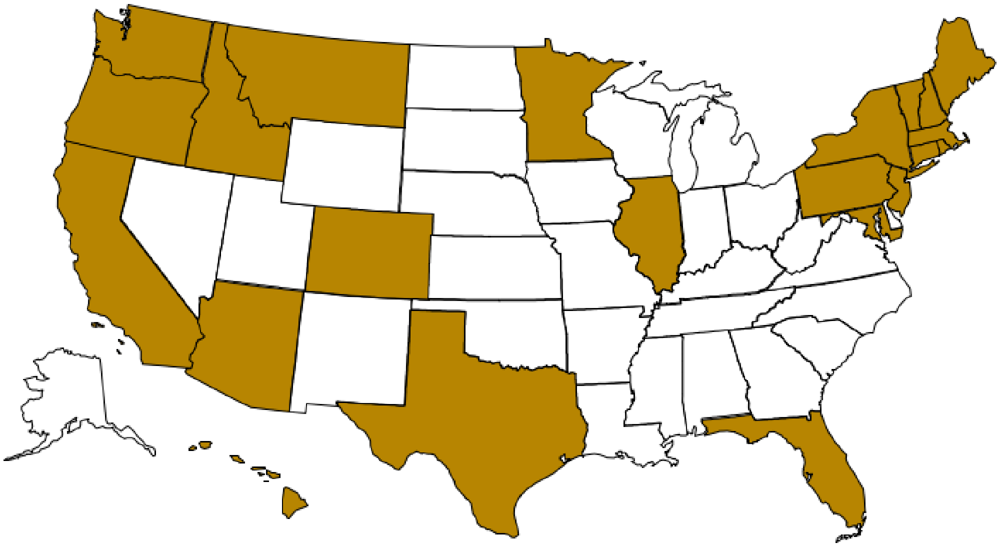

Figure 2. States with Publicly Available End-Use Load Profile Data[7]

As part of our research for this project, we conducted a comprehensive review of publicly available end-use load profiles and created an inventory, available on Berkeley Lab's website.[8] Data sources were added to the inventory if they provided publicly available hourly or more frequent (e.g., minute, seconds) load shape data. The review focused on end-use load profiles created after 2000, with the exception of the End-use Load and Consumer Assessment Program (ELCAP).

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[6] See End-Use Load Profiles for the U.S. Building Stock at https://www.nrel.gov/buildings/end-use-load-profiles.html for more information.

[7] The quantity of data and number of end-use load profiles that are available in each state varies greatly. See the end-use load profile inventory for more information. https://emp.lbl.gov/publications/end-use-load-profile-inventory

[8] https://emp.lbl.gov/publications/end-use-load-profile-inventory

Over 220 data sources were reviewed, but many source documents could not be located or did not contain sufficiently granular and publicly available data, or both. For example, some data sources contain consumption by time of use period (e.g., summer on-peak, winter-off-peak), particularly among state energy efficiency technical resource manuals. A list of the data sources reviewed, but not used, is included in a separate tab in the inventory with a brief description as to why they were not included. Overall, end-use load profiles are more available for residential buildings than commercial buildings. Table 1 provides a summary of the inventory.

Table 1. Summary of Berkeley Lab End-Use Load Profile Inventory

	Data Sources with EULP	End Uses
Residential	49	HVAC, water heating, lighting, appliances, miscellaneous electric loads
Commercial	39	HVAC, indoor and outdoor lighting, computer use, refrigeration, water heating, office equipment, cooking, office plug loads, and miscellaneous

Some utilities conduct their own end-use load research as part of the evaluation and planning process for demand side management programs, to inform potential studies, to perform technology assessments, and for other purposes. Although the results of utility load research may sometimes become public, it is not common for the supporting data to be made available outside of the utility. Even internally, the data collected for a specific study or purpose may not ultimately be used by other groups within a utility (e.g., for IRP).

The time-sensitive *economic* value of efficiency is typically determined using system avoided costs or wholesale electricity market prices. The values for avoided costs are typically derived through IRP or similar long-range resource capacity expansion modeling processes or avoided cost studies. Individual entities will have differing components and input values for each component of avoided cost, due to specific utility system resource needs and the need to consider other non-energy costs and benefits. Depending on whether only some or all of these components are used determines what types and amounts of energy efficiency are identified as economic (Mims, Eckman and Goldman 2017).[9]

In many states, electric utilities submit their avoided costs to their regulator for approval. However, in some states the data are considered confidential or proprietary. In contrast, in California and Massachusetts, the energy efficiency avoided cost model or calculator used by the utility is made available to the public. And in New England, there is an avoided cost study that is performed for the region that produces publicly available costs.

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[9] The avoided cost components used in the report are capacity, energy, transmission, distribution, spinning reserves, risk, carbon dioxide emissions, avoided cost to comply with state Renewable Portfolio Standards, and avoided demand reduction induced price effect.

Centrally organized wholesale electricity markets such as PJM and the New England independent system operator (ISO-NE) provide hourly locational marginal prices for energy, congestion, losses and ancillary services that can be used to determine the TSV-EE.[10]

The deployment of efficiency measures and programs can, in the near term, reduce fuel costs, and over time defer the need to add generation, expand transmission and distribution infrastructure, and decrease the requirement for additional ancillary services. Therefore, the economic value of efficiency depends on the cost, timing and magnitude of required investments in these utility system assets. As a result, the methodology for deriving the time-sensitive value of electric savings using hourly data is often implemented through an IRP process or other similar long-term system resource expansion modeling. While IRPs are typically conducted by vertically integrated utilities, similar long-term system resource expansion modeling may be carried out through processes used to establish avoided costs in organized markets. For example, both New England and California publish avoided cost studies for use in evaluating the cost-effectiveness of energy efficiency, which model the characteristics of specific generating resources as a proxy for cost avoided by energy efficiency savings.

The primary difference between IRP processes and avoided cost studies is that IRPs are designed to evaluate and select the most economic and reliable resources to meet both energy and peak capacity needs by considering the full range of resource alternatives, in order to provide adequate and reliable service to electric customers at the lowest system cost. These include new grid-scale generating capacity, power purchases, energy efficiency, demand response, cogeneration and district heating and cooling applications, and non-grid-scale distributed energy resources, including renewable energy.

3.2 Data resolution

When determining the resolution of time-sensitive energy, demand or economic value of efficiency that will be used in an analysis, the decision is often determined by the availability of an analyst's time and access to end-use and economic data. The simpler the analysis, the less time, resources, and data accessibility are required. A common reason to use higher resolution values is to achieve greater accuracy (i.e., achieving a better estimate of the value). That may be important for a variety of reasons, including addressing challenges created by changing grid conditions, a desire to focus energy efficiency budgets at reducing peak load or at times when economic value is highest, or interest in appropriately valuing efficiency. Common reasons to use low resolution values are to reduce the cost of the analysis or simply because such data are the best available. Figure 3 provides examples of ranges in resolution of the time-sensitive values.

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[10] Locational marginal prices (LMPs) represent short-run marginal costs. Using costs for time frames shorter than an energy efficiency measure's life undervalues the energy savings. Proper valuation requires a forecast of LMPs at least as long as the Effective Useful Life of the efficiency measures. Market models such as Aurora and EnCompass provide these longer term values for utilities to use.

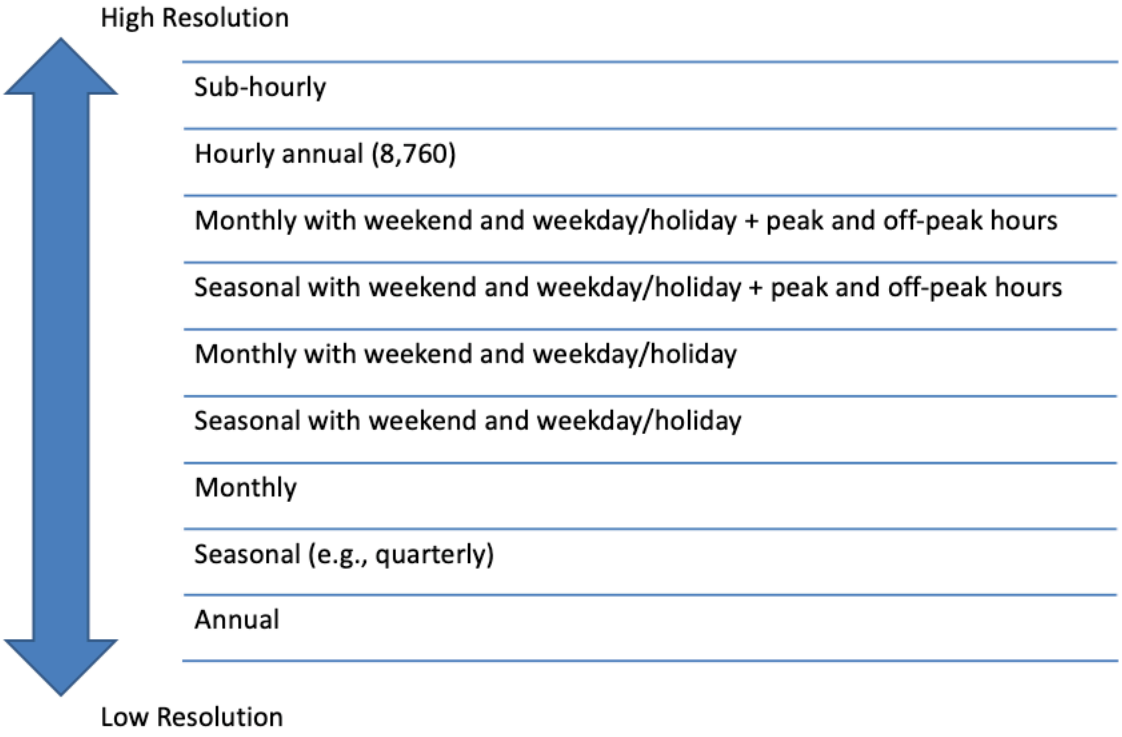

Figure 3. Examples of Data Ranges for the Time-Sensitive Value of Energy Efficiency

The resolution of time-sensitive data needed depend on the approach and purpose of the analysis. For example, data requirements for electricity resource planning depend on the approach used to incorporate energy efficiency into the planning process. Robust electricity resource planning requires that the TSV-EE be calculated in a way that is comparable to the granularity of supply options (e.g., hourly, on-peak vs. off-peak hours).[11] If efficiency is incorporated as a load decrement, the TSV-EE may be a lower resolution, such as seasonal or monthly energy savings.[12] Examples of data resolution varying by the purpose of the analysis are discussed below.

Energy efficiency program reporting: Annual energy and demand savings impacts (e.g., two savings numbers for the year) have historically been used for compliance reports on energy efficiency performance (Figure 4). However, some capacity markets require that measurement and verification plans include estimated demand reduction during specific hours (Figure 5). Similarly, energy efficiency plans that include a demand reduction goal or demand response requirements may also require estimated demand reductions during specific hours.

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[11] Resource availability must also be comparable between supply and demand sides (e.g., development lead times, maximum annual and cumulative capacity).

[12] For example, annual energy savings program data could be divided by 8,760 hours to create savings for each hour of the year. Similarly, seasonal energy savings could be divided by the hours in representative months to create savings for each hour of the year.

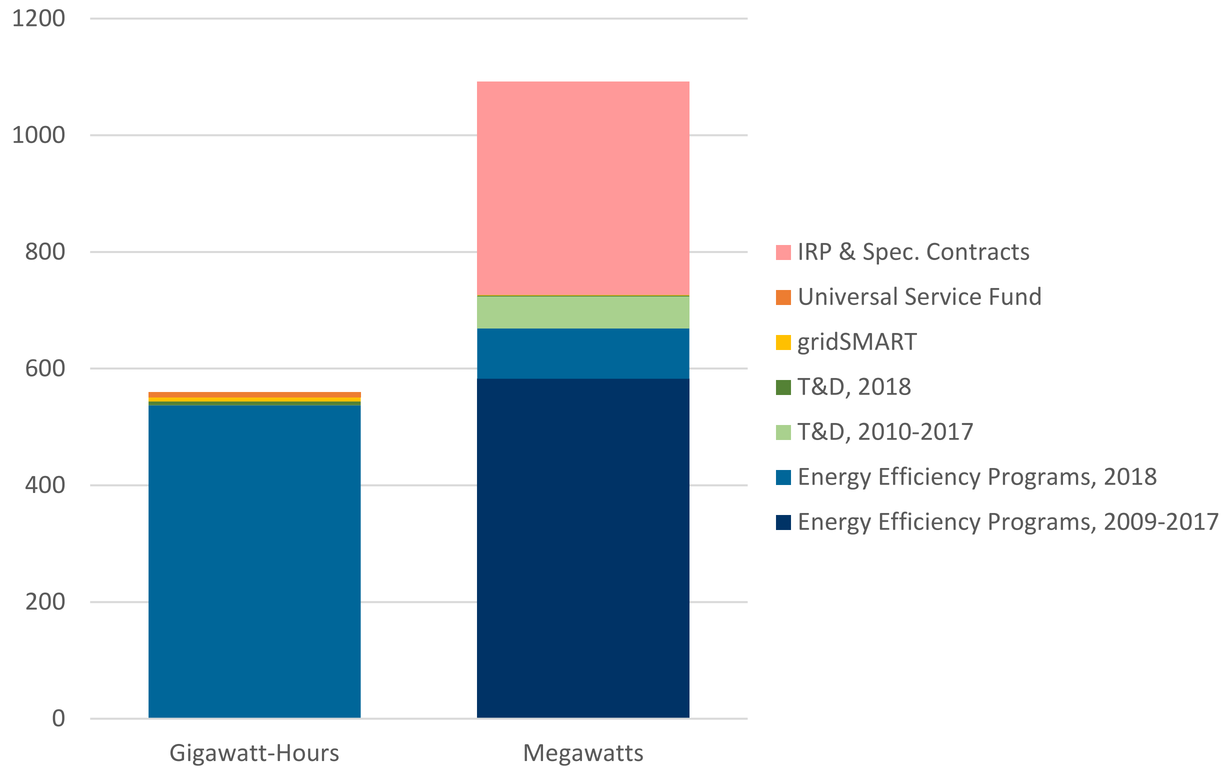

Figure 4. AEP Ohio 2016 Energy and Peak Demand Savings, by Source (Ohio Power 2019)

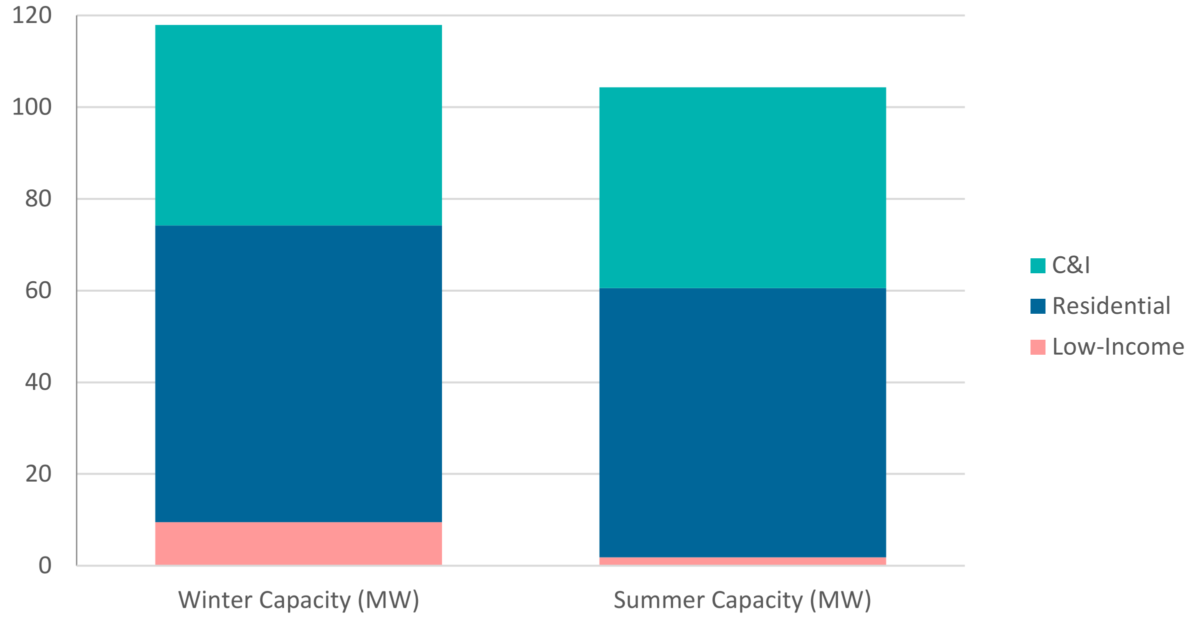

Figure 5. National Grid (Massachusetts) Summer and Winter 2017 Peak Demand Savings[13]

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[13] Data from Mass Save Data at https://www.masssavedata.com/Public/PerformanceDetails, 2017 Electric Master Data File.

