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# Grid Integration of Aggregated Demand Response, Part I: Load Availability Profiles and Constraints for the Western Interconnection

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# Disclaimer

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This project benefits synergistically from the CEC PIER funded work conducted by LBNL's Demand Response Research Center. The initial CEC funded study, Watson *et al.* 2012, created a framework upon which to evaluate California commercial, industrial, and agricultural end uses capabilities for slow (2 hour duration) and fast (20 minute duration) demand response. This DOE-funded Western Interconnection Demand Response and Storage Integration Study was conducted in parallel with the CEC PIER funded Collaboration with Lawrence Livermore National Laboratory Smart Grid Modeling (California), allowing the team to leverage the knowledge, data, and methods of both projects to determine demand response capabilities.

Brendan Kirby, Mark O'Malley, Mary Ann Piette, Aimee McKane, Phil Price, Andrew Satchwell, and Peter Cappers provided critical recommendations, pointers, and reviews throughout the project. Galen Barbose and Mitch Tian provided data for the estimation of DR potentials. We also thank two outside reviewers of the final report.

# Abstract

Demand response (DR) has the potential to improve electric grid reliability and reduce system operation costs. However, including DR in grid modeling can be difficult due to its variable and non-traditional response characteristics, compared to traditional generation. Therefore, efforts to value the participation of DR in procurement of grid services have been limited. In this report, we present methods and tools for predicting demand response availability profiles, representing their capability to participate in capacity, energy, and ancillary services. With the addition of response characteristics mimicking those of generation, the resulting profiles will help in the valuation of the participation of demand response through production cost modeling, which informs infrastructure and investment planning.

We present an approach for predicting demand response availability profiles for thirteen end-use loads within the Western Interconnection for the year 2020. For each end-use, we estimate an annual hourly load profile for each of the 36 balancing authority areas. These load profiles are further evaluated and filtered to obtain an estimate of the amount of load available to participate in each of five products (three ancillary services, an energy product, and a capacity product) for each hour of the 2020 calendar year. We supplement these DR availability profiles with expectations on constraints for the duration and frequency of the load responses, in order to best represent the expected electricity customer system, such as their willingness and capability (e.g., equipment) to participate in demand response events. Finally, we discuss the projected theoretical availability for full load participation.

The resulting availability profiles serve as input to a production cost model. In an accompanying report by the same authors (*Modeling Energy-Limited Demand Response in a Production Cost Model*), the integration of these availability profiles into the production cost model is discussed and the value of their participation is estimated.

**Keywords:** Demand response, ancillary services, production cost modeling, load modeling, resource valuation

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# Foreword

This report is one of a series stemming from the U.S. Department of Energy (DOE) Demand Response and Energy Storage Integration Study. This study is a multi-National Laboratory effort to assess the potential value of demand response and energy storage to electricity systems with different penetration levels of variable renewable resources and to improve our understanding of associated markets and institutions. This study was originated, sponsored, and managed jointly by the Office of Energy Efficiency and Renewable Energy and the Office of Electricity Delivery and Energy Reliability.

Grid modernization and technological advances enable resources, such as demand response and energy storage, to support a wider array of electric power system operations. Historically, thermal generators and hydropower in combination with transmission and distribution assets have been adequate to serve customer loads reliably and with sufficient power quality, even as variable renewable generation like wind and solar power become a larger part of the national energy supply. While demand response and energy storage can serve as alternatives or complements to traditional power system assets in some applications, their values are not entirely clear. This study seeks to address the extent to which demand response and energy storage can provide cost-effective benefits to the grid and to highlight institutions and market rules that facilitate their use.

The project was initiated and informed by the results of two DOE workshops; one on energy storage and the other on demand response. The workshops were attended by members of the electric power industry, researchers, and policymakers; and the study design and goals reflect their contributions to the collective thinking of the project team. Additional information and the full series of reports can be found at www.eere.energy.gov/analysis/.

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# Executive Summary

## Introduction

The goal of the Demand Response and Storage Integration Study is to estimate the value that demand response (DR) and storage resources can provide to the United States by participating in energy, capacity, and ancillary services in the year 2020. A key part of this investigation is an estimation of the capabilities of loads to respond to these grid service needs. This report focuses on describing the capabilities of loads to provide grid services via DR, and we investigate the loads within the Western Interconnection to develop the process of load analysis, with the goal of eventually expanding to the entire United States. The Western Interconnection, Eastern Interconnection, and Texas Interconnection are the three synchronous alternating current networks in the United States; all areas within an interconnection are electrically linked during normal operation.

The value that load resources can provide to the grid is estimated using a production cost model with hourly resolution; therefore, we estimate load capabilities for each hour. Though some grid services require sub-hourly response times, the production cost model provisions them for each hour according to projected grid needs within that hour. Load capabilities are disaggregated by end-use, balancing authority area, and market product. The assumed products are described in Table ES-1. This report does not presume to estimate precisely the amount of load available to respond to a given product in a given hour in the year 2020; rather, this report presents the results of an initial estimation effort based on available information, and forms a general framework to refine these estimates as more or better data emerge.

Table ES-1: Product Characteristics

| Products | | Physical Requirements | | | |
|---|---|---|---|---|---|
| Product Type | General Description | How fast to respond | Length of response | Time to fully respond | How often called |
| Regulation | Response to random unscheduled deviations in scheduled net load (bidirectional) | 30 seconds | Energy neutral in 15 minutes | 5 minutes | Continuous within specified bid period |
| Flexibility | Additional load-following reserve for large un-forecasted wind/solar ramps (bidirectional) | 5 minutes | 1 hour | 20 minutes | Continuous within specified bid period |
| Contingency | Rapid and immediate response to a loss in supply | 1 minute | ≤ 30 minutes | ≤ 10 minutes | ≤ Once per day |
| Energy | Shed or shift energy consumption over time | 5 minutes | ≥ 1 hour | 10 minutes | 1-2 times per day with 4-8 hour notification |
| Capacity | Ability to serve as an alternative to generation | Top 20 hours coincident with balancing authority area system peak | | | |

## Approach

Sector-specific end-uses are selected for inclusion in the study based on the magnitude of their electrical demand (their "load"), and their ability to control their demand in response to the needs of the electrical grid. Ultimately, we select thirteen end-uses for inclusion, based on their significant share of total load and their likelihood of having demand response enabling controls systems by 2020. These end uses span the residential, commercial, industrial, and municipal sectors, and are listed in Table ES-2. All available data on magnitude and the pattern of the selected end-uses are gathered and processed in order to predict hourly load profiles for the year 2020: one for each combination of end-use and balancing authority area. In addition to these end-uses, many types of manufacturing process loads are potential demand response providers (Starke *et al.* 2013). Table ES-3 lists how and where each of the products in ES-2 map.

Table ES-2: End-uses considered

| Residential | Commercial | Industrial | Municipal |
|---|---|---|---|
| • Space Cooling<br>• Space Heating<br>• Water Heating | • Space Cooling<br>• Space Heating<br>• Indoor Lighting<br>• Ventilation | • Agricultural Water Pumping<br>• Data Centers<br>• Refrigerated Warehouses | • Freshwater Distribution Pumping<br>• Road & Garage Lighting<br>• Wastewater Pumping |

Table ES-3: Participation of resources in ancillary services products. Shading colors identify resources which contribute to the same set of products.

| | Products | | | | |
|---|---|---|---|---|---|
| Resources | Regulation | Flexibility | Contingency | Energy | Capacity |
| Agricultural Pumping | | | ✔ | ✔ | ✔ |
| Commercial Cooling | ✔ | ✔ | ✔ | ✔ | ✔ |
| Commercial Heating | | | | ✔ | ✔ |
| Commercial Lighting | ✔ | ✔ | ✔ | | ✔ |
| Commercial Ventilation | ✔ | ✔ | ✔ | | ✔ |
| Data Centers | | | ✔ | ✔ | ✔ |
| Municipal Lighting | ✔ | ✔ | ✔ | | ✔ |
| Municipal Pumping | | | | ✔ | ✔ |
| Refrigerated Warehouses | | | | ✔ | ✔ |
| Residential Cooling | ✔ | ✔ | ✔ | ✔ | ✔ |
| Residential Heating | ✔ | ✔ | ✔ | ✔ | ✔ |
| Res. Water Heating | ✔ | ✔ | ✔ | ✔ | ✔ |
| Wastewater Pumping | | | | ✔ | ✔ |

To determine what fraction of these loads can respond to each of the products in each hour of the year, three flexibility filters are established:

- **Sheddability** refers to the percentage of the load for a given end-use which can be shed by a typical demand response strategy, assuming adequate communications, controls and incentives exist. For bi-directional products, this is the percentage of load that can be increased or decreased.
- **Controllability** refers to the percentage of the load for a given end-use which is associated with equipment that has the necessary communications and controls capabilities in place to trigger and achieve load sheds/shifts.
- **Acceptability** refers to the percentage of the load for a given end-use which is associated with equipment or services that are willing to accept the reduced level of service in a demand response event, in exchange for financial incentives.

Applying these criteria to the hourly load profiles results in five demand response availability profiles with hourly resolution (one for each product) for each combination of end-use and balancing authority area (BAA). The response characteristics of the end-uses are described as analogous to conventional generators by specifying response times, ramp rates, minimum and maximum up times, and allowable call frequency for each combination of end-use and product. The response time is the time between when a product signal is sent and when the end-use begins generating (shedding load) and the ramp rate describes the rate that generation (load sheds) can be increased or decreased. Minimum and maximum up-times refer to limits on the length of sheds, and the call frequency determines how often sheds can be called. For end-use resources which achieve load reductions by using some form of energy storage, where the storage medium must be "re-charged", the end-uses are modeled as storage and the timing and magnitude of the energy re-charge are specified. These generator profile parameters are shown graphically in Figure ES-1. The maximum “generation” at each hour is specified using the demand response availability profiles.

One example of the energy storage concept can be seen with agricultural irrigation. Energy is used to pump water onto fields to maintain soil moisture levels within an acceptable range as water leaves the soil through evaporation and uptake by crops. The water already within the field’s soil can be considered a form of storage, and during a demand response event irrigation can be curtailed due to this stored water, which keeps the soil moisture level in the appropriate range as water slowly leaves the soil (“dis-charging”). However, during normal operation, the grower will want to maintain a buffer above minimum soil moisture levels, so after an event they will pump more water to make up for what was not pumped during the demand response event (“re-charging” the soil). Other storage mediums considered include pumped storage of wastewater and freshwater for municipal treatment facilities and storage of thermal energy in buildings, domestic water heating, and refrigerated warehouses.

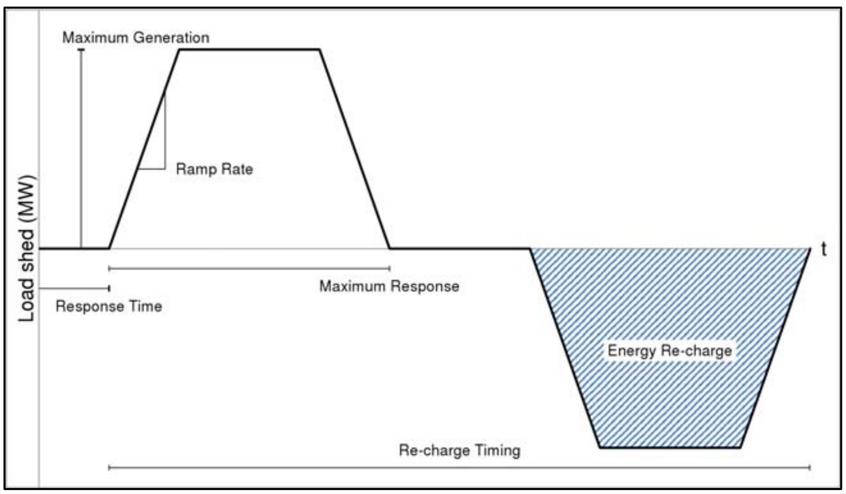

Figure ES-1: Demand response generator profile

## Results

Based on the assumptions made about the magnitude, behavior, and abilities of the selected end-uses within the Western Interconnection to respond, the demand response resources can contribute as much as 4.2 GW of the capacity product, 2.8 GW of the energy product, 3.0 GW of contingency reserves, 2.2 GW of flexibility reserves, and 1.8 GW of regulation reserves. Expressed as a fraction of total predicted Western Interconnection load in each hour, these values represent up to 2% of load for regulation reserves, 2.3% for flexibility reserves, 2.8% for contingency reserves, 2.3% for the energy product, and 3.5% for the capacity product. Hourly total loads are estimated using the Transmission Expansion Planning Policy Committee (TEPPC) PC1 reference case.

For comparison, regulation reserve requirements are typically approximately 1% of load, and the Western Electricity Coordinating Council requires spinning contingency reserves (the product most similar to this project's contingency reserves) at approximately 3% of load. Though the times of maximum DR resource availability may not align precisely with the times of maximum grid reserves requirements, there is the potential for DR resources to contribute a significant fraction of reserves requirements.

The interpretation of the availability values for the energy and capacity products differs from the interpretation of the ancillary services values. For each BAA, the energy product availability is combined with the maximum event durations for each resource to calculate the largest single-event energy shift that can be achieved. The availability of the capacity product from DR resources is only relevant during the 20 hours of highest load for each BAA; the average availability during these hours is referred to as the capacity value for the resources in that BAA.

The range of values for each product is shown in Figure ES-2. For each product, the range of total product availability within the Western Interconnection is calculated by summing the availability of each resource in each BAA. Though most of the total product availability is in a somewhat narrow range (the blue and red boxes, representing the range between the first and third quartile), the maximum availability can be several times larger, as shown by the long whiskers for each product, which represent the minimum and maximum values. The red boxes represent the range of the projected theoretical availability, representing the demand response availability assuming full participation.

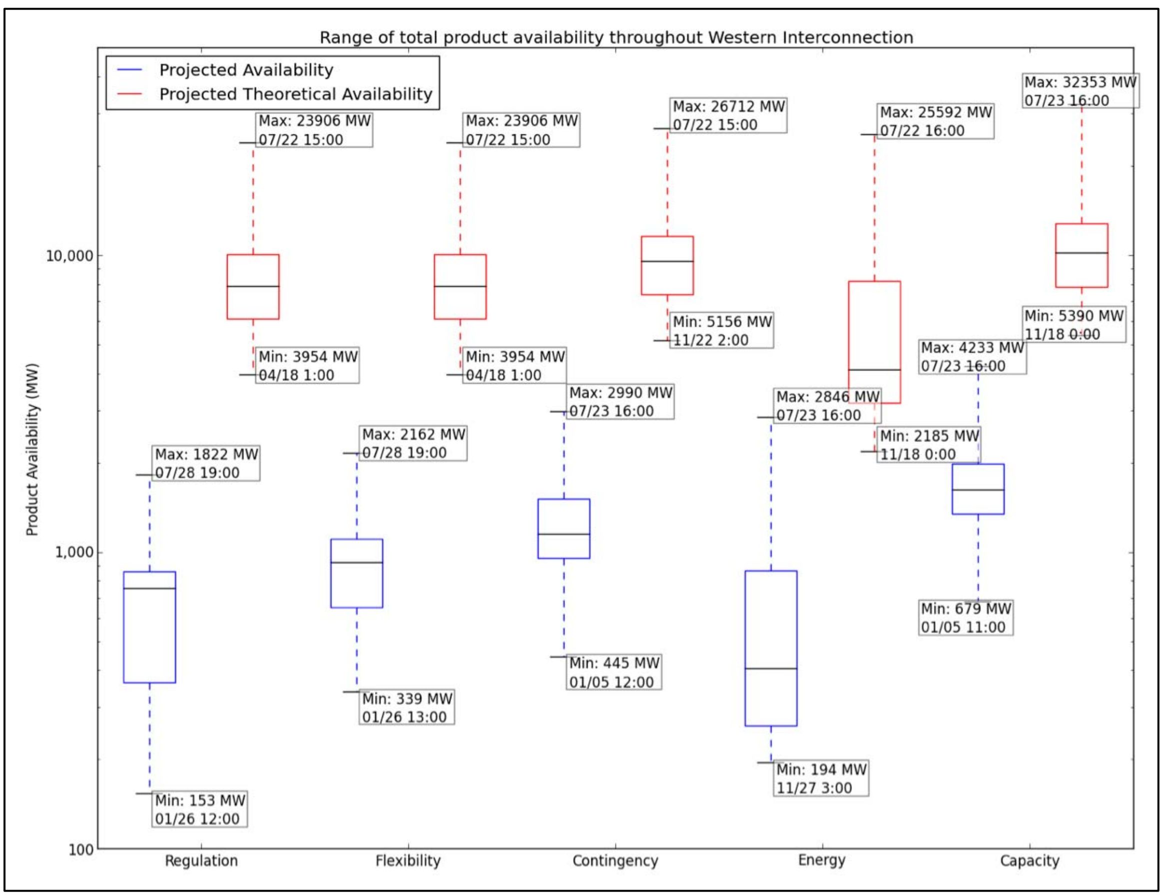


Figure ES-2: Product availability ranges with maximum and minimum hours

In general, product availability maximums are in the afternoons and evenings, there is significant availability throughout the year, and consistent patterns of availability emerge by product. The availability pattern for regulation reserves is shown in Figure ES-3. In the figure, the total availability of regulation reserves throughout the Western Interconnection for each hour is calculated by summing the availability for each resource in each BAA, is given a color code based on its magnitude (blue for minimum availability, and red for maximum), and then plotted on the left side of the figure, where the horizontal axis represents the days of the year and the vertical axis represents the hours of each day. The frequency of each color, representing the number of hours that the total product availability is in a certain range, is shown in the histogram to the right. For regulation reserves, there is usually more availability at night than during the day, as represented by the light blue and green horizontal band running through most of the year. However, during summer there is increased availability in the afternoon and early evening, as represented by the yellow, orange, and red in the upper center. Availability patterns for each of the products are presented in Appendix C.

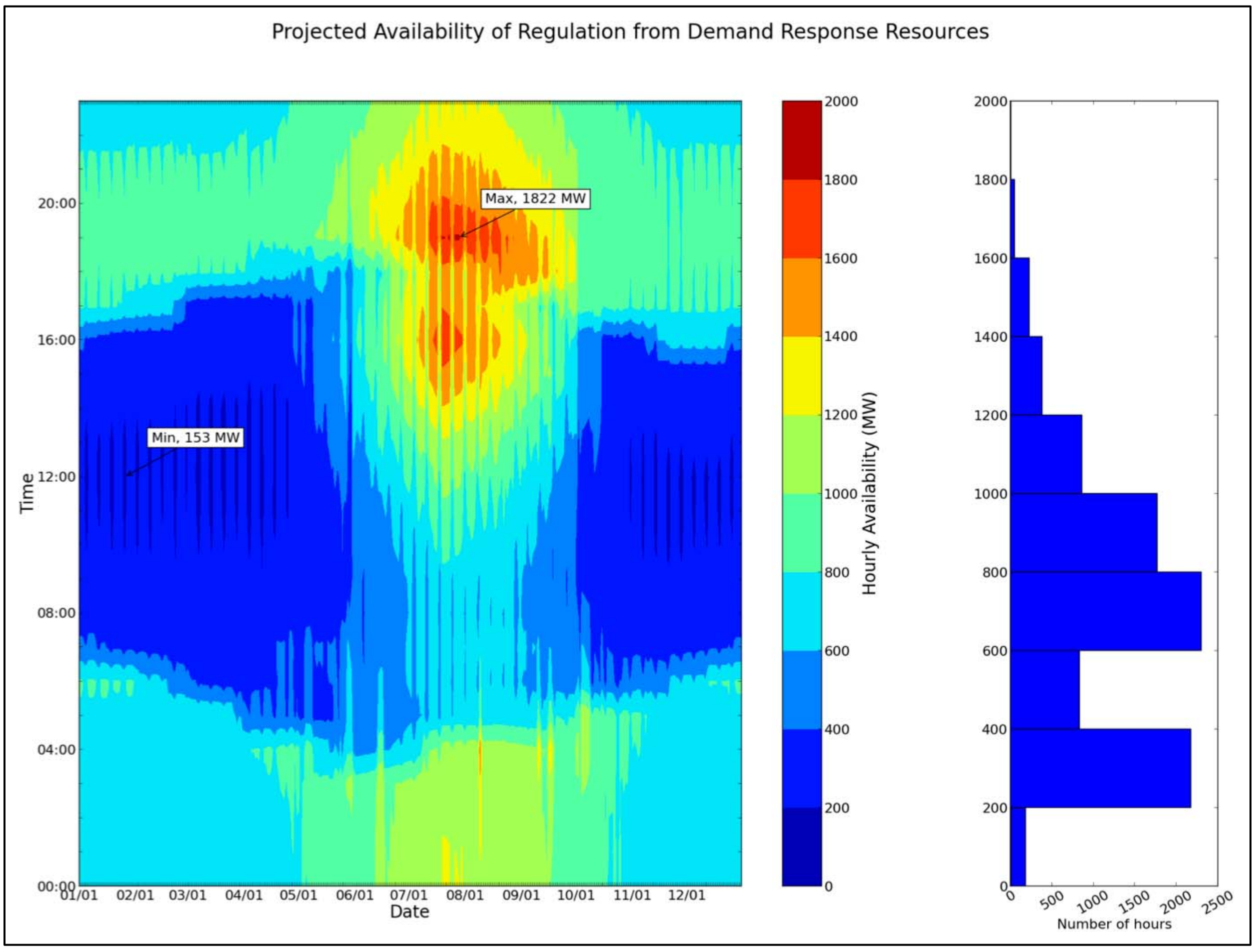

Figure ES-3: Regulation reserves availability pattern

These availability profiles can be disaggregated in several ways: one example is by resource. Over the course of a day, the availabilities from the resources vary, and reach their maximums at different times:

- Commercial lighting and ventilation peak during the hours of 8am to 6pm.
- Commercial and residential heating peak from 7am to 9am.
- Commercial and residential cooling peak from 12 noon to 8pm.
- Residential water heating peaks in the morning and evening.
- Municipal lighting peaks from 8pm to 4am.
- Refrigerated warehouses peak from 12 noon to 4pm.
- Agricultural pumping, data centers, municipal pumping, and wastewater pumping remain fairly flat.

These maximum availability times vary between balancing authority areas due to differences in the load shapes and assumed differences in the end-user population's willingness to shed load at different times of day (e.g. customers in areas with a history of afternoon demand response are assumed to be more willing to shed or shift loads in the afternoon, compared to those in other areas). The availability of each resource for contingency reserves across WECC is shown in Figure ES-4.

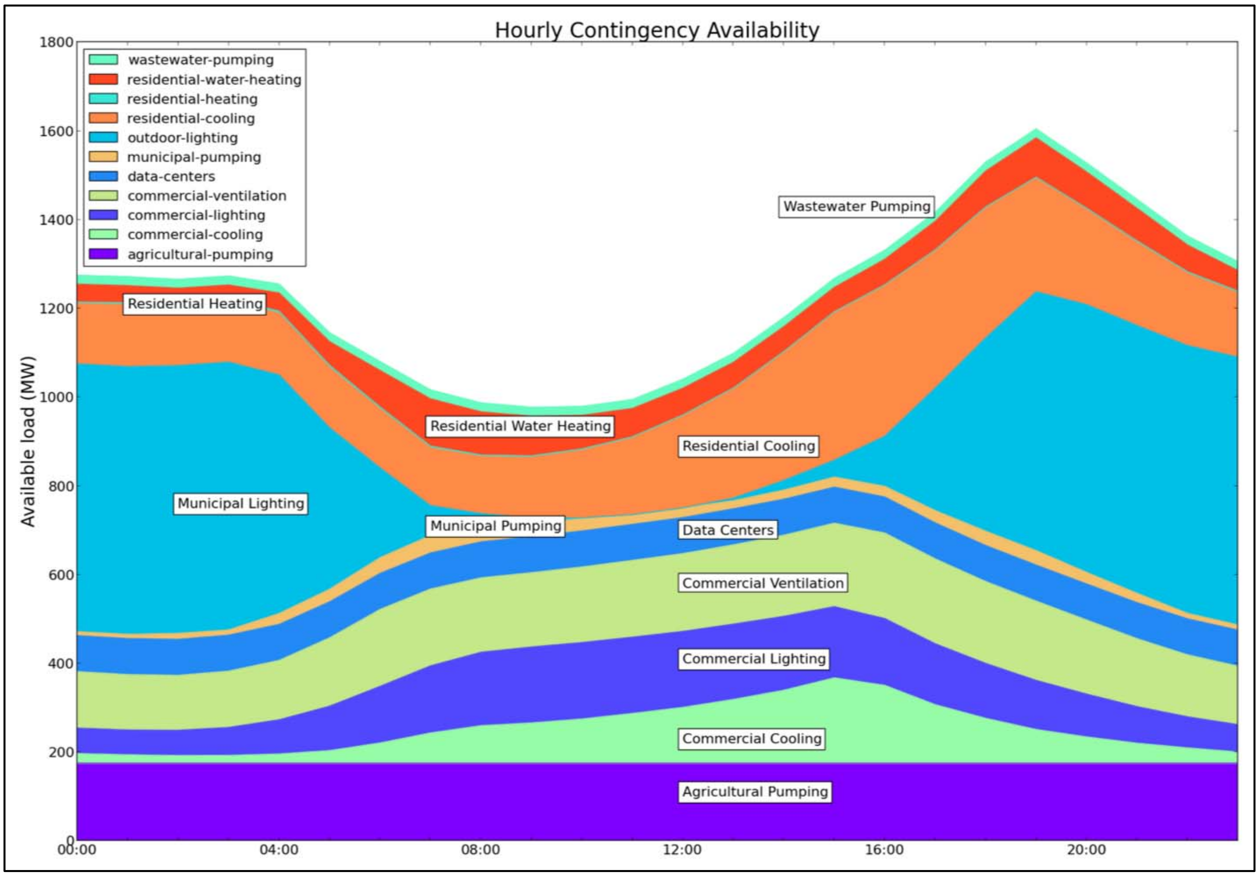


Figure ES-4: Contribution of each resource to contingency reserves

Over the course of a year, the availabilities from each resource also reach their maximums at different periods:

- Agricultural pumping, commercial cooling, residential cooling, and refrigerated warehouses peak in the summer.

- Municipal lighting, commercial heating, and residential heating peak in the winter.
- Data centers, residential water heating, commercial lighting, commercial ventilation, municipal pumping, and wastewater pumping loads remain fairly constant over the year, with a regular weekday-weekend usage pattern.

These patterns are shown in Appendix E.

Since the Controllability and Acceptability of the selected end uses are dependent on the actions of policymakers, utilities, and system operators over the next several years, it is also useful to analyze a projected theoretical availability case, which assumes full Controllability and Acceptability (i.e. all loads are able to participate, and choose to be available at all times). This projected theoretical availability represents the maximum achievable availability, assuming no change to the magnitude and pattern of load profiles. In this case, there is a maximum of 24 GW available for regulation and flexibility reserves, 27 GW available for contingency reserves, 26 GW available for the energy product, and 32 GW available for the capacity product. These numbers represent roughly a ten-fold increase in availability compared to the projected availability. The projected availability and projected theoretical availability are compared in Table ES-4.

Table ES-4: Total Western Interconnection product availability relative to load, projected availability and projected theoretical availability

| Product | Projected Availability (relative to total load) | Projected Theoretical Availability (relative to total load) |
|---|---|---|
| Regulation | 0.15 – 1.8 GW (0.2-2.0%) | 4.0 – 23.9 GW (6-20%) |
| Flexibility | 0.34 – 2.2 GW (0.4-2.3%) | 4.0 – 23.9 GW (6-20%) |
| Contingency | 0.45 – 3.0 GW (0.5-2.8%) | 5.2 – 26.7 GW (7-22%) |
| Energy | 0.19 – 2.8 GW (0.2-2.3%) | 2.2 – 25.6 GW (2-21%) |
| Capacity | 0.68 – 4.2 GW (0.8-3.5%) | 5.4 – 32.3 GW (7-27%) |

## Discussion, Conclusions, and Areas of Future Research

In this study, we conducted a detailed investigation of load capabilities, and our results provide an initial estimate of the magnitude of bulk power system services available from end-use loads, and constraints on their use. We present a transparent approach to predicting load availability that is as data-driven as possible. By design, the profiles are results of various aggregations and analysis decisions due to data limitations. Nonetheless, the results are the first significant efforts on how to produce such profiles. They are suitable for scoping studies, ground-truthing models, and prioritizing future data gathering and analyses. The use of analysis criteria using "sheddability", "controllability", and "acceptability" as qualitative and quantitative filters is novel, testable, and extensible to other regions in the US.

The process of integration of these end-uses into a production cost model and an analysis of their behavior in a test system under various scenarios will be described in the next report in this series (Hummon *et al.* 2013). The results from model runs in a full Western Interconnection model will be described in a subsequent report. These efforts assess the projected theoretical availability and economic incentives for load to participate in capacity, energy, and ancillary services markets; however, they do not cover the regulatory and market aspects of load participation. These regulatory and market issues are discussed in *Market and Policy Barriers for Demand Response Providing Ancillary Services in U.S. Markets* (Cappers *et al.* 2013) a report developed as part of this study.

Although this study produces an estimation of both the hourly projected availability and the projected theoretical availability for DR to participate in ancillary services in 2020, additional work is needed to fully interpret our results. For example, a detailed sensitivity analysis between various design and input decisions on model outcomes is still needed. Moreover, new high-resolution, end-use, load data are becoming available at a rapid pace. Limitations and uncertainty in the present study will be reduced as we incorporate such data. Our analysis does not take into account the economics of participation, the effort required to enable the end-uses to communicate with grid operators, the effort required to control the end-uses effectively, or the impact on the distribution grid of high penetrations of responsive load.

Finally, there have been few large-scale assessments of the capabilities of loads to respond to various DR products other than for shaving peak loads. Future work with potential to expand on the conclusions of this report includes:

- Collection and analysis of multi-region, high-resolution end-use demand data to improve estimates of baseline load profiles
- Field testing of the end-uses covered in this report to quantify their response characteristics and flexibility
- Analysis of distribution system stability during DR events in areas with high penetrations of responding load
- Detailed assessments of consumer behaviors and preferences regarding demand response participation, including customer fatigue (reduced willingness to respond to events in quick succession to previous events) and price elasticity (the relationship between price and magnitude of participation).

