# Resource Flexibility to Support Renewables Growth and Grid Stability: The Potential for Demand-Side Resources

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## Abstract

Renewable energy production has boomed across Europe over the past decade, increasing 84% between 2003 and 2013 and currently providing more than 25% of the EU's gross electricity consumption (Eurostat, October 2015). Many European utilities now "worry that the growth of [intermittent] solar and wind power is destabilising the grid, and may lead to blackouts or brownouts (Economist, 2013).

In response, utilities, grid operators, and regulators are looking for increased operational flexibility in the resources used to manage the grid, including flexibility from demand-side resources (DSRs)—the aggregated management of customer loads to increase or decrease demand to help balance the instantaneous supply and demand of electricity. To date, however, little research has been conducted on the potential for DSRs to provide flexibility beyond emergency curtailment of loads during periods of peak system demand.

This paper describes the methods and findings from a 2015 assessment of the potential for fast-responding DSRs to provide operational flexibility to the grid. The study, conducted for the U.S. utility with the highest penetration of renewable energy (Hawaiian Electric), assessed a range of grid-services that can be provided by DSRs, from almost instantaneous inertial/frequency response to regulation, spinning, and non-spinning reserves to traditional energy and capacity products.

Unlike most DSR evaluations conducted previously, the assessment 1) addressed multiple grid services and 2) characterized loads at an hourly level across all seasons by end-use, developing baseline load profiles by customer class and by building type. This evolution in assessment of DSR potential parallels a European-wide recognition of the increasing impact of renewables on grid stability and of the need to better understand the role that DSRs can play in maintaining reliability.

## Introduction

As in Europe, the amount of renewable energy produced in Hawaii as a share of total production has grown over the past several years. In 2015, 23% of the energy used by customers of the Hawaiian Electric Companies (Companies), which cover the islands of Oahu, Maui, Molokai, Lanai and Hawaii, came from renewable energy resources, including wind, solar, solid waste, geothermal, hydro, and biofuels (Hawaiian Electric Companies, 2015a). In 2015 the Hawaiian legislature enacted a mandate that 100% of the state's electricity come from renewable sources by 2045, making Hawaii the first U.S. state to adopt such a standard (State of Hawaii, 2015).

With so much renewable energy and the unique characteristics of Hawaii's islanded electric grid, the utility and many stakeholders are concerned about the looming challenges to maintenance of grid reliability. In order to address these challenges, the Hawaii Public Utilities Commission (Commission) has directed the Companies to consolidate existing demand response (DR)[1] programs into a single integrated DR portfolio and utilize DR to accommodate increased renewables onto the grid (McDonnell, 2015; Hawaii Public Utilities Commission, 2014). As part of this effort, the Companies have identified the system requirements for greater renewables integration and estimated

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[1] The term "demand response" (DR) is commonly used in the United States to refer to customer adjustments in load in response to a request from a utility or system operator. For purposes of this paper, the terms DSR and DR may be used interchangeably.

the costs for providing the requisite ancillary services (Hawaiian Electric Companies, 2014 and 2015b).

Subsequently, the Companies estimated the potential for DSRs to provide these services and the associated resource costs and resulting cost-effectiveness of various DSRs. Compared to most prior efforts across the United States, this study of DSR potential is unique in that it utilized hourly load profiles by customer type and end-use to estimate the achievable DSR potential by hour/season (as opposed to a single annual peak value) and for specific customer and equipment types. As of spring 2016, the Companies continue to assess the results of this study to select specific options to be part of a DSR program portfolio to support the statewide goal of 100% renewable electricity supply.

## Methodology

The research team followed a detailed bottom-up modeling framework that relied as much as possible on primary data available from the Companies for parameters such as on customer composition, equipment saturations, and DSR technology costs and participation rates gleaned from experience with pilot programs. All input variables feed into a proprietary DSR planning and cost-effectiveness model that was customized to meet the specific requirements for this study.[2]

The assessment of DSR potential then progressed as shown in Figure 1, from initial definition of the time horizon and scope of the study, through development of load forecasts, DSR program options and costs, and concluding with estimates of DSR potential and sensitivity analyses.