Building benchmarking: Some state and local policies require building owners to measure their building's energy use, compare it to buildings of similar type and size, and make those data publicly available (benchmarking and transparency policies). This comparison often requires annual energy use (e.g., a single number that represents the building's annual energy use) and other key performance indicators (Figure 6).

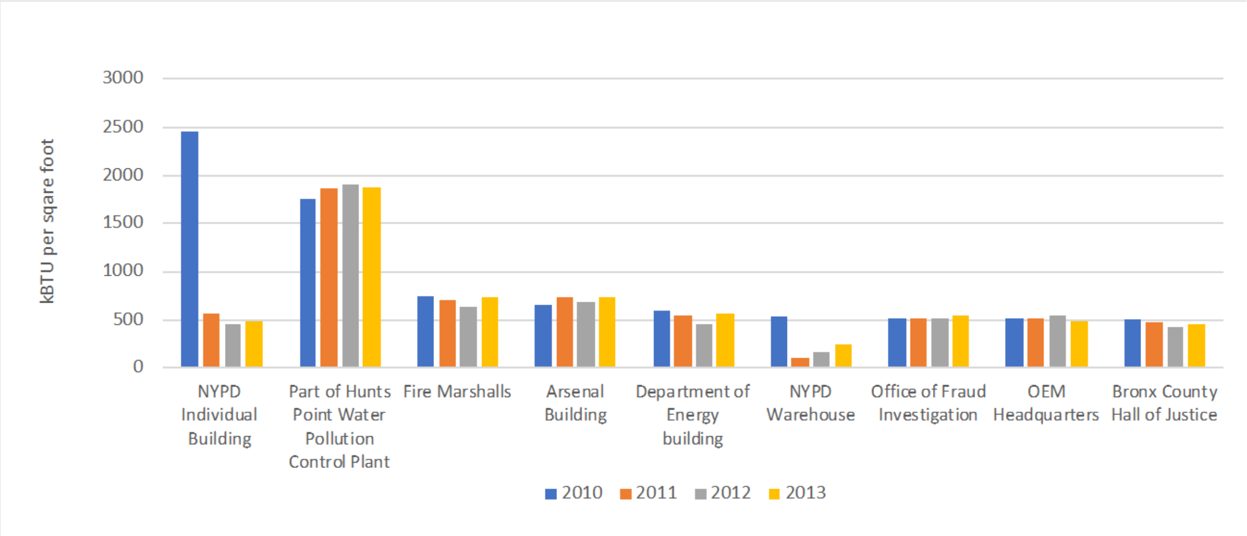

Figure 6. Excerpt of New York City Building Benchmarking Reporting Requirements (2010–2013) (LBNL analysis using data from New York City)[14]

Energy efficiency benefit-cost analysis: For benefit-cost analyses of efficiency programs, utilities may use system-wide modeled data at a monthly or hourly annual energy savings, and electric system avoided cost data.

Distribution system planning: Sub-hourly time-sensitive demand data may be needed for specific system levels, such as a distribution substation or a specific distribution feeder or line section. Figure 7 provides an hourly perspective on how different distributed energy resources can be used to meet a forecasted distribution system need.

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[14] NYC OpenData. NYC Municipal Building Energy Benchmarking Results. https://data.cityofnewyork.us/City-Government/NYC-Municipal-Building-Energy-Benchmarking-Results/vvj6-d5qx

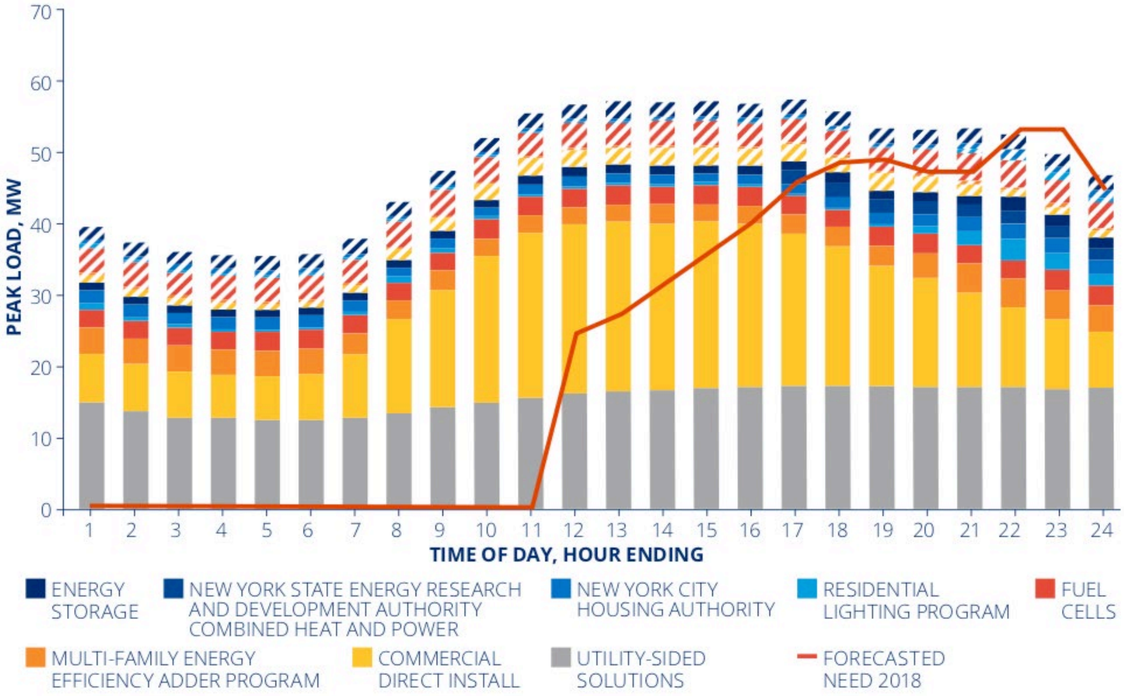

Figure 7. Example of Hourly Load Reduction Provided by Different Non-Wires Alternatives Resources (Chew et al. 2018)

Building operations, controls and energy management systems: Sub-hourly or very high granularity data and information are necessary. Emerging technology companies are collecting this very high-resolution information. Figure 8 and Figure 9 provide a comparison of the output provided from hourly resolution (Figure 8) and minute-by-minute resolution (Figure 9) for building energy management.

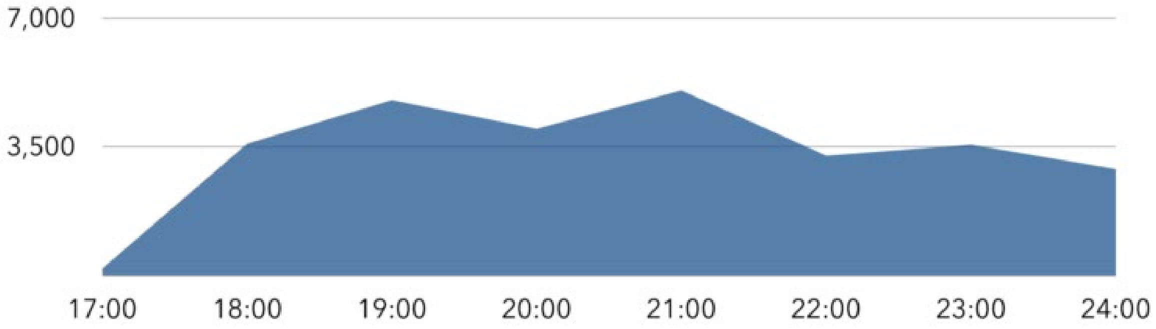

Figure 8. Pecan Street (Texas) Example of Hourly Residential Electricity Consumption[15]

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[15] Pecan Street Data. https://www.pecanstreet.org/dataport/about/

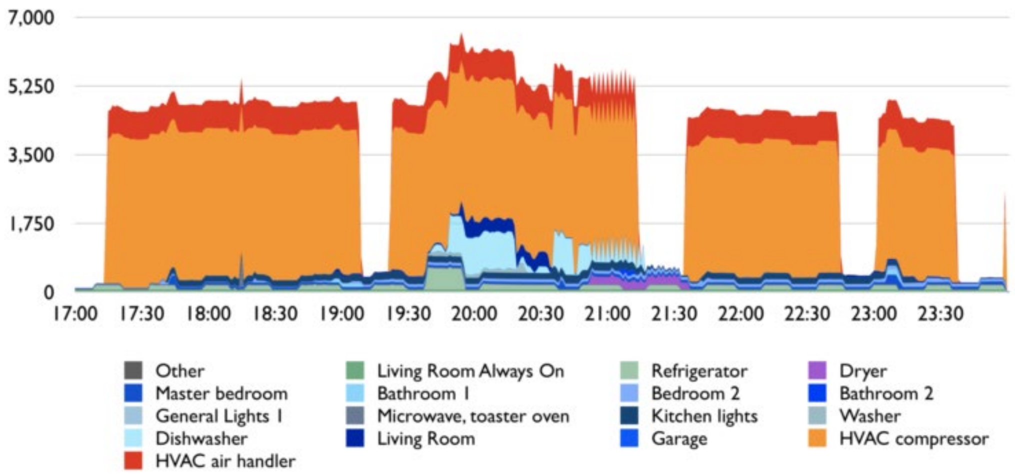

Figure 9. Pecan Street (Texas) Example of Residential Electricity Consumption by Minute[16]

Rate design: Figure 10 provides an example of the impact of using different timescales in efficiency analysis. It shows the results comparing the value of three common energy efficiency program types if evaluated on an hourly, time-of-use average, and annual average value in California. For air conditioning, which provides reductions coincident with higher system costs in this example, the hourly value is much higher than the other methods. Without an hourly estimate of reductions, or some other way to model capacity benefits, the results are not accurate. For flat load profiles such as refrigeration, there is no significant difference.

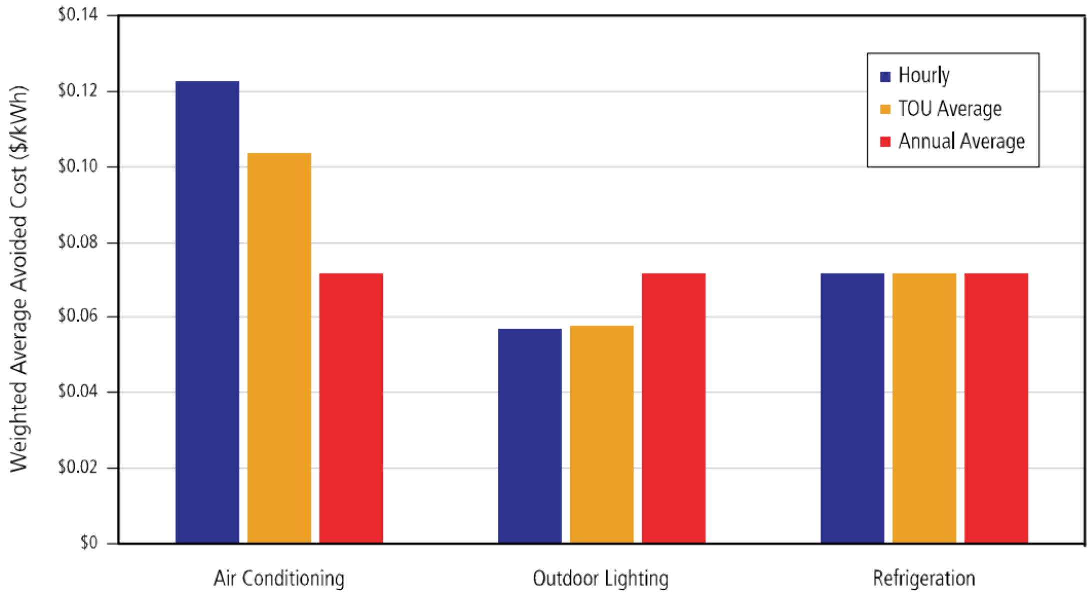

Figure 10. Weighted Average Avoided Cost for Three Programs Using Three Timescales (Price 2018; National Action Plan for Energy Efficiency 2008).

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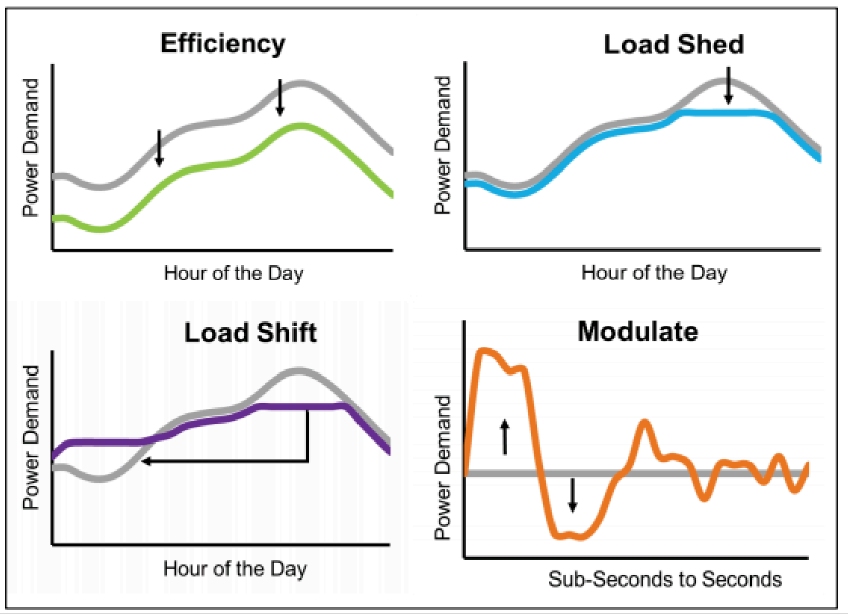
[16] Pecan Street Dataport collects second by second data for each end use. https://www.pecanstreet.org/dataport/about/

Grid-interactive Efficient Buildings

Many of the examples provided in this study discuss the use of energy efficiency data at hourly or seasonal resolution. Sub-hourly data are needed to capture all of the potential value streams that energy efficiency and other distributed energy resources may be able to provide.

Through its new DOE initiative, Grid-interactive Efficient Buildings,[17] DOE is developing a flexible building loads strategy that integrates sensing, controls, communication and intelligence with energy efficiency technologies to advance the role buildings can play in energy system operation and planning. If buildings have the appropriate advanced controls, they can manipulate traditional demand assets like lighting and heating, ventilation and air-conditioning equipment, and other onsite distributed energy resource (DER) assets (e.g., PV, energy storage and electric vehicle charging) to provide a variety of grid services for the benefit of building owners, occupants and the grid as a whole.

Energy efficiency can provide value to the grid by reducing demand and prices, relieving transmission and distribution congestion, and deferring and avoiding capital costs. Understanding the time-sensitive value of efficiency at the sub-hourly level, and monitoring and controlling building loads at that higher resolution, may allow additional grid services to support grid operations such as local and system capacity relief, regulation and contingency reserves. Figure 11 shows four types of load flexibility energy efficiency and demand response a building can offer on different timescales.



Source: Neukomm, Nubbe and Fares (2019).

Figure 11. Building Load Flexibility Curves

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[17] See https://www.energy.gov/eere/buildings/grid-interactive-efficient-buildings for more information.

4 Time-Sensitive Value of Efficiency Use Cases

This section discusses five use cases of time-sensitive energy, demand or economic value of efficiency and provides examples of their use:[18]

- Energy efficiency program planning and evaluation
- Distribution system planning
- Electricity resource planning
- Electricity rate design
- State and local government activities

4.1 Energy efficiency program planning and evaluation

Below are four examples of energy efficiency program planning and evaluation: (1) cost-benefit analysis, (2) potential assessments, (3) program design, and (4) impact evaluation. Each discussion provides examples of uses of time-sensitive value of efficiency. Figure 12 shows the relationship between these four components of energy efficiency program planning and evaluation.

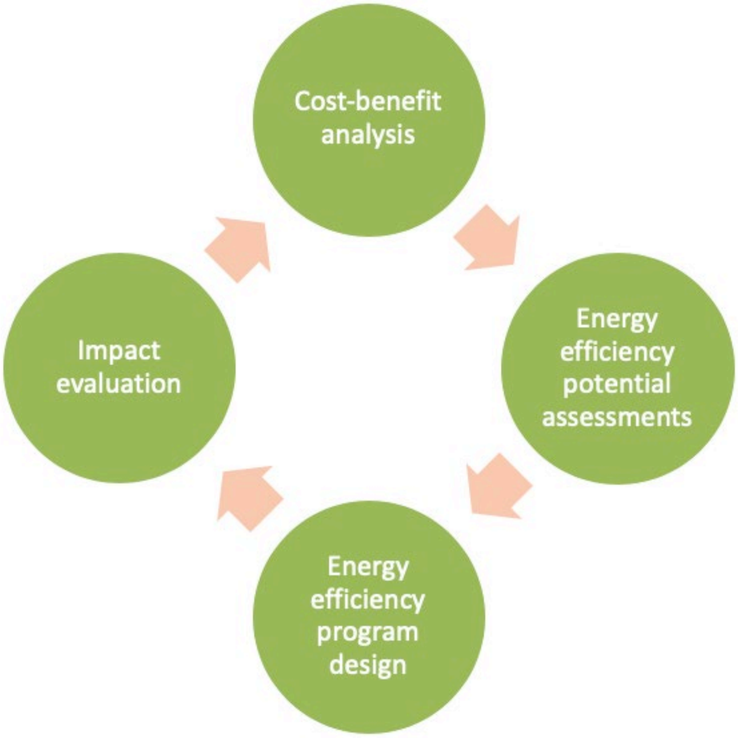

Figure 12. Energy Efficiency Program Planning and Evaluation Cycle

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[18] Berkeley Lab offers these as examples of time-sensitive value of efficiency use cases, not as an endorsement of specific methodologies or conclusions. The examples are not an exhaustive list.