These additional analyses will test the assumptions used in this report and refine projections of the potential capabilities of demand response resources to serve as alternatives and complements to conventional supply options. These future studies will require careful research designs that facilitate access to data for researchers and market participants. This topic is an important area of research and will require cooperation among national, state, and local agencies in developing a common vision for new technology, markets, and policies for advanced DR participation.

# CHAPTER 1: Introduction

## 1.1 Background

Electricity grid operators must continuously balance supply and demand on the grid. To meet the demand for electricity, power is generated, transmitted, and distributed to users; this process is aided by scheduling energy and holding ancillary services. While energy scheduling balances supply with forecasted load, ancillary services response to unexpected changes in load that occur in real time. A variety of ancillary services exist, and contrary to their name, these services are vital to maintaining a stable electric grid. In addition to the scheduling and dispatch of the grid assets, ancillary services react to unscheduled load-generation mismatches to keep the system frequency within acceptable limits and tie-line flows among balancing areas at their scheduled levels, and also provide backup generation able to quickly come online in the case of unexpected failure of generators or transmission lines. This subset is commonly referred to as operating reserves.

Though ancillary services have been traditionally provided by generators, many responsive end-uses are also capable of, and are beginning to come into use to provide, ancillary services in the United States (Ela *et al.* 2011). Some responsive end-uses can respond quicker than generation resources, as some end-uses can shed load instantaneously as soon as the control signal is received, while generators have limitations on their ramp rates due to the physical inertia of their mechanical and thermal systems. In addition, there may be less risk procuring ancillary services from large collections of small participants, compared to a few large ones.

Most states require their utilities to undergo some type of Integrated Resource Planning (IRP) process (SEEAction 2011). In an IRP process, the utilities must develop a long-term plan for how to provide their customers with safe and reliable service, at minimal cost, using a combination of supply-side and demand-side resources. Since the energy, capacity, and ancillary services needs of the grid can be fulfilled by a mixture of both traditional generation, energy efficiency, and responsive loads, the costs and benefits of each option must be assessed to determine the least-cost combination. Since the main incentives for loads to respond to grid needs are economic ones, market simulations must be conducted to determine the amount of load which can be expected to participate, and the resulting prices. This information can then be used to advise the ratio of resources to procure to provide services in the future.

Previous work has modeled participating loads, also known as demand response (DR), in several ways. Kwag and Kim (2012) demonstrate the modeling DR as generators using available generation magnitude, minimum and maximum generation length, participation rate, and a quadratic cost function dependent on power ‘generated,’ and show that system operating cost decreases with increasing load participation. Aalami *et al.* (2010) model electricity demand as having price elasticity and with some ability to shift the time of consumption, with the impact of several utility programs rewarding or penalizing consumers based on their load deviation, and ranks the model outcomes based on various metrics. Su and Kirschen (2009) model an electricity market where some consumers are price-responsive and can shift the time of consumption and conclude that the reduction in generating costs is shared amongst responsive and non-responsive consumers. Wang *et al.* (2003) see a similar benefit in a market where loads and generators can submit bids for both energy and some ancillary services. Behrangrad *et al.* (2011) model generators and loads bidding into a spinning reserve market, each with piecewise linear cost curves, and show that load participation can both reduce system cost and reduce generation-associated pollution.

This work demonstrates an approach for scoping the potential depth of end-uses supplying ancillary services. This approach is distinct from the previously mentioned work in several ways. First, the estimation of DR availability varies over the course of each day as well as over the course of a year according to weather effects, the behavior of end-use equipment, and the desires of their users. These variations must be taken into account for an accurate valuation of the loads. Second, the participation of the loads is constrained based on the inherent inconvenience of altering electricity consumption. Finally, the daily and seasonal variations in ancillary service market prices are incorporated into the valuation of load participation. This research is posed as a scoping study and does not presume to present definitive estimates of DR for the Western Interconnection. Rather, the overall research presents initial estimates of DR availability, a framework to further refine these estimate, and a way to value the aggregate response, taking into account their variability and constraints. This research highlights a number of current data needs and knowledge gaps.

This report is the first part of a series, with the overall approach to this project is summarized in Ma *et al.* (2013). Lawrence Berkeley National Laboratory's role in the project is the development of the load capability profiles, which can be implemented in production cost modeling of the power system. Production cost models are typically used by power system planners to evaluate options for system expansion; gauge aspects of reliability and market efficiency; and estimate fuel costs, operations and maintenance costs, and emissions. This phase of modeling focuses on the Western Interconnection, and is run by the National Renewable Energy Laboratory. Interpretation of the results of this modeling effort in a test system will be discussed in the second report of this series (Hummon *et al.* 2013), and interpretation of model runs in the full Western Interconnection will be discussed in a subsequent report. Market and policy issues are discussed in Cappers *et al.* (2013), also developed as part of this study.

## 1.2 Report Organization

The report is organized as follows:

- Chapter 1 describes the background of the project, and Section 1.3 describes our overall approach to load characterization.
- Chapter 2 describes our methodology for characterizing load capabilities for the Western Interconnection.
- Chapter 3 describes the results of our load characterization in the Western Interconnection.
- Chapter 4 discusses the implications of our works and its limitations, concludes the report, and offers suggestions for future research.

## 1.3 Overall Approach

This project is an assessment of the amount of load able to respond to energy and ancillary services calls in the year 2020, for each of the 8,784 hours of the year, the value of their participation to the grid in reducing overall system costs, and the compensation the responding loads might receive from market payments. The goal is not to make a precise projection of the amount of responsive load that will be available in any given hour; rather, the aim is to make a reasonable estimate of the potential magnitude and pattern of responsive load, and the constraints on its responses. The estimates can be refined through an iterative process based on the analysis of the results of the production cost model that can illustrate the types of resources of greatest value to the power system, and based on the projected costs in enabling and exercising these resources. For resources whose estimated value far exceeds their estimated cost, we can assume that the participation rate for these resources has been underestimated.

The load capabilities research focuses primarily on residential and commercial end-use loads, with some industrial and municipal loads selected based on Lawrence Berkeley National Laboratory's (LBNL) previous experience with demand response in these sectors (Woo and Herter 2006, Kiliccote *et al.* 2010, Goli *et al.* 2011, Ghatikar *et al.* 2012, Olsen *et al.* 2012, Watson *et al.* 2012, Marks *et al.* 2013). Specific end-uses within these sectors are selected for inclusion based on whether they possess a significant share of load and their likelihood of having DR controls by 2020 (if not there already). Table 1 lists the end-uses included in this study. The projected economics of participation, existence of utility programs in which the loads can participate, and policy issues related to load participation are outside the scope of our assessment.

Table 1: End-uses considered

| Residential | Commercial | Industrial | Municipal |
|---|---|---|---|
| • Space Cooling<br>• Space Heating<br>• Water Heating | • Space Cooling<br>• Space Heating<br>• Indoor Lighting<br>• Ventilation | • Agricultural Water Pumping<br>• Data Centers<br>• Refrigerated Warehouses | • Freshwater Distribution Pumping<br>• Road & Garage Lighting<br>• Wastewater Pumping |

The availability of loads is disaggregated by balancing authority areas (BAAs) within the Western Interconnection, of which there are 36. These areas are shown in Figure 1 (three small BAAs in Washington are omitted from the map: CHPD, DOPD, and GCPD). BAA abbreviations are expanded in the Glossary.

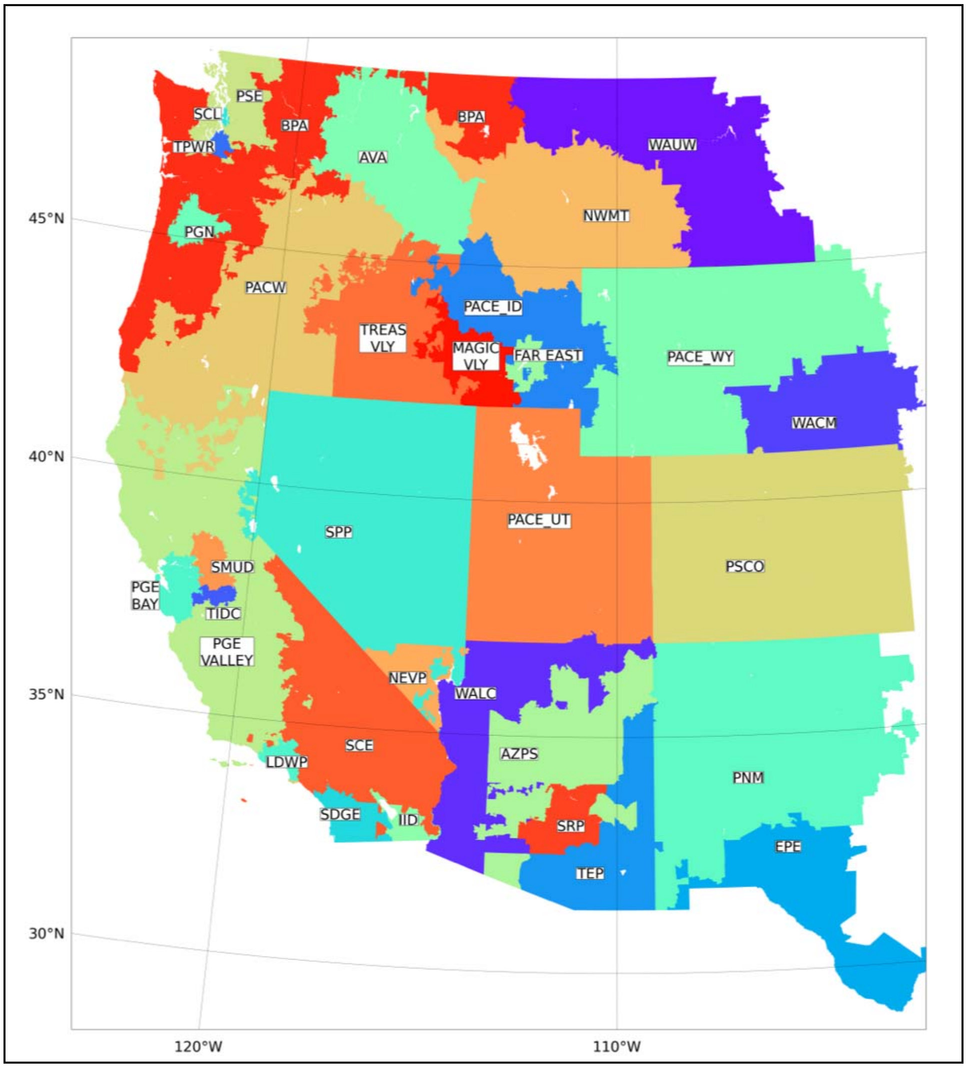

Figure 1: Balancing Authority Areas. Boundaries are approximate.

To estimate the magnitude of DR potentially available from a selected end-use at each hour, it is necessary to first estimate the magnitude of end-use loads at each hour. Representative load profiles for each end-use are scaled to match predicted energy consumption for each end-use in each BAA in 2020, and in some cases the load shapes are modified to account for weather differences between locations. A full listing of the load profiles generated, by BAA and resource, can be found in Appendix B.

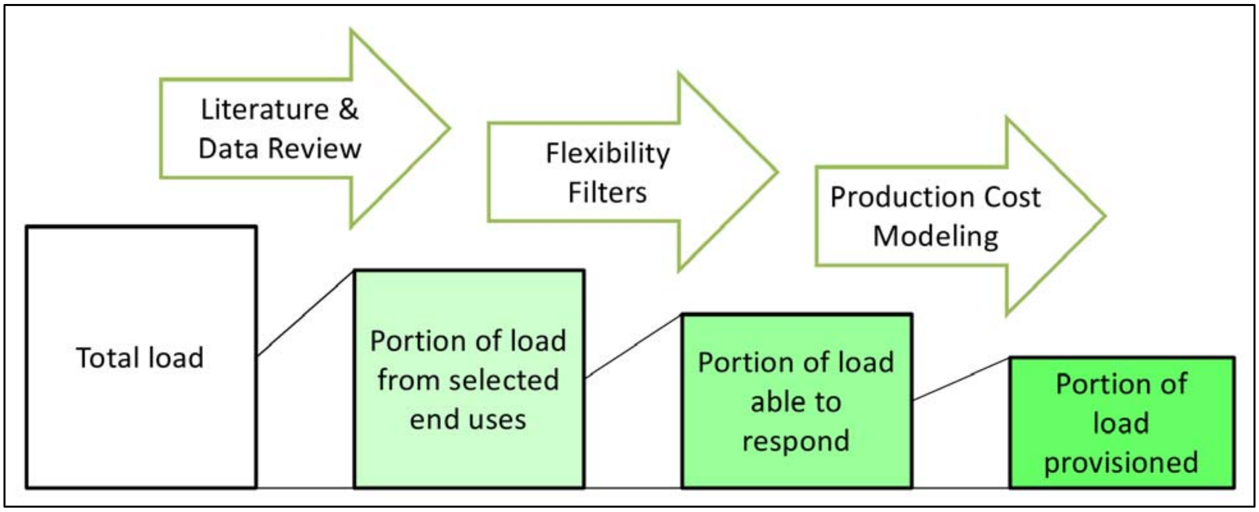

Figure 2: Filtering hierarchy from total load to provisioned DR for ancillary services.

The hourly load profiles for each end-use ("resources") are run through a set of filters to obtain an estimate of the load shed which could be achieved at any given hour ("availability profiles"), for energy, capacity, and ancillary services ("products"). A subset of this available load is coincident with the grid needs, and could be provisioned (reserved) in a production cost model, as shown in Figure 2. Each filter is a one-dimensional vector of 8,784 hourly values (the study year 2020 is a leap year) between 0 and 1, representing the fraction of load during each hour that meets each filter criteria.

Three "flexibility filters" are used to arrive at the overall flexibility values for each hour.

- **Sheddability** refers to the percentage of the load for a given end-use which can be shed by a typical demand response strategy, assuming adequate communications, controls and incentives exist. For bi-directional products, this is the percentage of load that can be increased or decreased.
- **Controllability** refers to the percentage of the load for a given end-use which is associated with equipment that has the necessary communications and controls in place to trigger and achieve load sheds/shifts.
- **Acceptability** refers to the percentage of the load for a given end-use which is associated with equipment or services that are willing to accept the reduced level of service in a demand response event, in exchange for financial incentives.

Depending on the end-use, these flexibility filter values may vary throughout the year, week, and day, and are affected by end-users' requirements and the corresponding operation schedules. Figure 3 shows an example of the flexibility factors and the resulting "overall flexibility" for commercial lighting, where the overall flexibility is a function of the individual flexibility filters and ranges between 3 and 5%. For each resource, in each hour, the lesser of the controllability filter value and the acceptability filter value is chosen as the participation rate. Only loads which are both controllable and acceptable for exercise can participate, but the assumption is that the most flexible portion of load and the most accepting portion are coincident. The participation rate is multiplied by the sheddability to compute overall flexibility.

These filters are described more deeply in Sections 2.2 and 2.3.

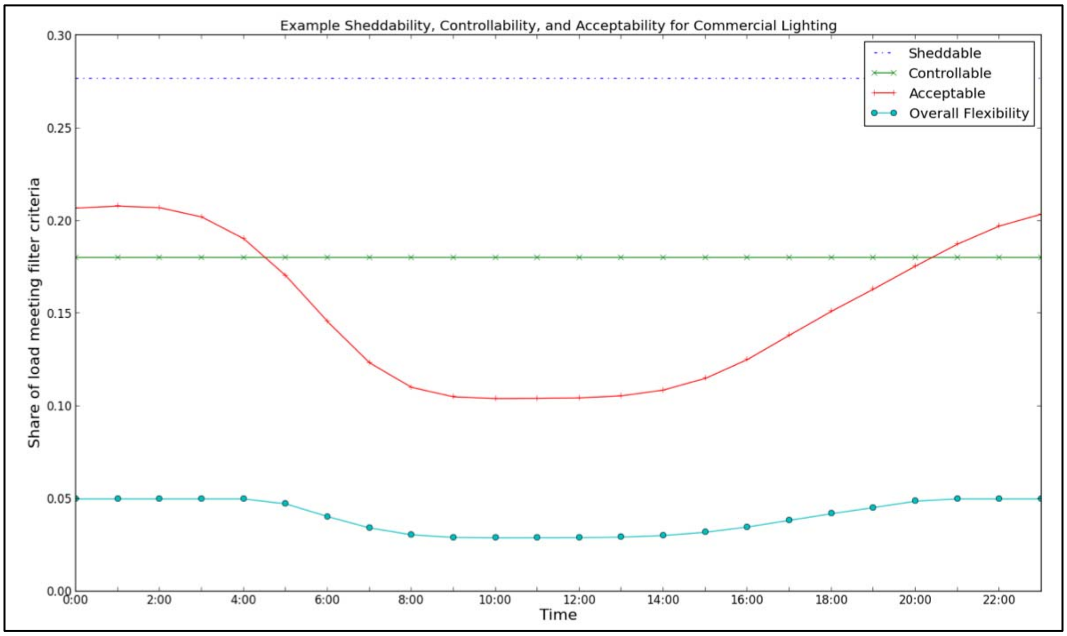


Figure 3: Illustration of flexibility filters combined to achieve overall flexibility for commercial lighting.

The end result of this approach to characterizing loads is two-fold: first, for each combination of end-use and product, an annual availability profile is produced, with hourly resolution. This resolution is necessary as it matches the resolution of the power system and market modeling, which the end-uses will participate in. Second, a generator profile and a set of constraints that can be used to interpret the availability profiles for each end-use is produced. Figure 4 demonstrates some of these constraints. The constraints considered are minimum and maximum shed length, number of calls in a given period of time, a requirement to re-charge 'borrowed' energy for some end-uses, and when this energy can be re-charged. For thermal end-uses, energy may be 'pre-charged' before an event begins by storing this thermal energy in the building for a short period of time. Depending on building characteristics and the details of the pre-charging regime, the amount of energy used may be more or less than during a typical day, but for simplicity all pre-charging/re-charging energy magnitude is set at 100% of shifted energy. Some pumping end-uses also have the ability to pre-charge by using inline storage, in these cases the pre-charge is achieved by advancing pumping schedules.

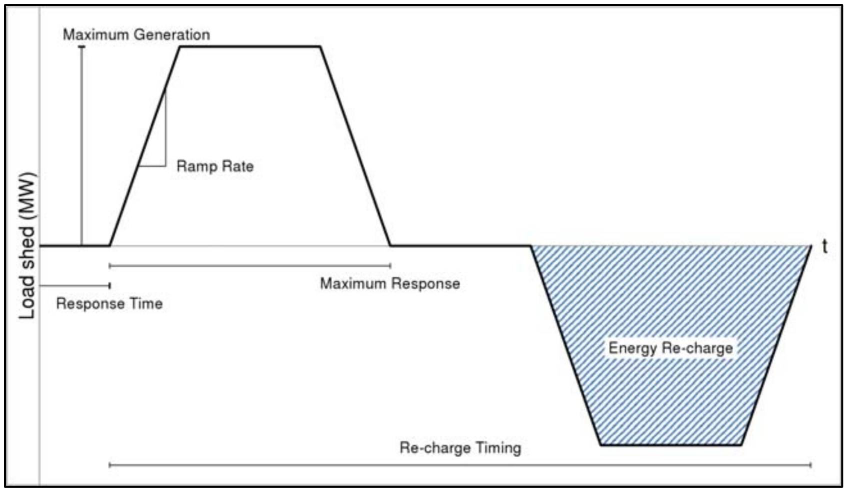

Figure 4: Demand response generator profile

The generated demand response availability profiles are indicative of the maximum availability of loads to respond to each product in each hour. Since the number of calls any particular load will respond to in a given timeframe is limited, a production cost model will consider these constraints when deciding which resources to procure in each hour. In addition, a production cost model schedules the energy re-charge when loads are exercised for the energy product. Finally, the model will limit the sum of the provisioned products in each hour to the magnitude of the most flexible product, capacity. This has the effect of ensuring that a certain MW of load cannot commit to multiple product simultaneously.

For the purposes of this project, DR is assumed to provide several ancillary services, as well as an energy product and a capacity product. These products vary in their response time, duration, and frequency of call. As such, not all resources can contribute to all products. Regulation is the fastest product and is called continuously, to balance short-term (<5 minute) mismatches of supply and demand. It is generally energy neutral over long time periods (>15 minutes). Contingency reserves are called in the event that a large generator or transmission line fails, and are brought online quickly while additional generation is needed. Flexibility reserves, a proposed product being considered by the California Independent System Operator, the Midcontinent Independent System Operator, and others, will be used to correct for unexpected large and long-lasting (several hours) errors in supply and demand, such as the ramping of a large solar or wind generation facility (Navid *et al*. 2011, Xu & Tretheway 2012). The capacity and energy products are slower and longer-lasting products, scheduled day-ahead and used to reduce the required generation energy over several hours. The details of these products are shown in Table 2.

Several criteria are considered when deciding which products each resource can contribute to. These include:

- **Time dependence**: whether the end-use's provided service is on a fixed schedule, or can be shifted in time without incident. For example, lighting loads in occupied space are time dependent, but the defrosting of evaporator coils in refrigeration systems is not.

- **Storage**: whether the end-use's provided service has energy storage (whether passive or active). For example, space heating and cooling loads have energy storage in the form of thermal mass of the served building, but ventilation loads do not.
- **Wear and tear**: Whether controlling the end-use for the selected product would cause a significant amount of wear and tear on equipment. For example, controlling a large chiller with control signals every 4 seconds would put undue wear and tear on the chiller, while controlling dimmable lighting at the same frequency should be much less harmful.
- **Independence**: whether the end-use is part of a standalone process, or if it must be coordinated with other end-uses up- or down-stream of it. For example, ventilation and heating or cooling systems should be controlled together, otherwise one system may try to compensate for the reduced service of the other by increasing its energy usage.

Table 2: Ancillary service, energy, and capacity products considered.

| Products | | Physical Requirements | | | |
|---|---|---|---|---|---|
| Product Type | General Description | How fast to respond | Length of response | Time to fully respond | How often called |
| Regulation | Response to random unscheduled deviations in scheduled net load | 30 seconds | Energy neutral in 15 minutes | 5 minutes | Continuous within specified bid period |
| Flexibility | Additional load following reserve for large un-forecasted wind/solar ramps | 5 minutes | 1 hour | 20 minutes | Continuous within specified bid period |
| Contingency | Rapid and immediate response to a loss in supply | 1 minute | ≤ 30 minutes | ≤ 10 minutes | ≤ Once per day |
| Energy | Shed or shift energy consumption over time | 5 minutes | ≥ 1 hour | 10 minutes | 1-2 times per day with 4-8 hour notification |
| Capacity | Ability to serve as an alternative to generation | Top 20 hours coincident with balancing authority area system peak | | | |

# CHAPTER 2: Methodology

End-use loads are selected for inclusion based on possession of a significant share of load and their likelihood of having demand response enabling controls systems by 2020. Load profiles for the included end-uses are collected from publically available data, or constructed based on a combination of sources (e.g. combining a monthly pattern from one source with a daily pattern from another). Flexibility filters are constructed, varying spatially and temporally, to filter the total end-use load into end-use load available to participate in energy and ancillary services. Finally, participating loads are translated into generator profiles to simulate the constraints that limit the participation of the available load.

Section 2.1 lists the sources of the load profiles to be used for the selected end-uses. Section 2.2 discusses the approach for filtering load profiles to yield demand response availability profiles. Section 2.3 discusses the assumptions used to assign magnitudes to the filters. Section 2.4 discusses the process of describing the loads as generation resources.

## 2.1 Load Profiles

*Commercial*: Commercial load profile simulations for California are obtained from the California Commercial End-use Survey (CEUS), conducted by the California Energy Commission (CEC). CEUS provides a stratified random sample of 2,800 commercial buildings, and collected their physical characteristics and equipment details, along with their demand data and weather data from nearby weather stations. The buildings were modeled using a custom-built software program (DrCEUS™, incorporating previously developed software SitePro[1] and eQuest[2], which uses DOE 2.2 for simulation), and the model parameters were calibrated using the measured data. The calibrated models were then run using typical weather profiles, to simulate the hourly demand experienced in a 'typical' year from the California building stock (California Energy Commission 2006).

The four selected end-uses (heating, cooling, lighting, and ventilation) make up 57% of the simulated electricity consumption of the commercial building stock. Figures 5a and 5b show the average demand for each day and the average demand for each hour, for each end-use. Looking at the daily averages, weekends and holidays can be observed as dips in load, and heating and cooling loads can be seen to rise and fall with the seasons. For the hourly averages, the occupancy impact on loads can be seen for lighting and ventilation, and the need to overcome the thermal capacitance and infiltration of the building can be seen for temperature-dependent loads. Load profiles for all considered end-uses are shown in Appendix D.

[1] https://www.itron.com/na/productsAndServices/Pages/Load%20Research%20Services.aspx
[2] http://www.doe2.com/equest/

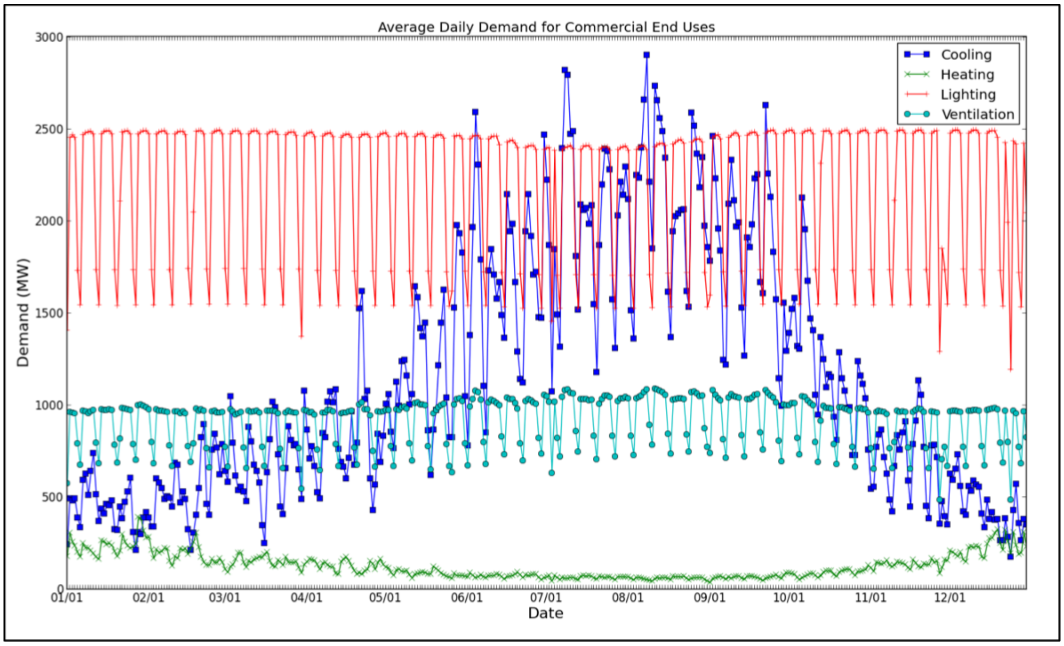


Figure 5a: CEUS simulated load profiles for selected end-uses: yearly profile showing average daily demand.

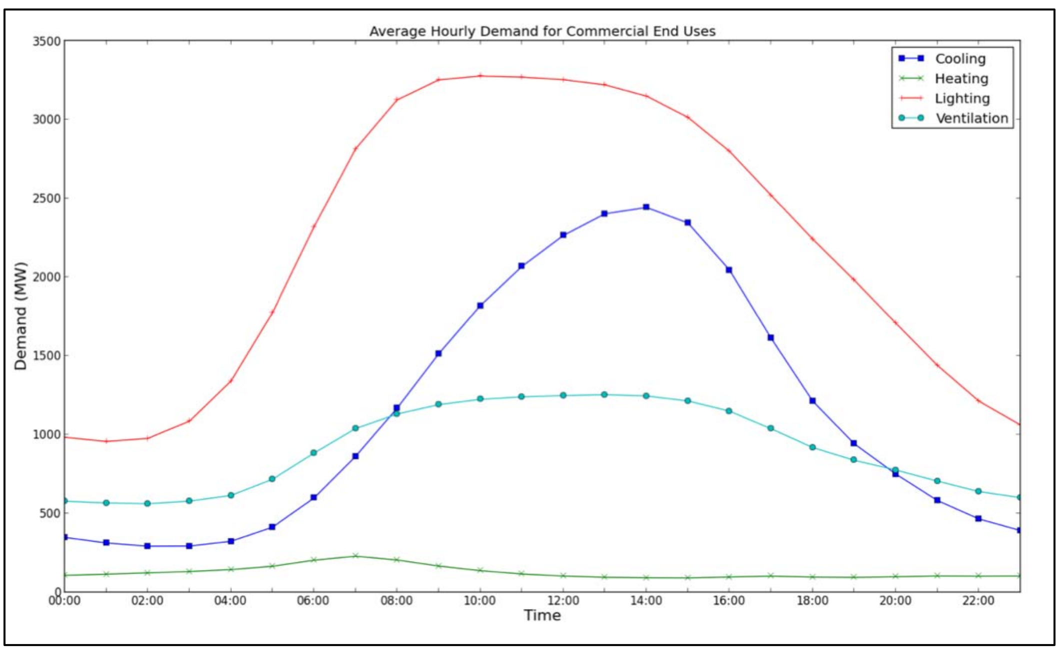


Figure 5b: CEUS simulated load profiles for selected end-uses: daily profile showing average hourly demand.

*Residential*: For residential loads, residential end-use forecast data from the California Energy Commission for the year 2020 is used (CEC 2012). Residential end-uses included for this project are space heating, cooling, and water heating.

For both residential and commercial loads, the California end-use data are extrapolated to the rest of the Western Interconnection based on Itron's predictions of monthly energy use for each balancing authority area (McMenamin and Sukenik 2012). Though CEUS contains end-use load data for 13 different climate zones within California, there is concern about extrapolating these load profiles to areas with vastly different weather patterns. To solve this problem, the various California load profiles and their relationship to different weather conditions are studied.

Using the California data, we observed a correlation between the average daily temperature variability ($T_{max}$-$T_{min}$) and the load variability ([$L_{max}$-$L_{min}$]/$L_{av}$) for heating and cooling loads. This relationship is assumed to exist in the non-California BAAs as well, so this correlation is extrapolated for BAAs with greater diurnal temperature swings.