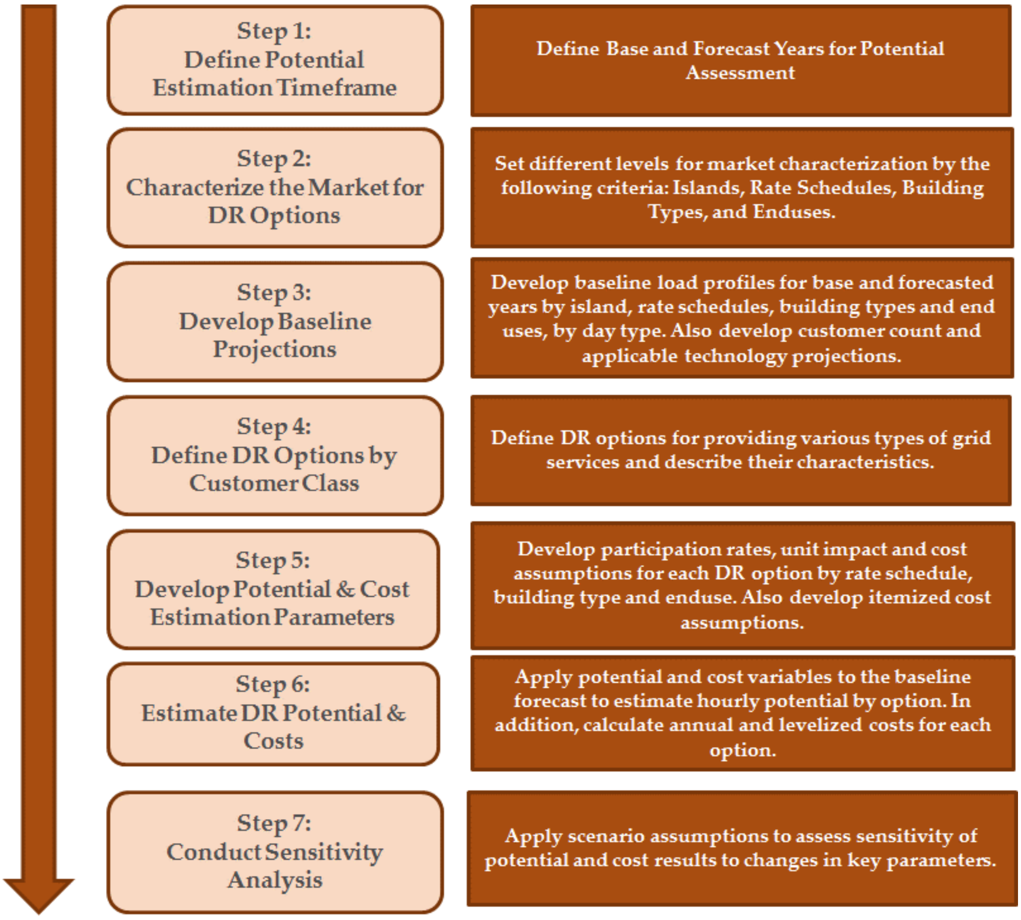

**Figure 1.** Key Steps in Estimation of DSR Potential Estimation Steps

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[2] Navigant's Demand Response Simulator (DR-Sim™) model incorporates utility-specific customer data, load patterns, and other characteristics to simulate operation of DSRs. The model has been applied to analysis by utilities and government regulators to project DSR potential, optimize DSR dispatch, and assess cost-effectiveness of program offerings.

The first three steps set the foundation for the assessment of DSR potential, but they do not address the methods that are unique to this analysis. Rather, the core methods of interest relate to steps four and five (defining DSR options and creating a framework for estimating DSR potential) and are the focus of the remainder of this methodology discussion.