Table 2 provides a summary of the motivation, type of TSV-EE used, and significance of the examples discussed in this section.

Table 2. Energy Efficiency Program Planning and Evaluation Use Case Examples Summary

Outcomes Enabled by Using TSV-EE	• Inform new program design, or existing program and measure incentive or rebate levels to achieve efficiency portfolio goals at least cost.
Types of TSV-EE Used	• Energy, demand, economic
Examples	• California Public Utilities Commission Avoided Cost Calculator • Massachusetts Benefit-Cost Ratio Models • Northwest Power and Conservation Council's Seventh Power Plan • Puget Sound Energy's 2017 Conservation Potential Assessment • Massachusetts End Use Load Study • California Pay-For-Performance Program • Tampa Electric Company Standard Offer • Oncor Commercial Standard Offer • ISO-NE Measurement and Verification Plans
Significance	• California and Massachusetts cost-benefit calculators employ hourly or seasonal end-use load profiles and avoided costs to identify cost-effective energy efficiency measures. • Northwest Power and Conservation Council and Puget Sound Energy's Conservation Potential Assessment create annual hourly energy efficiency supply curves that are used in long-term planning to identify the optimal amount of energy efficiency. • The Massachusetts End Use Load Study and the California, Tampa, and Oncor efficiency program examples highlight how time-sensitive energy and demand data are used to design energy efficiency programs. • The ISO-NE evaluation, measurement and verification (EM&V) plan highlights how time-sensitive demand data are necessary for efficiency programs that participate in the capacity market.

4.1.1 Benefit-cost analysis

Energy efficiency benefit cost analysis compares the relative benefits and costs from different perspectives. A benefit-cost ratio above one means the measure or program has positive net benefits. A benefit-cost ratio of less than one means the cost exceeds the benefits. If lifecycle benefits exceed costs, the measure or program is considered to be cost-effective. The accuracy of energy efficiency cost and benefit data varies regardless of the cost-effectiveness test being used, but more accurate data results in better results.

Energy efficiency benefit-cost analysis is very widely used. Utilities and program administrators use it in program planning and evaluation, and it is used by utilities and regulators to determine the level of investment in efficiency that a utility will make. Energy efficiency program administrators use it when designing and planning their energy efficiency programs (e.g., adding and removing energy efficiency measures from a program to increase or decrease the portfolio or program cost-effectiveness).

Some utilities employ annual hourly energy efficiency data to determine when savings occur, and the financial value associated with the savings. Other utilities use lower fidelity data, relying on on-peak and off-peak period savings or an average annual avoided cost.

There are many examples of the TSV-EE applied to cost-benefit tests for energy efficiency. Below are examples of resources in California and Massachusetts.

California Avoided Cost Model and Database for Energy Efficient Resources

The California Public Utilities Commission (CPUC) created the Avoided Cost Model, a publicly available tool that forecasts the long-term marginal costs used to evaluate the cost-effectiveness of distributed energy resources, including efficiency.[19]

Specifically, the Avoided Cost Model uses annual hourly (8,760) data to forecast both the long-term costs and components of avoided costs in California. Figure 13 provides an example output, showing the average hourly value of energy in climate zone 4 in 2019 and 2024.

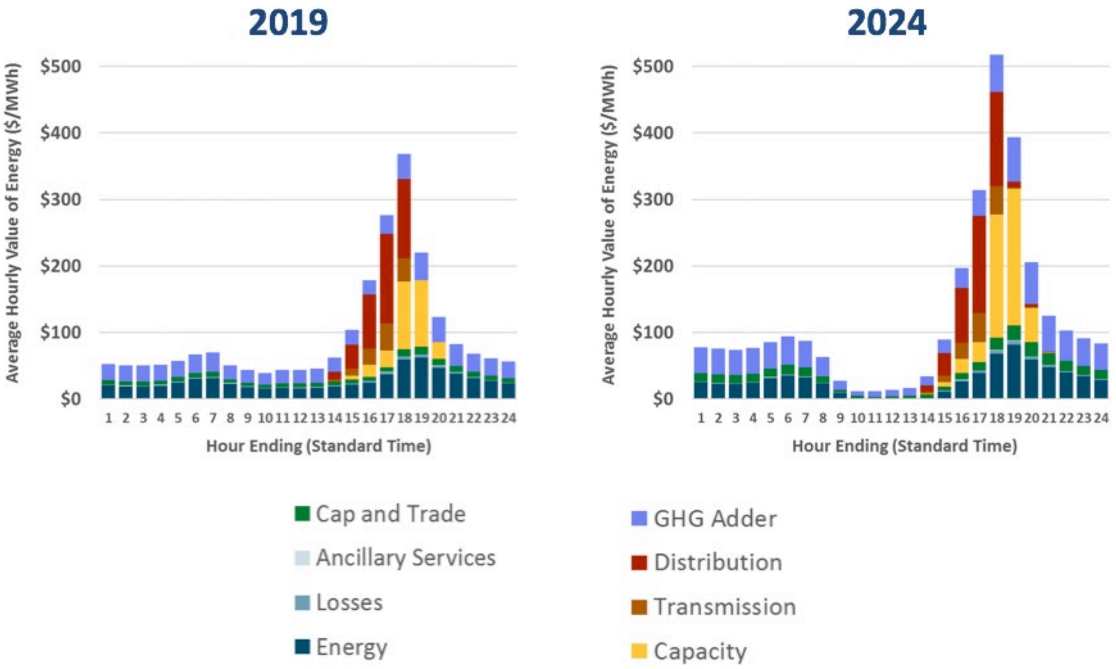

Figure 13. California Avoided Cost Model Output for Climate Zone 4 (hot and dry): 2019 and 2024

The Avoided Cost Model draws on DEER for time-sensitive load shape values, i.e., savings profiles. DEER is a publicly available resource that provides estimates of energy and demand savings potential for residential and nonresidential measures and the definition of the peak period for energy efficiency savings calculations.[20] The Avoided Cost Model provides the costs

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[19] E3. ACM: Avoided Cost Model. https://www.ethree.com/tools/acm-avoided-cost-model/. The CPUC hired E3 to update the 2018 Avoided Cost Calculator to reflect forecast changes, the type and cost of future resources, and the system load shape.

[20] The DEER database is available at http://www.deeresources.com/index.php/homepage.

and benefits of energy efficiency measures and programs for use by program administrators in California.

Air pollutant emissions reductions[21]

State air pollutant emissions reduction requirements exist in many states, and depending on the location and market structure, utilities may include avoided cost of compliance with carbon dioxide (CO_2) and other emissions regulations in their avoided cost. For example, the Pacific Northwest, California, and Massachusetts include, among other factors, avoided cost for energy, capacity, deferred transmission, distribution, and CO_2 emissions.

Emission rates (pounds per MWh) vary considerably over the course of the year due to numerous factors (e.g., fuel type, power plant fleet deployment, transmission and distribution congestion). For example, in ISO-NE average emission rates are lower than marginal emissions rates for sulfur dioxide and CO_2. Further, during the top five high electric demand days, all air pollutants have higher marginal emission rates than the marginal emission rate on all other days of the year. This is due to high quantities of coal and oil units operating on the high electric demand days (ISO-NE 2018c; ISO-NE 2019).

States, ISO/RTOs or utilities that use more granular emissions avoided costs (e.g., seasonal or hourly) may benefit from consideration of the time-sensitive energy value because it allows decision makers to prioritize energy efficiency measures whose efficiency savings occur when the economic value of the savings—including emissions—are the greatest.[22,23]

Massachusetts Utilities Benefit-Cost Ratio Models

Massachusetts' Green Communities Act requires that every three years all energy efficiency program administrators file energy efficiency plans that "provide for the acquisition of all available energy efficiency and demand reduction resources that are cost-effective or less expensive than supply."[24] Evaluation of cost-effectiveness occurs at the sector level (residential, low-income, and commercial and industrial).

Beginning with the 2013–2015 plans, the Massachusetts Department of Public Utilities directed program administrators to include their benefit-cost ratio models as part of their three-year energy efficiency plan filings.[25] The model uses the most recent avoided costs developed through a regional analysis (Knight et al. 2018), the 2018 Avoided Energy Supply Costs for New

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[21] Air pollution data are available on an hourly basis for all large fossil fuel generators (greater than 25 MW), through the U.S. Environmental Protection Agency. The U.S. Environmental Protection Agency also offers the Avoided Emissions and generation Tool (AVERT) to evaluate how efficiency and renewable energy reduces air pollutant emissions. AVERT offers several options to users so that the tool can be used with high- or low-resolution data. For example, modeling options enable the user to evenly reduce generation across all hours of the year, designate the percentage reduction in fossil fuel generation, or manually input hourly annual reductions from efficiency.

[22] Recent data from ISO-NE shows that average emission rates (pounds per MWh) are lower than marginal emissions rates for sulfur dioxide and CO_2. Further, during the top five high electric demand days, all air pollutants have higher marginal emission rates than the marginal emission rate on all other days of the year. ISO-NE 2018c; ISO-NE 2019.

[23] For more information on air pollutant emissions reductions and energy efficiency see SEE Action (2016).

[24] MA General Law c 25, section 21 (b)(1).

[25] Massachusetts utility benefit-cost ratio models are available at http://ma-eeac.org/plans-updates/.

England (AESC), which clearly designates statewide and utility-specific avoided cost values. The 2018 AESC included estimates of avoided costs for program administrators throughout New England to support their internal decision making and regulatory filings for energy efficiency program cost-effectiveness analyses. The AESC 2018 includes avoided costs for energy, capacity, transmission, distribution, CO_2 emissions, renewable portfolio standard (RPS) compliance, and Demand Reduction Induced Price Effects, as well as other resource data.

Energy consumption load profiles are provided for summer and winter on-peak and off-peak periods. Coincidence factors are used to determine the utility system peak demand consumption by load profile, and are provided for summer and winter peak day, on-peak and seasonal peak. In the utilities' filings for 2019–2021 energy efficiency plans, 41 end-use load profiles are used in the benefit-cost ratio models.

4.1.2 Energy efficiency potential assessments

Potential assessments identify the cost, availability and performance characteristics of energy efficiency resources. The objective of the assessment is to provide accurate and reliable information regarding the amount, end-use or savings load profile, availability, and cost of acquiring or developing the energy efficiency resources. For reference, see Mosenthal and Loiter (2007) and Neubauer (2014).[26] Common uses of the assessments include informing energy efficiency program design; serving as inputs to IRP or capacity expansion models where energy efficiency resources compete with other electricity system resources on the basis of cost, reliability, economic risk and other factors such as environmental impacts; or to inform state energy efficiency goals.

Several types of energy efficiency potential can be calculated:

- *Technical potential:* The expected amount of technically feasible savings that may be realized over time from a measure, regardless of cost.
- *Economic potential:* Commonly determined by applying a cost-effectiveness limit to all measures that comprise the technical potential in a jurisdiction. The limit may be as simple as a maximum cost per kilowatt-hour or involve a more complex evaluation of a measure's energy savings and peak demand reduction benefits, other power system benefits, and non-power system benefits.[27]
- *Achievable potential:* Typically determines the subset of economic potential that the efficiency program administrator can obtain cost-effectively.

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[26] Also see the Energy Efficiency Potential Studies Catalog–DOE's catalog of potential studies conducted across the nation: https://www.energy.gov/eere/slsc/energy-efficiency-potential-studies-catalog.

[27] Another approach used to calculate economic potential involves allowing energy efficiency resources to compete directly against supply-side resources to assess whether developing more energy efficiency at varying cost levels increases or decreases the electric system cost.

Northwest Power and Conservation Council's Seventh Northwest Conservation and Electric Power Plan and Puget Sound Energy's 2017 Conservation Potential Assessment

In the *Seventh Northwest Conservation and Electric Power Plan*, the Northwest Power and Conservation Council—a national leader in estimating energy efficiency potential—developed conservation supply curves based on the amount and profile of efficiency available at a variety of cost groupings, by year (Northwest Power and Conservation Council 2016). The supply curves were made using hourly annual end-use load profiles and served as an input to the regional planning model for optimization with all other resources. As an alternative to forecasting customer efficiency adoption rates, the council assumed that over a 20-year planning period, 85 percent of the technical potential of energy efficiency can be acquired through ratepayer-funded programs, improved codes and standards, market transformation programs, marketing efforts, voluntary programs, electricity pricing mechanisms and other tools.[28] The council found that energy efficiency alone could cost-effectively meet all load growth in 90 percent of the 800 future conditions (scenarios) evaluated.

Another example of an energy efficiency potential assessment that includes conservation supply curves is Puget Sound Energy's (PSE's) *2017 IRP Demand-Side Resource Conservation Potential Assessment Report* (PSE 2017). The utility developed efficiency supply curves using hourly annual end-use load profiles as an input to its integrated resource planning process (PSE 2017). The potential assessment is unique because it disaggregated the achievable technical energy and peak demand potential to the ZIP-code level for the utility's service territory, adding a locational layer to the time-sensitive efficiency data.[29]

A key factor that distinguishes the Council's and PSE's approaches to estimating energy efficiency potential from practices by many other utilities is that economic potential is determined by directly comparing energy efficiency against supply-side resources in a capacity expansion model. This process allows the cost-effectiveness of efficiency to be determined dynamically by the models, rather than through the use of avoided costs derived independently, without consideration of the potential impact of efficiency on the timing and magnitude of future resource needs. Determining the economic assessment in this way requires levelized cost of energy calculations for energy efficiency. Puget Sound Energy relied on the Total Resource Cost test to define what costs and benefits to include when calculating the levelized cost of energy. Hourly annual avoided costs were used to determine the benefit of each measure.

4.1.3 Energy efficiency program design

This section focuses on ratepayer or utility customer funded energy efficiency programs. These are programs that customers fund and the utility or program administrator implements to directly support the uptake of cost-effective energy efficiency measures. There are many types

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[28] The Council conducted a 20-year retrospective review of energy efficiency development in the region that verified this planning assumption. See NWPCC (2007).

[29] The energy efficiency potential was optimized at the system level, not ZIP code level, for the integrated resource plan. The ZIP code level efficiency potential may be used to inform the distribution planning process.

of energy efficiency programs, including rebate, direct install, upstream or midstream incentive, commissioning and new construction programs. There are also several objectives that energy efficiency programs may seek to achieve, such as resource acquisition, market transformation or education and training.

Given the variety of program types and objectives, energy efficiency program design must consider many components, including program cost-effectiveness, energy and demand savings, the amount of the incentive payment to the customer (if applicable), whether the incentive payment will be upstream or midstream[30] of the customer, how to market the program, and how to verify program savings.[31]

Program cost-effectiveness is one of the most influential components in program design, and energy efficiency benefit-cost analysis is typically the source of determining program cost-effectiveness (see Section 4.1.1.). As with the other energy efficiency program planning efforts, use of TSV-EE can help program administrators prioritize measures or programs that save energy during high or low demand periods. It also can inform new program design, or existing program and measure incentives or rebate levels, to achieve efficiency portfolio goals at least cost.

Examples from Massachusetts, California, Florida and Texas illustrate the use of TSV-EE to guide program design.

Massachusetts

Eight program administrators are sponsoring long-term research to better understand residential load profiles for all major residential electric end uses in Massachusetts (Navigant 2018). The purpose of the research is to help inform energy and peak demand savings calculations for program evaluation and design, as well as to help program administrators identify the future savings potential of existing homes. The first phase of the research, published in July 2018, made several program recommendations based on the time-sensitive demand and energy value of efficiency, including the following:

- Early retirement for central air-conditioning and heat pumps can increase peak demand savings and energy savings.
- Residential end-use loads vary widely during peak times. Electric clothes dryers, dehumidifiers, electric water heaters and pool pumps may all be opportunities for peak demand savings with low impact on occupant comfort.
- Electrification of water heating presents opportunities for ongoing peak demand and energy reduction. Heat pump water heaters offer both peak demand and energy savings.

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[30] Upstream programs provide an incentive to product manufacturers, and midstream programs provide an incentive to product distributors. Both reduce the cost to program participants.

[31] Other considerations at the portfolio level include continuity of programs over time, service for all customer classes, and customer education.

- Residential lighting is the biggest contributor to winter peak load. Early retirement programs—removing inefficient products from service when they are still operating and replacing them with more efficient products—could reduce peak load and produce energy savings.