For each climate zone in California, this correlation is modeled using a linear regression. For each non-California BAA to be approximated with the California data, the most similar California climate zone is selected based on seasonal energy consumption patterns. The California climate zone's regression equation is combined with average temperatures in the non-California BAA to estimate the load variability in each month. The California climate zone load curve is then scaled and offset to match both the predicted monthly energy consumption and the predicted daily load variability in the target BAA.

*Agricultural Pumping*: Seasonal load shapes are derived based the estimated irrigation water requirements in each BAA. The irrigation demand estimate is based on United Stated Department of Agriculture (USDA) records of the crops grown by each state (USDA 2009) and their typical planting/harvest dates (USDA 2010), along with historical evapotranspiration patterns (National Oceanic and Atmospheric Administration 1982). Load magnitude is determined by the number, size, and average operating hours of pumps in each state (USDA 2009), and state magnitudes are disaggregated into balancing authority areas based on coverage area, with metropolitan areas excluded. Based on previous analysis of California agricultural load, we project a flat load shape. Though some utilities offer agricultural time-of-use (TOU) rates to encourage load to be shifted to off-peak hours, adoption of TOU irrigation schedules by growers has not been widespread.

*Data Centers*: The Environmental Protection Agency's (EPA) Energy Star program estimates that the energy use of the nation's servers and data centers in 2006 more than doubled the electricity that was consumed for this purpose in 2000 and, for 2006, is estimated to be 3% of the total U.S. electricity consumption (EPA 2007). For the purpose of this analysis, we assume that the data center load is 3% of annual average demand for each BAA. Data centers tend to have relatively constant levels of electricity consumption, and thus we assume a flat load curve for both the year and the day. Further information is needed to accurately model the spatial and temporal distribution of data center load.

*Municipal Lighting (also referred to as Outdoor Lighting)*: The municipal lighting load pattern is assumed to follow the sunrise and sunset times over the course of the year, and the magnitude is estimated from a report estimating potential benefits from LED lighting conversions (US DOE 2011c). The considered end-uses are road lighting, parking lighting, and area/flood lighting. Sunrise/sunset times over the course of a year are obtained from the US Naval Observatory for one representative city in each BAA (United States Naval Observatory 2012).

*Municipal and Wastewater Pumping*: A rule-of-thumb energy intensity value (100 kWh/person/year) is applied to the population of each BAA (determined from the zip codes comprising each BAA and US Census data). This energy intensity figure is consistent with estimates by the Electric Power Research Institute (2000). Municipal daily load profiles are obtained from an LBNL report, *Water Supply Related Electricity Demand in California* (House 2007). Municipal monthly load profiles are obtained from the *Urban Water Use in California*, Figure 3-3 (California Department of Water Resources 1994). Wastewater pumping loads are assumed to be flat.

*Refrigerated Warehouses*: The seasonal load shape is determined by the temperature variation of each BAA (colder weather leading to lower load for refrigerated warehouses), and the daily load shape is based on CEUS data on refrigerated warehouses in California. Total annual energy is estimated by the amount of storage volume in each state (USDA 2012) and an assumed energy intensity factor (1.3 kWh/$ft^3$-year), determined via literature review and consultation with industry experts (Scott 2012). To break down state energy consumption into its constituent BAAs, the population in each BAA is used, compiled based on population data from the 2010 Census.

### 2.1.1 Additional Loads to be Considered in Future Studies

Several end-uses were considered for inclusion in this project, but eventually omitted, due to either insufficient information on their capabilities, perceived low load magnitude, or predicted nonexistent participation ability. However, future studies may benefit from inclusion of these end-uses, which include:

- Residential refrigerators and freezers
- Residential and commercial cleaning appliances (dishwashers, washing machines, dryers)
- Residential and commercial pool pumps
- Commercial electric water heating
- Electric vehicle charging (and potentially discharging)
- Miscellaneous plug loads

Industrial manufacturing loads are considered in a related report (Starke *et al.* 2013).

## 2.2 Flexibility Factors

To obtain an amount of participating load in each hour from the load profiles, a “flexibility” value is used for each hour, representing the fraction of load that is willing and able to participate in demand response at that hour. The true magnitude of participating load in 2020 can be estimated but is impossible to precisely predict. As more information becomes available, the assumed flexibility can be updated. The first assumptions that must be made are which loads can participate in which products. The assumed ability of each resource to contribute to these products is shown in Table 3.

Table 3: Participation of resources in ancillary services products. Shading colors identify resources which contribute to the same set of products.

| | Products | | | | |
|---|---|---|---|---|---|
| Resources | Regulation | Flexibility | Contingency | Energy | Capacity |
| Agricultural Pumping | | | ✔ | ✔ | ✔ |
| Commercial Cooling | ✔ | ✔ | ✔ | ✔ | ✔ |
| Commercial Heating | | | | ✔ | ✔ |
| Commercial Lighting | ✔ | ✔ | ✔ | | ✔ |
| Commercial Ventilation | ✔ | ✔ | ✔ | | ✔ |
| Data Centers | | | ✔ | ✔ | ✔ |
| Municipal Lighting | ✔ | ✔ | ✔ | | ✔ |
| Municipal Pumping | | | | ✔ | ✔ |
| Refrigerated Warehouses | | | | ✔ | ✔ |
| Residential Cooling | ✔ | ✔ | ✔ | ✔ | ✔ |
| Residential Heating | ✔ | ✔ | ✔ | ✔ | ✔ |
| Res. Water Heating | ✔ | ✔ | ✔ | ✔ | ✔ |
| Wastewater Pumping | | | | ✔ | ✔ |

The determination of the demand response available for ancillary services by hour is shown in Equation 1. The determination of each of these factor values is described in Section 2.3.

$$DR(hour, BAA, end\ use, product) = Load * Participation\ rate * Shed\ Rate \qquad (1)$$

In this equation, the participation rate is the percentage of load that is willing and able to respond to a product, and the shed rate (sheddability) is the proportion of the responding load that is shed in typical DR strategies. The product of these two factors yields the overall flexibility rate of the load in question, at the hour in question. Shed rate is based on the LBNL Demand Response Research Center's field experience with customers in California, and is a static value for a given end-use/product combination. The Participation rate is defined in Equation 2.

$$Participation\ rate(hour, BAA, end\ use, product) = \min\,(Acceptability, Controllability) \qquad (2)$$

In this equation, the Controllability is a static value representing the share of the loads that are projected to have the necessary controls for the corresponding DR products. In some cases, controllability can be time-varying based on operator schedules, if the control scheme is not fully automated and requires some manual oversight or intervention. The Acceptability factor is a time-varying value that represents the willingness of customers to shed load at a particular hour. It is assumed that the most controllable portions of load are also the most willing to participate in DR, and vice versa: therefore the smaller of the two values at any given hour is taken as the participation rate, representing the loads that satisfy both criteria. For end-uses whose participation rate is not assumed to be time-varying, a single Participation value is used.

The value of the Acceptability factor is assumed to vary inversely with occupancy for commercial and residential end-uses, and is assumed to be constant for agricultural irrigation, municipal lighting, municipal pumping, municipal wastewater treatment, and refrigerated warehouses (a static Participation rate is used for these end-uses). Occupancy is assumed to be inferred from the interior lighting load for commercial buildings and the water heating load for residential end-uses. A maximum and minimum acceptability value is assigned to each BAA-end-use-product combination, based on previous experience with demand response demonstrations and historical penetration of DR programs in each BAA and end-use. Depending on the ratios of the load and acceptability throughout the day and through the year, the maximum available load in any day may be coincident with utility "peak" hours, coincident with "partial peak" hours, or during the "off-peak" hours.

## 2.3 Flexibility Factor Determination

Ancillary services, energy, and capacity product flexibility factors (sheddability, controllability, and availability) are derived for each end-use by expanding on the methodology and assumptions used in Watson, *et.al.* (2012), a report which estimated California's demand response availability for energy and capacity (2 hour duration) and ancillary services (20 minute duration) on typical hot and cold peak days, using current controllability levels and increased technical potential (increased penetration of communicating control technologies). Following is a brief description of how these values are derived for each sector. A full listing of the range of values for each combination of resource and product can be found in Appendix A.

### 2.3.1 Commercial Loads

Table 4 shows the range in flexibility factor values for the four commercial building end-uses (heating, cooling, ventilation and lighting).

***Sheddability and Controllability.*** Sheddability and controllability values, derived by end-use and building type for the Watson *et al.* report, are weighted by building type-specific end-use annual energy usage data from CEUS, the Northwest Power and Conservation Council, and the Commercial Building Energy Consumption Survey, to obtain weighted end-use specific sheddability and controllability values for each state. "Current controllability" values are used to estimate controllability for energy and capacity products in 2020, while "technical potential" controllability values are used for projected 2020 ancillary services controllability.

***Acceptability.*** Acceptability is time-varying over the course of a day, based on region and estimated building occupancy (lighting load is used as a proxy for occupancy). For each region and end-use, minimum and maximum acceptability values are used, corresponding to the maximum and minimum occupancy hours of the day, respectively. Intermediate values are interpolated. Maximum and minimum values for each region are determined based on current utility programs and pilots and on projections as to what 2020 programs and related participation may be. As such, California is projected to continue to have higher acceptability values for cooling, ventilation, and indoor lighting load response, but have minimal heating response given the low penetration of electric space heating in California (therefore this end-use will not be targeted by California utilities, and customers will not be comfortable with heating DR). Low levels of minimum acceptability (~2%) for all commercial end-uses were assumed for the rest of the Western Interconnection due to the level of current programs in these areas. These values may increase depending on the aggressiveness of specific programs and policies.

Table 4. Commercial Cooling and Heating Values

<table>
<tr><th rowspan="3"></th><th colspan="3">Energy and Capacity</th><th colspan="5">Ancillary Services</th></tr>
<tr><th rowspan="2">Sheddability</th><th rowspan="2">Controllability</th><th rowspan="2">Acceptability</th><th rowspan="2">Sheddability</th><th rowspan="2">Controllability</th><th colspan="3">Acceptability</th></tr>
<tr><th>Regulation</th><th>Flexibility</th><th>Contingency</th></tr>
<tr><td rowspan="2">Heating</td><td rowspan="2">46 – 51%</td><td rowspan="2">10 – 25%</td><td>Default<br>Daily min: 0%<br>Daily max: 75-77%</td><td rowspan="2">53 – 64%</td><td rowspan="2">7-16%</td><td rowspan="2">Daily min: 0%<br>Daily max: 0.6%</td><td rowspan="2">Daily min: 0%<br>Daily max: 1.8%</td><td rowspan="2">Daily min: 0%<br>Daily max: 1.8%</td></tr>
<tr><td>Northwest<br>Daily min: 3%<br>Daily max: 75-77%</td></tr>
<tr><td rowspan="2">Cooling</td><td rowspan="2">41 – 49%</td><td rowspan="2">15-25%</td><td>Default<br>Daily min: 3%<br>Daily max: 75-77%</td><td rowspan="2">50 – 58%</td><td rowspan="2">7-16%</td><td>Default<br>Daily min: 0%<br>Daily max: 2%</td><td>Default<br>Daily min: 0%<br>Daily max: 2%</td><td>Default<br>Daily min: 0%<br>Daily max: 2%</td></tr>
<tr><td>California<br>Daily min: 35%<br>Daily max: 75-77%</td><td>California<br>Daily min: 3%<br>Daily max: 7%</td><td>California<br>Daily min: 10%<br>Daily max: 21%</td><td>California<br>Daily min: 3%<br>Daily max: 77%</td></tr>
<tr><td rowspan="2">Ventilation</td><td rowspan="2">46-49%</td><td rowspan="2">17-25%</td><td rowspan="2">Daily min: 3%<br>Daily max: 75-77%</td><td rowspan="2">53 – 59%</td><td rowspan="2">8-16%</td><td>Default<br>Daily min: 0%<br>Daily max: 2%</td><td>Default<br>Daily min: 0%<br>Daily max: 2%</td><td>Default<br>Daily min: 0%<br>Daily max: 2%</td></tr>
<tr><td>California<br>Daily min: 3%<br>Daily max: 7%</td><td>California<br>Daily min: 10%<br>Daily max: 21%</td><td>California<br>Daily min: 10%<br>Daily max: 21%</td></tr>
<tr><td rowspan="2">Indoor Lighting</td><td rowspan="2">26 – 28%</td><td rowspan="2">15-17%</td><td rowspan="2">Daily min: 3%<br>Daily max:75-77%</td><td rowspan="2">26 – 28%</td><td rowspan="2">7-11%</td><td>Default<br>Daily min: 0%<br>Daily max: 2%</td><td>Default<br>Daily min: 0%<br>Daily max: 2%</td><td>Default<br>Daily min: 0%<br>Daily max: 2%</td></tr>
<tr><td>California<br>Daily min: 3%<br>Daily max: 7%</td><td>California<br>Daily min: 10%<br>Daily max: 21%</td><td>California<br>Daily min: 10%<br>Daily max: 21%</td></tr>
</table>

### 2.3.2 Residential Loads

A framework similar to the commercial approach is used to determine residential load flexibility values. While multiple residential loads were considered, heating and cooling responses are better known. Water heating and refrigerator demand response are in the developmental phase, but included here for completeness.

*Heating and Cooling:* The level of residential heating and cooling load response possible depends on the type of site-based control available, including user adjustments of standard or programmable thermostat setpoints (Manual), automatic adjustment of temperature setpoints through programmable communicating thermostats (PCT), and direct load control (DLC). While all three control mechanisms could be used to respond for Energy or Capacity products, given the current utility programs and communications infrastructures, only DLC is assumed to be able to be used for ancillary services. However, since this assumption was made, an ARPA-E project aiming to demonstrate the use of PCTs for ancillary services was selected for funding and has begun work[3]. Depending on the outcome of the ARPA-E project, modification to our assumptions may be warranted. The range in flexibility factors for residential heating and cooling can be seen in Table 5.

***Sheddability.*** Based on a review of past field test results, it is assumed that 20% of manual thermostat-controlled heating and cooling electricity usage could be sheddable, while 30% could be shed using PCTs. Direct load control has typically been used to turn on and off residential air conditioning compressors which typically make up 70% of the electrical load of a residential air conditioning system, thus an aggressive 70% sheddability value is used for DLC-controlled cooling systems. DLC has not typically been used on residential heating systems, thus it is assumed that there is no DLC-based heating response.

***Controllability.*** Controllability values for 2020 are derived from 2009 Residential Energy Consumption Survey (RECS) data for the manual and PCT case and from Brattle (2012) for the DLC case, resulting in 2% of houses with PCTs in 2020 and 12.5% DLC in most of the Western Interconnection (26% DLC in Utah). Though the potential for the use of PCTs has been shown, wide adoption is not foreseen in the near future.

***Acceptability.*** The prevalence of current utility programs and pilots in residential heating and cooling is used as a guide to determine the corresponding projected acceptability values. As such, acceptability for manual and PCT-based responses are assumed to be low and only in the regions where pilots have taken place (for example, California and the Northwest). Direct load controllers have typically been installed as part of utility programs. As such, it is assumed that the DLC acceptability values will be the same as the corresponding controllability values. It is assumed that all control method can contribute to energy and capacity, but that only DLC is fast enough to contribute to ancillary services. However, demonstrations of PCT control for ancillary services have begun, so this assumption may need to be revised in the future.

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[3] http://arpa-e.energy.gov/?q=arpa-e-projects/integration-renewables-demand-management

Table 5. Residential Cooling and Heating Values

| | Cooling | | | Heating | | |
|---|---|---|---|---|---|---|
| | Sheddability | Controllability | Acceptability | Sheddability | Controllability | Acceptability |
| Manual | 20% | 31 – 52% | Daily min: 2%<br>Daily max: 3% | 20% | 39% - 48% | *Default*<br>0% |
| | | | | | | *Northwest*<br>Daily min: 1%<br>Daily max: 1.5% |
| PCT | 30% | 2% | *Default*<br>0% | 30% | 2% | *Default*<br>0% |
| | | | *California, Northwest*<br>Daily min: 2%<br>Daily max: 3% | | | *Northwest*<br>Daily min: 1%<br>Daily max: 1.5% |
| DLC | 70% | *Default*: 13% | *Default*<br>Daily min: 13%<br>Daily max: 19% | N/A | N/A | N/A |
| | | *Utah*: 26% | *Utah*<br>Daily min: 26%<br>Daily max: 39% | | | |

*Refrigerators and Water Heaters:* There are a number of on-going studies evaluating and developing communication and control mechanisms and infrastructures for direct load control of residential refrigerators and water heaters for demand response and ancillary services. Based on research to date, it is assumed that 25% of electric water heating electricity loads and 5% of refrigerator electricity loads could be sheddable. It is assumed that there could be an increased level of DLC for residential electric water heaters similar to that projected for residential heating and cooling – however, this may be a higher penetration than would be reasonable given the current state of research and program development. It is assumed that refrigerator demand response programs will not yet be in place for 2020, reflected in the 0% controllability and acceptability values assumed. Thus, refrigerators are omitted from the resource assessment. Values for sheddability, controllability, and acceptability for refrigerators and water heaters are shown in Table 6.

Table 6. Residential Electric Water Heating and Refrigerator Values

| | Electric Water Heating | | | Refrigerators | | |
|---|---|---|---|---|---|---|
| | Sheddability | Controllability | Acceptability | Sheddability | Controllability | Acceptability |
| DLC | 25% | *Default*: 13% | *Default*<br>Daily min: 13%<br>Daily max: 19% | 5% | 0% | 0% |
| | | *Utah*: 26% | *Utah*<br>Daily min: 26%<br>Daily max: 39% | | | |

### 2.3.3 Industrial Non-Manufacturing Loads

Demand response in the industrial sector is not a new concept; in fact there are several decades of DR history in the form of interruptible tariffs. However, information on load flexibility is not as readily available as in the commercial or residential sectors, so many assumptions are made. Note that only a select group of industrial non-manufacturing end-uses are included here based on the Demand Response Research Center's previous experience with these end-uses, there are many others that can be considered as discussed in Starke *et al.* (2013).

*Agricultural Irrigation Pumping:* A shed rate of 100% represents the full shutdown of pumps. As automated demand response is not widespread in agriculture, the participation rate is expected to be low, but should still represent a significant minority of load, since farms have built-in water storage in their soil. A participation rate of 15% is assumed for the capacity and contingency products, and a participation rate of 10% is assumed for the energy product.

*Data Centers:* Given that data center loads are relatively flat throughout the day and year, a flat shed rate of 3% is assumed for all products at all hours, with a 100% participation rate. Data centers with attached office space exhibit a diurnal load profile peaking during daytime, but the variability is due to conventional commercial end-uses which are not considered as part of this resource.

*Municipal Lighting:* A temporary 5% shed in lighting load is likely to be un-noticeable, and thus available 100% of the time for all products in which municipal lighting participates.

*Municipal and Wastewater Pumping:* Demonstrations of DR in wastewater pumping show that there is easily-achievable DR available in the range of 5% of total plant load, so that value is assumed for sheddability. A participation rate of 50% represents that not all plants will have the spare capacity or control systems necessary to shed load.[4]

*Refrigerated Warehouses:* There is a large amount of thermal storage present in refrigerated warehouses, and temporary deviations in air temperature do not easily transfer into stored product. Therefore, full participation is assumed, but only for small load shifts, which can ride the temperature-change transient without affecting product. Load sheds of 10% are assumed to be available for the shorter-duration capacity and contingency products, and 5% is assumed to be available for the energy product.

## 2.4 Modeling Loads as Generation Resources

After the resources are filtered to obtain estimates of hourly DR availability profiles, the end-use DR potential participation in energy transactions requires additional parameters to be input into a production cost model. These resources are modeled similarly to generators. The parameters used are response time, ramp rate, minimum and maximum duration, and

[4] Due to a programming bug, a participation rate of 10% was used in the dataset initially sent to NREL.

constraints on call frequency. For loads which respond by shifting load rather than shedding it, an energy re-charge is required, and the timing and magnitude of this re-charge are also parameters. For these resources, there are hourly availability profiles for both the load curtailment and the load recovery. The speed of energy re-charge is constrained as well. For end-uses with a constant load profile, re-charge occurs at the same rate as the daily availability, while for variable end-uses, re-charge is constrained to the difference between scheduled availability during re-charge hours and maximum daily availability (precluding the creation of a new peak due to re-charge). These parameters are listed for all resources in Tables 7 and 8. The 'faster' response times are used for regulation, flexibility, and contingency reserves, while the 'slower' ramp times are used for the energy and capacity products.

For some thermal end-uses, this energy re-charge can occur before an event (a pre-charge), with the building thermal mass providing energy storage (Yin *et al.* 2010). For example, pre-cooling to enable commercial cooling energy shifting and pre-heating to enable commercial heating energy shifting are limited to 6am-6pm and 3am-7am, respectively; these times are selected as roughly adjacent to the maximum load hours for these resources. Ideally, energy re-charge/pre-charge via pre- and post-cooling would be constrained to occur immediately adjacent to an energy shift, whenever it occurred, but due to typical limitations in production cost models they are modeled on a 24-hour cycle with restricted hours of charging. Some pumping loads also have inline storage that can be used by re-scheduling pump operation.

Whereas a conventional generator has a maximum ramp rate set by the physical constraints of the generator, an aggregation of loads can be switched off fairly rapidly, the main delay coming from the time it takes for control systems to enact all of the load reductions. For many end-uses, load reductions can be achieved within one minute if proper communications and controls are in place. Since the amount of load participating is variable, but the time required to shed is constant, the ramp rate is variable: this is modeled by using an assumed ramp time with the variable availability profile to calculate hourly ramp rate. For the industrial process resources (agricultural pumping, municipal pumping, refrigerated warehouses, and wastewater pumping), a start-up cost is specified for the energy product. Some resources also have costs based on shed length.

Figure 4, in Section 1.3, shows these parameters graphically in the context of a single response event with associated energy storage re-charge. Since the loads must respond in a manner similar to conventional generators, they are subject to the same constraints, namely: ramp rate, maximum time to achieve full output, and minimum response length. Loads with energy re-charge requirements behave as an energy storage medium, without losses.

Table 7: Product constraints

| Resource | Minimum Duration | Maximum Duration | Call Limits | Energy Re-charge/ Pre-charge |
|---|---|---|---|---|
| Agricultural Pumping | 1 hour | 8 hours | 1 per day | 100% within 24 hours |
| Commercial Cooling | 5 minutes | N/A | N/A | 100% within 24 hours Limited to 6am-6pm |
| Commercial Heating | 5 minutes | N/A | N/A | 100% within 24 hours Limited to 3am-7am |
| Commercial Lighting | N/A | N/A | N/A | N/A |
| Commercial Ventilation | 5 minutes | N/A | N/A | N/A |
| Data Centers | N/A | 4 hours | N/A | 100% within 24 hours |
| Municipal Lighting | N/A | N/A | N/A | N/A |
| Municipal Pumping | N/A | 2 hours | 1 per day | 100% within 24 hours |
| Residential Cooling | 5 minutes | N/A | N/A | 100% within 24 hours Limited to 6am-6pm |
| Residential Heating | 5 minutes | 1 hour | N/A | N/A |
| Residential Water Heating | 5 minutes | N/A | N/A | 100% within 24 hours |
| Refrigerated Warehouses | N/A | 4 hours | 1 per day | 100% within 24 hours |
| Wastewater Pumping | N/A | 3 hours | 1 per day | 100% within 24 hours |

Table 8: Resource ramping times for slow and fast responses.

| Resource | Faster Response Ramp Time | Slower Response Ramp Time |
|---|---|---|
| Agricultural Pumping | 1 minute | 1 minute |
| Commercial Cooling | 1 minute | 15 minutes |
| Commercial Heating | 1 minute | 15 minutes |
| Commercial Lighting | 30 seconds | 30 seconds |
| Commercial Ventilation | 1 minute | 15 minutes |
| Data Centers | 1 minute | 15 minutes |
| Municipal Lighting | 40 seconds | 40 seconds |
| Municipal Pumping | 1 minute | 5 minutes |
| Residential Cooling | 1 minute | 15 minutes |
| Residential Heating | 1 minute | 15 minutes |
| Residential Water Heating | 30 seconds | 30 seconds |
| Refrigerated Warehouses | 1 minute | 5 minutes |
| Wastewater Pumping | 1 minute | 5 minutes |

# CHAPTER 3:
# Results: DR Profiles

In this section, two sets of results are explored. The first set is the estimation of the DR availability in 2020, based on the three flexibility factors described in the previous section (Sheddability, Controllability, and Acceptability). This base case is described in Section 3.1. Notes on interpretation of values and a summary of BAA statistics are in Section 3.2 and 3.3. The second set of results to be explored is the "projected theoretical availability".

Since the Controllability and Acceptability of the selected end uses are dependent on the actions of policymakers, utilities, and system operators over the next several years, it is also useful to analyze a projected theoretical availability which assumes full Controllability and Acceptability (i.e. all loads are able to participate, and choose to be available at all times). This projected theoretical availability represents the maximum achievable availability, assuming no change to the magnitude and pattern of load profiles. This projected technical availability case is evaluated in Section 3.4.

The availability profiles of both sets of results can be analyzed and visualized in several ways: ranges of values, temporal distributions over the year, availability from the various end-uses, availability by BAA, etc. This section discusses some of these disaggregations.

The full datasets are available by request from the Demand Response Research Center for analysis.

## 3.1 Projected Demand Response Availability in 2020

Based on this study's assumptions about the magnitude and behavior of the selected end-uses within the Western Interconnection, Figure 6 shows the range of availability for each product. The pattern of availability for regulation reserves is shown in Figure 7, and the pattern of availability for the energy product is shown in Figure 8. Availability patterns for all products are contained in Appendix C. The disaggregation of the availability of contingency reserves into end-uses is shown in Figures 9a and 9b. Patterns can be seen at the seasonal level, weekly level, and daily level. Disaggregations for all products into end-uses are contained in Appendix D.

Looking at the maximum availability of a given product in the year, demand response can be seen to contribute up to 4,233 MW for the capacity product, 2,846 MW for the energy product, 2,990 MW of contingency reserves, 2,162 MW of flexibility reserves, and 1,822 MW of regulation reserves. Expressed as a fraction of total Western Interconnection load, these values represent up to 2% of load for regulation reserves, 2.3% for flexibility reserves, 2.8% for contingency reserves, 2.3% for the energy product, and 3.5% for the capacity product. Maximum availabilities for each product are not coincident, and the sum of the non-coincident maximums for each BAA is greater than the coincident maximum.

For comparison, regulation reserve requirements are typically approximately 1% of load, and the Western Electricity Coordinating Council requires spinning contingency reserves (the product most similar to this project's contingency reserves) at approximately 3% of load. Though the times of maximum DR resource availability may not align precisely with the times of maximum grid reserves requirements, there is the potential for DR resources to contribute a significant fraction of reserves requirements.

The availability of regulation reserves is greatest during the evening, night, and early morning hours, due to the relative magnitude of municipal lighting in the daily availability profile. The seasonal maximum is in summer evenings, due to the magnitude and seasonality of cooling loads. The energy product is most available in the afternoon, especially during summer. This is due to the magnitude and seasonality of cooling loads. Though there is a maximum of 2,846 MW available for the energy product, for the majority of the year there is less than 600 MW available. The energy product typically has lower availability than the other products due to its longer duration, which excludes many end-uses without significant storage.

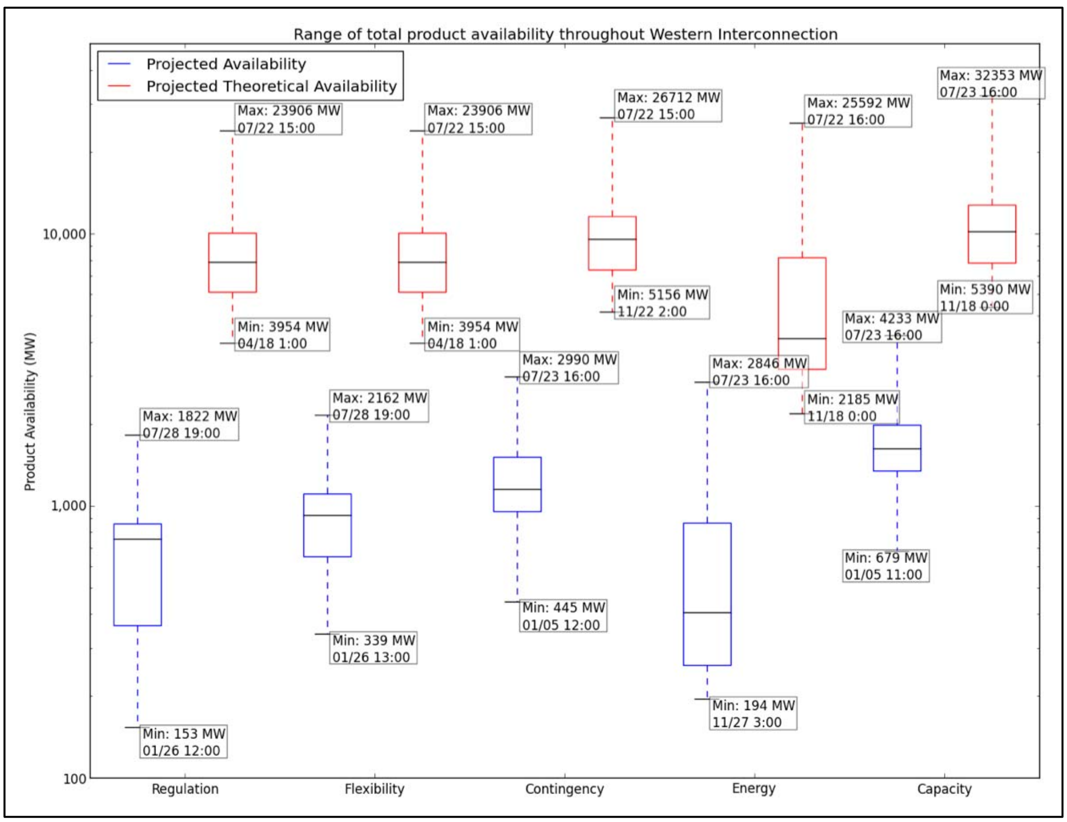

Figure 6: Product availability ranges with maximum and minimum hours

As seen in Figure 6, though most of the total projected product availability is in a somewhat narrow range (the blue boxes, representing the range between the first and third quartile), the maximum availability can be several times larger, as shown by the long whiskers for each product (representing the minimum and maximum values). The projected theoretical potential is also shown in red. The projected theoretical availability is discussed further in Section 3.4.