## DSR Options to Provide Resource Flexibility

Once the baseline projections were developed, the next step in our analysis is to define and characterize the various DR options that the Companies can potentially use to help fulfill various grid service requirements. DR options can broadly be categorized into two classes: those providing capacity and those providing ancillary services. It is primarily the latter that contribute to grid flexibility and that are the primary subject of this paper. However, both resource types were assessed during the investigation and thus the authors present findings relating to the potential DSRs to provide both capacity and ancillary services.

**Capacity DSRs** include the majority of the worldwide megawatts accounted for by DSRs and are characterized by long advanced notification times (e.g., one hour or greater), few annual dispatches (e.g., under 10 per year), and long event duration (e.g., four hours or more per dispatch). The DSR potential analysis for the Companies addressed the following specific capacity DSR resources:

- *Critical Peak Incentives* for which participants are notified of DSR events an hour in advance and need to sustain the load reduction for 4 hours. Participants are paid for the actual energy reduced during those hours.
- *Time of Use (TOU) rates* that provide a permanent load shifting opportunity by offering relatively high electricity rates during the early mornings and early evenings when electricity supply is routinely tight, and relatively low rates during the daytime hours when solar production threatens to create an oversupply of generation.[3]
- *A Day Ahead Load Shift* option is offered to Large C&I customers where participants are sent day-ahead notification of high prices during certain pre-specified hours. Participants have the option of reducing load during the high-priced event period in order to lower their electricity costs bill or continue to maintain their normal usage during these periods and pay higher electricity prices. Alternatively, this option can incentivize load *increases* through day-ahead notification of lower-than-normal prices.
- *Real Time Pricing* sends dynamic hourly price signals to customers to reduce load in response to prices. No separate incentives are provided and participant savings are based on response to real time prices.
- *A Minimum Load option* is specifically designed to address the dip in net load during hours of high solar production. Under this option, participants are paid an incentive to increase load over their baseline use during high solar hours.
- *A PV Curtailment option* is also designed to address the daytime dip in net load. Residential customer with rooftop photovoltaics (PV) receive a smart relay device installed on their PV systems through which the Companies can disconnect the system to stop energy flow into the grid during high solar hours. Customers are paid for the amount of energy they would have otherwise fed to the grid.

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[3] The Companies are proposing a three-tiered TOU rate for residential customers with a low "midday" price from 9 am to 4 pm (the lowest price among the three tiers), a high on peak period price from 4 pm to midnight, and a moderate off-peak period price between 12 am to 9 am.

**Ancillary services DSRs** fulfill different types of grid services requirements such as contingency and supplemental reserves, regulation services, and frequency response. They need to provide a high level of operational flexibility and be highly dispatchable in order to balance supply and demand. Participating loads need to exhibit low degrees of variability in load availability and ability to shed, in order to enhance forecasting requirements. In addition, performance of loads needs to be measured and verified in near real time, and unlike traditional DR which refers to load curtailment, some ancillary services DSRs need to *increase* load during certain hours to help balance over-generation from renewables.

The Hawaiian Electric Companies plan to utilize demand side load to provide the following types of grid services, briefly described below: [4]

- **Fast Frequency Response**: Fast Frequency Response is the automatic response of generation resources to a change in frequency. Resource must immediately respond to a change in frequency by changing its output in proportion to the change in frequency. The response is must occur within 0.5 seconds or less. The response needs to be measureable at the output of the resource within 10 seconds of the change in frequency and must be maintained for a minimum of 10 minutes.
- **Non-Spin Auto Response (10-Minute Reserves):** These are off-line fast-start resources that are not operated under normal load and generation conditions and are used as supplemental reserves resource for the restoration of regulation and/or contingency reserves. For loads to provide Non-Spin Auto Response, they need to respond within 10 minutes and maintain response for an hour.
- **Regulation Reserves:** These resources have the ability to respond to commands from Automatic Generation Control (AGC) to increase or decrease its generation output in a known and consistent manner. The response needs to be initiated immediately upon receipt of the AGC command and completed within 2 seconds of the AGC command. The load response needs to be sustained for a minimum of 30 minutes to be included as regulation.