California

Southern California Edison (SCE) offered a pay-for-performance program through an all-source request for offers to meet its Local Capacity Requirement after retiring a 2,200 megawatt (MW) nuclear plant in 2013. The request for offers was focused on two geographic areas: the West Los Angeles Basin and Moorpark. Energy efficiency was included as a resource, and bids were evaluated on a "least-cost, best-fit" basis (SCE 2013). Contracts provided payment for kilowatt savings, summer on-peak and off-peak energy savings, and winter on-peak energy savings, in five installments (Szinai, Borgeson and Levin 2017). Efficiency bids selected by SCE contributed over 130 MW (~7 percent of the selected megawatts) to the West Los Angeles Basin Local Capacity Requirement and 6 MW (~2 percent of the selected megawatts) to the Moorpark Local Capacity Requirement.[32]

Florida

Florida investor-owned utilities are focused on peak demand reductions and use time-sensitive energy or demand value to choose their energy efficiency offerings based on the ability of the measure to reduce consumption during peak hours. Tampa Electric Company (TECO) provides a standard offer for several of its commercial energy efficiency programs, depending on the amount of peak demand reductions associated with the savings. TECO defines its peak at 5:00 p.m. in August and 7:00 a.m. in January, Monday–Friday. Table 3 shows example program offers.

Table 3. TECO Energy Efficiency Standard Offers[33]

Program	Incentive
Commercial and Industrial (C&I) Lighting	$148/kW in conditioned space and $75/kW for non-conditioned space
C&I Conservation Value	$200/kW rebate for peak demand savings for measures not covered by other TECO energy efficiency programs
C&I Chiller	Up to $146/kW, depending on the size of the chiller and the savings

Texas

Several utilities in Texas offer residential, hard-to-reach and commercial standard offer programs that provide a payment to contractors based on the time-sensitive value of installed efficiency measures. For example, Table 4 displays the 2017 values the utility Oncor provided to contractors for its commercial standard offer program.

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[32] SCE. Local Capacity Requirements ("LCR") RFO. https://www.sce.com/procurement/solicitations/lcr-rfp

[33] TECO Energy. Save Energy. https://www.tecoenergy.com/business/saveenergy/

Oncor defined the peak period as 1:00 p.m. to 7:00 p.m. during June, July, August and September, and 6:00 a.m. to 10:00 a.m. and 6:00 p.m. to 10:00 p.m. during December, January and February, excluding weekends and federal holidays. These are also referred to as the *summer peak period* and the *winter peak period* during which the utilities' system peaks are likely to occur. Summer and winter demand savings are determined by applying a coincidence factor for each season. Depending on the measure, either a summer peak or a winter peak demand (usually the higher of the two) would be reported as the c*laimed peak demand* value.

Table 4. Excerpt of Oncor Commercial Standard Offer Program Contractor Incentives (Oncor 2017)

Description	Measure Life	$/kW for On Peak Demand Reduction	$/kWh for Annual Energy Reduction
Air Cooled Chiller	25	387.81	0.125
LED	15	209.21	0.057
ENERGY STAR Commercial Dishwasher	11	193.11	0.054
Hot Food Holding Cabinet	12	164.21	0.041
Zero Energy Doors for Refrigerated Cases	12	123.16	0.025
Lodging Guest Room Occupancy Sensors	10	86.51	0.022
Refrigeration Evaporator Fan Controls	16	49.57	0.010
Vending Machine Controls	5	20.64	0.021
Pre-Rinse Spray Valves (Food Service)	5	12.38	0.004

4.1.4 Impact evaluation[34]

Impact evaluation includes a range of retrospective assessments and activities aimed at determining the effects of efficiency policies, portfolios, programs or projects. Impact evaluation can document metrics such as performance (e.g., time-sensitive energy and/or demand savings, or avoided air emissions) and provide data necessary for determining cost-effectiveness. Impact evaluation activities have three primary objectives, as shown in Figure 14:

- Document the benefits (i.e., impacts) of a program and determine whether the subject program (or portfolio of programs) has met its goals.
- Identify ways to improve current and future programs by determining why program-induced impacts occurred.
- Support energy demand forecasting and resource planning by understanding the historical and future resource contributions of energy efficiency as compared to other energy resources.

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[34] Steve Schiller contributed to writing this section.

Evaluation, Measurement and Verification Terms and Methods

Evaluation is the term associated with assessing programs (and program portfolios and policies).

Evaluation, measurement and verification (EM&V) is often used as a catchall term for both program and individual projects or for efficiency measure impact (kilowatt or kilowatt-hour savings) determinations.

Measurement and verification (M&V) is only associated with assessing project and individual measure impacts. M&V is also one way that programs are evaluated. For example, M&V can be applied to a sample of projects, and the results extrapolated to the entire program population of projects.

Besides M&V methods, two other methods are commonly used for efficiency program impact evaluation: (1) deemed savings methods and (2) comparison group methods. Solely using fully deemed savings values is not considered M&V. M&V, as defined by the efficiency industry, always requires some level of site measurements.

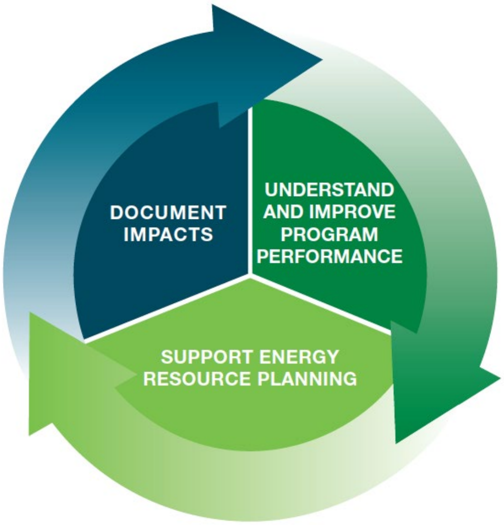

Figure 14. Evaluation, Measurement and Verification Objectives (State and Local Energy Efficiency Action Network 2012)

Impact evaluations, or EM&V, utilize energy savings information from facilities where efficiency measures are installed, as well as information about the measures themselves, to determine temporal variations in savings and specific metrics of interest, such as peak and coincident[35] demand savings. Thus, with adequate data, EM&V can provide time-sensitive profiles of kilowatt and kilowatt-hour savings. Combined with appropriate avoided cost data, these

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[35] The timing of savings from each project or site where efficiency measures are installed is not necessarily aligned exactly with the electricity system peak, which is how the avoided peak demand is defined. The metric that represents the fraction of the peak demand reduction from an efficiency measure, across all installations, that occurs at the time of a utility system's peak is referred to as the measure's *coincidence factor.* In some cases, coincidence factor is defined as the ratio of peak demand to *maximum* demand, rather than *diversified* demand. This definition simply incorporates the diversity factor adjustment in the derivation of the coincidence factor.

savings profiles can be used to calculate the time-sensitive value of efficiency that specific, implemented efficiency actions have provided. While in current practice not all EM&V efforts utilize time-sensitive data or provide time-sensitive results, the three methods mentioned in the text box above (deemed savings, M&V and control groups) can all be used to generate time-sensitive energy and demand values.

For deemed savings methods,[36] the time-sensitive characteristics of the savings resulting from implemented measures can be specified. Deemed savings are often specified in a jurisdiction's technical reference manual and will typically include peak demand savings values. They also may include savings load profiles, coincident peak demand savings factors or both.[37] For control group methods[38] the determined impacts also can indicate time-sensitive energy or demand value if time-sensitive consumption data are available for both the treatment and control groups (e.g., via interval meters).

ISO New England Measurement and Verification Process

ISO New England (ISO-NE) requires demand resources that participate in the wholesale electric market to provide measurement and verification plans. Demand resources include energy efficiency, and are defined by ISO-NE[39] as follows:

- On-peak demand resources "offer on their reduced electricity consumption during summer peak hours (non-holiday weekdays, 1:00 pm to 5:00 pm during June, July and August) and winter peak hours (non-holiday weekdays 5:00 pm to 7:00 pm during December and January)."
- Seasonal-peak demand resources "offer on their reduced electricity consumption during the summer months of June, July and August and during the winter months of December and January, in hours on non-holiday weekdays when the real-time system hourly load is equal to or greater than 90% of the most recent 50/50 system peak-load forecast for the applicable summer or winter season."

The measurement and verification plan must use one of the identified ISO-NE methodologies or provide acceptable justification for an alternative methodology proposed for the project. The identified approaches are as follows:

- *Partially Measured Retrofit Isolation/Stipulated Measurement:* This method is for measures where performance or operational factors can be measured on a short-term basis during baseline and post-installation periods, or measured where proxy variables

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[36] Deemed savings are predetermined estimates of energy or peak demand savings attributable to individual energy efficiency measures. They are sometimes referred to as *unit energy savings* or *stipulated savings values*.

[37] See SEE Action (2018), including an appendix with state-by-state information. Regional resources include the Northeast Energy Efficiency Project's Loadshape Catalogue, Regional Energy Efficiency Database and Mid-Atlantic Technical Reference Manual.

[38] Comparison group EM&V methods determine program savings based on the differences in energy consumption between a comparison group and program participants. Comparison group approaches include randomized control trials and quasi-experimental methods.

[39] source

with algorithms or stipulated factors can provide an accurate estimate of the resource performance.

- *Retrofit Isolation/Metered Equipment:* This method is for retrofits with performance and operational factors that can be measured using interval meters installed on an end use.
- *Whole Facility/Regression:* Energy savings are estimated using metered data on overall energy use in a facility and identifying the impact of demand resources through a range of techniques (e.g., simple billing, multivariate regression analysis).
- *Calibrated Simulation:* This approach uses calibrated computer building energy models to determine energy efficiency measure savings.

All measurement and verification plans require detailed information on the demand resources, such as the estimated demand reduction during on-peak or seasonal peak hours. Other measurement and verification plan requirements include the specific energy efficiency measures installed, the projected life of the measures installed, how the measures will be installed, and how the demand resource will produce verifiable energy savings in ISO-NE's jurisdiction.

Demand resources must submit measurement and verification plans as part of the resource qualification package that allows them to participate in the forward capacity auction. Existing demand resources must recertify their measurement and verification plans in advance of subsequent auctions.

4.2 Distribution system planning

Electric distribution system planning focuses on assessing needed physical and operational changes to the local grid to provide safe, reliable and affordable electricity (Schwartz 2018). There are several types of distribution system analysis, such as power flow, power quality, fault and dynamic analysis (Tang et al. 2017). For the purposes of this study, we focused on how TSV-EE is used in distribution system planning.[40]

Several jurisdictions, including California, District of Columbia, Hawaii, Illinois, Massachusetts, Michigan, Minnesota, Nevada, New York, Rhode Island and Washington, require consideration of energy efficiency and other DERs in distribution system planning and operations[41](Schwartz and Homer 2019; Homer et al. 2017; Schwartz and Mims 2018; Schwartz 2018; Baatz, Relf and Nowak 2018). In an increasing number of states, including California and New York, this includes competitive procurement processes which are open to DERs (including efficiency) that can potentially defer or avoid distribution system upgrades (Homer et al. 2017; Schwartz and Homer 2019). Bidders must demonstrate load reductions during designated peak demand

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[40] For a broader perspective on distribution system planning, see De Martini et al. (2016); Homer et al. (2017); Cooke, Homer, and Schwartz (2018); and ICF (2018). Berkeley Lab's presentations for trainings on distribution systems and planning are available online. See for example, the Electricity Markets Policy Group's Mid-Atlantic Distribution Systems and Planning Training https://emp.lbl.gov/publications/mid-atlantic-distribution-systems-and

[41] Other states may have similar requirements, as the number of states adopting such requirements is growing.

hours identified by the utility to mitigate potential operational or reliability constraints on distribution systems. A growing body of literature describes successful implementation of such non-wires alternatives (NWAs) for DERs to cost-effectively defer distribution system upgrades (Dyson et al. 2018).

Time-Sensitive Value of DERs

Many of the same opportunities and challenges to appropriately valuing efficiency exist for other DERs (e.g., demand response, photovoltaics, energy storage, electric vehicle charging) as well. Understanding when (and where) DERs are saving or generating electricity will produce more robust electricity planning and DER valuation. This report focuses on the time-sensitive value of efficiency, but there is a growing body of research on the time-sensitive value of other DERs.[42]

Following are examples of considering energy efficiency in distribution system planning from three perspectives: (1) a municipal utility (Sacramento Municipal Utility District [SMUD]), (2) a state policy requirement (New York), and (3) and an investor-owned utility perspective (Pacific Power).[43] There are other examples of state policy requirements and utilities considering NWAs[44] that are not provided in this section.[45]

Table 5 provides a summary of the motivation, type of TSV-EE used, and significance of the examples discussed in this section.

Table 5. Distribution System Planning Use Case Examples Summary

Motivation for using TSV-EE	Identify lower cost NWAs that defer infrastructure expansion; inform hosting capacity analysis and renewable energy integration
Type of TSV-EE	Demand, energy
Examples	SMUD, New York and Pacific Power
Significance	SMUD: Hourly energy efficiency profiles were used as part of its integrated DER planning study. New York and Pacific Power: Hourly efficiency savings are used when utilities assess NWAs to traditional distribution system expansion.

California: Sacramento Municipal Utility District (SMUD)

This publicly owned utility and Black & Veatch conducted an integrated DER planning study in 2017 to assess the impact of DERs, including efficiency, on SMUD's system (Black and Veatch 2017). The goal of the study was to identify opportunities to engage customers, maximize net benefits of DERs, and address risks presented by DERs. The study built on a DER planning process established in prior research by considering interaction of DERs. Energy efficiency is considered a DER in the analysis.

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[42] For more information on DER valuation, see Boero et al. (2018), Electricity Advisory Committee (2019), Frick et al. (2018), Eckman et al. (2019).

[43] California Assembly Bill 327 (Perea, Chapter 611, Statutes of 2013) and a series of California PUC orders set requirements for California investor-owned utilities to consider energy efficiency and other DERs in distribution system planning.

[44] Non-wires alternatives are nontraditional investments or market operations that may defer, mitigate or eliminate the need for traditional transmission and distribution investments.

[45] See Schwartz and Homer (2019) for a more comprehensive discussion of non-wires alternatives.

Black & Veatch developed a customer database including information on a customer's historical DER adoption, building characteristics, electricity use, customer demographics, customer segment and meter locations. Using SMUD's technical, economic and achievable potential for each DER and the customer database, Black & Veatch identified the technical and economic potential of each DER technology for each customer. In addition, the firm assigned an "adoption propensity" value to each customer based on its characteristics.

Next, the study assigned actual adopters based on a random number generator. If a customer was selected, then the system size was based on the customer's specific DER potential for the chosen technology. After customers were assigned a DER technology and the systems were properly sized based on the technical and economic potential, an operation profile was assigned to each adopter. The operation profile included an hourly energy efficiency profile, making use of time-sensitive energy or demand value. Table 6 shows the amount of energy efficiency, as a percent of SMUD's 2017 sales, included for three years of the analysis.

Table 6. Bulk System DER Scenarios by Year (LBNL analysis using SMUD and U.S. Energy Information Administration [EIA] data)

Technology	2020	2025	2030
	Percent of SMUD System Peak		
Customer Photovoltaic (PV)	7	11	15
Combined Heat and Power (CHP)	2	3	4
Customer Energy Storage	0	1	1
Dispatchable Demand Response	7	8	8
Nondispatchable Demand Response	3	3	3
	Percent of 2017 Sales		
Energy Efficiency	5	7	10

The study indicated that DER adoption was likely to be widespread throughout SMUD territory, but unevenly distributed. Clusters of high DER adoption are expected to be driven by a combination of demographics, technical and economic factors. Understanding this clustering could help SMUD proactively plan for distribution upgrades and engage early with customers on solutions to mitigate impacts. The utility is using the maps to assess distribution and bulk level impacts and understand potential financial impacts of DER adoption.

New York

As part of the New York Reforming the Energy Vision process, the New York Public Service Commission in Docket/Case 14-M-0101 ordered investor-owned utilities within the state to file distribution system implementation plans. In April 2018, the Department of Public Service released a staff white paper providing guidance on the plans. They must include energy efficiency, including "the resources and capabilities used for integrating energy efficiency within system and utility business planning, including among other things, infrastructure deferral opportunities as part of NWAs, peak and load reduction and/or energy shaping with an explanation of how integration is supported by each of those resources and capabilities, or other shared savings/benefits opportunities" (New York Public Service Commission 2018).

Time-sensitive demand and energy value of efficiency is used in distribution system planning when NWAs are considered. The most well-known NWAs example is Consolidated Edison's Brooklyn-Queens Demand Management project, which successfully deferred $1.2 billion of traditional network upgrades (41 MW customer-side, 11 MW utility-side) using a combination of energy efficiency (primarily), voltage optimization, battery storage and other DERs (Coddington, Sciano, and Fuller 2017).