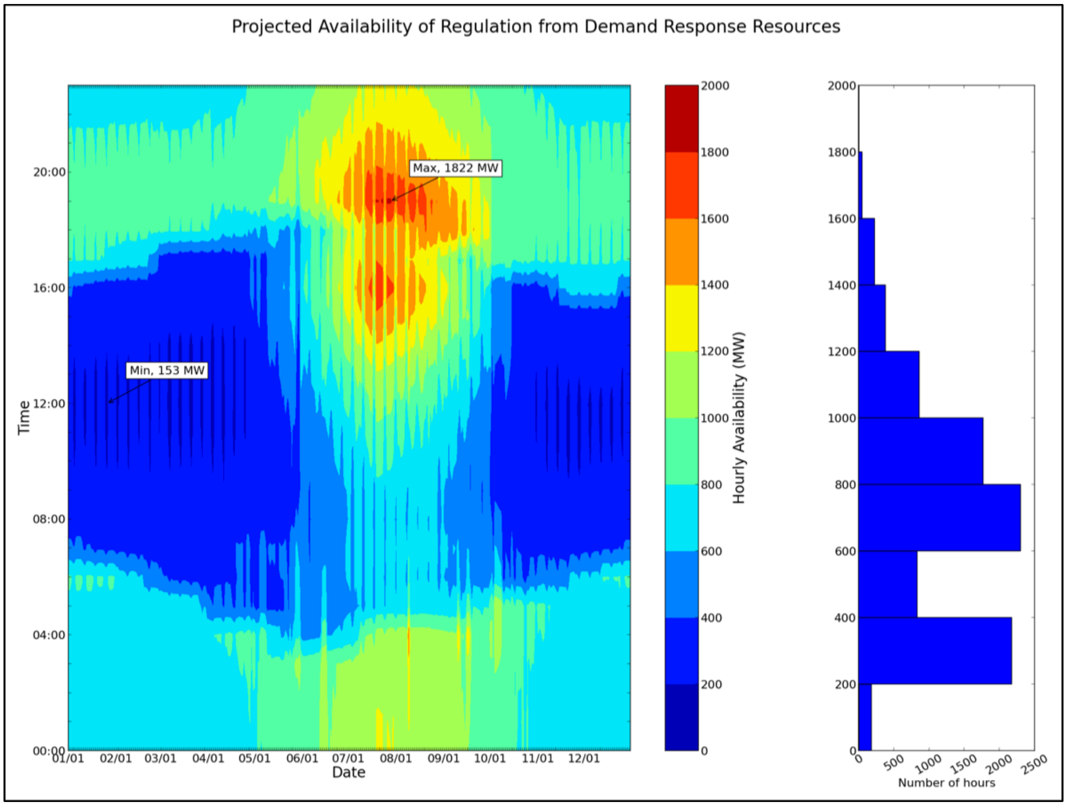

Figure 7: Availability pattern for regulation reserves

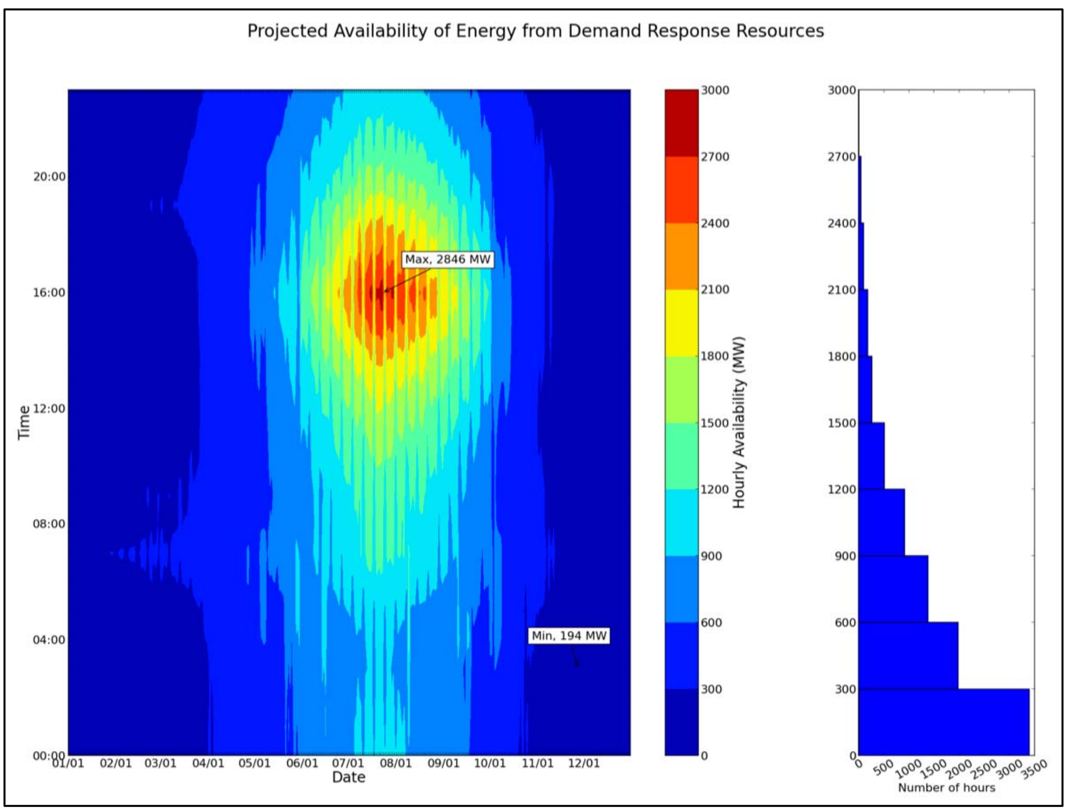

Figure 8: Availability pattern for the energy product

Over the course of a day, the availabilities from the resources vary, and reach their maximums at different times:

- Commercial lighting and ventilation peak during the hours of 8am-6pm.
- Commercial and residential heating peak from 7am-9am.
- Commercial and residential cooling peak from 12pm-8pm.
- Residential water heating peaks in the morning and evening.
- Municipal lighting peaks from 8pm-4am.
- Refrigerated warehouses peak from 12pm-4pm.
- Agricultural pumping, data centers, municipal pumping, wastewater pumping remain fairly flat.

These maximum availability times varied between balancing authority areas due to differences in the regional load shapes and assumed differences in the end-user population's willingness to shed load at different times of day (e.g. customers in areas with a history of afternoon demand response will be more willing to shed or shift loads in the afternoon compared to those in other areas).

Over the course of a year, the availabilities from each resource also reach their maximums at different periods:

- Agricultural pumping, commercial cooling, residential cooling, and refrigerated warehouses peak in the summer.
- Municipal lighting, commercial heating, and residential heating peak in the winter.
- Data centers, residential water heating, commercial lighting, commercial ventilation, municipal pumping, and wastewater pumping loads remain fairly constant over the year, with a regular weekday-weekend usage pattern.

These patterns are shown in Appendix E.

The daily and seasonal contributions of end-uses to contingency reserves can be seen in Figures 9a and 9b, respectively. Seasonally, residential cooling, commercial cooling, and agricultural irrigation peak in the summer, while municipal lighting and residential water heating peak in the winter. Daily, commercial cooling, lighting, and ventilation peak during mid-day, residential cooling peaks in the afternoon, and municipal lighting peaks at night. Commercial heating is omitted from the figures as less than 1 MW is available for contingency reserves; commercial heating has greater availability for the slower energy and capacity products.

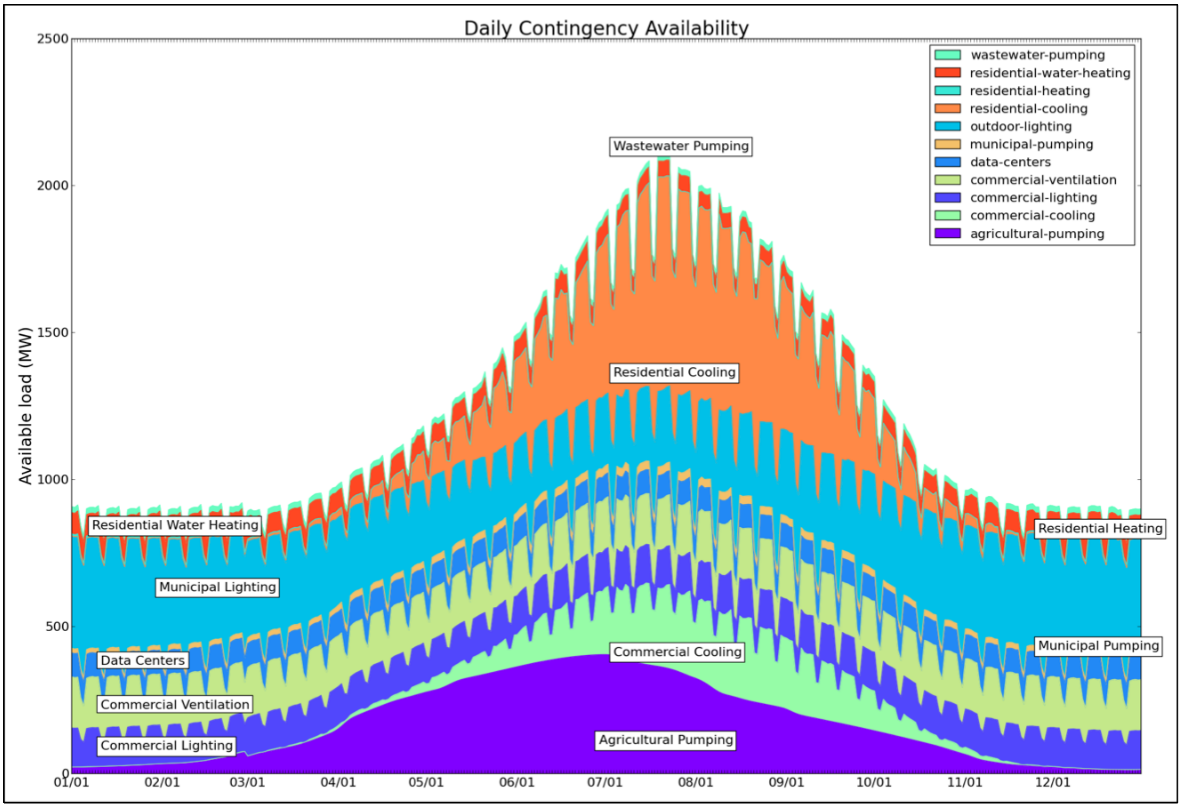


Figure 9a: Average daily contingency reserve availability over one year, by resource

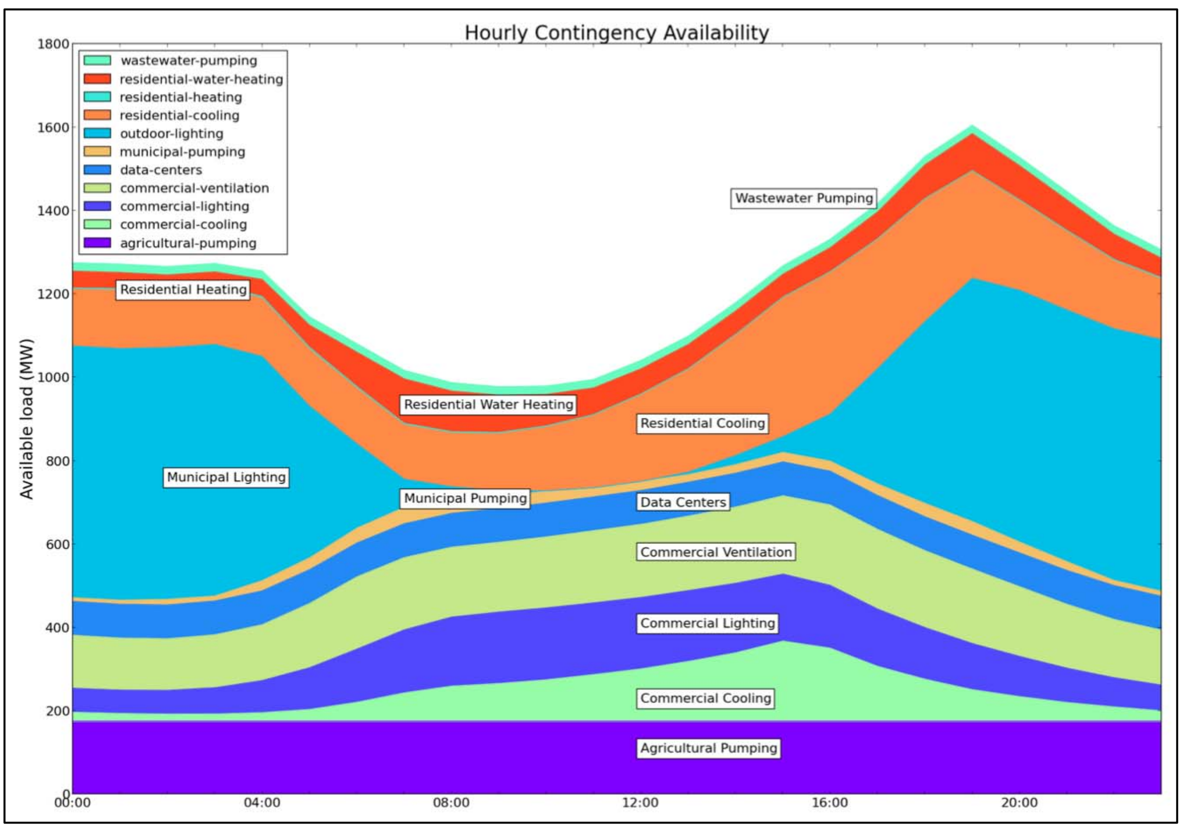


Figure 9b: Average hourly contingency reserve availability over one day, by resource

By dividing the hourly capacity product availability by the predicted load for each hour of the year, an estimation of the overall load flexibility can be established (the capacity product is chosen as it is the product with greatest potential). The 2020 load values used were the Transmission Expansion Planning Policy Committee (TEPPC) PC1 reference case (Western Electricity Coordinating Council 2011). For virtually the entire year, 1-3% of the total load can be shed, as shown in Figure 10. This available load fraction reaches its maximum during summer weekday mornings and evenings, and is at its minimum mid-day on winter weekends. This relative availability is less variable than the absolute capacity availability, as the total load and the available capacity are positively correlated (i.e. the increased cooling loads in summer also result in increased cooling availability). Patterns for all products relative to load can be seen in Appendix C. The availability of regulation ranges from 0.2-2.0% of load, flexibility ranges from 0.4-2.3%, contingency ranges from 0.5-2.8%, and energy ranges from 0.2-2.3%.

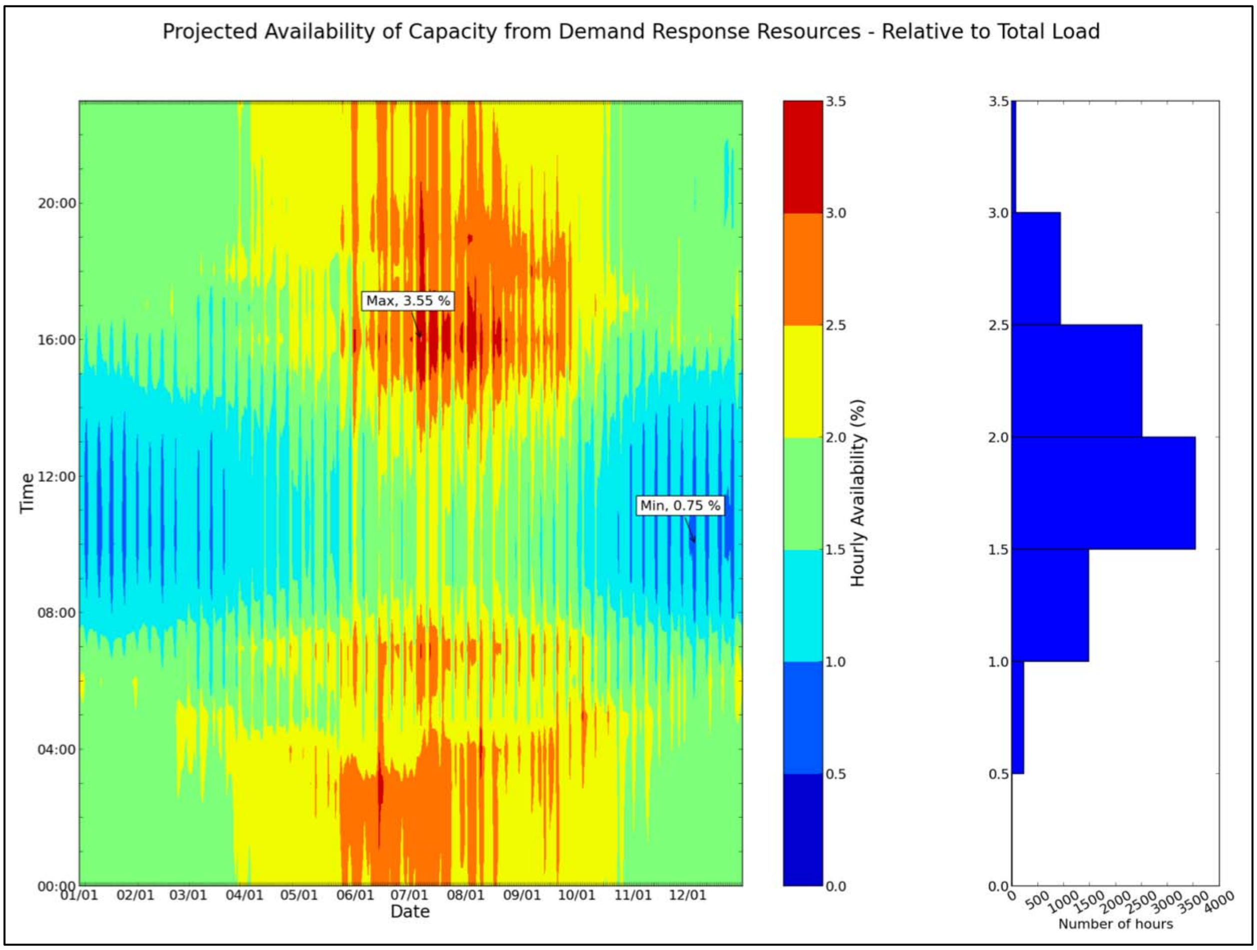


Figure 10: Ratio of capacity product availability to total load.

This ratio of product availability to load can also be explored geographically. Figure 11 shows the average contingency reserve availability as a percentage of average load over the course of the year, disaggregated by BAA. Generally, there is more availability in the southwestern states compared to the northwestern ones, with the PACE_ID BAA being a notable exception, with an average contingency product availability at 3.1% of average load. These ratios are influenced by the underlying load composition of the BAAs.

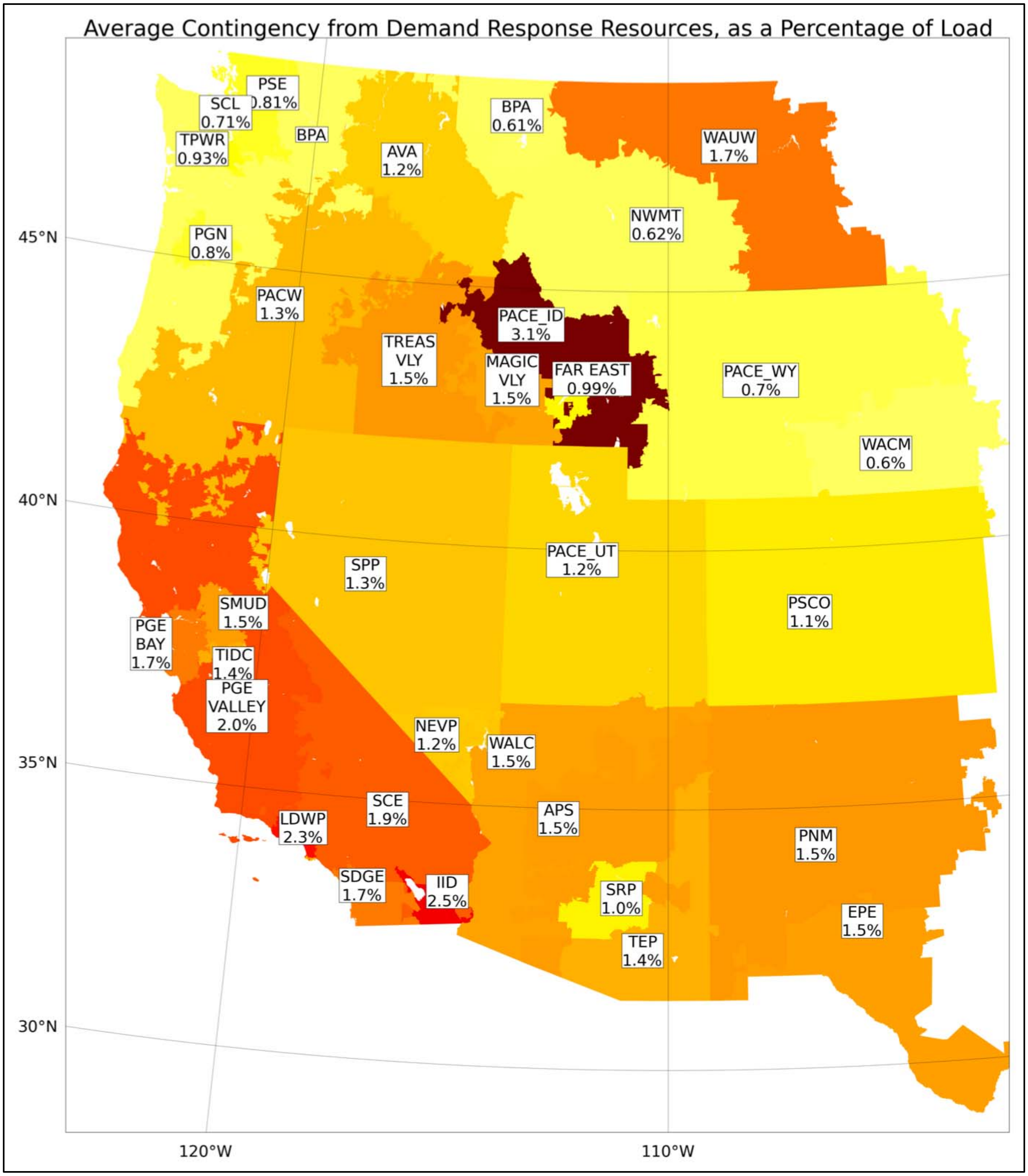


Figure 11: Ratio of average Contingency reserves availability from DR resources to average load, by BAA

## 3.2 Capacity and Energy Interpretations

Though capacity product availability was calculated as time-series values, for the purposes of grid planning it is a single number, representing additional generation capabilities during the top 20 hours of load. To find this value for the collection of demand response resources in each BAA, the top 20 hours of load in the BAA are identified, the capacity product availability from each resource is summed for each of the top hours, and the 20 hourly values are averaged to come up with a singular capacity value. The top load hours are derived from the TEPPC 2010 Study Program's PC1 reference case (Western Electricity Coordinating Council 2011). Thus, the capacity value represents the average DR availability from the selected resources during the 20 hours of highest load. Illustrations of this derivation in PSE, SCE, and AVA are shown in Figures 12a, 12b, and 12c, respectively. PSE is a winter-peaking system with maximum load capabilities in winter, and SCE is a summer-peaking system with maximum load capabilities in summer. However, there are also BAAs whose load peaks in the winter, but have maximum load capabilities in summer, such as AVA. In these cases, the collection of resources included in this study is suboptimal for meeting the capacity needs of the BAA.

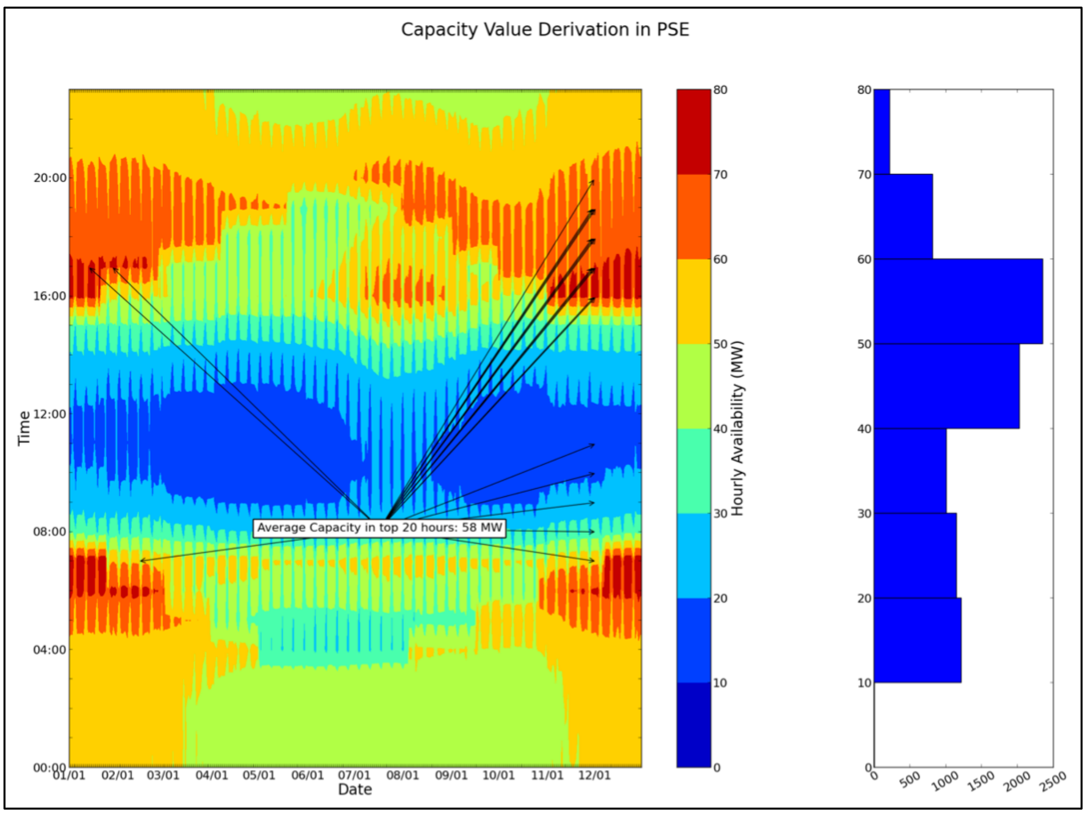


Figure 12a: Capacity value derivation in PSE

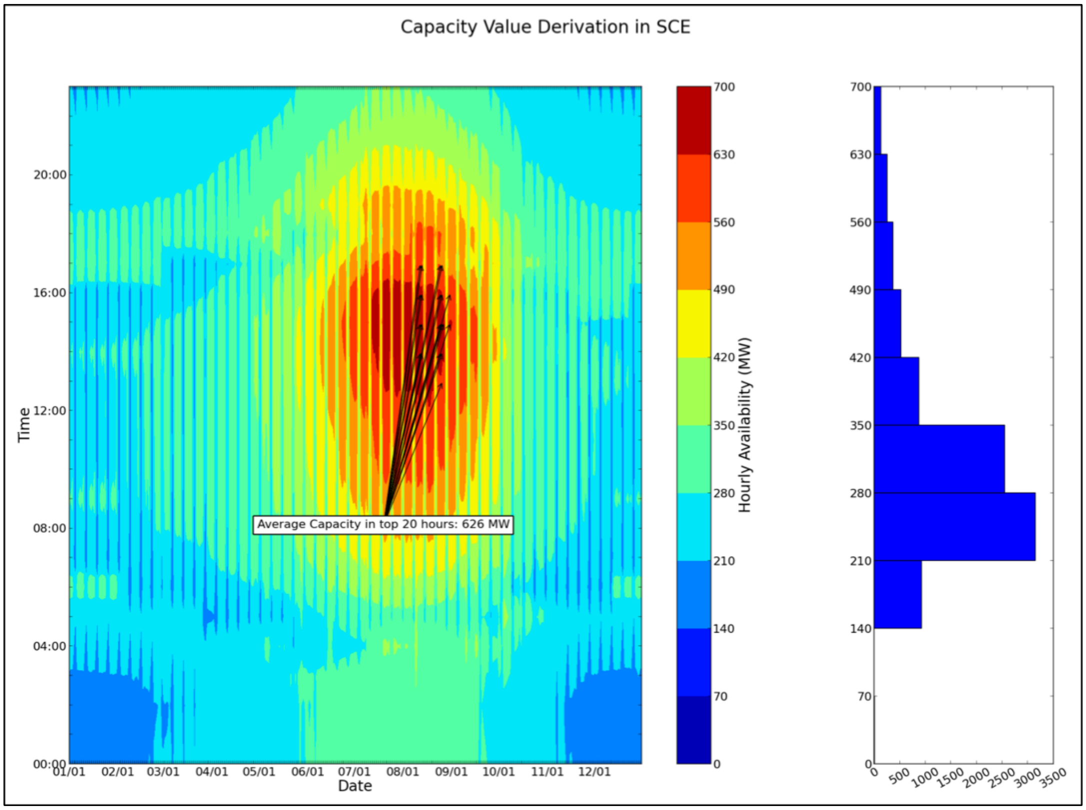


Figure 12b: Capacity value derivation in SCE

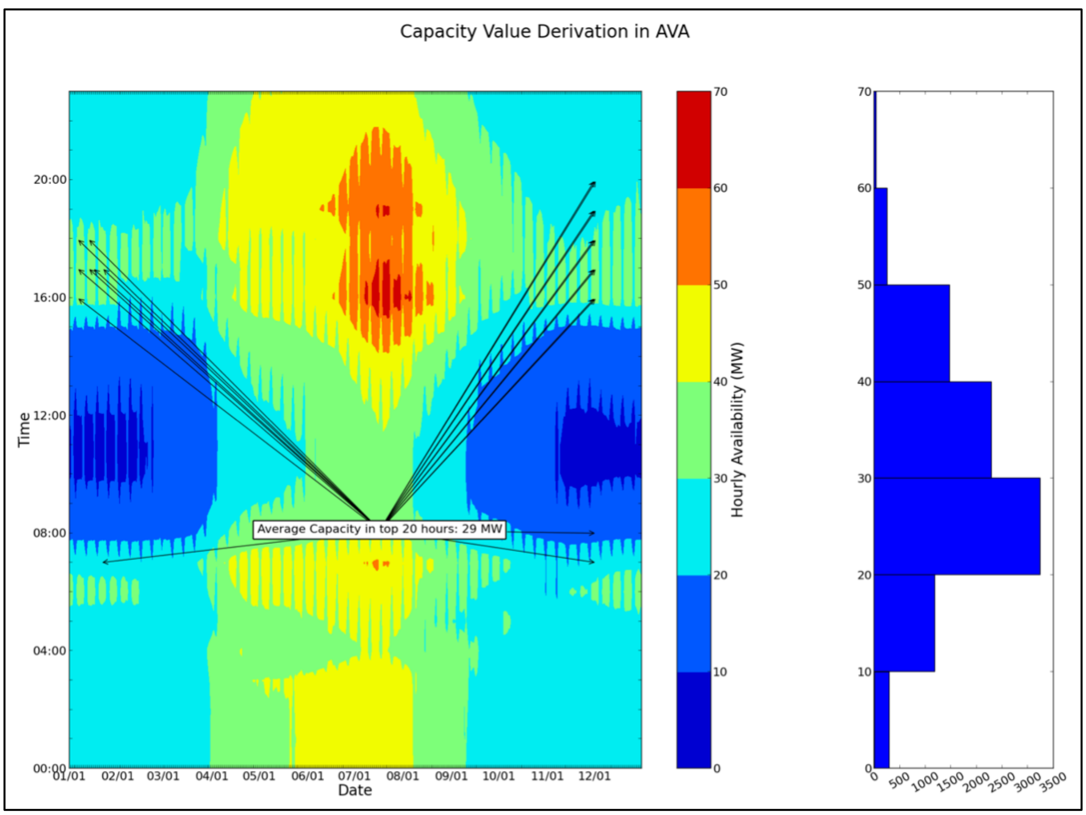


Figure 12c: Capacity value derivation in AVA

To estimate the maximum magnitude of energy which can be shifted in a single event using the energy product, an "available shift" was calculated for each hour by summing the potential energy shift from each resource (the sum of the availability from the start hour through the length of the maximum shed duration). For some resources, a maximum shed duration was not specified, but the lengths of the responses are constrained by the resource's need for energy re-charge: for these resources, the maximum shed duration was assumed to be equal to the re-charge duration. For resources with 24 hour re-charge windows, a 12-hour shed and 12-hour re-charge are assumed. The resulting values for each BAA are shown in Table 13.