Table 1 lists the characteristics of DSR options that provide ancillary services, according to the Companies.

**Table 1.** Characteristics of DR Options Providing Ancillary Services

| DR Option | Notification | Activation Speed | Max. Event Duration |
|---|---|---|---|
| **Fast Frequency Response** | Concurrent with event | Instant; response must be measurable w/in 10 secs of the change in frequency | 10 minutes |
| **Non-Spin Auto-Response** | Concurrent with event | Full response within 10 minutes | 1 hour |
| **Regulation Reserves** | Continuous | Begin responding immediately; completed within 2 seconds | 15-30 minutes |

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[4] Based on ancillary services definitions and descriptions provided by the Hawaiian Electric Companies. See Docket 2007-0341, *IDRPP Supplemental Report*, filed November 20, 2015

## Framework for Estimation of DSR Potential

The DSR potential estimation method in this study follows the approach described in a study published by the Lawrence Berkeley National Lab (LBNL, 2013).

Based on the approach followed in the LBNL study, three sets of "flexibility factors" are developed to estimate DSR potential. The hourly load profiles by customer class, building type and end use, developed in the previous step, are run through these filters to estimate the amount of load decrease/increase that could be achievable at any given hour from a particular end use under each DSR option. The three flexibility factors are as follows:

- ***Acceptability*** refers to the percentage of load that customers are willing to shed in exchange for financial incentives, and is akin to what the industry commonly terms as "participation rate".[5]
- ***Controllability*** refers to the percentage of load for a given end use that has the necessary controls & communication capabilities for load sheds/shifts.
- ***Sheddability*** refers to the percentage of controllable or acceptable load that can be shed by a DR strategy. For bi-directional loads, it refers to both load decrease and increase.

The study used the first two factors, "acceptability" and "controllability" to estimate the effective participation rate, expressed as a percentage of the available load in any given hour. The participation rate is defined as:

- *Participation rate (DR option) = min (Acceptability, Controllability)*

For the model, the authors developed a 24-hour acceptability profile by end use for each building type and for each DSR option. This reflects the willingness of customers to provide load reductions/increase at a particular hour. For end uses where participation is not assumed to be time-varying, a single participation percentage was applied over all hours of the day. Moreover, the willingness to participate in DR options also varies by the customer's business type. For example, hotel cooling loads are likely to have lower willingness to participate than office cooling loads. Therefore, for a given end use, acceptability levels by building type were varied to reflect the customer's business situation and consequent willingness to participate in order to provide load reductions/increase.

The controllability is a static value that represents the share of loads that are projected to have the necessary controls for a specific option. The smaller of the two values in any given hour represents the amount of participating load available in that hour for load reduction/increase. Participation assumptions were heavily informed by discussions with key account managers across all islands. In addition, the authors drew on insights from discussions with control vendors who are familiar with and/or have experience working on the Hawaiian Islands. Lastly, the study relied on a number of established secondary information sources in the industry to develop these assumptions.[6,7]

Once the amount of participating load was estimated, this value was multiplied by the sheddability factor, which represents the fraction of participating load that can be increased or

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[5] The study assigned costs to each DSR option, including participant incentives, technology costs, and various program marketing and administrative costs. The Acceptability factor reflects what the study team and the Companies concluded are achievable participation rates given the assumed incentives.

[6] Key secondary information source are: (a) Grid Integration of Aggregated Demand Response, Part I: Load Availability Profiles and Constraints for the Western Interconnection", LBNL, NREL, DOE; September 2013; (b) Assessment of Industrial Loads for Demand Response across U.S. Regions of the Western Interconnect; ORNL, September 2013; (c) FERC DR Survey database; available at: https://www.ferc.gov/industries/electric/indus-act/demand-response/2012/survey.asp; (d) PacifiCorp Demand-Side Resource Potential Assessment for 2015-2034; Volume 5: Class 1 and 3 DSM Analysis Appendix; January 30, 2015.