The Joint Utilities filed their most recent distribution system implementation plans in July 2018, including responses to staff guidance (New York Public Service Commission Case 16-M-0411). The plans included examples of energy efficiency as NWAs:

- Rochester Gas & Electric plans to use targeted efficiency near Station 51 (a planned NWA) to identify savings that will reduce the peak demand that would otherwise be met with the NWA.[46]
- Orange & Rockland met with C&I customers in the area of the Pomona NWA program to identify customer efficiency solutions and used data loggers to measure energy savings and demand reductions achieved. The effort resulted in more than 1 MW of peak demand reduction from efficiency, which supported the deferral of the Pomona substation upgrade (Orange and Rockland 2018).
- National Grid plans to integrate existing energy efficiency and demand response efforts within the NWA procurement process. The company anticipates that 5 of the 15 potential NWA opportunities have potential for energy efficiency and demand response integration (National Grid 2018).

Oregon: Pacific Power[47]

Pacific Power and Energy Trust of Oregon are using targeted energy efficiency and distributed renewables to test potential deferral of a distribution substation upgrade. The two-year pilot is designed for quick deployment of energy efficiency to approximately 3,000 residential, commercial and industrial customers to reduce substation load. The pilot has four goals: (1) reduce peak demand in the identified geographic area and quantify the load reduction during a specific time-period, (2) document and evaluate the ability to replicate the targeted efficiency strategy in other regions served by Pacific Power and Energy Trust of Oregon, (3) develop processes for coordinated implementation between Pacific Power and Energy Trust

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[46] Energy efficiency and demand response options are under concurrent exploration, utilizing RG&E's existing EE and DR programs which are not a part of the Station 51 request for proposals (RFP). For that reason, the megawatt need described in the RFP contains three tiers per year. If significant demand reduction is achieved through the RG&E's EE/DR initiatives, the final megawatt reduction required through the RFP may be reduced. See https://www.rge.com/wps/portal/rge/saveenergy/innovation/non-wiresalternatives/

[47] Other utilities in Oregon are also involved in distribution system planning. Pacific Power is one example, and the section is not meant to be comprehensive.

of Oregon, and (4) determine if changes need to be made to improve targeted deployment of existing energy efficiency and renewable offerings and/or develop new offerings.

The first pilot is wrapping up in the first quarter of 2019, and a second pilot is underway, with an implementation phase running from June 2019 to December 2020. The intention of the second pilot is to integrate the learnings from the first pilot and test additional strategies, such as selectively promoting key efficiency measures that coincide with system peak, as well as better tracking and evaluating the demand reductions. A bottom-up billing analysis is planned for the second pilot, while the first will rely on engineering estimates based on deemed savings and representative end-use load profiles.

4.3 Electricity resource planning[48]

This section discusses resource planning by utilities and planning for centrally organized wholesale electricity capacity markets. An overview of utility resource planning and long-range planning in centrally organized wholesale electricity capacity markets is provided in sections 4.3.1 and 4.3.2.

Table 7 provides a summary of the motivation, type of TSV-EE used, and significance of the examples discussed in this section.

Table 7. Electricity Resource Planning Use Case Examples Summary

Motivation for using TSV-EE	Identify optimal amount of energy efficiency to include in a reliable, least cost system through utility planning or competition in electricity markets.
Type of TSV-EE	Energy and demand
Examples	Utility planning: PacifiCorp Integrated Resource Plan Electricity market: ISO-NE and PJM capacity markets
Significance	Utility planning: PacifiCorp creates hourly energy efficiency supply curves that are used as an input in its capacity expansion modeling. This allows energy efficiency to compete as a resource in long-term planning. Electricity market: Energy efficiency that performs during designated time periods can be bid into ISO-NE an PJM's capacity markets.

4.3.1 Utility resource planning

The objective of long-term resource planning by electric utilities is to identify a resource portfolio and management strategy that provides an adequate, efficient, economical and reliable power supply while controlling for the risks associated with the future uncertainties.

Understanding the current trajectory (forecast) of energy and peak load demand is the first step in electric utility resource planning. Electricity demand forecasts are used to predict total electricity consumption (measured in kilowatt-hours) and peak load (measured in kilowatts). Energy efficiency is generally addressed in utility resource planning in one of two ways: (1) as an

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[48] Tom Eckman, a Berkeley Lab subcontractor, contributed to this section.

assumed amount of energy efficiency savings subtracted from the load forecast (Kahrl et al. 2016) usually determined by using avoided cost as an economic threshold[49] or (2) as a resource option that can be selected by an optimization model. This section focuses on the second approach because it uses the TSV-EE.[50]

Using the second, more robust, method for addressing energy efficiency in electricity resource planning, capacity expansion models simulate the economic dispatch of both the existing and potential future power systems to allow energy efficiency to compete directly with supply side (i.e., generation) alternatives and DERs so the most economical solution to both energy and capacity resources needs can be identified. In such analyses, both the energy and capacity characteristics of efficiency measures are modeled.

The capacity expansion models use reliability criteria and economic decision rules (often referred to as *optimization logic*) to determine the type, amount and schedule for the new resource development required to meet the forecasted future need for energy and capacity. These models also can determine whether retirements of existing resources—or power purchase contracts with existing resources—would be economic.[51]

PacifiCorp's Integrated Resource Plan

An investor-owned utility that operates in six states, PacifiCorp conducts a systemwide IRP that treats energy efficiency as a resource (using the capacity expansion approach discussed above). Efficiency measures are bundled together based on their cost (e.g., those measures with a cost range of $10–$20/megawatt-hour [MWh]), with hourly demand impacts calculated based on underlying end-use load profiles. The energy efficiency bundle inputs are created as part of the utility's Conservation Potential Assessment. According to PacifiCorp's IRP, the "hourly load shapes are created by spreading measure level annual energy savings over 8,760 load shapes differentiated by state, sector, market segment and end-use accounting for hourly variance of efficiency impacts by measures" (PacifiCorp 2017).

These cost bundles are then offered to the model to compete against all other resources and are selected based on being the lowest-cost, lowest-risk resource based on forecasted electricity system needs. Figure 15 shows PacifiCorp's 2017 IRP energy efficiency (Class 2 DSM) potential over the 20-year planning period by cost bundle ($/MWh), by state.

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[49] Most avoided cost studies select one or more representative supply side resources. For example, simple cycle combustion turbines are often selected to serve as a proxy for the cost of supplying new peaking capacity, and combined cycle combustion turbines are used as a proxy for the cost of supplying base load energy.

[50] Using the first method, the utility may identify the amount of energy efficiency savings through an energy efficiency potential assessment, preset standard or target, or another planning exercise. Even if the utility chooses to use the preset standard or target, it may also consider scenarios with higher amounts of efficiency. Resource planning inputs are often aggregated across all programs, with the resulting resource plans providing a single energy efficiency reduction value for each year of the plan. Depending on the approach used, time-sensitive efficiency values may or may not be used.

[51] For more information on energy efficiency in integrated resource planning, see Frick et al. (2019).

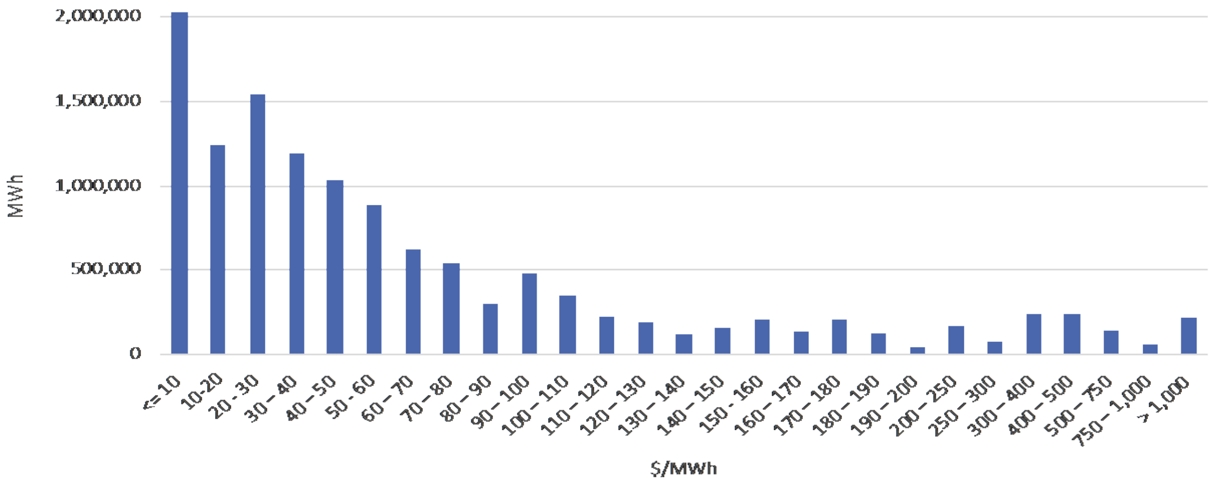

Figure 15. Class 2 DSM (energy efficiency) Megawatt-hour Potential by Cost Bundle

4.3.2 Planning for capacity markets in centrally organized wholesale markets

U.S. ISOs and RTOs serve two-thirds of the electricity load.[52] Here, we focus on the ISO-NE and PJM capacity markets, because they allow energy efficiency to participate in the market as a resource.

ISO-NE is the RTO that serves six New England states (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont. PJM is the RTO that serves all or parts of 13 U.S. states (Delaware, Indiana, Illinois, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia) and the District of Columbia.

ISO-NE Forward Capacity Market

At least three of ISO-NE's processes require time-sensitive values: the energy efficiency forecast, bids from energy efficiency resources in the forward capacity market (FCM), and the evaluation, measurement and verification process for energy efficiency resources. For more information on TSV-EE in the energy efficiency forecast and evaluation, measurement and verification process, see Appendix A.

ISO-NE's FCM allows energy efficiency to participate as an on-peak demand resource or a seasonal peak demand resource by offering capacity reductions as a resource in the annual forward capacity auctions.[53]

- On-peak demand resources "offer on their reduced electricity consumption during summer peak hours (non-holiday weekdays, 1:00 p.m. to 5:00 p.m. during June, July and

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[52] For more information on RTOs and ISOs, see FERC (2015).

[53] ISO New England. 2019. About Demand Resources. https://www.iso-ne.com/markets-operations/markets/demand-resources/about

August) and winter peak hours (non-holiday weekdays 5:00 p.m. to 7:00 p.m. during December and January)."

- Seasonal-peak demand resources "offer on their reduced electricity consumption during the summer months of June, July and August and during the winter months of December and January, in hours on non-holiday weekdays when the real-time system hourly load is equal to or greater than 90% of the most recent 50/50 system peak-load forecast for the applicable summer or winter season."

The auctions are held three years in advance of when the resources will be available, and efficiency resources compete with generation and demand response resources in the auction. The lowest-priced offers clear the auction, are designated as capacity resources with capacity supply obligations, and receive fixed monthly payments for their capacity obligation (See Peterson et al. 2006).

In 2014, the forward capacity market was revised to include a pay-for-performance design. Under this design, a capacity resource that delivers more energy (or reserves) during a capacity scarcity condition[54] compared to its share-of-system capacity supply obligation receives additional revenues, and a resource that delivers less is penalized. While energy efficiency resources were exempted from the pay-for-performance design if a capacity scarcity condition occurs outside of on-peak or seasonal peak hours, New England market participants are currently exploring ways in which the performance of energy efficiency could be assessed for capacity scarcity conditions that occur in other hours. Such an approach requires a method that estimates energy efficiency performance in all hours and not just during a specific set of peak-period hours.[55]

PJM Regional Portfolio Model

As in ISO-NE's situation, at least three of PJM's processes require time-sensitive values: the energy efficiency forecast, bids from energy efficiency resources in the Regional Portfolio Model, and the evaluation, measurement and verification process for energy efficiency resources.

The Reliability Pricing Model (RPM) is PJM's three-year forward resource adequacy construct. Similar to the ISO-NE FCM construct, the RPM facilitates a competitive procurement of existing and new supply resources based on offers. PJM sets a minimum quantity of resources that it will purchase (based on its forecast of summer peak load four years into the future) and a maximum price it will pay for that quantity of resources. PJM conducts a sealed bid auction each May to purchase a sufficient quantity of resources to meet its expected peak load for the

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[54] A capacity scarcity condition occurs when there are insufficient capacity resources available in real time to meet both energy and reserve requirements for reliable system operations.

[55] The final report on assessing energy efficiency performance in all hours is available at https://www.iso-ne.com/static-assets/documents/2019/06/eefinaldraftreportfinal.docx

power year that starts in June, three years into the future, using a minimum quantity and maximum price construct similar to that used in New England.

As in New England, PJM allows market participants to offer energy efficiency as a resource in the RPM. Participants may bid energy efficiency into the RPM as a capacity performance product, meaning it must provide sustained, predictable demand reduction throughout the year. If an energy efficiency resource cannot meet the annual requirement alone, it can be combined with other resources to meet the requirement. The energy efficiency resource value is based on average demand reduction during the Energy Efficiency Performance hours, which are weekdays between 2:00 p.m. to 6:00 p.m. June–August, and 8:00 a.m. to 9:00 a.m. and 6:00 p.m. to 8:00 p.m. in January and February.

PJM RPM Energy Efficiency Performance Hours

Energy efficiency performance hours are defined as the hours ending 15:00 through 18:00 EPT (Eastern Prevailing Time) during all days from June 1 through August 31, inclusive, of such delivery year, that is not a weekend or federal holiday.

Winter hours are hours ending 8:00 through 9:00 EPT and hour ending 19:00 through 20:00 EPT during all days January 1 through February 28, inclusive, of such delivery year, that is not a weekend or federal holiday.

4.4 Electricity rate design

Electricity retail rate design, or the structure of electricity prices to consumers, affects how, and in some cases when, consumers use electricity. There is a long history of research on electricity rate design; however, there are few examples of electric utilities using the time-sensitive value of efficiency to inform rate design.

Time-based rates are electricity prices that vary with time and are intended to provide utility customers with price signals that better reflect the time-sensitive and marginal costs of producing and delivering electricity (Cappers, Hans, and Scheer 2015). Well-designed time-based rates can provide the appropriate price signals for participation in demand response, while also providing consumers with a financial incentive to participate in energy efficiency opportunities.[56]

Electric utilities have implemented time-based rates to explicitly integrate resources such as distributed solar, electric vehicles, storage, and demand response, typically with the goal of better aligning the prices with economic efficiency concerns (i.e., to better align electricity prices with marginal system costs) (Satchwell, Cappers, and Barbose 2019). Similarly, utilities

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[56] Regulators and consumer advocates have expressed concern regarding the impact of time-based rates on vulnerable populations. For more information see: Certner, Wein and Slocum (2010); John Howat, National Consumer Law Center, in Wood et al. (2016); Cappers et al. (2016b); George et al. (2018); Faruqui (2015); and Waite et al. (2018).

can use time-based rates to create an increased value proposition for consumers to install energy efficiency measures that lower peak demands, and by encouraging customers to shift electricity consumption from peak to off-peak periods.

Recent research found that rate design may have a critical impact on the adoption of DERs, including energy efficiency (Satchwell, Cappers, and Barbose 2019). As regulators and utilities consider rate design, they may wish to explicitly consider the impact of new rate design on energy efficiency adoption. The TSV-EE may help utilities identify efficiency savings that will be more valuable, and those that will be less valuable during designated rate periods, and use that information to inform their procurement strategy.

The sections below discuss examples of residential and nonresidential time-based rate structures that improve the value proposition for efficiency. Table 8 provides a summary of the motivation, type of TSV-EE used, and significance of the examples discussed in this section.

Table 8. Electricity Rate Design Use Case Examples Summary

Motivation for using TSV-EE	Currently TSV-EE is not used in rate design.
Type of TSV-EE	None
Examples	Appendix A provides examples of residential and non-residential rates that could be coupled with the time-sensitive energy or demand value of efficiency to help identify measures and programs that save energy during times of system need or influence adoption of efficiency programs.
Significance	Utilities can use time-based rates to create an increased value proposition for consumers to install energy efficiency measures that lower peak demands, and by encouraging customers to shift electricity consumption from peak to off-peak periods to the extent retail rate designs are aligned with time-sensitive energy savings.

4.4.1 Residential rate design

The rate structure for residential customers typically includes a fixed customer charge and a volumetric price that is applied to the customer's electricity usage.[57] Historically, residential consumers have had limited, but effective, options to control their electricity usage. Direct load control demand response programs and installation of energy efficiency measures in households have enabled consumers to reduce their consumption and save money on electricity bills. Smart appliances, programmable communicating thermostats, advanced metering infrastructure, and recent advances in information and communication technologies—coupled with effective delivery mechanisms such as time-based rates and automation—can provide consumer benefits.