## 3.3 BAA Summaries

Based on our analysis, there exists a wide range of load flexibility amongst the 36 BAAs. Not only are there large differences in average relative flexibility, there are also differences in the variability of this flexibility. These differences are due to differences in the relative magnitude of end-uses in each BAA and assumed differences in the end-user population's willingness to shed load. The range of product ability by BAA can be seen in Figures 13a, 13b, and 13c for regulation, flexibility, and contingency reserves, respectively. The product availability relative to load for all products can be seen in Table 9.

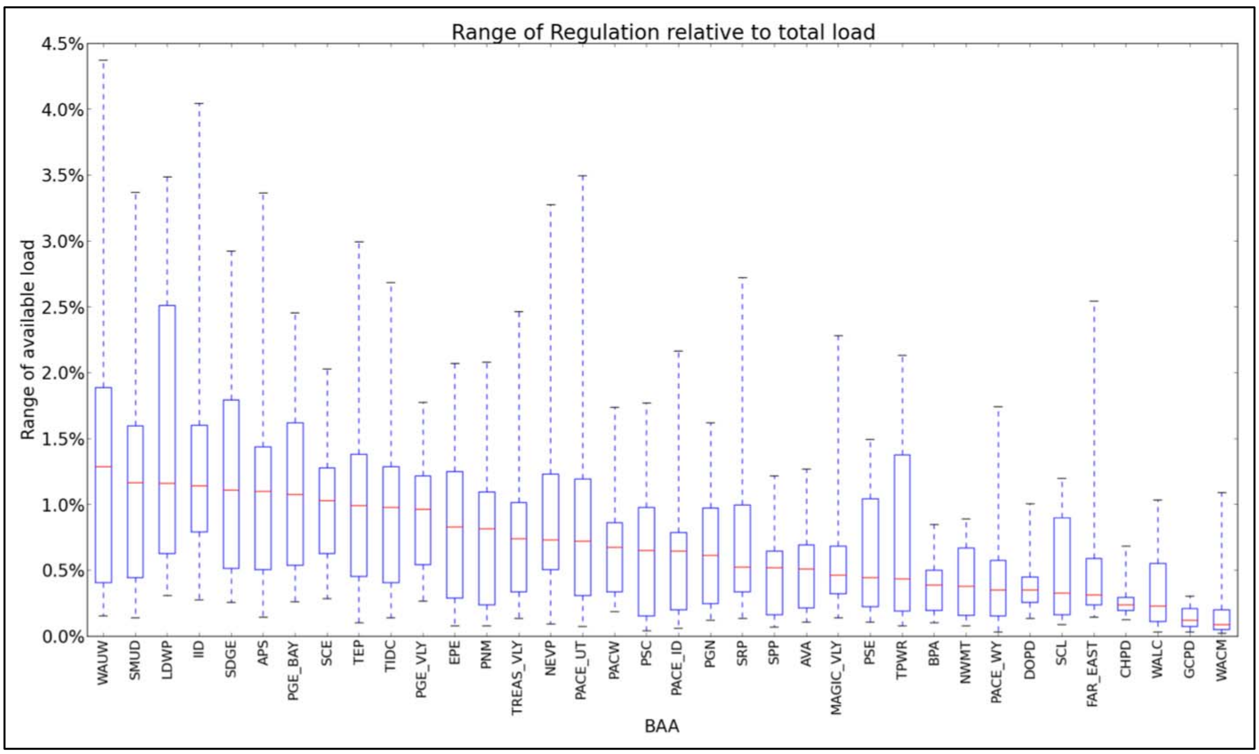


Figure 13a: Regulation reserves availability relative to total load, by BAA

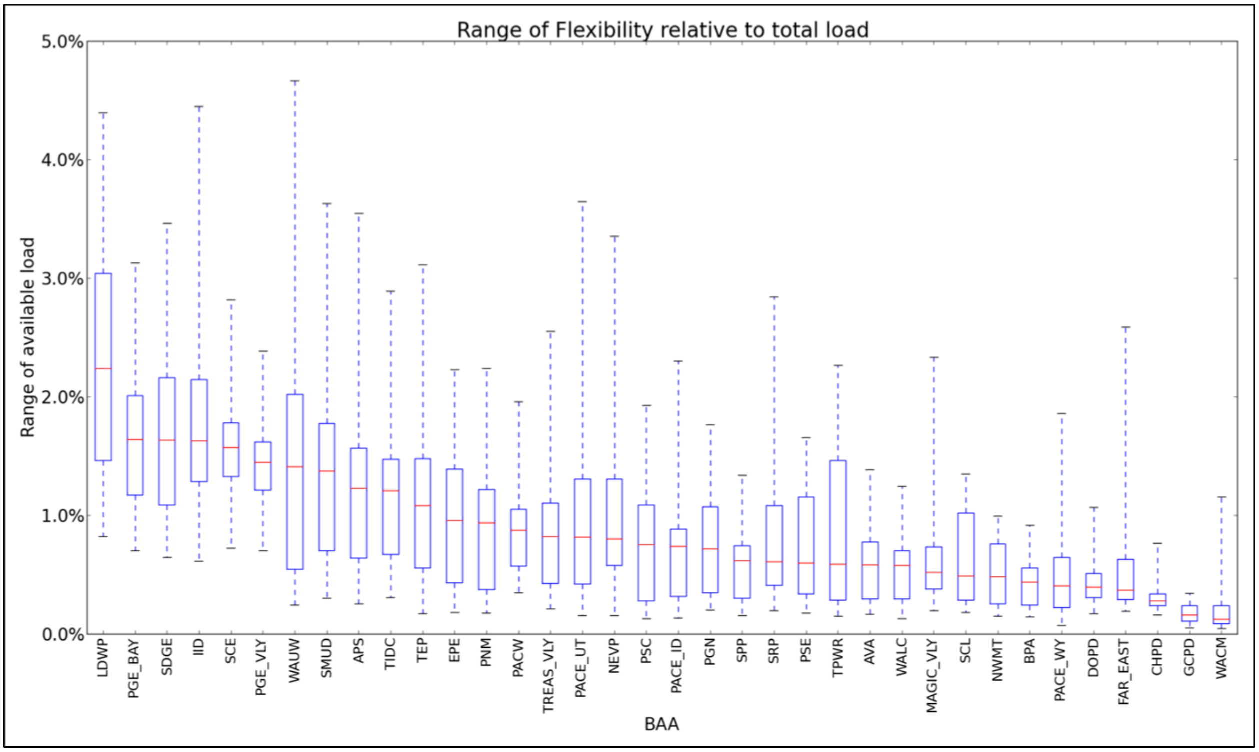

Figure 13b: Flexibility reserves availability relative to total load, by BAA

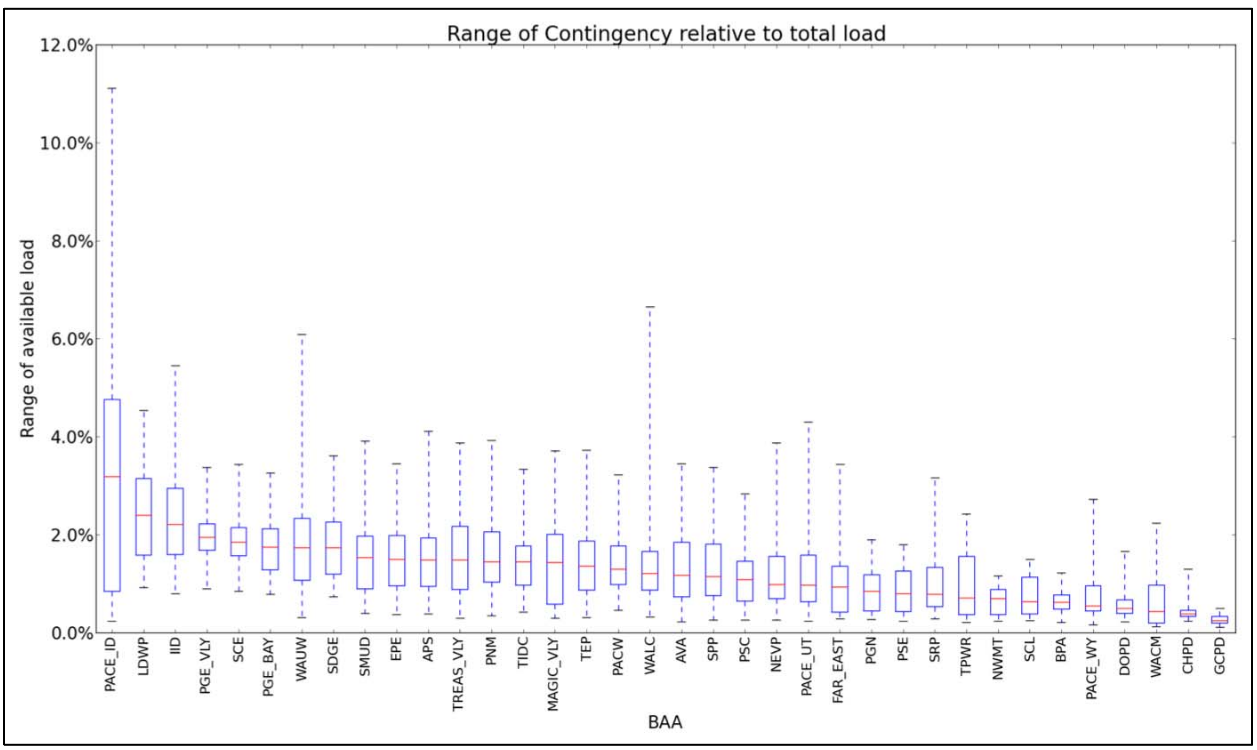

Figure 13c: Contingency reserves availability relative to total load, by BAA

Table 9: Summary of Product Capabilities, by Balancing Authority Area

| BAA | Hourly product availability relative to hourly total load: Minimum % - Maximum % (Average %) | | | | |
|---|---|---|---|---|---|
| | Regulation | Flexibility | Contingency | Energy | Capacity |
| APS | 0.14-3.36 (1.06) | 0.25-3.54 (1.19) | 0.38-4.10 (1.50) | 0.17-3.61 (1.03) | 0.52-5.17 (2.20) |
| AVA | 0.11-1.27 (0.46) | 0.16-1.38 (0.54) | 0.22-3.44 (1.23) | 0.20-2.33 (0.80) | 0.35-4.09 (1.78) |
| BPA | 0.10-0.85 (0.35) | 0.14-0.91 (0.40) | 0.21-1.22 (0.61) | 0.20-1.06 (0.42) | 0.31-1.90 (0.98) |
| CHPD | 0.13-0.69 (0.25) | 0.16-0.76 (0.30) | 0.23-1.29 (0.41) | 0.19-1.37 (0.37) | 0.33-2.32 (0.87) |
| DOPD | 0.14-1.00 (0.36) | 0.17-1.06 (0.41) | 0.22-1.66 (0.53) | 0.19-1.78 (0.49) | 0.34-2.66 (0.99) |
| EPE | 0.08-2.07 (0.75) | 0.18-2.23 (0.89) | 0.37-3.44 (1.49) | 0.17-3.74 (0.88) | 0.51-5.61 (2.28) |
| Far East | 0.14-2.54 (0.50) | 0.19-2.59 (0.55) | 0.28-3.43 (0.99) | 0.24-3.26 (0.84) | 0.40-4.32 (1.46) |
| GCPD | 0.03-0.30 (0.13) | 0.05-0.34 (0.16) | 0.11-0.49 (0.25) | 0.09-0.42 (0.18) | 0.15-1.11 (0.51) |
| IID | 0.27-4.04 (1.28) | 0.61-4.45 (1.86) | 0.80-5.45 (2.45) | 0.23-4.99 (1.76) | 1.14-6.18 (3.00) |
| LDWP | 0.31-3.49 (1.44) | 0.82-4.39 (2.15) | 0.92-4.53 (2.26) | 0.19-1.81 (0.51) | 1.41-5.08 (2.83) |
| Magic Vly. | 0.14-2.28 (0.61) | 0.20-2.33 (0.66) | 0.30-3.71 (1.46) | 0.20-3.36 (1.08) | 0.41-4.50 (1.89) |
| NEVP | 0.09-3.27 (0.94) | 0.15-3.35 (1.02) | 0.26-3.87 (1.25) | 0.15-4.73 (1.07) | 0.33-5.22 (1.67) |
| NWMT | 0.08-0.89 (0.40) | 0.15-0.99 (0.49) | 0.23-1.16 (0.62) | 0.16-1.23 (0.32) | 0.36-2.58 (1.24) |
| PACE_ID | 0.06-2.16 (0.60) | 0.14-2.30 (0.70) | 0.23-11.10 (3.13) | 0.16-6.77 (2.04) | 0.36-12.07 (3.79) |
| PACE_UT | 0.07-3.50 (0.88) | 0.16-3.64 (0.98) | 0.24-4.30 (1.18) | 0.15-4.45 (0.82) | 0.36-5.98 (1.85) |
| PACE_WY | 0.03-1.74 (0.42) | 0.07-1.86 (0.48) | 0.16-2.73 (0.70) | 0.11-2.99 (0.49) | 0.23-4.02 (1.15) |
| PACW | 0.19-1.74 (0.62) | 0.35-1.96 (0.83) | 0.46-3.22 (1.34) | 0.23-2.57 (0.73) | 0.65-4.62 (2.06) |
| PGE Bay | 0.26-2.45 (1.04) | 0.70-3.13 (1.58) | 0.78-3.26 (1.69) | 0.17-1.80 (0.47) | 1.20-3.73 (2.15) |
| PGE Vly. | 0.26-1.78 (0.88) | 0.70-2.38 (1.41) | 0.89-3.37 (1.96) | 0.20-2.22 (0.78) | 1.34-4.06 (2.42) |
| PGN | 0.12-1.62 (0.59) | 0.20-1.76 (0.69) | 0.27-1.90 (0.80) | 0.19-1.37 (0.38) | 0.40-2.86 (1.38) |
| PNM | 0.08-2.08 (0.73) | 0.17-2.24 (0.86) | 0.35-3.92 (1.53) | 0.17-2.92 (0.83) | 0.48-4.88 (2.27) |
| PSC | 0.04-1.77 (0.57) | 0.13-1.92 (0.69) | 0.25-2.84 (1.07) | 0.12-2.10 (0.48) | 0.34-4.05 (1.72) |
| PSE | 0.11-1.49 (0.60) | 0.18-1.65 (0.70) | 0.23-1.80 (0.81) | 0.19-0.95 (0.39) | 0.37-2.77 (1.44) |
| SCE | 0.29-2.03 (0.97) | 0.72-2.81 (1.56) | 0.85-3.43 (1.87) | 0.19-2.88 (0.78) | 1.32-4.52 (2.39) |
| SCL | 0.09-1.20 (0.49) | 0.18-1.35 (0.61) | 0.24-1.50 (0.71) | 0.17-0.64 (0.32) | 0.41-3.04 (1.54) |
| SDGE | 0.26-2.92 (1.10) | 0.64-3.46 (1.59) | 0.73-3.61 (1.70) | 0.17-1.64 (0.51) | 1.09-3.99 (2.09) |
| SMUD | 0.14-3.37 (1.09) | 0.30-3.63 (1.31) | 0.40-3.91 (1.50) | 0.19-2.96 (0.80) | 0.50-4.25 (1.68) |
| SPP | 0.07-1.22 (0.44) | 0.16-1.33 (0.56) | 0.26-3.37 (1.29) | 0.12-2.47 (0.72) | 0.37-3.96 (1.81) |
| SRP | 0.14-2.72 (0.72) | 0.19-2.84 (0.81) | 0.28-3.16 (1.02) | 0.13-3.55 (0.91) | 0.43-4.66 (1.74) |
| TEP | 0.10-2.99 (0.98) | 0.17-3.11 (1.07) | 0.31-3.72 (1.40) | 0.15-3.53 (0.94) | 0.41-4.33 (1.78) |
| TIDC | 0.14-2.68 (0.90) | 0.30-2.89 (1.14) | 0.43-3.33 (1.41) | 0.16-3.02 (0.79) | 0.57-3.62 (1.60) |
| TPWR | 0.08-2.13 (0.75) | 0.15-2.27 (0.84) | 0.21-2.42 (0.93) | 0.20-0.55 (0.32) | 0.26-2.60 (1.07) |
| Treas. Vly. | 0.14-2.46 (0.74) | 0.21-2.55 (0.82) | 0.29-3.87 (1.54) | 0.26-2.94 (1.05) | 0.42-4.44 (2.02) |
| WACM | 0.02-1.09 (0.16) | 0.04-1.15 (0.20) | 0.12-2.23 (0.60) | 0.09-2.14 (0.46) | 0.18-3.17 (0.98) |
| WALC | 0.03-1.03 (0.32) | 0.13-1.24 (0.51) | 0.33-6.65 (1.48) | 0.13-9.36 (1.17) | 0.51-11.32 (2.74) |
| WAUW | 0.15-4.37 (1.15) | 0.24-4.67 (1.29) | 0.31-6.09 (1.72) | 0.26-3.46 (0.82) | 0.38-6.65 (2.01) |

## 3.4 Projected Theoretical Availability in 2020

The projected theoretical availability of end-use availability was estimated by assuming full participation from the selected end-uses, setting controllability and acceptability to 100% in all hours. In this case, there is a maximum of 23,906 MW available for regulation and flexibility reserves, 26,712 MW available for contingency reserves, 25,592 MW available for the energy product, and 32,353 MW available for the capacity product. Generally, projected theoretical availability is around 10 times higher than the projected availability, with variations due to the end-use mixture in each area and the assumed controllability and acceptability. Tables 10, 11, and 12 show the projected maximum availability (MW), the projected cumulative availability (MWh), and the projected theoretical potential for both, for each of the ancillary services products. The maximum energy shift and capacity value, for both projected availability and projected theoretical potential, are listed in Table 13.

The projected theoretical availability of resources to contribute to the capacity product and contingency reserves, relative to total load, is shown in Figures 14a and 14b. Due to the dominance of cooling loads, this relative potential reaches its maximum during summer afternoons. For the capacity product, 7-27% of load is available, 7-22% is available for contingency reserves, 2-20% is available for the energy product, and 6-20% is available for flexibility and regulation reserves. This projected theoretical availability far exceeds current product requirements, which are under typically less than 5% of load. Projected theoretical availabilities for all products relative to load are contained in Appendix C.

Table 10: Projected Availability, Maximum and Cumulative, and Projected Theoretical Potential – Regulation Reserves

| Region | Projected Availability | | Projected Theoretical Availability | | Projected Cumulative Availability | Projected Cumulative Theoretical Availability |
|---|---|---|---|---|---|---|
| | Min | Max | Min | Max | | |
| Arizona | 12 MW | 307 MW | 525 MW | 5,089 MW | 797 GWh | 13,219 GWh |
| California North | 37 MW | 349 MW | 595 MW | 3,418 MW | 1,291 GWh | 11,248 GWh |
| California South | 55 MW | 497 MW | 906 MW | 5,095 MW | 1,854 GWh | 17,371 GWh |
| Colorado | 3 MW | 129 MW | 337 MW | 1,871 MW | 332 GWh | 6,318 GWh |
| Idaho | 3 MW | 75 MW | 96 MW | 796 MW | 149 GWh | 2,153 GWh |
| Montana | 1 MW | 12 MW | 53 MW | 253 MW | 48 GWh | 1,002 GWh |
| Nevada | 1 MW | 20 MW | 51 MW | 311 MW | 54 GWh | 968 GWh |
| Nevada South | 2 MW | 134 MW | 90 MW | 1,722 MW | 256 GWh | 3,114 GWh |
| New Mexico | 2 MW | 60 MW | 157 MW | 911 MW | 190 GWh | 3,145 GWh |
| Northwest | 23 MW | 193 MW | 713 MW | 2,826 MW | 785 GWh | 13,569 GWh |
| Utah | 3 MW | 186 MW | 198 MW | 1,414 MW | 219 GWh | 4,013 GWh |
| Wyoming | 1 MW | 28 MW | 51 MW | 406 MW | 327 GWh | 1,105 GWh |
| Total – Western Interconnection* | 153 MW | 1,822 MW | 3,954 MW | 23,906 MW | 6,139 GWh | 77,226 GWh |

*Columns may not sum to totals due to non-coincident maxima and independent rounding

Table 11: Projected Availability, Maximum and Cumulative, and Projected Theoretical Availability – Flexibility Reserves

| Region | Projected Availability | | Projected Theoretical Availability | | Projected Cumulative Availability | Projected Cumulative Theoretical Availability |
|---|---|---|---|---|---|---|
| | Min | Max | Min | Max | | |
| Arizona | 19 MW | 329 MW | 525 MW | 5,089 MW | 898 GWh | 13,219 GWh |
| California North | 95 MW | 453 MW | 595 MW | 3,418 MW | 1,936 GWh | 11,248 GWh |
| California South | 145 MW | 683 MW | 906 MW | 5,095 MW | 2,877 GWh | 17,371 GWh |
| Colorado | 9 MW | 139 MW | 337 MW | 1,871 MW | 399 GWh | 6,318 GWh |
| Idaho | 4 MW | 78 MW | 96 MW | 796 MW | 165 GWh | 2,153 GWh |
| Montana | 2 MW | 14 MW | 53 MW | 253 MW | 59 GWh | 1,002 GWh |
| Nevada | 2 MW | 23 MW | 51 MW | 311 MW | 68 GWh | 968 GWh |
| Nevada South | 4 MW | 139 MW | 90 MW | 1,722 MW | 276 GWh | 3,114 GWh |
| New Mexico | 5 MW | 66 MW | 157 MW | 911 MW | 224 GWh | 3,145 GWh |
| Northwest | 38 MW | 216 MW | 713 MW | 2,826 MW | 940 GWh | 13,569 GWh |
| Utah | 6 MW | 192 MW | 198 MW | 1,414 MW | 364 GWh | 4,013 GWh |
| Wyoming | 1 MW | 29 MW | 51 MW | 406 MW | 66 GWh | 1,105 GWh |
| Total – Western Interconnection* | 339 MW | 2,162 MW | 3,954 MW | 23,906 MW | 8,273 GWh | 77,226 GWh |

Table 12: Projected Availability, Maximum and Cumulative, and Projected Theoretical Availability – Contingency Reserves

| Region | Projected Availability | | Projected Theoretical Availability | | Projected Cumulative Availability | Projected Cumulative Theoretical Availability |
|---|---|---|---|---|---|---|
| | Min | Max | Min | Max | | |
| Arizona | 32 MW | 494 MW | 598 MW | 5,221 MW | 1,204 GWh | 14,241 GWh |
| California North | 114 MW | 535 MW | 733 MW | 3,941 MW | 2,395 GWh | 13,914 GWh |
| California South | 166 MW | 749 MW | 1,040 MW | 5,477 MW | 3,318 GWh | 19,635 GWh |
| Colorado | 20 MW | 212 MW | 459 MW | 2,301 MW | 706 GWh | 8,168 GWh |
| Idaho | 7 MW | 138 MW | 136 MW | 1,184 MW | 394 GWh | 3,639 GWh |
| Montana | 3 MW | 18 MW | 62 MW | 267 MW | 75 GWh | 1,078 GWh |
| Nevada | 4 MW | 49 MW | 68 MW | 462 MW | 158 GWh | 1,530 GWh |
| Nevada South | 7 MW | 190 MW | 105 MW | 1,749 MW | 339 GWh | 3,280 GWh |
| New Mexico | 10 MW | 104 MW | 217 MW | 1,117 MW | 389 GWh | 4,087 GWh |
| Northwest | 63 MW | 298 MW | 942 MW | 3,259 MW | 1,338 GWh | 15,806 GWh |
| Utah | 10 MW | 228 MW | 228 MW | 1,488 MW | 442 GWh | 4,379 GWh |
| Wyoming | 3 MW | 43 MW | 65 MW | 441 MW | 96 GWh | 1,252 GWh |
| Total – Western Interconnection* | 445 MW | 2,990 MW | 5,156 MW | 26,712 MW | 10,855 GWh | 90,011 GWh |

*Columns may not sum to totals due to non-coincident maxima and independent rounding

Table 13: Projected Availability and Projected Theoretical Availability of Energy and Capacity Products

| BAA | Projected Capacity | Projected Theoretical Capacity | Projected Energy Shift | | Projected Theoretical Energy Shift | |
|---|---|---|---|---|---|---|
| | | | Min | Max | Min | Max |
| APS | 162 MW | 1,920 MW | 60 MWh | 1,312 MWh | 502 MWh | 16,385 MWh |
| AVA | 29 MW | 214 MW | 32 MWh | 285 MWh | 275 MWh | 3,200 MWh |
| BPA | 68 MW | 788 MW | 97 MWh | 478 MWh | 801 MWh | 5,456 MWh |
| CHPD | 5.2 MW | 65 MW | 7 MWh | 35 MWh | 57 MWh | 391 MWh |
| DOPD | 3.3 MW | 50 MW | 4 MWh | 25 MWh | 32 MWh | 295 MWh |
| EPE | 31 MW | 434 MW | 17 MWh | 252 MWh | 152 MWh | 2,767 MWh |
| Far East | 7.6 MW | 82 MW | 6 MWh | 97 MWh | 52 MWh | 1,184 MWh |
| GCPD | 2.6 MW | 24 MW | 4.4 MWh | 9.5 MWh | 30 MWh | 82 MWh |
| IID | 41 MW | 302 MW | 8 MWh | 326 MWh | 60 MWh | 3,230 MWh |
| LDWP | 140 MW | 817 MW | 43 MWh | 412 MWh | 313 MWh | 3,619 MWh |
| Magic Vly. | 24 MW | 235 MW | 8 MWh | 216 MWh | 68 MWh | 2,588 MWh |
| NEVP | 168 MW | 1,853 MW | 32 MWh | 1,428 MWh | 246 MWh | 17,572 MWh |
| NWMT | 17 MW | 211 MW | 15 MWh | 86 MWh | 100 MWh | 952 MWh |
| PACE_ID | 36 MW | 282 MW | 4 MWh | 251 MWh | 32 MWh | 2,866 MWh |
| PACE_UT | 193 MW | 1,455 MW | 48 MWh | 1,731 MWh | 304 MWh | 11,944 MWh |
| PACE_WY | 28 MW | 387 MW | 11 MWh | 293 MWh | 97 MWh | 3739 MWh |
| PACW | 50 MW | 424 MW | 49 MWh | 426 MWh | 433 MWh | 4,731 MWh |
| PGE Bay | 173 MW | 1,084 MW | 60 MWh | 646 MWh | 439 MWh | 6,144 MWh |
| PGE Vly. | 314 MW | 2,113 MW | 104 MWh | 1,537 MWh | 825 MWh | 14,817 MWh |
| PGN | 53 MW | 310 MW | 43 MWh | 232 MWh | 342 MWh | 2,690 MWh |
| PNM | 54 MW | 627 MW | 25 MWh | 393 MWh | 243 MWh | 4,701 MWh |
| PSC | 112 MW | 1,415 MW | 54 MWh | 827 MWh | 456 MWh | 10,147 MWh |
| PSE | 58 MW | 389 MW | 54 MWh | 150 MWh | 398 MWh | 1,584 MWh |
| SCE | 626 MW | 4,141 MW | 173 MWh | 2,775 MWh | 1,334 MWh | 26,381 MWh |
| SCL | 26 MW | 168 MW | 17 MWh | 35 MWh | 130 MWh | 329 MWh |
| SDGE | 89 MW | 606 MW | 36 MWh | 401 MWh | 278 MWh | 4,005 MWh |
| SMUD | 84 MW | 792 MW | 27 MWh | 655 MWh | 214 MWh | 7,352 MWh |
| SPP | 56 MW | 475 MW | 12 MWh | 294 MWh | 102 MWh | 3,323 MWh |
| SRP | 196 MW | 2,183 MW | 58 MWh | 1,357 MWh | 480 MWh | 17,043 MWh |
| TEP | 49 MW | 570 MW | 25 MWh | 435 MWh | 203 MWh | 5,519 MWh |
| TIDC | 13 MW | 115 MW | 4 MWh | 99 MWh | 30 MWh | 1,076 MWh |
| TPWR | 9.0 MW | 52 MW | 9 MWh | 17 MWh | 74 MWh | 174 MWh |
| Treas. Vly. | 58 MW | 585 MW | 26 MWh | 425 MWh | 220 MWh | 5,085 MWh |
| WACM | 61 MW | 634 MW | 16 MWh | 528 MWh | 150 MWh | 6,532 MWh |
| WALC | 32 MW | 562 MW | 7 MWh | 362 MWh | 58 MWh | 2,430 MWh |
| WAUW | 2.1 MW | 21 MW | 1 MWh | 17 MWh | 14 MWh | 209 MWh |