[7] The Companies considered higher participation levels for Hawaii than what has been commonly observed in the mainland since significantly high energy prices and strong customer interest in renewable generation and environmental issues are likely to lead to higher customer adoption of DR programs.

decreased during DR events or in response to time-varying rates. The DR potential was then estimated as:

- *DR potential = Load * Participation rate * Sheddability*

The primary source for the sheddability assumptions was the LBNL published study on the topic (LBNL, 2013). In addition, we referred to other secondary sources to develop sheddability assumptions.[8] For loads providing certain specific types of services such as inertial or primary frequency response, we assumed that 100% of the participating load can be shed during DR events. For specific emerging technologies such as Electric Vehicles (EVs), PV system batteries and Grid Interactive Water Heating (GIWH) technologies, we researched these to assess to what extent these end use loads could be considered eligible for providing different types of fast responding services.

For a given DR option, the authors assumed participation to ramp up over a timeframe of five years using an S-shaped diffusion curve, from the point a particular option is deployed. This was based on most commonly observed deployment experience of DR programs in agreement with review by Companies staff. A faster ramp up of programs within a shorter timeframe (say three years), is possible, if the Companies were to undertake an aggressive rollout of programs. The study assumed all options, other than time-varying rates, to be deployed beginning 2016. The start date for pricing options is dependent on AMI rollout schedules by island.

## Findings of DSR Potential

The assessment of DSR potential addressed five separate Hawaiian Islands, each with unique customer bases, transmission infrastructure, and renewables portfolios. This paper reports findings only from the island of Oahu, which includes the capital of Honolulu and which is home to approximately two-thirds of the population of the Hawaiian Islands (Hawaiian Electric Companies, 2015a).

Key observations from these results for **load curtailment potential** are as follows:

- Fast Frequency Response has highest load reduction potential. Its potential reaches close to 130 MW during middle of the day, which is equivalent to around 18% of Oahu’s net load in that hour.
- Load curtailment potential from all other DR options is less than 10% of the net load at any given hour. Among these other options, Critical Peak Incentive has highest potential that ranges between 55-60 MW during midday and evening hours. Its contribution to the potential is at approximately 8% of the net load.
- Load curtailment potential for ancillary service such as Non-Spin Auto Response and Regulation Reserves range approximately between 2-4% of the net load (10-50 MW of load reduction, depending on the hour of the day).

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[8] Key sources are: (a) FERC DR Survey database; available at: https://www.ferc.gov/industries/electric/indus-act/demand-response/2012/survey.asp; (b) PacifiCorp Demand-Side Resource Potential Assessment for 2015-2034; Volume 5: Class 1 and 3 DSM Analysis Appendix; January 30, 2015.

Figure 2 below shows hourly load curtailment potential by DR option for an average weekday in September of 2025, expressed as a percentage of net hourly system load.