Well-crafted retail rate designs are critical to provide an economic incentive to manage energy use, to reduce peak consumption and during critical peak periods, and to shift consumption to

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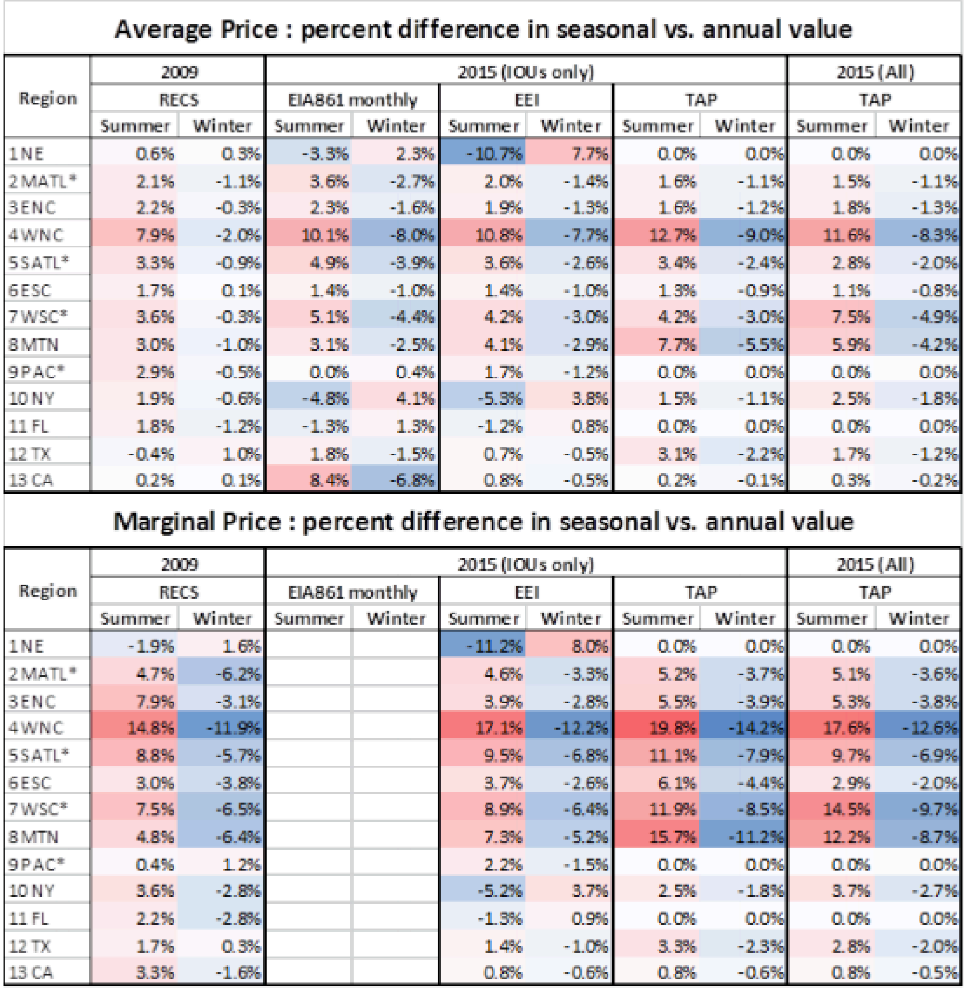
[57] Emerging trends in residential rate design are discussed below.

lower-cost periods; yet the majority of U.S. residential consumers have a flat electricity rate, meaning that each kilowatt-hour consumed has the same price.

Research by Berkeley Lab indicates that 43 percent of residential default tariffs include seasonal pricing, most of which only define summer and winter rates (Coughlin and Beraki 2018). Of these tariffs, most average prices and marginal prices are higher in the summer, and the magnitude of seasonal variation is greater for marginal prices than for average prices. Figure 16 shows the percent difference between summer and winter prices and the average price for four data sources (Residential Energy Consumption Survey [RECS], EIA form 861, Electric Edison Institute [EEI], and the Berkeley Lab Tariff Analysis Project [TAP]). In Figure 16, the color indicates if the seasonal price is higher (red) or lower (blue) than the annual price, and the value is the percentage difference between the seasonal and annual price.



Average Price : percent difference in seasonal vs. annual value

Region	2009		2015 (IOUs only)						2015 (All)	
	RECS		EIA861 monthly		EEI		TAP		TAP	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
1 NE	0.6%	0.3%	-3.3%	2.3%	-10.7%	7.7%	0.0%	0.0%	0.0%	0.0%
2 MATL*	2.1%	-1.1%	3.6%	-2.7%	2.0%	-1.4%	1.6%	-1.1%	1.5%	-1.1%
3 ENC	2.2%	-0.3%	2.3%	-1.6%	1.9%	-1.3%	1.6%	-1.2%	1.8%	-1.3%
4 WNC	7.9%	-2.0%	10.1%	-8.0%	10.8%	-7.7%	12.7%	-9.0%	11.6%	-8.3%
5 SATL*	3.3%	-0.9%	4.9%	-3.9%	3.6%	-2.6%	3.4%	-2.4%	2.8%	-2.0%
6 ESC	1.7%	0.1%	1.4%	-1.0%	1.4%	-1.0%	1.3%	-0.9%	1.1%	-0.8%
7 WSC*	3.6%	-0.3%	5.1%	-4.4%	4.2%	-3.0%	4.2%	-3.0%	7.5%	-4.9%
8 MTN	3.0%	-1.0%	3.1%	-2.5%	4.1%	-2.9%	7.7%	-5.5%	5.9%	-4.2%
9 PAC*	2.9%	-0.5%	0.0%	0.4%	1.7%	-1.2%	0.0%	0.0%	0.0%	0.0%
10 NY	1.9%	-0.6%	-4.8%	4.1%	-5.3%	3.8%	1.5%	-1.1%	2.5%	-1.8%
11 FL	1.8%	-1.2%	-1.3%	1.3%	-1.2%	0.8%	0.0%	0.0%	0.0%	0.0%
12 TX	-0.4%	1.0%	1.8%	-1.5%	0.7%	-0.5%	3.1%	-2.2%	1.7%	-1.2%
13 CA	0.2%	0.1%	8.4%	-6.8%	0.8%	-0.5%	0.2%	-0.1%	0.3%	-0.2%

Marginal Price : percent difference in seasonal vs. annual value

Region	2009		2015 (IOUs only)						2015 (All)	
	RECS		EIA861 monthly		EEI		TAP		TAP	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
1 NE	-1.9%	1.6%			-11.2%	8.0%	0.0%	0.0%	0.0%	0.0%
2 MATL*	4.7%	-6.2%			4.6%	-3.3%	5.2%	-3.7%	5.1%	-3.6%
3 ENC	7.9%	-3.1%			3.9%	-2.8%	5.5%	-3.9%	5.3%	-3.8%
4 WNC	14.8%	-11.9%			17.1%	-12.2%	19.8%	-14.2%	17.6%	-12.6%
5 SATL*	8.8%	-5.7%			9.5%	-6.8%	11.1%	-7.9%	9.7%	-6.9%
6 ESC	3.0%	-3.8%			3.7%	-2.6%	6.1%	-4.4%	2.9%	-2.0%
7 WSC*	7.5%	-6.5%			8.9%	-6.4%	11.9%	-8.5%	14.5%	-9.7%
8 MTN	4.8%	-6.4%			7.3%	-5.2%	15.7%	-11.2%	12.2%	-8.7%
9 PAC*	0.4%	1.2%			2.2%	-1.5%	0.0%	0.0%	0.0%	0.0%
10 NY	3.6%	-2.8%			-5.2%	3.7%	2.5%	-1.8%	3.7%	-2.7%
11 FL	2.2%	-2.8%			-1.3%	0.9%	0.0%	0.0%	0.0%	0.0%
12 TX	1.7%	0.3%			1.4%	-1.0%	3.3%	-2.3%	2.8%	-2.0%
13 CA	3.3%	-1.6%			0.8%	-0.6%	0.8%	-0.6%	0.8%	-0.5%

Figure 16. Magnitude of Seasonal Variation Compared to Annual Prices for Residential Tariffs (Coughlin and Beraki 2018)

In 2015, about 14 percent[58] of U.S. utilities offered residential customers a time-of-use rate, with about 1.7 percent of residential customers enrolled (Hledik et al. 2017). [59] The three most common type of time-based residential rates are (1) time-of-use, (2) critical peak pricing,[60] and (3) variable peak pricing[61] (Satchwell, Cappers and Barbose 2019). Of the utilities that offer time-based rates, most are implemented through voluntary (i.e., opt-in) enrollment, and a few offer time-based rates as the default residential rate (Cappers et al. 2016a). While there are many variations of time-based rate structures, they mostly differ with regard to the timing of the peak and off-peak periods and magnitude of peak to off-peak pricing ratio (Satchwell, Cappers and Barbose 2019).

A growing body of research on time-based residential rate structures has emerged because of increased interest by regulators and utilities. Recent research identified five residential rate design trends: (1) increased pursuit of residential time-based rates, (2) development of rates and programs to promote midday load building, (3) increased application of residential three-part rates (demand charge, volumetric charge and fixed customer charge), (4) development of new net-metering alternatives, and (5) development of new electric vehicle-specific rates (Satchwell, Cappers and Barbose 2019). However, there is little research on the impacts of residential time-based rates on energy efficiency. Appendix A provides examples of residential time-based rates that could be coupled with the time-sensitive energy or demand value of efficiency to help identify measures and programs that save energy during times of system need or influence adoption of efficiency programs.

4.4.2 Non-residential rate design

For non-residential (commercial and industrial) customers, retail rate structure varies by size. For small non-residential customers, the structure typically is the same as residential customers. Larger non-residential customers also pay demand (kW) charges. In some jurisdictions, customers can choose to purchase electricity from alternative retail suppliers, which offer a wide variety of rate structures ranging from flat electric rates to time-based rates (Gonzalez 2015).

Demand charges are based on the consumer’s highest energy usage in a specified time interval—for example, 15 minutes or an hour—over the course of the billing period, typically a month. Some demand charges include a “ratchet,” meaning that the highest demand a

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[58] This figure does not include implementation of TOU rates in California. San Diego Gas & Electric begin transitioning its ~1.3 million residential customers to TOU in March 2019. PG&E (~4M residential customers) and SCE (~4.3M residential customers) will transition their residential customers to TOU rates in late 2020 through 2021.

[59] The majority of utilities have less than one percent of customers enrolled. A few utilities, such as Arizona Public Service, Ohio Power, PEPCO, Public Service of Oklahoma and Salt River Project have very high participation, which drives the overall participation rate up (Hledik et al. 2017; EIA 2017).

[60] It is important to differentiate CPP, which is a time-based rate intended to induce episodic energy and ideally demand reductions, with critical peak rebate (or peak-time rebate), which is an incentive-based program that seeks to accomplish the same goal. This discussion focuses on time-based rates, not incentive-based programs, so we do not discuss the various jurisdictions that have defaulted their residential customers onto critical peak rebate programs (e.g., Delaware, Maryland).

[61] VPP is a form of TOU, where the on-peak price can change daily, either based on a pre-set schedule of prices or tied to wholesale market electricity prices.

customer registers in a billing period may apply over the course of the following year. Demand charges have typically been applied to the individual peak demand of each customer, regardless of whether that occurs during peak periods for the utility system. In other words, demand charges typically are based on non-coincident usage which does not necessarily occur during the utility system peak or cause associated costs. Often, the volumetric energy charge is a flat rate, but they may have a choice of time-based rates (Linvill and Lazar 2018).

Non-residential customers typically have more time-based rate options than residential customers, although while time-based rates such as time-of use, critical peak pricing, critical peak rebate, variable peak pricing, and real time pricing are becoming more common, most commercial customers are on tariffs that do not send price signals that encourage load shaping or shifting.[62] Appendix A provides examples of time-based rates for non-residential customers that could be coupled with the time-sensitive energy or demand value of efficiency to help identify measures and programs that save energy during times of system need or influence adoption of efficiency programs.

4.5 State and local government activities

Most electricity system related state and local government activities could benefit from the consideration of time-sensitive valuation (e.g., building benchmarking reporting, air pollutant emissions factors, renewable portfolio standards, research & development programs, state building fleet energy management and upgrades). This section focuses on two examples of state and local government activities that employ the TSV-EE—energy efficiency resource standards and other peak demand reduction goals and building energy codes. Table 9 provides a summary of the motivation, type of TSV-EE used, and significance of the examples discussed in this section.[63]

Table 9. State Activities Use Case Examples Summary

Outcomes Enabled by Using TSV-EE	Achieve state goals at least cost (e.g., building energy codes). Inform development of state standards to align with state energy goals (e.g., energy efficiency resource standards)
Type of TSV-EE	Energy, demand
Examples	Energy efficiency resource standards, peak demand reduction goals and performance incentives are examples that often require peak demand reductions; California Title 24 building energy codes
Significance	• 26 states of energy efficiency resource standards in place, four states require peak demand reductions • 6 states have performance incentives linked to peak demand reductions • California uses their building energy code to require commercial buildings to be capable of interacting with the grid

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[62] A more robust conversation about retail rates options for commercial customers can be found in Schwartz et al. (2017).

[63] In addition to the examples described in this section, there are a variety of electricity system related state activities that would benefit from the consideration of the time-sensitive valuation (e.g., building benchmarking, air pollutant emissions factors, renewable portfolio standards).

4.5.1 *Energy efficiency resource standards and other peak demand reduction goals*

Energy efficiency resource standards and other peak demand reduction goals
State energy efficiency resource standards require utilities (or third-party program administrators) to procure a designated amount of energy efficiency, typically over a long-term period. Some 26 states have such a policy in place (Goldman et al. 2018). Only four of these states address the TSV-EE in their standard, by requiring peak demand reductions. The standards vary by state, from less than 1 percent to 2.5 percent of retail electricity sales annually.

Texas was the first state to adopt an energy efficiency resource standard in 1999. The state required electric utilities to offset 10 percent of load growth in peak demand through end-use energy efficiency (Texas Legislature 1999). In 2007, after several years of meeting this goal, the state legislature increased the standard to require electric utilities to offset 15 percent of load growth by the end of 2008 and 20 percent of load growth by the end of 2009 (Texas Legislature 2007). The savings targets are expressed in terms of peak demand reductions, and the utilities and PUC of Texas have devoted significant efforts to improving the consistency of approaches used to estimate peak demand reductions across measures in the state technical reference manual (TRM).[64] Pennsylvania enacted an energy efficiency resource standard in 2008 that included both energy savings and peak demand reduction targets. In 2012, the Pennsylvania PUC directed the utilities to continue to track and report demand reduction benefits from installed energy efficiency measures (PA PUC 2012, 2015).

Four states (Colorado, Illinois, Ohio[65] and Texas) require electric utilities to achieve both energy and peak demand reduction goals through energy efficiency resource standards.[66] Peak demand reductions from energy efficiency are permitted to contribute to achieving the goal. Some states, such as Texas, achieve the majority of demand reductions with demand response.[67] In contrast, in Colorado in 2017, Xcel Energy saved 73 MW of demand with energy efficiency while saving much less, 24 MW, with demand response (Xcel 2017a). Additionally, in two states (California and Florida), the public utility commissions set peak demand reduction requirements as part of an energy efficiency proceeding. The Tennessee Valley Authority sets energy efficiency and demand response goals as part of its integrated resource planning process. In TVA's 2019 IRP, it established goals of 1,800 MW of efficiency by 2028 and 2,200 MW by 2038 (TVA 2019).

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[64] Texas utilities have been reporting peak demand impacts of efficiency programs since 2002. A consistent definition of this metric was part of the PUC evaluation effort and came into effect after 2012. A TRM is a resource that contains energy efficiency measure information used in program planning, implementation, tracking, and reporting and evaluation of impacts associated with the subject measures (SEE Action 2017).

[65] In July 2019, Ohio passed House Bill 6, a law amending the energy efficiency resource standard and ending the requirement that utilities achieve energy efficiency and peak demand reductions as of December 31, 2020. See: https://www.legislature.ohio.gov/legislation/legislation-documents?id=GA133-HB-6

[66] See ACEEE's Energy Efficiency Resource Standards at https://database.aceee.org/state/energy-efficiency-resource-standards.

[67] Approximately half of the demand savings achieved in 2017 were from the Commercial Load Management program. See http://www.texasefficiency.com for each utility's annual energy efficiency plan and report.

States and public utility commissions also require that utilities reduce peak demand, or use certain resources to meet peak demand through a variety of policies. While these policies are not focused on the use of efficiency to reduce or meet peak demand needs, energy efficiency that reduces electricity system peak may lower the utility's peak demand reduction goal and thus qualify. For example, Maryland's EmPower Act required 15 percent reduction of per capita peak demand consumption by 2015. More recently, Massachusetts passed the Clean Peak Energy Standard which requires the state Department of Energy Resources (DOER) to "develop a program requiring retail electricity providers to meet a baseline minimum percentage of sales with qualified clean peak resources that dispatch or discharge electricity to the distribution system during seasonal peak periods or reduce loads on the system."[68] Also, as discussed in section 4.2, utilities seek to meet electricity system using strategies to reduce distribution system peak demand through NWAs.

In addition, six states (Hawaii, Massachusetts, Michigan, New York, Rhode Island and Vermont) provide an opportunity for utilities and other PAs to earn financial incentives for achieving or exceeding pre-specified peak demand savings targets, which requires reporting of peak demand savings (Baatz, Relf and Nowak 2018).