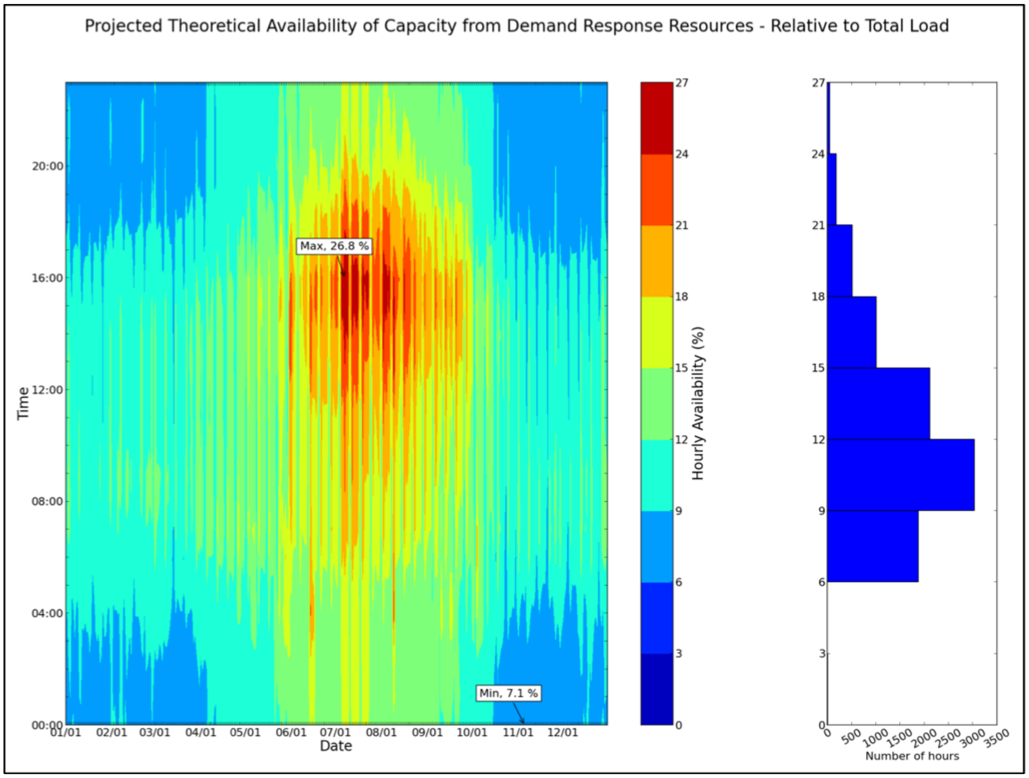


Figure 14a: Projected theoretical availability of the capacity product across the Western Interconnection, relative to total load

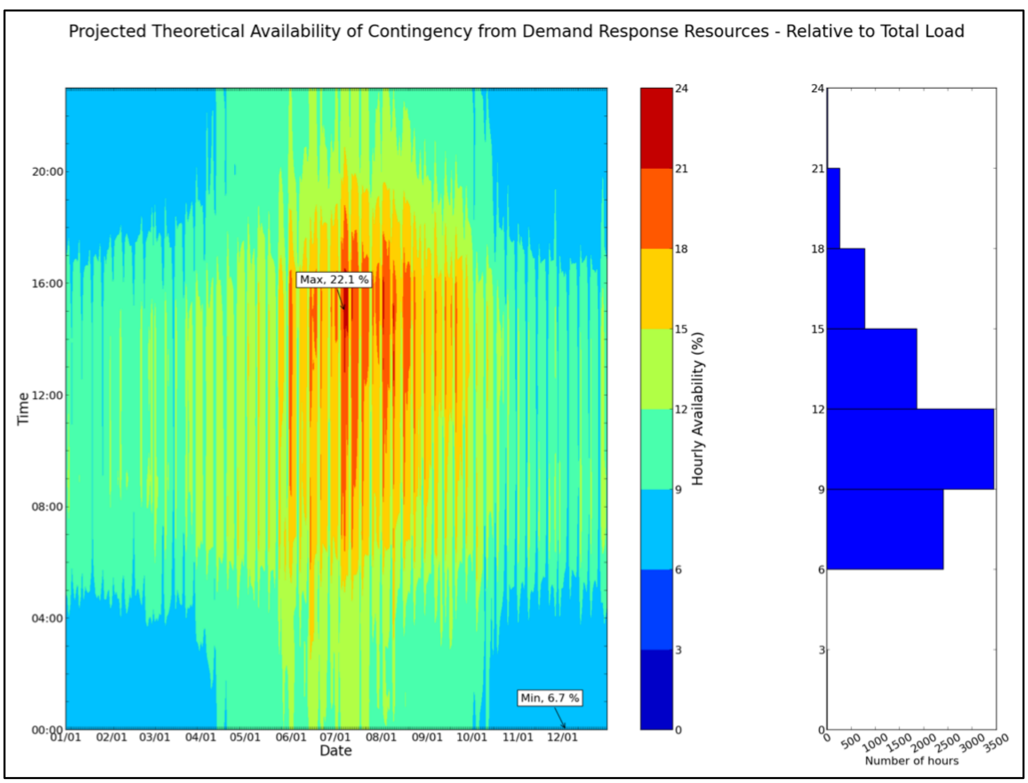


Figure 14b: Projected theoretical availability of contingency reserves across the Western Interconnection, relative to total load

# CHAPTER 4: Discussion, Conclusions, and Areas of Future Research

## 4.1 Discussion

Our analysis of load capabilities predicts significant availability from end-use resources. Our results are similar in magnitude to estimates made in the 2012 Federal Energy Regulatory Commission (FERC) survey by the Western Energy Coordinating Council (WECC), the organization responsible for coordination within the Western Interconnection. We predict a maximum availability of 4,233 MW from the capacity product, the product with greatest availability. WECC reported potential peak load reductions of 5,284 MW and realized peak load reductions of 2,870 MW (FERC 2012). However, this total includes 15 types of peak load reduction programs, many of which do not map to our selected products.

Our results, relative to total load, are slightly lower than current figures for PJM and ISO New England (ISO-NE). PJM serves the mid-Atlantic region and parts of the eastern Midwest, while ISO-NE serves Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont. Recent DR events in PJM shed ~5% of load in one zone, and ISO-NE projects a DR capacity of ~6.6% of their peak load (PJM 2013, ISO-NE 2013). However, PJM and NE-ISO have different market rules and structures than the Western Interconnect that may provide additional revenue streams (e.g., forward capacity market revenues), able to attract additional DR-capable loads and that encourage enablement and customer outreach.

Though our projected load availability seems consistent with other estimates, care should be taken in interpreting our results. Our analysis does not take into account the economics of participation, the effort required to enable the end-uses to communicate with grid operators, the effort required to control the end-uses effectively, or the impact on the distribution grid of high penetrations of responsive load. A sensitivity analysis, linking the nonlinear association between decisions about load capabilities and their resulting valuations, would be useful in identifying the most important input parameters. Data to confirm and refute the predictions of load capabilities must be gathered and analyzed, and our load capability assumptions revised. An assessment of the uncertainty and variability in the overall availability profiles would be a valuable addition.

In conducting this study, we also note the paucity of high-resolution, broadly representative, time-series data on the electrical demand of end-uses. Therefore, many high-level assumptions are made to extrapolate and interpolate the data gathered into a format that is suitable for the market and grid modeling. Current and future work, such as the newly released *Commercial and Residential Hourly Load Profiles for all TMY3 Locations in the United States* (National Renewable Energy Laboratory 2013), can offer a more accurate assessment of the baseline behavior of loads.

## 4.2 Conclusions

We conducted a detailed investigation of end-use capabilities and load data, and developed key filters to estimate their availability. Our results provide an initial estimate of the magnitude of bulk power system services available from end-use loads, and constraints on their use. We present a transparent approach to predicting end-use availability that is as data-driven as possible. By design, the DR data sets are results of various aggregations and analysis decisions due to data limitations. Nonetheless, the results are the first significant efforts on how to produce such data sets. They are suitable for scoping studies, ground-truthing models, and prioritizing future data gathering and analyses. The use of analysis criteria using "sheddability", "controllability", and "acceptability" as qualitative and quantitative filters is novel, testable, and extensible to other regions in the US.

The resulting DR data sets from this report serve as input to a production cost model. We discuss the resulting valuation of DR, including how characteristics of products are valued, in accompanying "results" reports (Hummon *et al.* 2013). Our efforts to value load participation assess the projected theoretical availability and economic incentives for load to participate in capacity, energy, and ancillary services markets; however, they do not cover the regulatory and market aspects of load participation. These issues are discussed in a recently released report developed as part of this project, *Market and Policy Barriers for Demand Response Providing Ancillary Services in U.S. Markets* (Cappers *et al.* 2013).

## 4.3 Future Research

There have been few large-scale assessments of the capabilities of electric end-use loads to respond to various wholesale market products other than for shaving peak loads. In this work, a relatively small number of case studies and experiences gathered in the field through demonstration projects are extrapolated to a large and diverse population of loads across several states. This work has also relied heavily on engineering estimates of end-use load characteristics and their controllability.

Further work to assess the capabilities of end-use loads to respond to a variety of wholesale market products and situations expected to occur due to large scale deployment of renewable resources is needed. Such work will assist in confirming and refining the assumptions of end-use load flexibility. There are key outstanding questions that exist well beyond the scope of this study which include:

- What communications and control architecture will be the lowest cost platform to enable these loads to participate in the wholesale markets and products described in this report?
- What are the latency, control, and communications challenges for fast demand response systems both on the grid side and within the building and end-use load controls?

- What type of aggregation system allows the best deployment platform to automate these systems and use them in multiple DR products? How can we automate once and use many times?
- What is the frequency, duration and response time of individual and aggregated DR resources?
- What price points and payment options will motivate the end-users to participate and enroll their loads in these wholesale market products?

Suggested follow-on work includes:

- Collection and analysis of multi-region, high-resolution end-use demand profiles to improve estimates of baseline load and DR data sets.
- Field testing DR end-uses and control systems to quantify their response characteristics and flexibility. This should include the telemetry and control system architectures and equipment costs.
- Analysis of distribution system stability during DR events in areas with high penetrations of flexible loads.
- Detailed assessments of consumer behavior and preferences regarding demand response participation, including customer fatigue (reduced willingness to respond to events in close proximity to previous events) and price elasticity (the relationship between price and magnitude of participation).

These additional analyses will test the assumptions used in this report and refine projections of the potential capabilities of demand response resources to serve as alternatives and complements to conventional supply options. These future studies will require careful research designs that facilitate access to data for researchers and market participants. This is a large area of research and will require cooperation among national, state, and local agencies in developing a common vision for new technology, markets, and policies for advanced DR participation.

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# GLOSSARY

*Abbreviations*

| | |
|---|---|
| BAA | Balancing Authority Area |
| CEC | California Energy Commission |
| CEUS | Commercial End-use Survey |
| DLC | Direct Load Control |
| DR | Demand Response |
| DRRC | Demand Response Research Center |
| EPA | Environmental Protection Agency |
| FERC | Federal Energy Regulatory Commission |
| GWh | Gigawatt-hour |
| LBNL | Lawrence Berkeley National Laboratory |
| MW | Megawatt |
| NPCC | Northwest Power and Conservation Council |
| NREL | National Renewable Energy Laboratory |
| PCT | Programmable Communication Thermostat |
| RECS | Residential Energy Consumption Survey |
| TOU | Time of Use |
| USDA | United States Department of Agriculture |
| US DOE | United States Department of Energy |

*Balancing Authority Area Abbreviations*

| | |
|---|---|
| APS | Arizona Public Service Company |
| AVA | Avista Corporation |
| BPA | Bonneville Power Administration |
| CHPD | PUD No. 1 of Chelan County |
| DOPD | PUD No. 1 of Douglas County |
| EPE | El Paso Electric Company |
| Far East | Idaho Power – Far East Region |
| GCPD | PUD No. 2 of Grant County |
| IID | Imperial Irrigation District |
| LDWP | Los Angeles Department of Water and Power |
| Magic Vly. | Idaho Power – Magic Valley Region |
| NEVP | Nevada Power Company |
| NWMT | NorthWestern Energy |
| PACE_ID | PacifiCorp East - Idaho |
| PACE_UT | PacifiCorp East – Utah |
| PACE_WY | PacifiCorp East – Wyoming |
| PACW | PacifiCorp West |
| PGE Bay | Pacific Gas and Electric Company – San Francisco Bay Area |
| PGE Vly. | Pacific Gas and Electric Company – Central Valley |
| PGN | Portland General Electric Company |
| PNM | Public Service Company of New Mexico |
| PSC | Public Service Company of Colorado |
| PSE | Puget Sound Energy |
| SCE | Southern California Edison |
| SCL | Seattle City Light |
| SDGE | San Diego Gas and Electric |
| SMUD | Sacramento Municipal Utilities District |
| SPP | Sierra Pacific Power Company |
| SRP | Salt River Project |
| TEP | Tucson Electric Power Company |
| TIDC | Turlock Irrigation Distict |
| TPWR | City of Tacoma, Department of Public Utilities |
| Treas. Vly. | Idaho Power – Treasure Valley Region |
| WACM | Western Area Power Administration – Colorado-Missouri Region |
| WALC | Western Area Power Administration – Lower Colorado Region |
| WAUW | Western Area Power Administration – Upper Great Plains West |

Adapted from *Western Interconnection Balancing Authorities (38).*
http://www.wecc.biz/library/WECC%2520Documents/Publications/WECC_BA_Map.pdf

# Appendix A - Tables of Flexibility Factor Values

The range of values accounts for both differences between BAAs and differences between hours within BAAs. For resources assumed to have time-varying participation, controllability and acceptability values were used. For resources assumed to have constant participation rates, only a participation value is specified.

| Commercial Cooling | | | |
|---|---|---|---|
| Product | Sheddable | Controllable | Acceptable |
| Regulation | 51-58% | 7-16% | 0.3-7% |
| Contingency | 51-58% | 7-16% | 3-77% |
| Flexibility | 51-58% | 7-16% | 1-21% |
| Energy | 41-49% | 15-25% | 3-77% |
| Capacity | 41-49% | 15-25% | 3-77% |

| Commercial Heating | | | |
|---|---|---|---|
| Product | Sheddable | Controllable | Acceptable |
| Regulation | 53-64% | 7-16% | 0-0.6% |
| Contingency | 53-64% | 7-16% | 0-1.8% |
| Flexibility | 53-64% | 7-16% | 0-1.8% |
| Energy | 46-51% | 10-25% | 0-77% |
| Capacity | 46-51% | 10-25% | 0-77% |

| Commercial Lighting | | | |
|---|---|---|---|
| Product | Sheddable | Controllable | Acceptable |
| Regulation | 26-28% | 7-11% | 0.3-7% |
| Contingency | 26-28% | 7-11% | 1-21% |
| Flexibility | 26-28% | 7-11% | 1-21% |
| Energy | 26-28% | 15-17% | 3-77% |
| Capacity | 26-28% | 15-17% | 3-77% |

| Commercial Ventilation | | | |
|---|---|---|---|
| Product | Sheddable | Controllable | Acceptable |
| Regulation | 53-59% | 8-16% | 0.3-7% |
| Contingency | 53-59% | 8-16% | 1-21% |
| Flexibility | 53-59% | 8-16% | 1-21% |
| Energy | 46-49% | 17-25% | 3-77% |
| Capacity | 46-49% | 17-25% | 3-77% |

| Residential Cooling | | | |
|---|---|---|---|
| Product | Sheddable | Controllable | Acceptable |
| Regulation | 70% | 13-26% | 0-39% |
| Contingency | 70% | 13-26% | 13-39% |
| Flexibility | 70% | 13-26% | 0-39% |
| Energy | 20-70% | 2-52% | 13-39% |
| Capacity | 20-70% | 2-52% | 13-39% |

| Residential Heating | | | |
|---|---|---|---|
| Product | Sheddable | Controllable | Acceptable |
| Regulation | 30% | 2% | 0-1.5% |
| Contingency | 30% | 2% | 0-1.5% |
| Flexibility | 30% | 2% | 0-1.5% |
| Energy | 20-30% | 2-48% | 0-1.5% |
| Capacity | 20-30% | 2-48% | 0-1.5% |

| Residential Water Heating | | | |
|---|---|---|---|
| Product | Sheddable | Controllable | Acceptable |
| Regulation | 25% | 13-26% | 13-39% |
| Contingency | 25% | 13-26% | 13-39% |
| Flexibility | 25% | 13-26% | 13-39% |
| Energy | 25% | 13-26% | 13-39% |
| Capacity | 25% | 13-26% | 13-39% |

| Agricultural Irrigation Pumping | | |
|---|---|---|
| Product | Sheddable | Participation rate |
| Regulation | 100% | 0% |
| Contingency | 100% | 15% |
| Flexibility | 100% | 0% |
| Energy | 100% | 10% |
| Capacity | 100% | 15% |

| Data Centers | | |
|---|---|---|
| Product | Sheddable | Participation rate |
| Regulation | 3% | 100% |
| Contingency | 3% | 100% |
| Flexibility | 3% | 100% |
| Energy | 3% | 100% |
| Capacity | 3% | 100% |

| Municipal Lighting | | |
|---|---|---|
| Product | Sheddable | Participation rate |
| Regulation | 5% | 100% |
| Contingency | 5% | 100% |
| Flexibility | 5% | 100% |
| Energy | 0% | 0% |
| Capacity | 5% | 100% |

| Municipal Pumping | | |
|---|---|---|
| Product | Sheddable | Participation rate |
| Regulation | 0% | 0% |
| Contingency | 5% | 50% |
| Flexibility | 5% | 50% |
| Energy | 5% | 25% |
| Capacity | 5% | 25% |

| Refrigerated Warehouses | | |
|---|---|---|
| Product | Sheddable | Participation rate |
| Regulation | 0% | 100% |
| Contingency | 10% | 100% |
| Flexibility | 0% | 100% |
| Energy | 5% | 100% |
| Capacity | 10% | 100% |

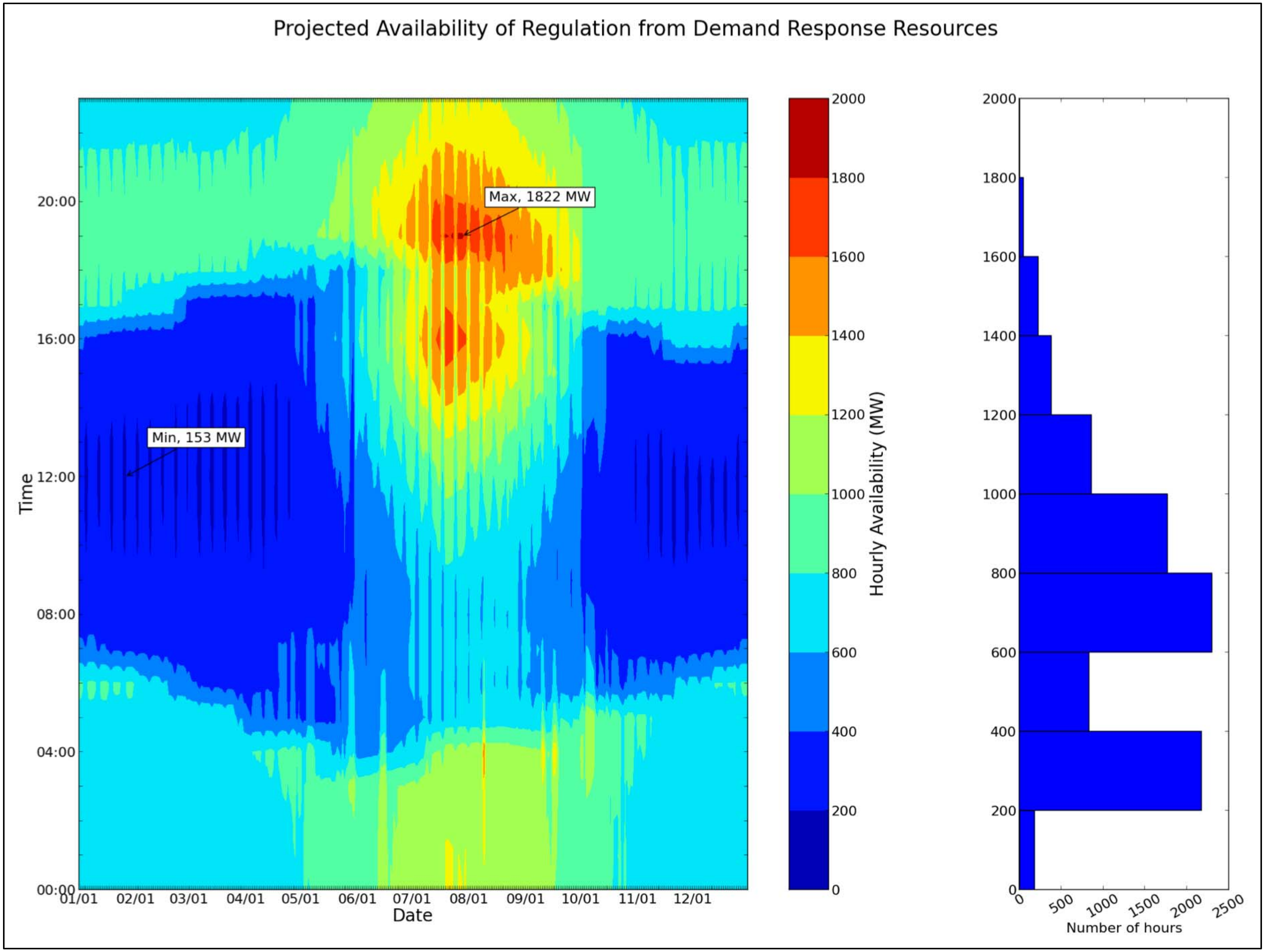
| Wastewater Pumping | | |
|---|---|---|
| Product | Sheddable | Participation rate |
| Regulation | 0% | 0% |
| Contingency | 5% | 50% |
| Flexibility | 5% | 50% |
| Energy | 5% | 25% |
| Capacity | 5% | 25% |

# Appendix B – Table of Files

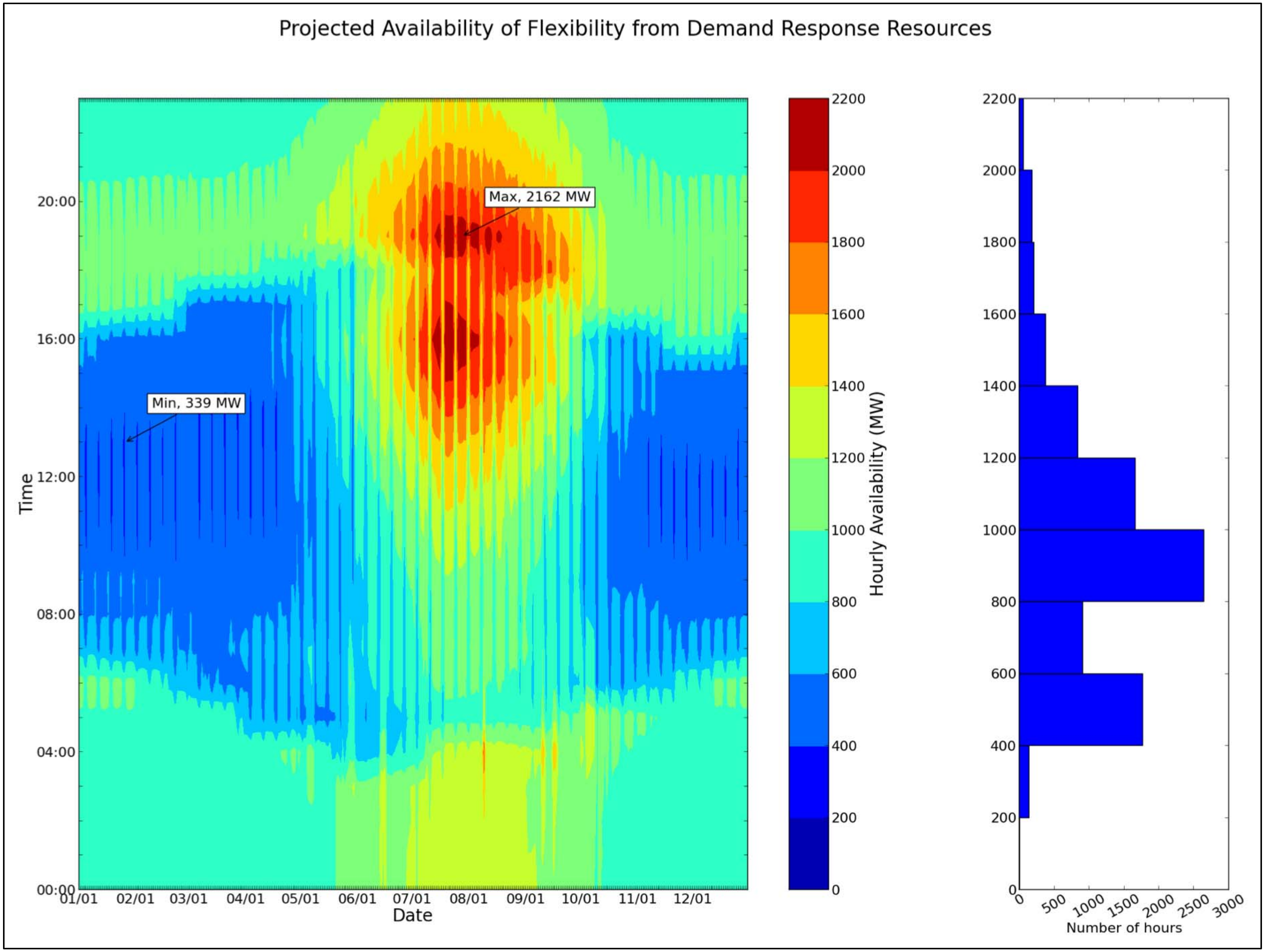
| BAA | Agricultural Pumping | Commercial Cooling | Commercial Heating | Commercial Lighting | Commercial Ventilation | Data Centers | Municipal Lighting | Municipal Pumping | Refrigerated Warehouses | Residential Cooling | Residential Heating | Residential Water Heating | Wastewater Pumping |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| APS | ✔ | ✔ |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| AVA | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| BPA | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| CHPD |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| DOPD |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| EPE | ✔ | ✔ |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| Far East | ✔ |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| GCPD |  |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| IID | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| LDWP |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| Magic Vly. | ✔ |  |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| NEVP | ✔ | ✔ |  | ✔ | ✔ | ✔ | ✔ | ✔ |  | ✔ | ✔ | ✔ | ✔ |
| NWMT | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| PACE_ID | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| PACE_UT | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| PACE_WY | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| PACW | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| PGE Bay |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| PGE Vly. | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| PGN |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| PNM | ✔ | ✔ |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| PSC | ✔ | ✔ |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| PSE |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| SCE | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| SCL |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| SDGE |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| SMUD | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| SPP | ✔ | ✔ |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| SRP | ✔ | ✔ |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| TEP | ✔ | ✔ |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| TIDC | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| TPWR |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| Treas. Vly. | ✔ |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| WACM | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| WALC | ✔ | ✔ |  | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| WAUW | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |

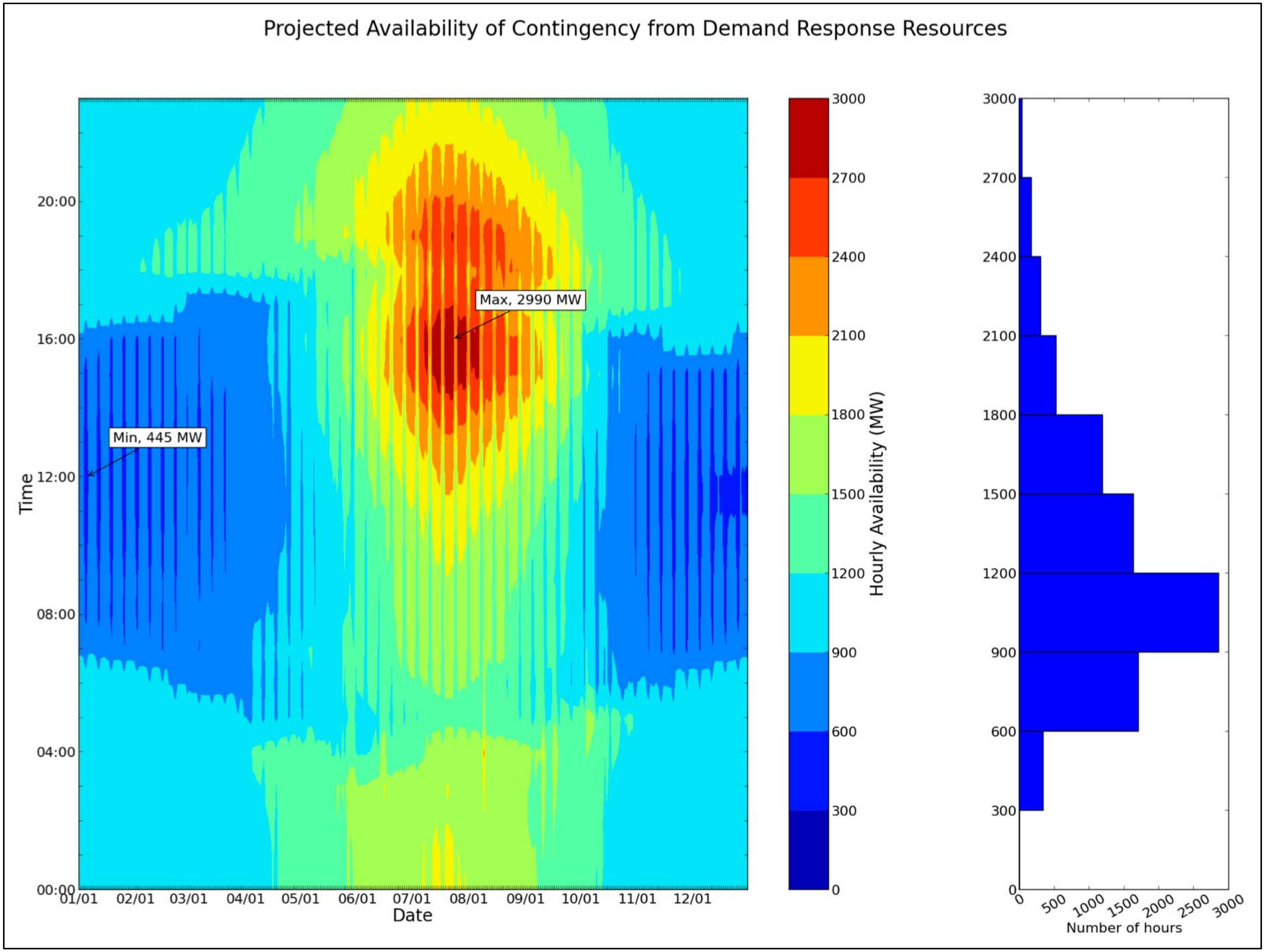
# Appendix C – Product availability patterns