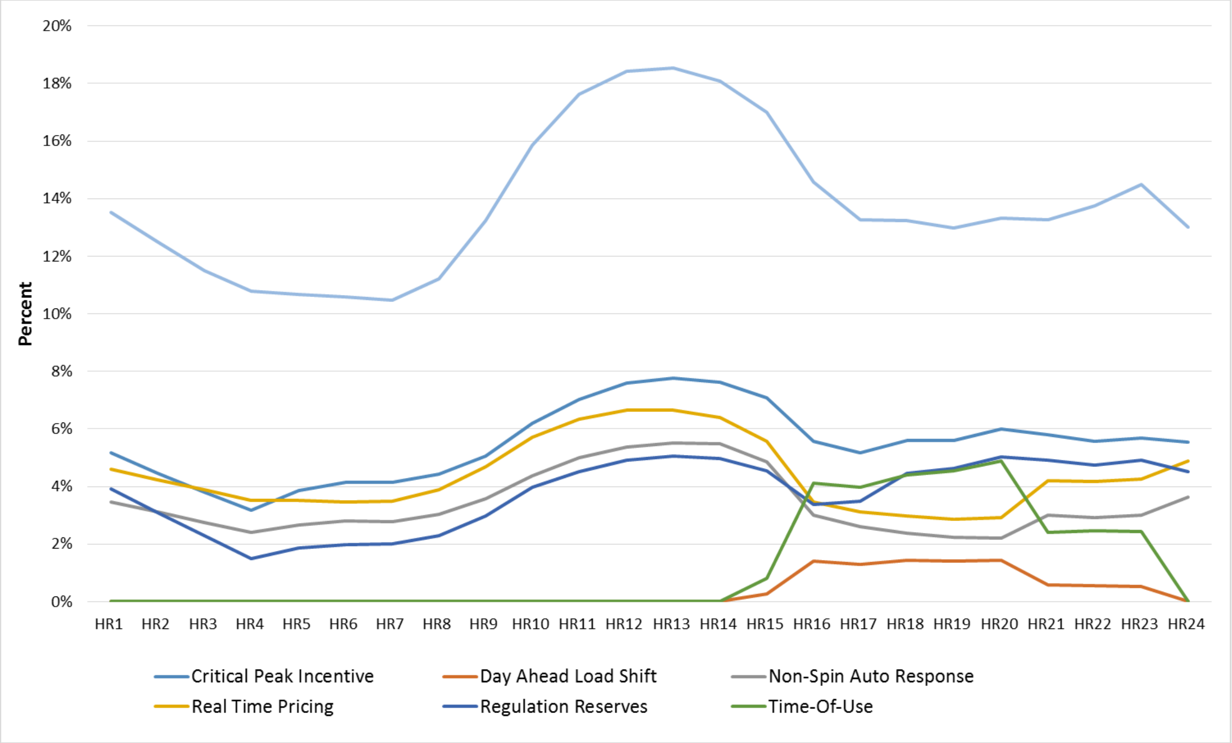

**Figure 2.** Oahu Load Reduction Potential Results by DR Option for an Average September 2025 Weekday (% of Net Load)

DSRs hold potential for load augmentation as well as load curtailment, as illustrated in Figure 3, which shows hourly **load increase potential** by DR option as a percentage of net hourly system load.

Key observations from these results are:

- The PV Curtailment option has highest load increase potential at approximately 150 MW during the midday hours. This translates into approximately 20% of net load during those hours.[9]
- The Minimum Load option, which pays customers incentives to increase load during the six hour period from 10 am to 4 pm, could provide 50-60 MW of load increase during those hours (translates into approximately 7-8% of net load increase).
- Load increase potential from TOU rates during midday hours (9 am to 4 pm) is approximately 25-30 MW, which in turn translates into 3.5-4.5% increase in net load through shifting from peak period hours to midday hours. Load increase potential during off-peak hours (12 am to 9 am, as defined in the three tier OU rates) approximates 10-20 MW.

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[9] Note that even though this study estimates the potential for a PV Curtailment option and establishes it as one that has largest load increase potential, it is unlikely to be considered as a program in the Companies application filing to the Commission. This study considered an exhaustive set of options for the purposes of potential estimation only. However, the selection of specific options under a portfolio of different DR programs by the Companies is a component of program design and outside the scope of the potential study.