In sum, no state expressly allows a time-sensitive valuation of efficiency-generated savings in their energy efficiency resource standards, but six states (California, Colorado, Florida, Illinois, Ohio[69] and Texas), as well as the Tennessee Valley Authority, have peak demand reduction goals where energy efficiency is eligible to contribute to meeting the goal.

4.5.2 Building energy codes

Building energy codes are adopted by state or local governments and vary widely. Codes typically identify cost-effective requirements that reduce energy consumption; in California codes require buildings to be able to effectively communicate with the electricity grid.[70]

California considers the TSV-EE when developing building energy codes under Title 24, and is the only state to do so. To assess the cost-effectiveness of efficiency measures, the California Energy Commission (CEC) uses "time-dependent valuation" of energy. The valuation of energy differs based on the hour of the year to reflect the cost to consumers, the utility and society. The values also vary by fuel type (e.g., gas, electricity, propane), location (e.g., climate zone) and building type (e.g., residential, nonresidential). Measures that save energy on-peak are valued more than measures that do not.

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[68] Mass.gov. Clean Peak Energy Standard. https://www.mass.gov/service-details/clean-peak-energy-standard

[69] In July 2019, Ohio passed House Bill 6, a law amending the energy efficiency resource standard and ending the requirement that utilities achieve energy efficiency and peak demand reductions as of December 31, 2020. See: https://www.legislature.ohio.gov/legislation/legislation-documents?id=GA133-HB-6.

[70] See California 2018, Section 110.12 – Mandatory Requirements for Demand Management.
Also, ASHRAE and IECC commercial building codes have added many control measures in the last four code cycles. While controls do not require interacting with the electricity grid, they enable building owners to more easily control building energy usage during times of peak demand or high electricity prices.

Figure 17 shows the average day from one climate zone from the time-dependent valuation framework from the 2019 update to Title 24. The units on the y-axis have been converted from a lifecycle $/kWh value to the thousand British thermal units (kBtu)/kWh value for building code compliance (Ming et al. 2017). It illustrates that energy efficiency that occurs between hours ending 16 and 18 produces significantly more value than efficiency that occurs at other times of the day. In California, this means that higher cost efficiency measures that save energy between hours ending 16 and 18 may be cost-effective and could be included in the building energy code.

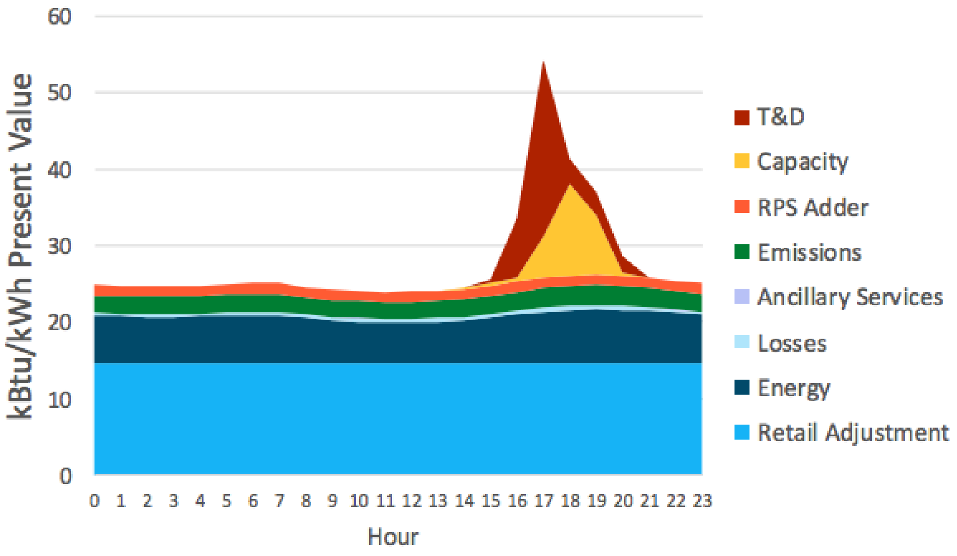

Figure 17. Time-Dependent Valuation Output for 2019 Update to California Title 24

5 Considerations for Using Time-Sensitive Value of Efficiency

The TSV-EE is important to many issues confronting the electricity system today. For example, changes due to increased adoption of distributed energy resources, technology cost reductions, and generation retirements in the United States make the TSV-EE critical to resource planning. In states as varied as Arizona, California, Florida, Hawaii, Minnesota, Nevada, Texas and Vermont, increased adoption of DERs is already affecting resource planning for utilities and RTOs and ISOs.

Other considerations, such as equipment and compliance controls that modify the profile of end uses (e.g., lighting and heating) and connected devices that could reduce or change energy consumption may result in end-use load profiles that are significantly different than what we see today (Schwartz et al. 2017). Among the research areas of DOE's Grid-Interactive Efficient Buildings initiative is understanding how building load profiles will change with multiple types of DERs connected to the electricity system and providing grid support services in real time.[71]

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[71] See DOE. Grid-Interactive Efficient Buildings. https://www.energy.gov/eere/buildings/grid-interactive-efficient-buildings.

Using the TSV-EE will help utilities, RTOs/ISOs, and state and local decision makers craft efficiency plans and programs that are more effective in achieving their energy goals. Potential areas of future research include the following:

- Development of easy-to-use tools to estimate the TSV-EE
- Development of tools to facilitate the handling and use of interval data
- Development of energy efficiency savings profiles for individual measures
- Opportunities for building owners and operators to use TSV-EE to identify how to meet grid needs
- Electricity rate design impacts on customer adoption of energy efficiency measures and participation in energy efficiency programs
- Considering TSV-EE to refine state energy efficiency resource standards
- Using TSV-EE to enable state and local building energy codes to more accurately estimate cost-effectiveness of proposed requirements
- Considering TSV-EE on the emissions of electricity generation and the environmental (including public health) impacts of those emissions
- Identifying a consistent TSV-EE framework that could be utilized across any state/jurisdiction/utility
- Incorporating the TSV-EE into the *National Standard Practice Manual* (Woolf et al. 2017) as a more granular form of the Resource Value Test

6 Conclusions

Most energy efficiency measures produce energy savings that vary in magnitude over the course of a year. The economic value of the hourly electricity savings—on system wide and per-kWh basis—also varies over the course of a year because the avoided cost of generating, transmitting and distributing electricity during peak demand periods may be significantly higher than during off-peak, or lower load, hours. Yet, use of time-sensitive data on when energy savings occur and the economic value of such savings in utility planning, state policies and wholesale electricity markets is relatively limited.

Data limitations exist, and work by DOE—through the creation of national end-use load profiles for residential and commercial building stocks—is seeking to reduce these limitations. Current end-use load research is focused on the East and West coasts, with limited activity in the Midwest, South and Southwest. Data on the time-sensitive economic value of efficiency, through utility avoided costs, varies by region and utility, with large gaps in publicly available data in the South and Midwest.

Higher-resolution data—at least hourly annual (8,760 hours)—may be important for determining the time-sensitive value of efficiency for a variety of reasons. For example, some regions may wish to focus energy efficiency budgets on reducing peak load and peak emissions to get the most value. Regions with high levels of variable renewable energy resources will particularly benefit from control-based efficiency measures to take greatest advantage of these low-marginal cost resources in real time. In any case, the purpose of the analysis will determine the necessary level of time-sensitive value of efficiency. The most granular data are not always necessary. Lower resolution data, grouped by seasonal on-peak and off-peak hours, can provide useful insights about the time-sensitive value of efficiency as well.

Each of the five use cases—energy efficiency processes, distribution system planning, electricity resource planning, rate design and state energy policies—showcase several examples of how the time-sensitive value of efficiency can be used for more effective outcomes.

We offer the following guidance that utilities, states and others can consider to enable the time-sensitive value of energy efficiency:

- *Advanced metering infrastructure:* When analyzing the benefits and costs of potential investments in advanced metering infrastructure, evaluate its uses for collecting or disaggregating data on end-use load profiles, calibrating building energy models to enhance accuracy of modeled end-use load profiles, creating energy efficiency savings profiles, offering time-based pricing options aligned with energy efficiency opportunities, and providing price signals to thermostats, energy management systems and other grid-connected devices.
- *Data collection:* Review data collection practices for energy efficiency planning and programs to ensure data are current, use accurate assumptions, cover all market sectors, and are sufficiently granular for uniform usage in cost-effectiveness screening, electricity resource planning and modeling, and measurement and verification.

The following guidance can be used by utilities, states and others to consider how to utilize the time-sensitive value of energy efficiency:

- *Utility energy efficiency programs:* Use TSV-EE to help prioritize efficiency and other DER programs to meet the utility's goals.
- *Evaluation, measurement and verification:* Review current EM&V practices to determine if the frequency of updates to deemed savings methods using coincidence factors are sufficient to account for electricity system shape changes.
- *Evaluation, measurement and verification:* Review current EM&V practices to determine if values are being used consistently as inputs to other electricity resource planning processes.
- *Deferral of distribution system upgrades:* Use the TSV-EE to assess opportunities for cost-effective deferral of a subset of planned distribution system upgrades for load relief and reliability (e.g., non-wires alternatives).
- *Electricity resource planning:* Review current approaches for incorporating energy efficiency into resource planning to determine if the TSV-EE is appropriately considered.

Identify the avoided cost components used to value efficiency and verify they are complete and consistent across planning processes.

- *Electricity rates:* If time-sensitive rates are in place or under consideration, review alignment of energy efficiency programs with the time-sensitive value of efficiency to provide additional opportunities for bill savings.
- *State activities:* Assess to what extent any energy efficiency regulatory or statutory requirements should focus on particular time periods; for example, during times of peak electricity system demand and highest costs and emissions, or to help integrate variable energy resources.

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Appendix A. Additional Information on Use Cases

Benefit-Cost Analysis

The California Standard Practice Manual established five cost-benefit tests for energy efficiency in 1983 that are still used to determine energy efficiency cost-effectiveness in the United States today. In 2017 a new cost-benefit manual, the *National Standard Practice Manual,* was published. The *National Standard Practice Manual* Resource Value Framework can be used to define a jurisdiction's primary cost-effectiveness test, which is referred to as a Resource Value Test. The Resource Value Framework is based on six principles that encompass the perspective of a jurisdiction's applicable policy objectives, and it includes and assigns value to all relevant impacts (costs and benefits) related to those objectives. All tests in the *National Standard Practice Manual* require both utility system benefits and costs be included in the cost-effectiveness evaluation, shown in Table A - 1.

Table A - 1. Energy Efficiency Cost-Effectiveness Tests (Energy and Environmental Economics and Regulatory Assistance Project 2008)

Test	Perspective	Key Question Answered	Categories of Costs and Benefits Included
Utility Cost Test	The utility system	Will utility system costs be reduced?	Includes the costs and benefits experienced by the utility system
Total Resource Cost Test	The utility system plus participating customers	Will utility system costs plus program participants' costs be reduced?	Includes the costs and benefits experienced by the utility system, plus costs and benefits to program participants
Societal Cost	Society as a whole	Will total costs to society be reduced?	Includes the costs and benefits experienced by society as a whole
Resource Value Test	Regulator/ decision makers	Will utility system costs be reduced, while achieving applicable policy goals?	Includes the utility system costs and benefits, plus those costs and benefits associated with achieving relevant policy goals

Utility system benefits include:

- Avoided energy costs
- Avoided generating capacity costs
- Avoided reserves
- Avoided transmission and distribution capacity costs
- Avoided transmission and distribution marginal line losses
- Avoided ancillary services
- Energy price suppression effects (e.g., demand reduction induced price effect)
- Avoided cost of complying with renewable portfolio standards
- Avoided environmental compliance costs
- Avoided credit and collection costs

- Reduced fuel price, environmental compliance and decision risk[72]
- Increased reliability or reduced cost for achieving the same level of reliability

Example utility system costs:

- Energy efficiency measure costs (utility portion of cost)
- Other financial or technical support costs
- Program administration costs
- Evaluation, measurement and verification costs
- Shareholder incentives

To calculate the lifecycle avoided energy, generation, transmission and distribution capacity costs, and transmission and distribution line losses, the analyst must know when energy efficiency savings will occur[73] and what the value is to the utility system at that time, and then calculate present value.

Measurement and Verification

M&V methods use one of the four approaches indicated in Table A - 2 to document energy efficiency measure savings. As with deemed savings and control group methods, time-sensitive energy and demand value can also be determined through M&V, but only if time-sensitive consumption data are available. New advances in M&V, known as M&V 2.0, are of particular interest for improving the ability of evaluators to obtain reliable time-sensitive and real time impact results.

Table A - 2. Industry-Accepted International Performance Measurement and Verification Protocol: M&V Options[74]

Approach	*Description*	*Measurement Boundary*	*Typical Application*
Option A Key-Parameter Measurement	Short-term measurement of key parameters affecting energy use	Equipment or system	Lighting retrofit: power measured, hours estimated
Option B All-Parameter Measurement	Short-term or long-term measurement of all parameters affecting energy use	Equipment or system	Variable-speed drive retrofit of a pump: continuous measurement of pump (kW)
Option C Whole Facility	Whole-building utility billing analysis	Building	Deep energy retrofit with system interactions
Option D Calibrated Simulation	Calibrated building simulation modeling	Building and/or subsystem	Beyond-code new construction project with no existing baseline

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[72] Energy efficiency, demand response, distributed generation and storage affect the need for investment in new electricity infrastructure, across generation, transmission and distribution systems.

[73] Coincidence factors and diversity factors, if applicable, must be applied to energy savings to determine the hourly demand savings.

[74] See the Internal Performance Measurement and Verification Protocol: Core Concepts 2015, Efficiency Valuation Organization. www.evo-world.com.

M&V 2.0 involves access to better and more end use energy consumption data from smart meters, advanced metering infrastructure (AMI), smart devices, and wireless and non-intrusive load metering (big data), as well as improved analytical tools. Such tools include automated M&V, benchmarking and behavior analytics.

M&V 2.0 is a dynamic field that is rapidly changing. Research by Berkeley Lab clarified the role of M&V 2.0 versus standard M&V (Franconi et al. 2017). Some of the distinguishing features are the capability of M&V 2.0 to use automated analytics to provide ongoing, near-real time savings estimates and increased data granularity (e.g., frequency, volume or end-use detail)–all of which can support reliable and cost-effective determination of time-sensitive efficiency savings.

The Berkeley Lab research indicated a variety of uses for near-real time savings estimates:

- Determine savings quantities for a collection of installations under a program, as a basis for determining payments from a program administrator to a program implementer.
- Determine net savings attributable to a program for determination of program cost-effectiveness and goal achievement, as part of a broader impact evaluation.
- Demonstrate savings to the end-use customer at different times, establish customer confidence and maintain customer engagement.
- Provide early feedback on program implementation to correct problems at the project or program level.

Several states, including Illinois, Missouri, New Mexico, New York and Virginia, are requiring utilities to use M&V 2.0 or exploring the benefits of it (Granderson and Fernandes 2017). Missouri recently published a guidebook on the adoption of M&V 2.0 that suggested creating a narrower definition that would hone in on the time-sensitive demand value: “a method of calculating saving that supports new types of services and business models by increasing the granularity of measurements in time (e.g., peak-coincident impacts) or location (e.g., customer-level savings estimates)” (Goldman 2018).

Information on M&V 2.0 pilots are just beginning to be available, with summaries of existing pilots available from a few sources (Granderson and Fernandes 2017).

ISO-NE Energy efficiency load forecast

ISO-NE has several load forecasts, including an energy efficiency forecast which is used to forecast future peak loads net of the reductions produced by energy efficiency, which is a major input into the long-term regional system planning process.[75] The energy efficiency forecast is comprised of three main variables: future program administrator energy efficiency budgets, the projected average production cost of efficiency ($/MWh), and peak-to-energy ratios (MW/gigawatt-hour [GWh]).

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[75] For more information on ISO-NE gross and net forecasts, see ISO-NE, Load Forecast at https://www.iso-ne.com/system-planning/system-forecasting/load-forecast.

The energy efficiency budget data originates from state energy efficiency program administrators and regulatory agencies (ISO-NE 2018a). For example, in Massachusetts, utilities and the Massachusetts Energy Efficiency Advisory Council collaboratively develop three-year energy efficiency plans that are submitted to the Department of Public Utilities for approval. The 2019–2021 plan was filed with the department in October 2018. When approved, the budgets are used as an input to the ISO-NE's energy efficiency forecast. ISO-NE assumes that budgets are held constant after the last year of the approved budget (ISO-NE 2018a).

The average production cost of efficiency (denominated in dollars spent per kWh saved) is calculated using a three-year average, based on data provided by program administrators. For example, for the 2018 energy efficiency forecast, the production cost was based on 2014–2016 average efficiency program costs. ISO-NE assumes that the production cost of efficiency increases in the base year by 2.5 percent for inflation plus an additional 1.25 percent each year thereafter (ISO-NE 2018a).