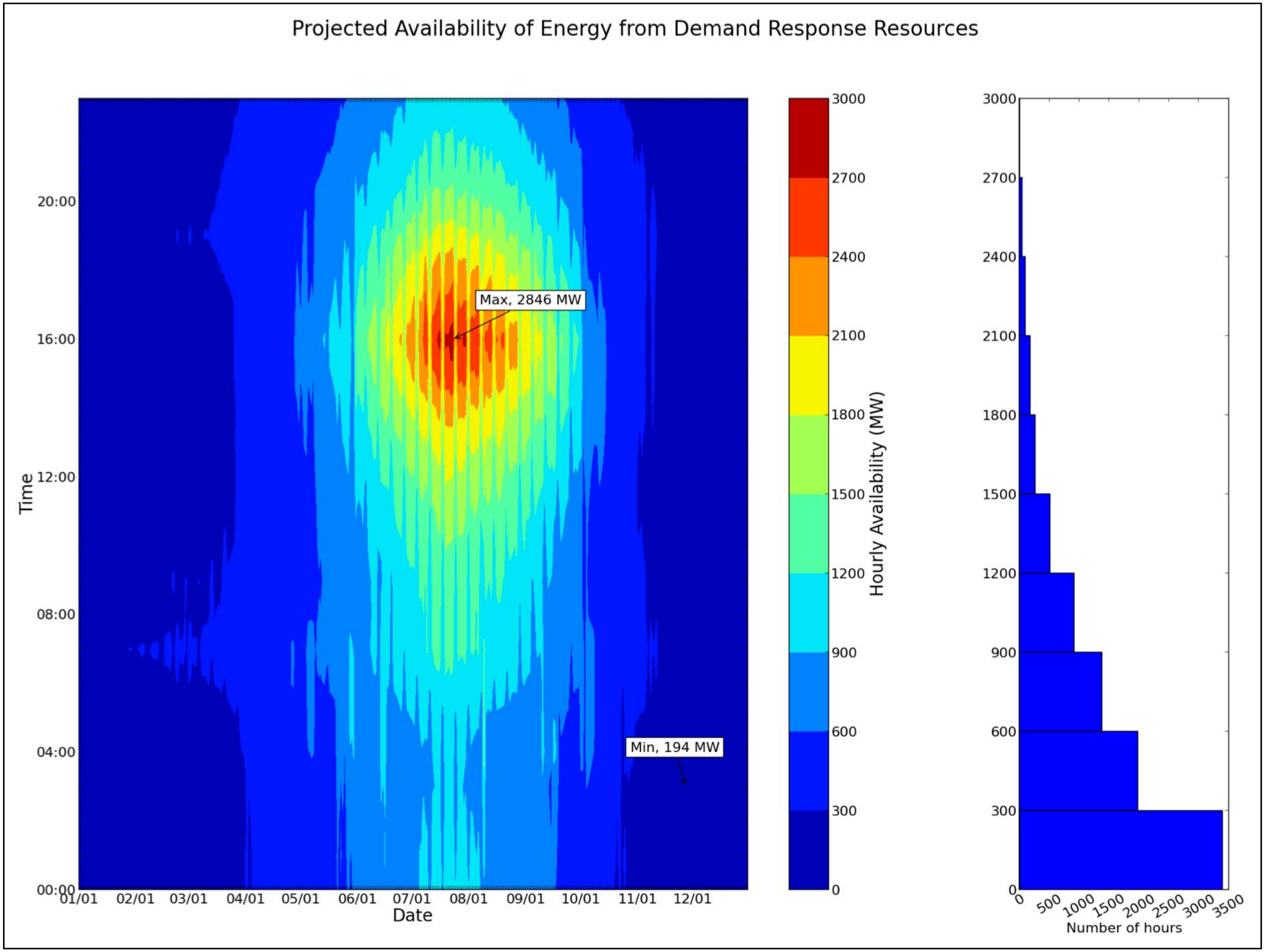
## Estimated Product Availability

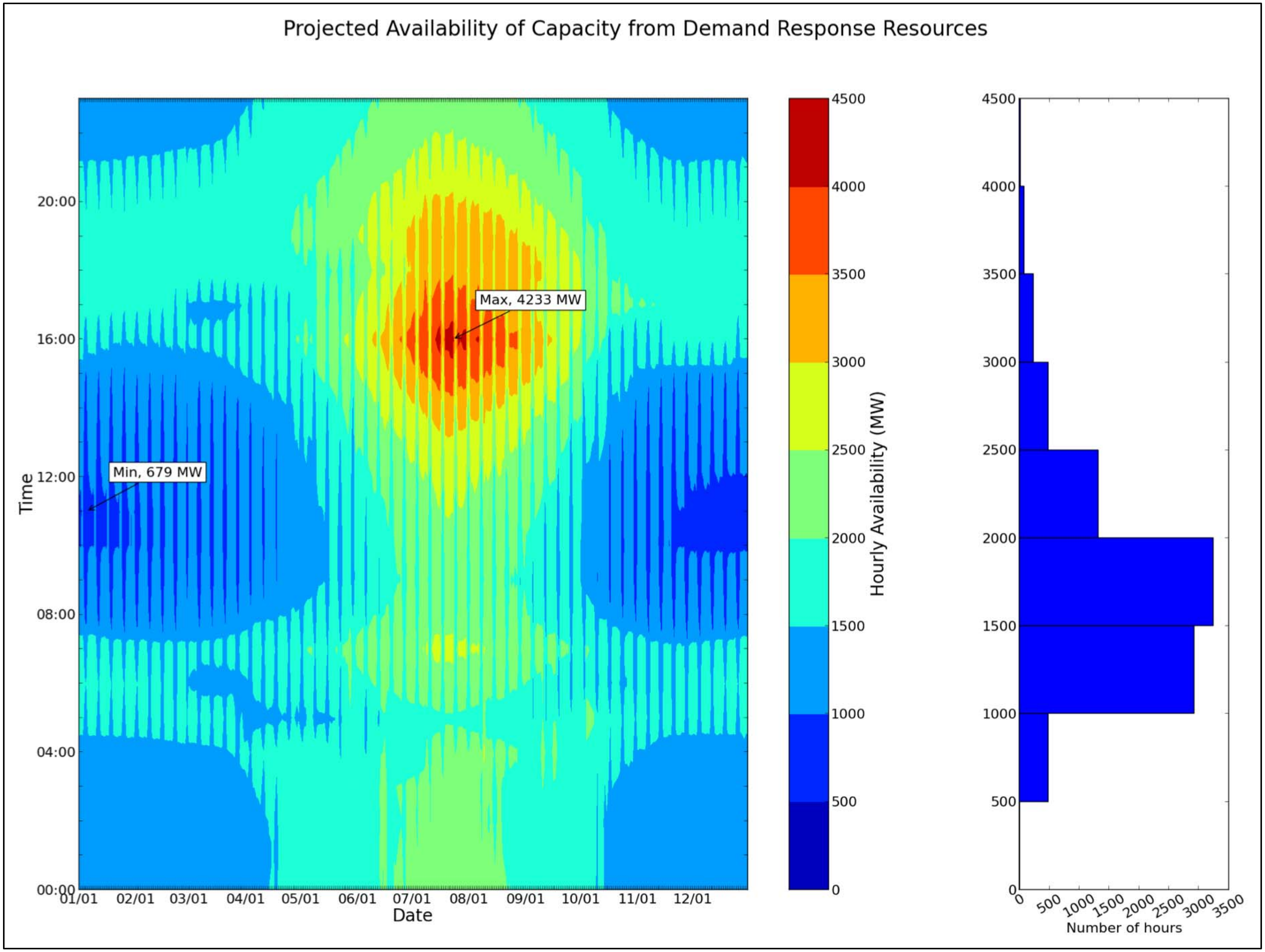


Projected Availability of Regulation from Demand Response Resources
Max, 1822 MW
Min, 153 MW
Time
00:00
04:00
08:00
12:00
16:00
20:00
Date
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Hourly Availability (MW)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Number of hours
0
500
1000
1500
2000
2500

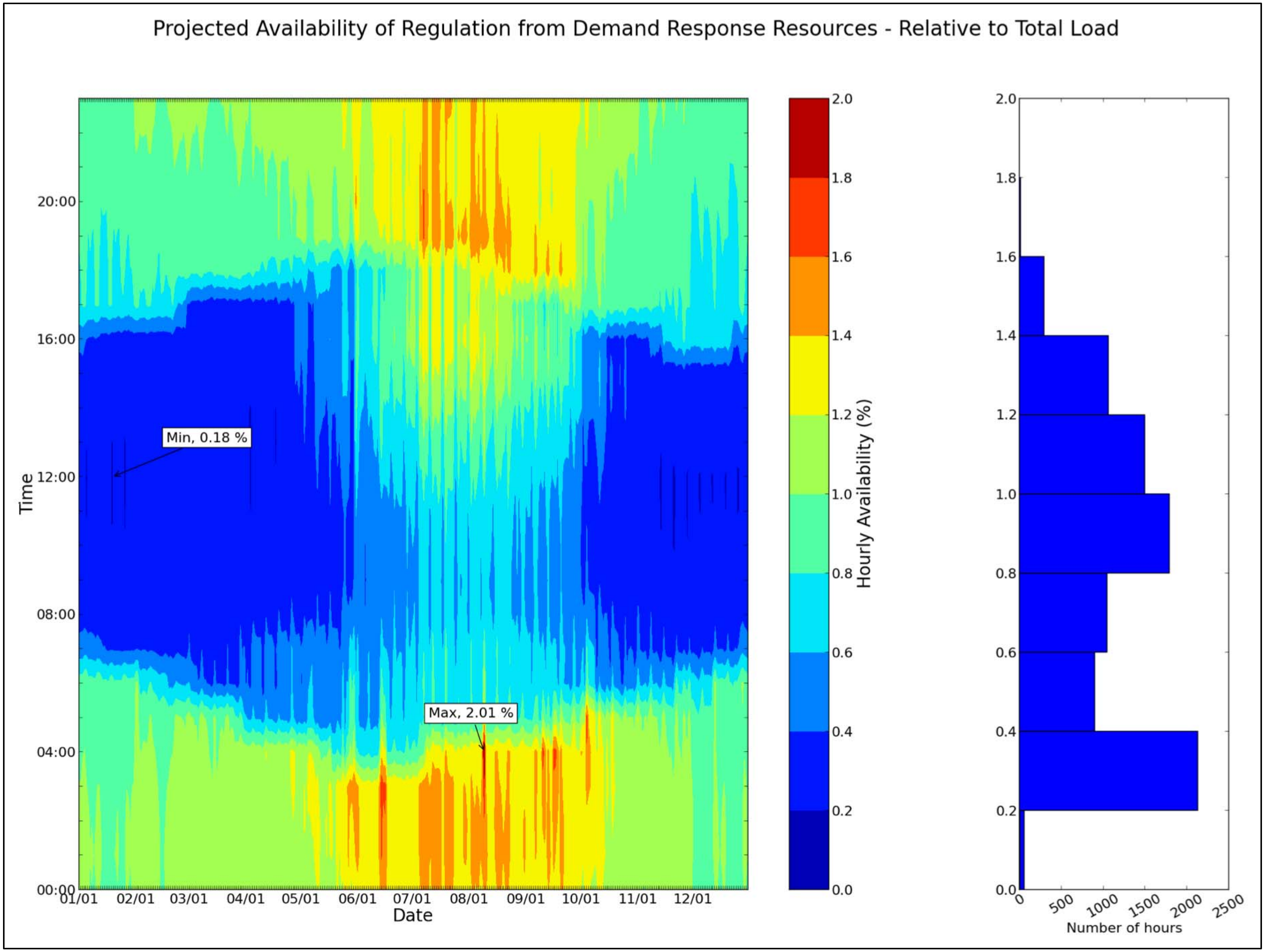

Projected Availability of Flexibility from Demand Response Resources
Max, 2162 MW
Min, 339 MW
Time
Date
Hourly Availability (MW)
Number of hours
00:00
04:00
08:00
12:00
16:00
20:00
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
500
1000
1500
2000
2500
3000


Projected Availability of Contingency from Demand Response Resources
Max, 2990 MW
Min, 445 MW
Time
00:00
04:00
08:00
12:00
16:00
20:00
01/01 02/01 03/01 04/01 05/01 06/01 07/01 08/01 09/01 10/01 11/01 12/01
Date
Hourly Availability (MW)
0 300 600 900 1200 1500 1800 2100 2400 2700 3000
Number of hours
0 500 1000 1500 2000 2500 3000

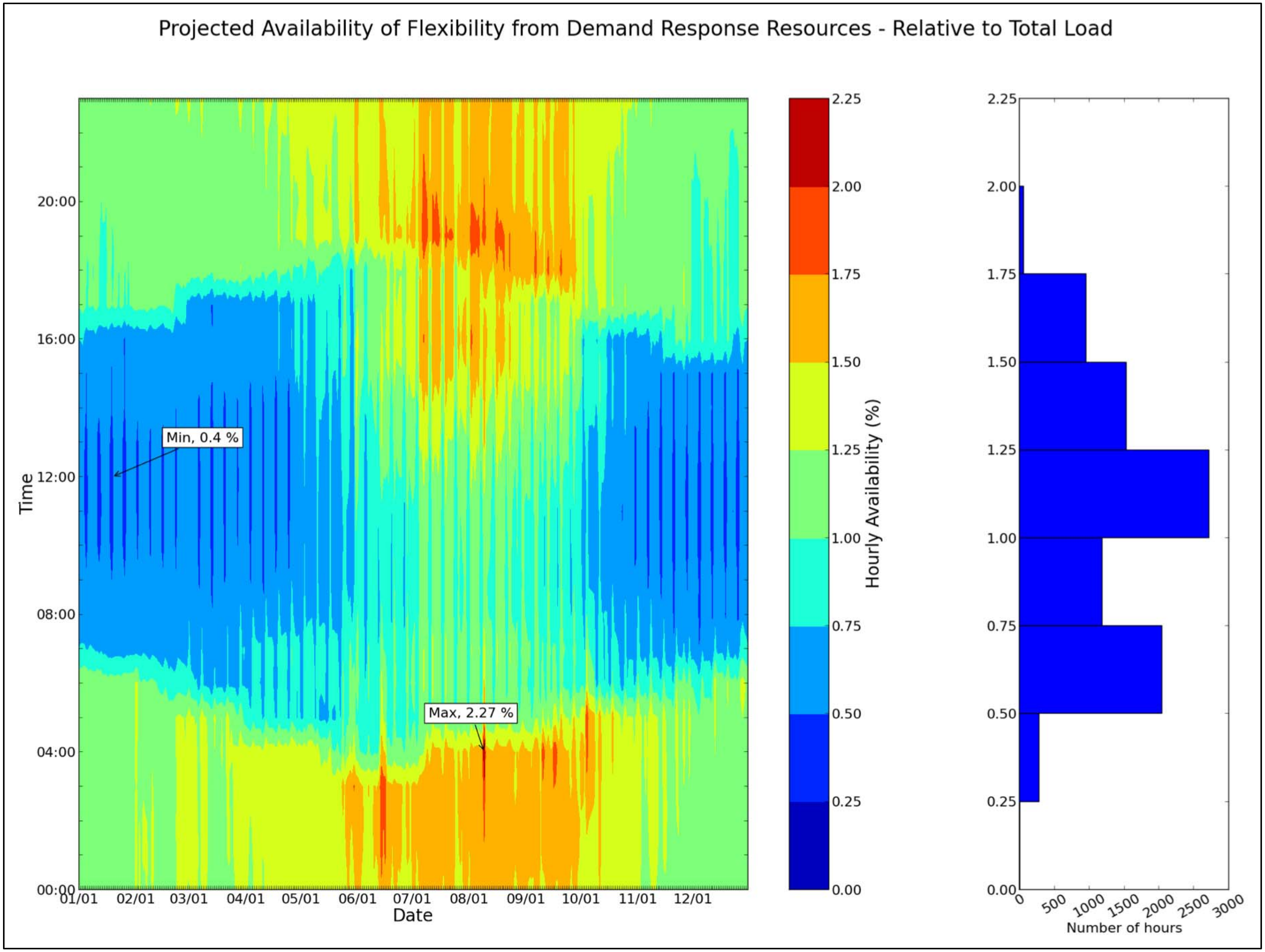

Projected Availability of Energy from Demand Response Resources
Max, 2846 MW
Min, 194 MW
Time
00:00
04:00
08:00
12:00
16:00
20:00
Date
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Hourly Availability (MW)
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
Number of hours
0
500
1000
1500
2000
2500
3000
3500


Projected Availability of Capacity from Demand Response Resources
Max, 4233 MW
Min, 679 MW
Time
Date
Hourly Availability (MW)
Number of hours
00:00
04:00
08:00
12:00
16:00
20:00
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
0
500
1000
1500
2000
2500
3000
3500
4000
4500

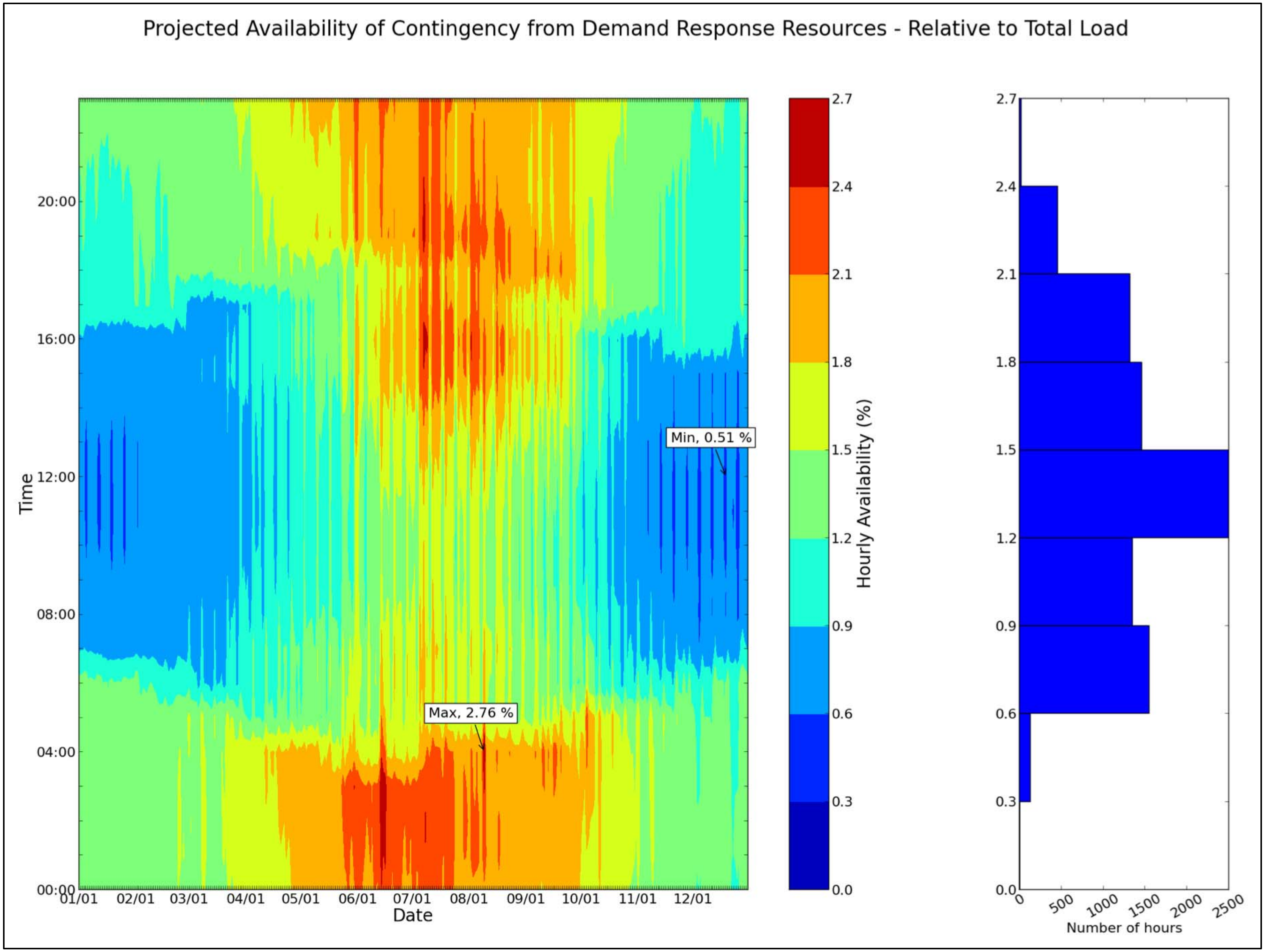
## Product Availability Relative to Total Load

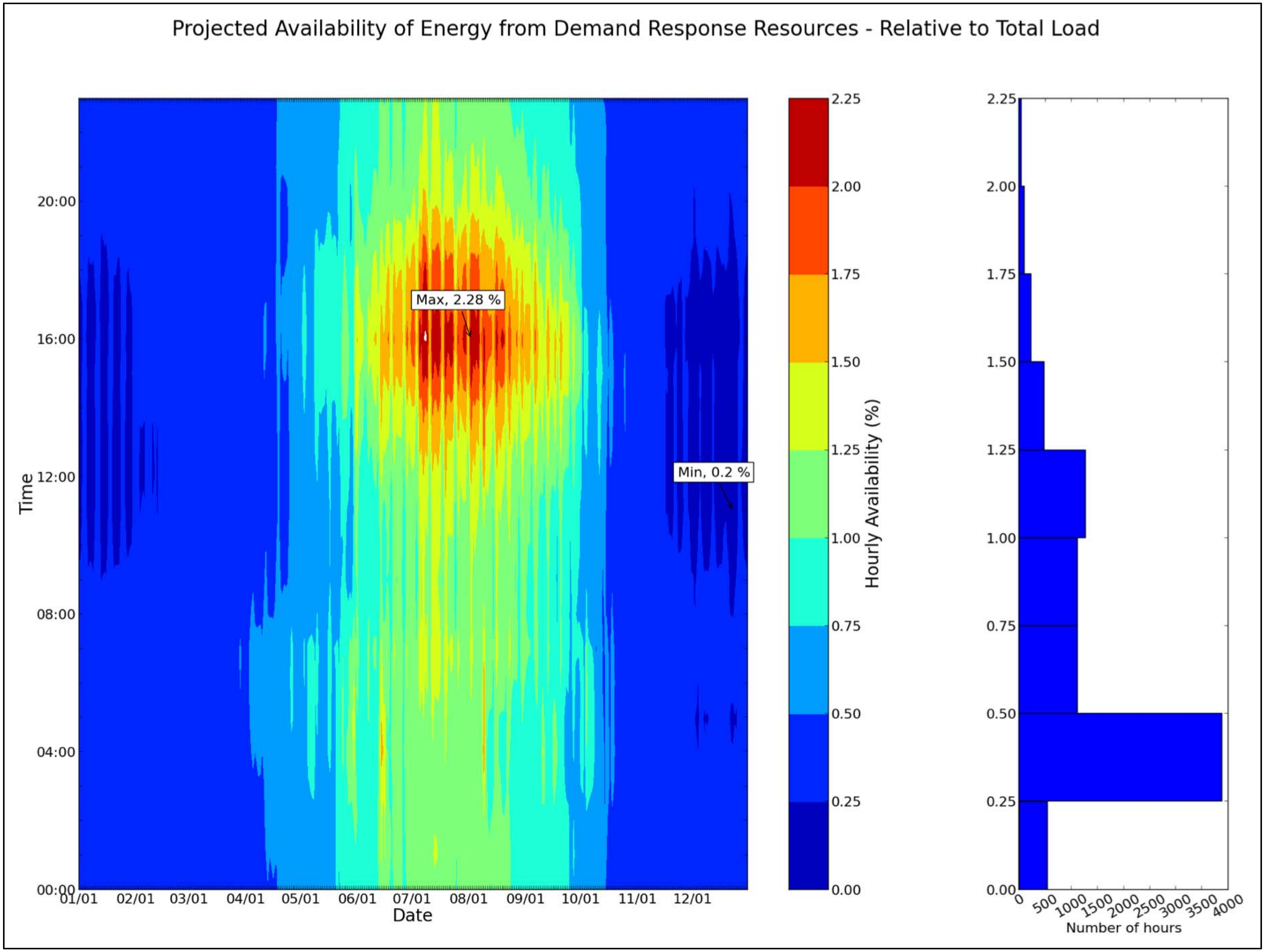


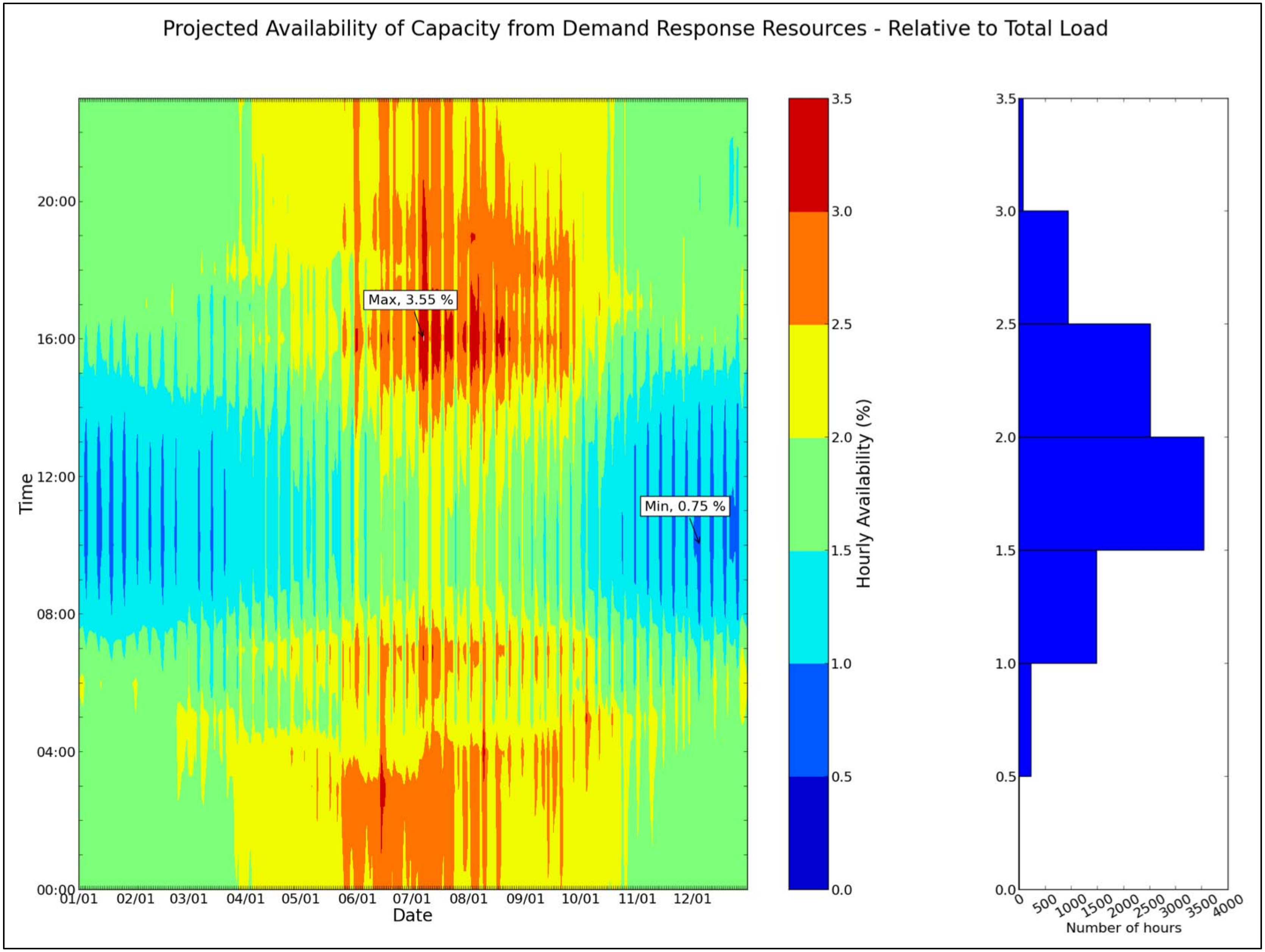
Projected Availability of Regulation from Demand Response Resources - Relative to Total Load
Min, 0.18 %
Max, 2.01 %
Time
Date
Hourly Availability (%)
Number of hours