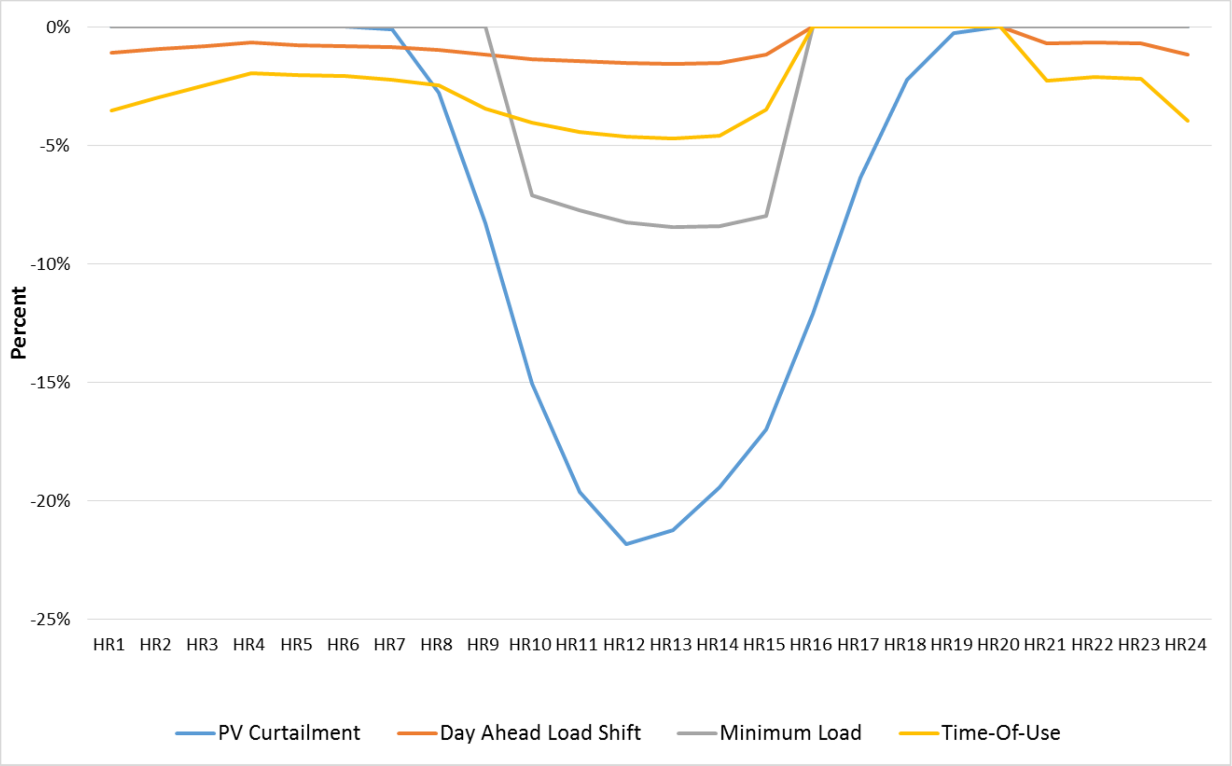

**Figure 3.** Oahu Load Increase Potential Results by DR Option for an Average September 2025 Weekday (% of Net Load)

Figure 4 shows a breakdown of the Fast Frequency Response potential for Oahu by end use. Key observations are:

- Among the different end uses, Electric Vehicles represent a highly flexible resource with approximately 40-50 MW of potential during the late evening hours when majority of the vehicles are placed for charging.
- Batteries too represent a flexible resource that could potentially provide 10-50 MW of load reduction during the hours these batteries are being charged from PV systems.[10]
- Cooling loads are estimated to provide 30-40% contribution in the total Fast Frequency Response potential. However, water heating potential has higher contribution than cooling during early morning hours when water heating load is high. On an average, potential from cooling load is 20-50 MW while potential from water heating load is 10-30 MW.

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[10] Note that these batteries are tied to PV systems. However, under current rules, DG PV customers are now allowed to export power to the utility. Therefore, in order to access the resource and realize curtailment from these customers, the non-export requirement will need to be violated.