The peak-to-energy ratio is also calculated using a three-year average. As with the production cost, for the 2018 energy efficiency forecast, the 2018 peak-to-energy ratio is based on the 2014–2016 average as reported by program administrators.[76] A single value is used for the ratio statewide and is held constant through the forecast period. The peak-to-energy ratio determines the reduction in peak-period demand; a time-sensitive value that is produced by the energy efficiency programs implemented in each of the six New England states. The forecasted reduction in peak-period demand based on the energy efficiency forecast is used to determine future peak loads net of the reductions produced by energy efficiency, which is used in the long-term regional system planning process.

Distribution System Planning

Nevada

In 2017, Nevada passed a law that requires utilities to file their first distributed resources plan by April 1, 2019. Energy efficiency is included in the definition of a distributed resource in Nevada.[77] The plans must be part of integrated resource planning and include five components: "(1) evaluate locational benefits and costs of distributed resources; (2) propose or identify standard tariffs, contracts or other mechanisms for the deployment of cost-effective distributed resources; (3) propose cost-effective methods of effectively coordinating existing programs approved by the Commission; (4) identify additional spending necessary to integrate cost-effective distributed resources into distribution planning; and (5) identify barriers to the deployment of distributed resources."[78] The Public Utilities Commission of Nevada opened a docket to implement the law in 2017 and in October 2018, following a stakeholder process, issued regulations on the distribution system plans requirements.[79] The regulations require that

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[76] ISO-NE. 2018. Final 2018 Energy Efficiency Forecast. https://www.iso-ne.com/static-assets/documents/2018/04/eef2018_final_fcst.pdf

[77] Nevada Public Utility Commission Docket 17-08022. Temporary Regulation issued 10/08/18.

[78] Nevada Senate Bill 146 (2017).

[79] Docket 17-08022: http://pucweb1.state.nv.us/PDF/AxImages/DOCKETS_2015_THRU_PRESENT/2017-8/30483.pdf.

the distributed resource forecast include "system, substation and feeder level net load projections and energy and demand characteristics for all distributed resource types," indicating that time-sensitive demand and energy value of efficiency will be used.

Time-Based Residential Rate Design

Arizona

Over half of residential customers of Arizona Public Service are enrolled in a time-of-use rate (APS 2018). The utility offers three residential time-of-use plans, two of which include a demand charge. The demand charge is calculated based on the highest single hour of energy used during the on-peak period for each billing cycle. All three plans have the same on-peak hours, from 3:00 p.m.–8:00 p.m. on weekdays.[80] All other hours are considered off-peak. While the utility's annual DSM report includes this program, it does not offer insights into any energy efficiency actions rate participants are taking that may reduce demand during on-peak hours.

Illinois

Investor-owned utilities in Illinois are required to offer their customers a real-time electricity rate. Ameren Illinois offers Power Smart Pricing, and Commonwealth Edison's program is Hourly Pricing. Ameren's program uses day-ahead hourly market prices set by MidContinent Independent System Operator (MISO) to determine hourly electricity rates for program participants; Commonwealth Edison relies on PJM day-ahead hourly market prices. Customers enrolled in these programs receive next-day hourly electricity prices the evening prior and can plan their electricity consumption based on the pricing. Elevate Energy, the program administrator for both utilities, has undertaken a number of analyses that compare bill impacts of participants in the real-time rate to consumers on a flat rate. The most recent analysis found that 23 percent of Commonwealth Edison's customers with smart meters, 29 percent of low-income customers, and 78 percent of high energy users would have saved money on the real-time versus flat rate billing (Elevate Energy 2016). The time-sensitive value of efficiency and real-time electricity rates may provide consumers with opportunities to reduce electricity consumption through energy efficiency when price rates are highest.

California

A 2015 decision by the California Public Utilities Commission (CPUC) requires the three large California investor-owned utilities to transition most of their residential customers to a time-of-use rate (CPUC 2015). To learn more about how customers would respond to the time-of-use rate, utilities implemented an opt-in residential time-of-use pilot program from June 2016 to December 2017. During the pilot period, the utilities enrolled more than 50,000 customers.

Nine rate structures were tested in the rate pilot (eight are shown here because SDG&E did not pursue its third rate structure). Table A - 3 shows the percentage reduction and absolute demand impact of the rate structures.

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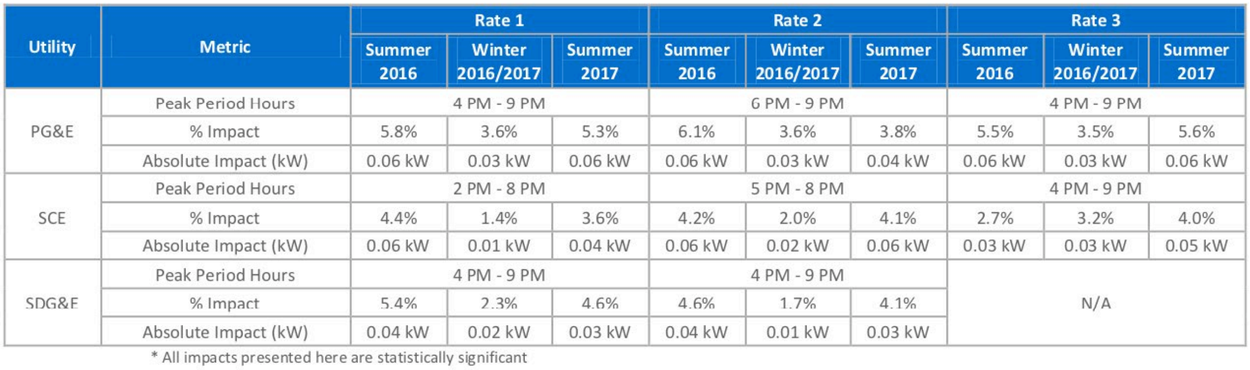
[80] APS. Residential. https://www.aps.com/en/residential/accountservices/serviceplans/Pages/plans.aspx

Table A - 3. Weekday Peak Period Load Reductions (George et al. 2018)*



Utility	Metric	Rate 1			Rate 2			Rate 3		
		Summer 2016	Winter 2016/2017	Summer 2017	Summer 2016	Winter 2016/2017	Summer 2017	Summer 2016	Winter 2016/2017	Summer 2017
PG&E	Peak Period Hours	4 PM - 9 PM			6 PM - 9 PM			4 PM - 9 PM		
	% Impact	5.8%	3.6%	5.3%	6.1%	3.6%	3.8%	5.5%	3.5%	5.6%
	Absolute Impact (kW)	0.06 kW	0.03 kW	0.06 kW	0.06 kW	0.03 kW	0.04 kW	0.06 kW	0.03 kW	0.06 kW
SCE	Peak Period Hours	2 PM - 8 PM			5 PM - 8 PM			4 PM - 9 PM		
	% Impact	4.4%	1.4%	3.6%	4.2%	2.0%	4.1%	2.7%	3.2%	4.0%
	Absolute Impact (kW)	0.06 kW	0.01 kW	0.04 kW	0.06 kW	0.02 kW	0.06 kW	0.03 kW	0.03 kW	0.05 kW
SDG&E	Peak Period Hours	4 PM - 9 PM			4 PM - 9 PM			N/A		
	% Impact	5.4%	2.3%	4.6%	4.6%	1.7%	4.1%			
	Absolute Impact (kW)	0.04 kW	0.02 kW	0.03 kW	0.04 kW	0.01 kW	0.03 kW			

* All impacts presented here are statistically significant

An evaluation of the pilot found that most of the time-of-use rates resulted in small reductions in energy consumption, but did not offer insights into the cause of the energy reductions (e.g., installation of an energy-efficiency measure, conservation, load shifting) (George et al. 2018).

After the pilot was completed, the utilities crafted plans for a default, or opt-out, time-of-use program. San Diego Gas & Electric will implement its default time-of-use rate first, beginning in March 2019; Southern California Edison and Pacific Gas & Electric will follow in 2020 (CPUC 2018).

The utilities file quarterly reports with the CPUC on progress towards implementing their default time-of-use rate. These reports provide details on how the utilities plan to educate their customers of the impending rate change, as well as how customers may manage the change. The utilities use hourly avoided costs and end-use load profiles in their energy efficiency program planning, as discussed above.

Minnesota

The Minnesota Public Utilities Commission approved Xcel Energy’s petition for a residential default time-of-use pilot in May 2018 (Xcel 2017b). The pilot will use three time periods and be offered to 10,000 customers over a two-year period. The customers will be auto-enrolled in the rate and have an opportunity to opt out of the program. The Commission approved the program with limited modifications, most of which required the utility to provide the Commission with data on enrollment, customer bill impacts, energy usage, market and educational communications provided to customers, and development of a transition plan for time-of-use pilot participants and a plan to fully implement a time-of-use rate for all residential customers. Table A - 4 shows Xcel Energy’s time-of-use pilot period and rates.

Table A - 4. Xcel Energy Minnesota time-of-use pilot periods and rates

		TOU Ratio	Rates - Cents per kWh		
			Average Monthly	June-September	October-May
TOU Pilot Rate					
On-Peak	3pm-8 pm Weekdays	4.2	23.821	25.949	22.385
Mid-Peak	Other Hours	1.95	11.07	12.125	10.43
Off-Peak	12am-6am All days	1	5.676	5.676	5.676

In its application, Xcel Energy discussed several times how the time-of-use pilot will encourage energy efficiency (Xcel 2018):

> - *The pilot will increase conservation opportunities for customers, as participants receive advanced metering capabilities to facilitate communication between the utility and customer, in service of driving on-peak energy efficiency and load-shifting behaviors.*
> - *The pilot project stands to generate significant benefits, including learnings about the ability of residential customers to respond to price signals and tailored educational messages. Those responses may include engaging in energy efficiency and shifting energy usage to nonpeak periods.*
> - *This [advanced meter infrastructure devices] will allow for a much more granular view of the customer load and how the residential [time-of-use] rates will impact pilot customers, enabling greater energy efficiency and time-shifting usage patterns.*
> - *The pilot also provides participants with increased energy usage information, education, and support to encourage energy efficiency and shifting energy usage to daily periods where the system is experiencing low load conditions.*

Time-based Non-Residential Rate Design Examples

A review of nonresidential rates (Table A - 5) from a sample of utilities shows the significant variation in nonresidential rate structure, which may produce different customer value propositions when combined with the time-sensitive value of efficiency. Results from additional examples are discussed below. As with residential rate design, there is limited research on if time-based rates result in increased adoption of energy efficiency.

- *Default TOU:* All commercial, industrial and agricultural customers are required to be on TOU rates in California. Evaluation of PG&E's 2015 program year found that small and medium commercial consumers[81] showed load reductions in all price periods ranging from 0.3 to 3.4 percent. Agricultural customers showed small increases in off-peak periods (0.4 to 1.0 percent) and load reductions of 2.4 percent during peak periods (Patton and Hansen 2016).

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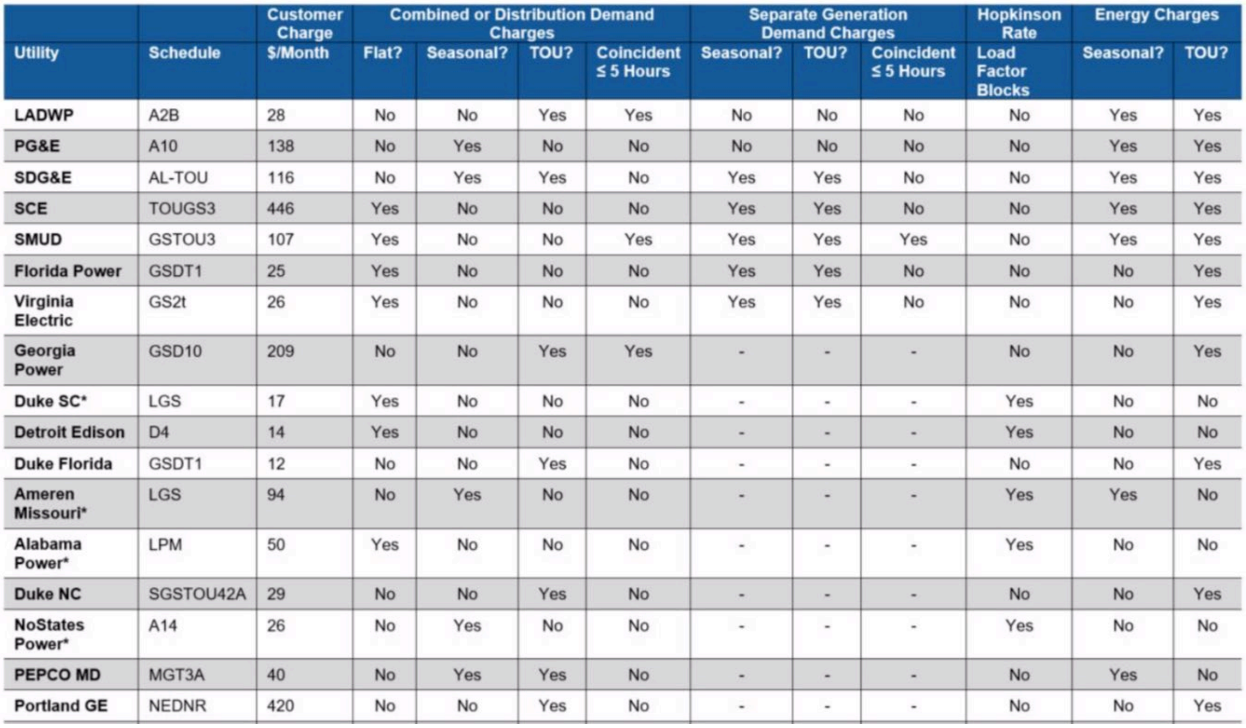
[81] Small and medium commercial customers and agricultural customers were evaluated. This includes the smallest non-residential customers on an energy-only (volumetric) rate; customers with energy and demand charges with demand between 200 kW and 500 kW; and customers with energy and demand charges with demand below 200 kW, where at least 70 percent of the energy consumption is from agricultural uses. Patton and Hansen (2016).

- *Critical Peak Pricing (CPP) plus energy audit:* Sacramento Municipal Utility District piloted a program where small commercial energy audits were combined with enrollment in CPP. Participants achieved, on average, a 20 percent reduction in peak demand, with office buildings saving the most. (SMUD 2013)
- *Variable Peak Pricing (VPP):* Successful implementations of VPP, such as those by Oklahoma Gas & Electric (OG&E), demonstrate that although more complex than TOU and CPP, VPP can provide stronger price signals and solicit a greater response. Residential and small commercial customers with programmable communicating thermostats in OG&E's Smart Study Together Pilot were estimated to reduce peak load by about 30 percent (DOE 2013).
- *Real Time Pricing (RTP):* Public utility commissions in five states have mandated RTP tariffs for large C&I customers (New York, New Jersey, Pennsylvania, Maryland and Illinois). Approximately 70 utilities offer voluntary RTP tariffs, primarily targeted to large C&I customers (Goldman and Levy 2010). Many reports document the benefits associated with commercial RTP instead of a flat rate price (See Chiles et al. 2015; Barbose et al. 2004; Barbose et al. 2005; and Barbose et al. 2006).

Table A - 5. Overview of Non-Residential Rates Applicable to 300 kW Commercial Customer (Linvill and Lazar 2018)



		Customer Charge	Combined or Distribution Demand Charges				Separate Generation Demand Charges			Hopkinson Rate	Energy Charges	
Utility	**Schedule**	**$/Month**	**Flat?**	**Seasonal?**	**TOU?**	**Coincident ≤ 5 Hours**	**Seasonal?**	**TOU?**	**Coincident ≤ 5 Hours**	**Load Factor Blocks**	**Seasonal?**	**TOU?**
LADWP	A2B	28	No	No	Yes	Yes	No	No	No	No	Yes	Yes
PG&E	A10	138	No	Yes	No	No	No	No	No	No	Yes	Yes
SDG&E	AL-TOU	116	No	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes
SCE	TOUGS3	446	Yes	No	No	No	Yes	Yes	No	No	Yes	Yes
SMUD	GSTOU3	107	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes
Florida Power	GSDT1	25	Yes	No	No	No	Yes	Yes	No	No	No	Yes
Virginia Electric	GS2t	26	Yes	No	No	No	Yes	Yes	No	No	No	Yes
Georgia Power	GSD10	209	No	No	Yes	Yes	-	-	-	No	No	Yes
Duke SC*	LGS	17	Yes	No	No	No	-	-	-	Yes	No	No
Detroit Edison	D4	14	Yes	No	No	No	-	-	-	Yes	No	No
Duke Florida	GSDT1	12	No	No	Yes	No	-	-	-	No	No	Yes
Ameren Missouri*	LGS	94	No	Yes	No	No	-	-	-	Yes	Yes	No
Alabama Power*	LPM	50	Yes	No	No	No	-	-	-	Yes	No	No
Duke NC	SGSTOU42A	29	No	No	Yes	No	-	-	-	No	No	Yes
NoStates Power*	A14	26	No	Yes	No	No	-	-	-	Yes	No	No
PEPCO MD	MGT3A	40	No	Yes	Yes	No	-	-	-	No	Yes	No
Portland GE	NEDNR	420	No	No	Yes	No	-	-	-	No	No	Yes