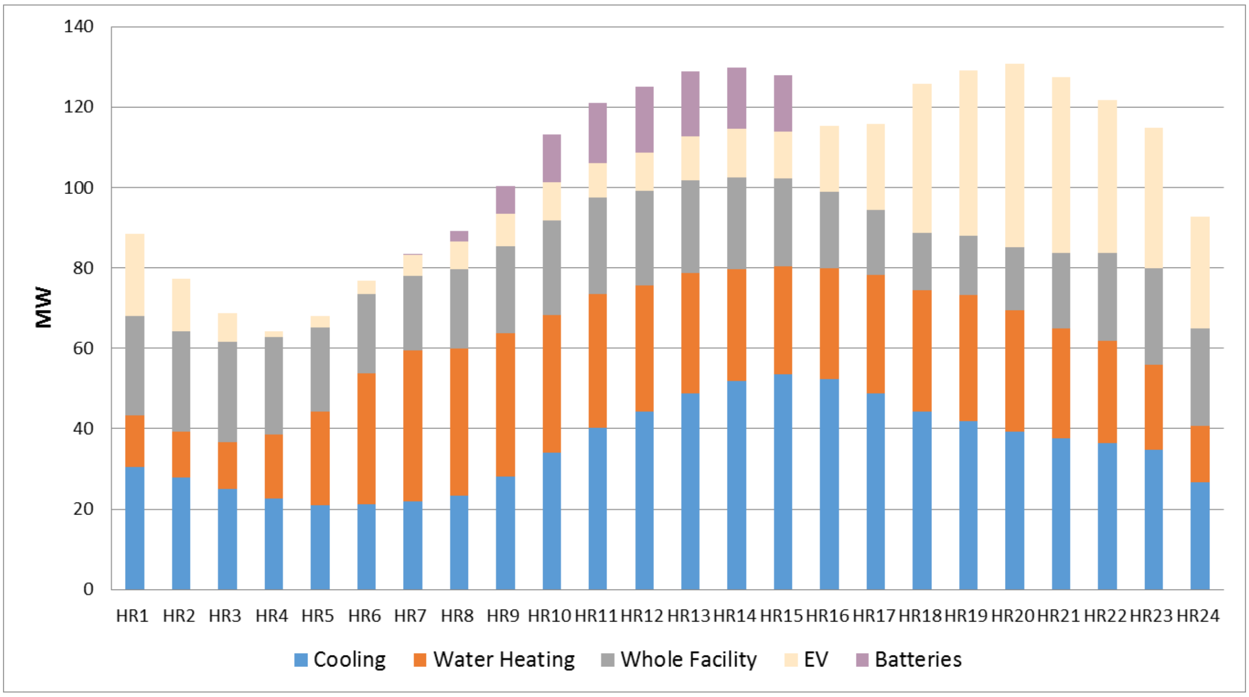

**Figure 4.** Oahu Fast Frequency Response Load Reduction Potential by End Use for an Average September 2025 Weekday (MW)[11]

## Conclusions

Unlike most evaluations of DSR potential conducted previously, this assessment 1) addressed multiple grid services and 2) characterized loads at an hourly level across all seasons by end use, developing baseline load profiles by customer class and by building type over the entire analysis timeframe (2016-2030). One of the most illuminating findings was that Fast Frequency Response—automated load reductions within 10 seconds of an event—held the most potential for load curtailment. While fast response is commonly more difficult and/or expensive to establish, the Companies experience is that participation rates are much higher since the 10 minute maximum duration limits customer impacts that might otherwise inhibit participation.[12]

A next step for any utility or government jurisdiction looking at DSR potential is assess the cost-effectiveness of the various DR program options—which are economical and at what megawatt levels. The analysis conducted to date included assumptions of cost, including incentive levels to attract participation, but not benefits. The benefits of DSR resources are more difficult to estimate when DSRs are providing grid flexibility as opposed to simply deferring installed capacity. The Companies are refining their avoided cost estimates, and it remains to be seen to what extent the higher costs of automated, flexible DSR resources are offset by the higher value of the grid services that they provide.

The UK's electricity regulator Ofgem recently widened the scope of its DSR efforts "to look at sources of flexibility [including] modifying consumption patterns…to provide a service" to the grid (Ofgem, 2015). This shift in policy reflects a European-wide recognition of the increasing impact of renewables on grid stability and of the need to better understand the role that DSRs can play in maintaining reliability.

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[11] Whole Facility end use in this figure represents loads associated with Industrial, Warehouse and Water Pumping segments, which are represented as building types in the above figure.

[12] In the Companies evaluation of its "Fast DR" pilot program, customers reported little concern with as many as 80 events per year, in part because event duration was limited to one hour, as opposed to the four-hour duration common in other DR programs (Navigant 2015).

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