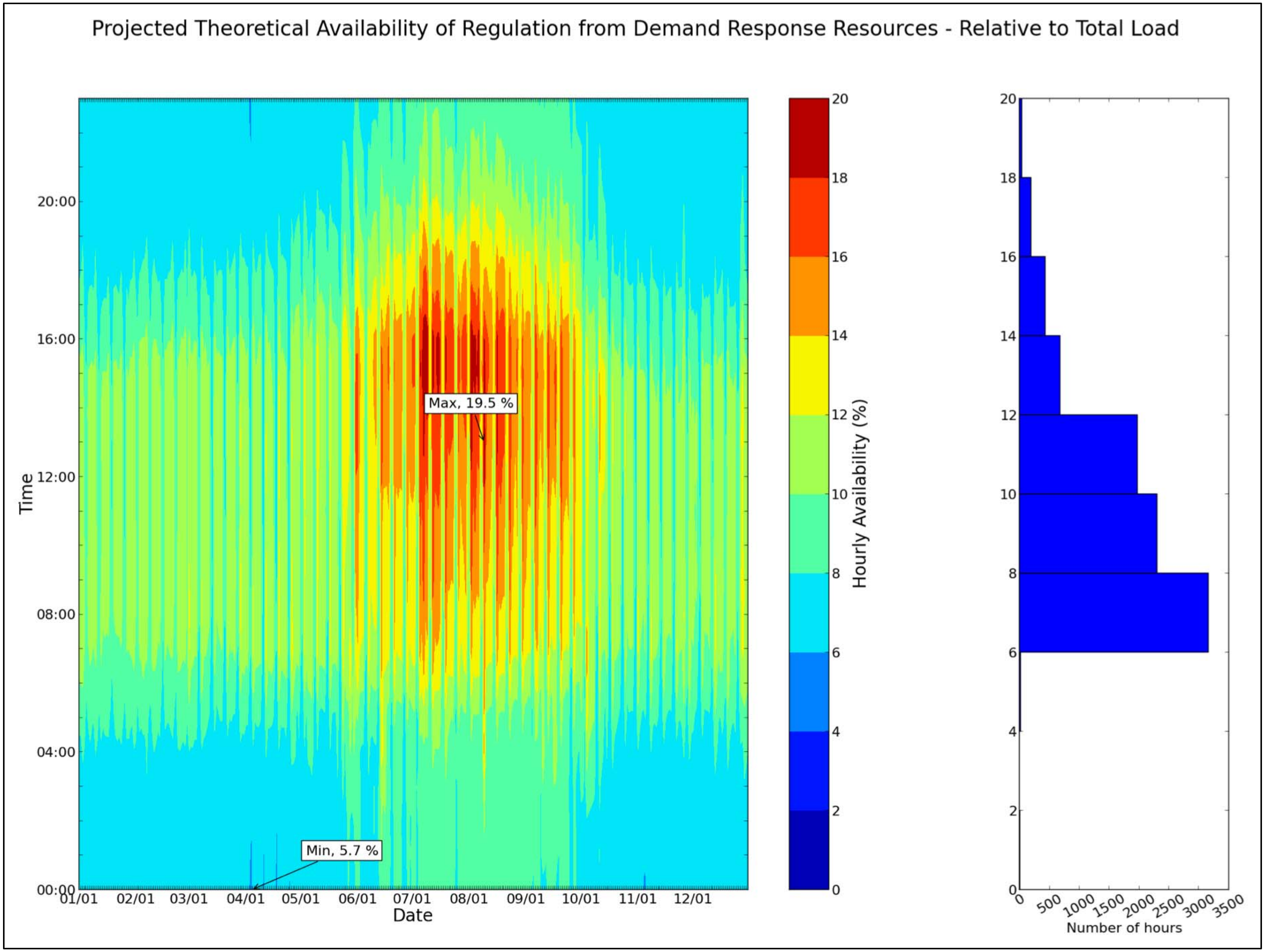
Projected Availability of Flexibility from Demand Response Resources - Relative to Total Load
Min, 0.4 %
Max, 2.27 %
Time
Date
Hourly Availability (%)
Number of hours
00:00
04:00
08:00
12:00
16:00
20:00
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
2.25
0
500
1000
1500
2000
2500
3000


Projected Availability of Contingency from Demand Response Resources - Relative to Total Load
Time
Date
Hourly Availability (%)
Number of hours
Min, 0.51 %
Max, 2.76 %
00:00
04:00
08:00
12:00
16:00
20:00
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
0.0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4
2.7
0
500
1000
1500
2000
2500

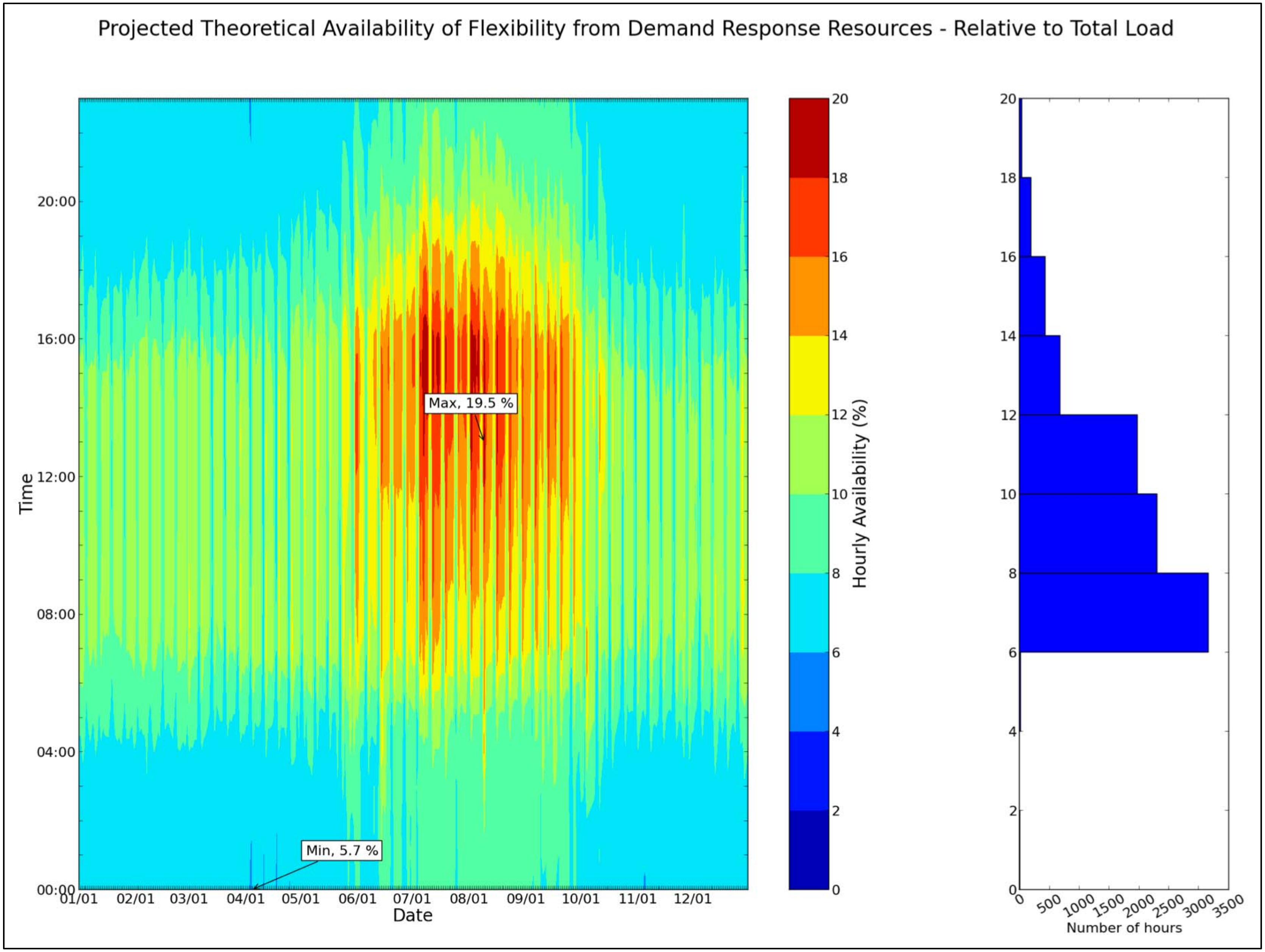

Projected Availability of Energy from Demand Response Resources - Relative to Total Load
Max, 2.28 %
Min, 0.2 %
Time
00:00
04:00
08:00
12:00
16:00
20:00
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Date
Hourly Availability (%)
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
2.25
Number of hours
0
500
1000
1500
2000
2500
3000
3500
4000

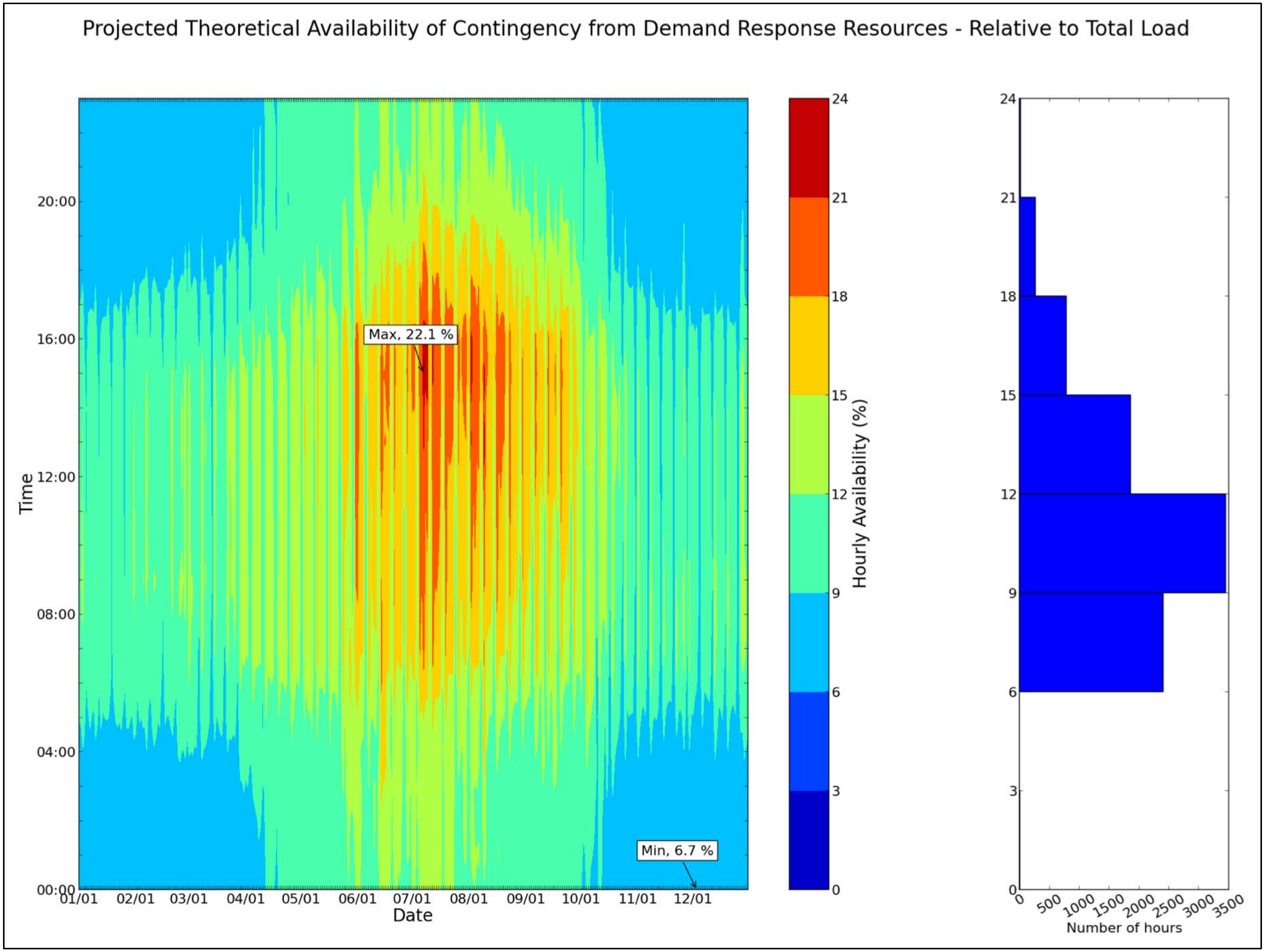

Projected Availability of Capacity from Demand Response Resources - Relative to Total Load
Max, 3.55 %
Min, 0.75 %
Time
20:00
16:00
12:00
08:00
04:00
00:00
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Date
Hourly Availability (%)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
500
1000
1500
2000
2500
3000
3500
4000
Number of hours

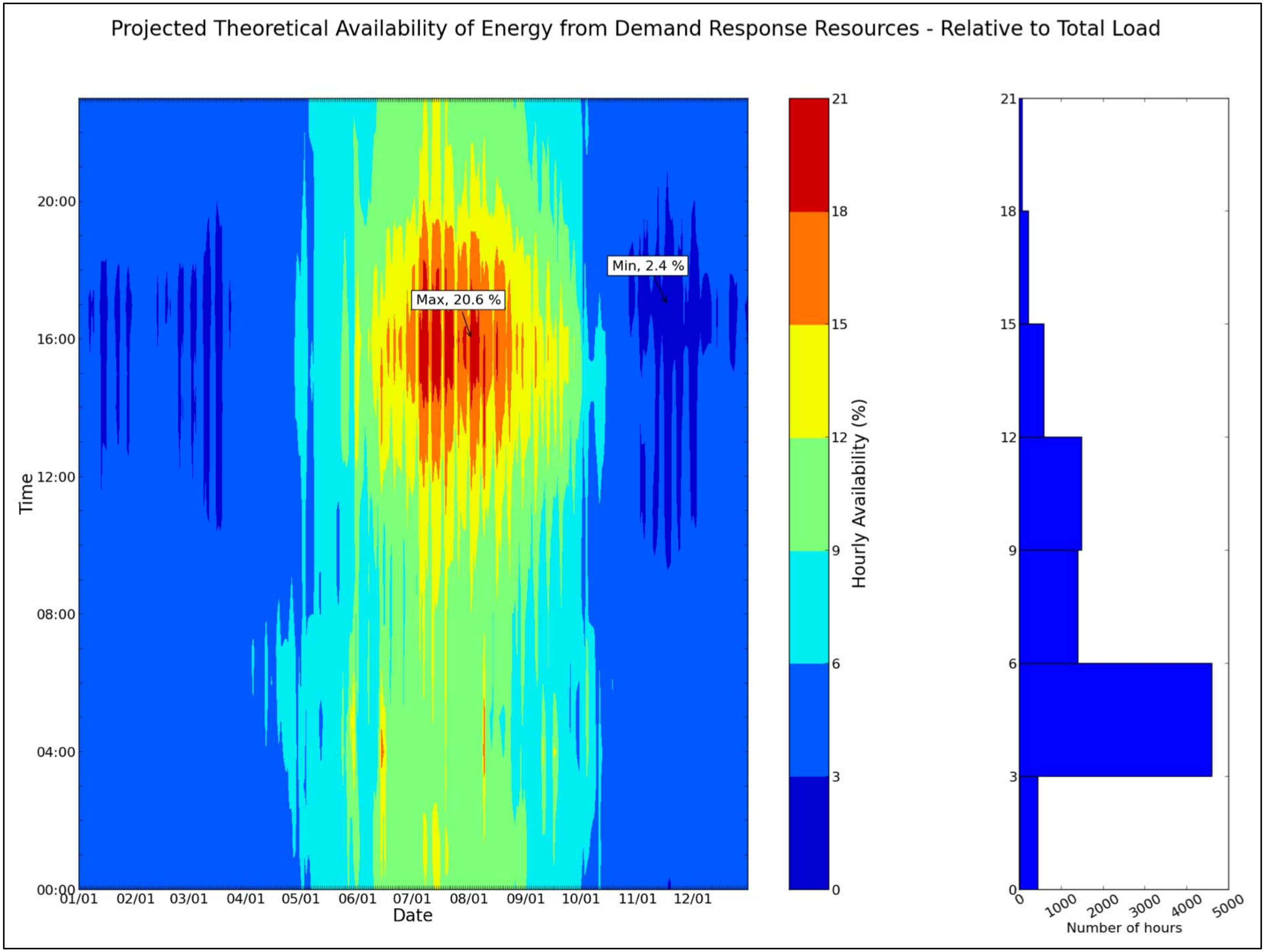
## Technical Potential Relative to Total Load



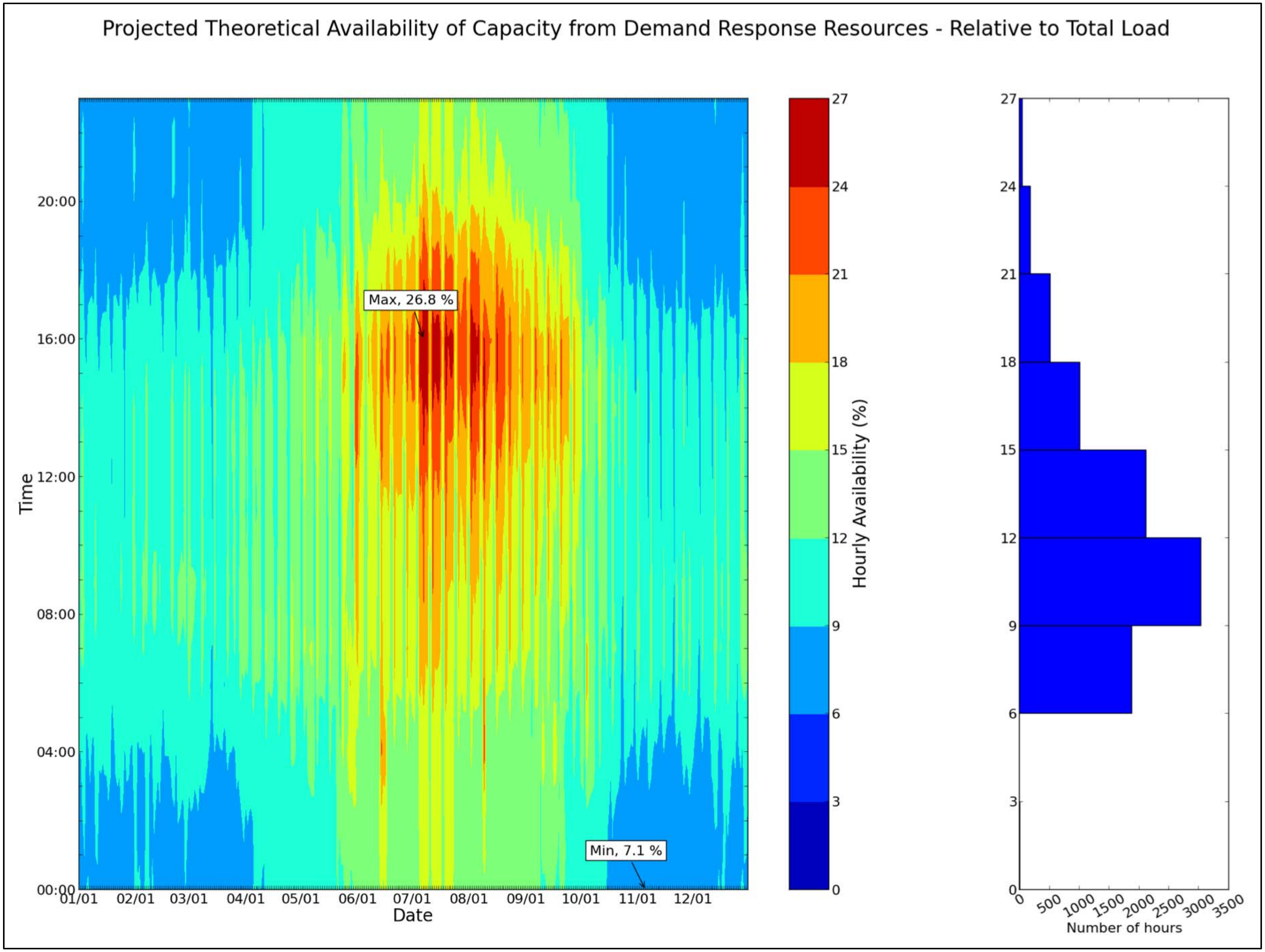
Projected Theoretical Availability of Regulation from Demand Response Resources - Relative to Total Load
Max, 19.5 %
Min, 5.7 %
Time
Date
Hourly Availability (%)
Number of hours


Projected Theoretical Availability of Flexibility from Demand Response Resources - Relative to Total Load
Max, 19.5 %
Min, 5.7 %
Time
00:00
04:00
08:00
12:00
16:00
20:00
Date
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Hourly Availability (%)
0
2
4
6
8
10
12
14
16
18
20
Number of hours
0
500
1000
1500
2000
2500
3000
3500

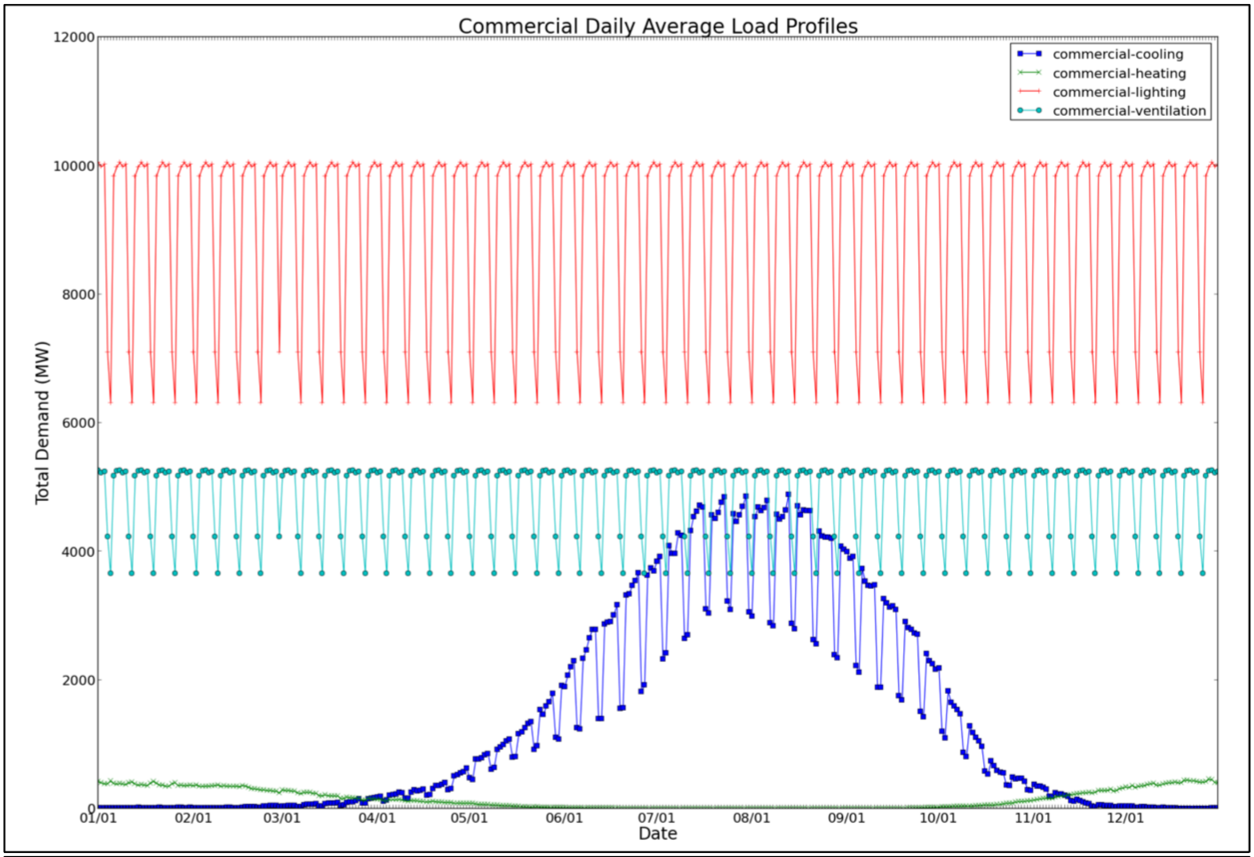

Projected Theoretical Availability of Contingency from Demand Response Resources - Relative to Total Load
Max, 22.1 %
Min, 6.7 %
Time
00:00
04:00
08:00
12:00
16:00
20:00
Date
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Hourly Availability (%)
0
3
6
9
12
15
18
21
24
Number of hours
0
500
1000
1500
2000
2500
3000
3500

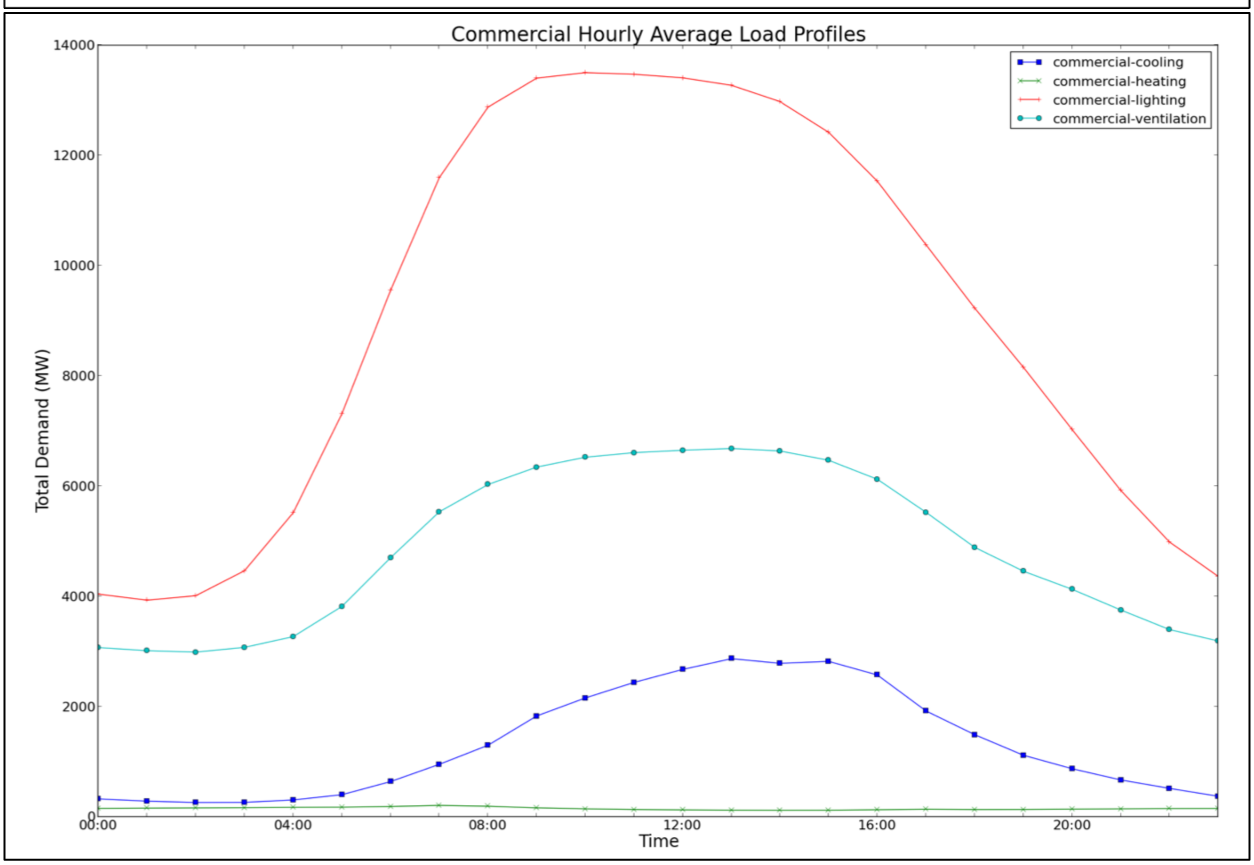


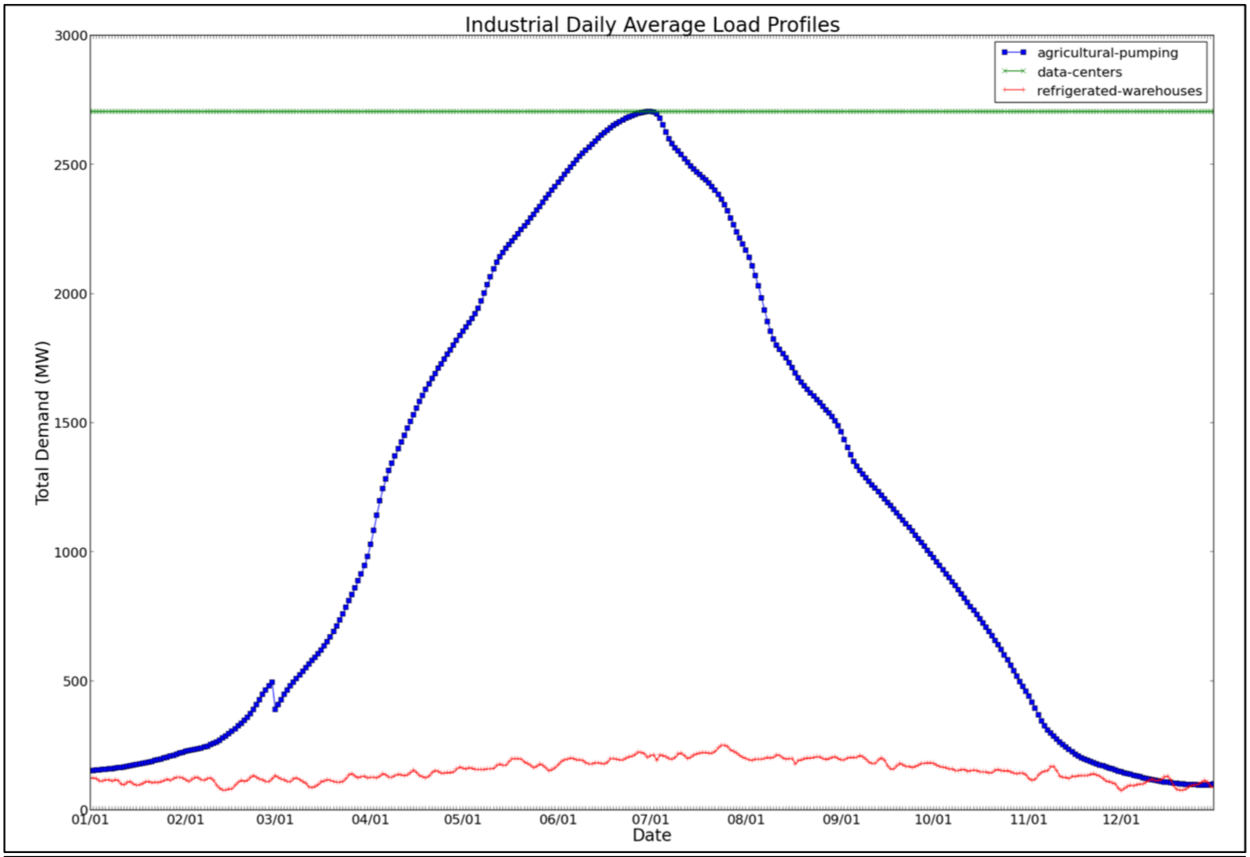
Projected Theoretical Availability of Energy from Demand Response Resources - Relative to Total Load
Max, 20.6 %
Min, 2.4 %
Time
00:00
04:00
08:00
12:00
16:00
20:00
Date
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Hourly Availability (%)
0
3
6
9
12
15
18
21
Number of hours
0
1000
2000
3000
4000
5000

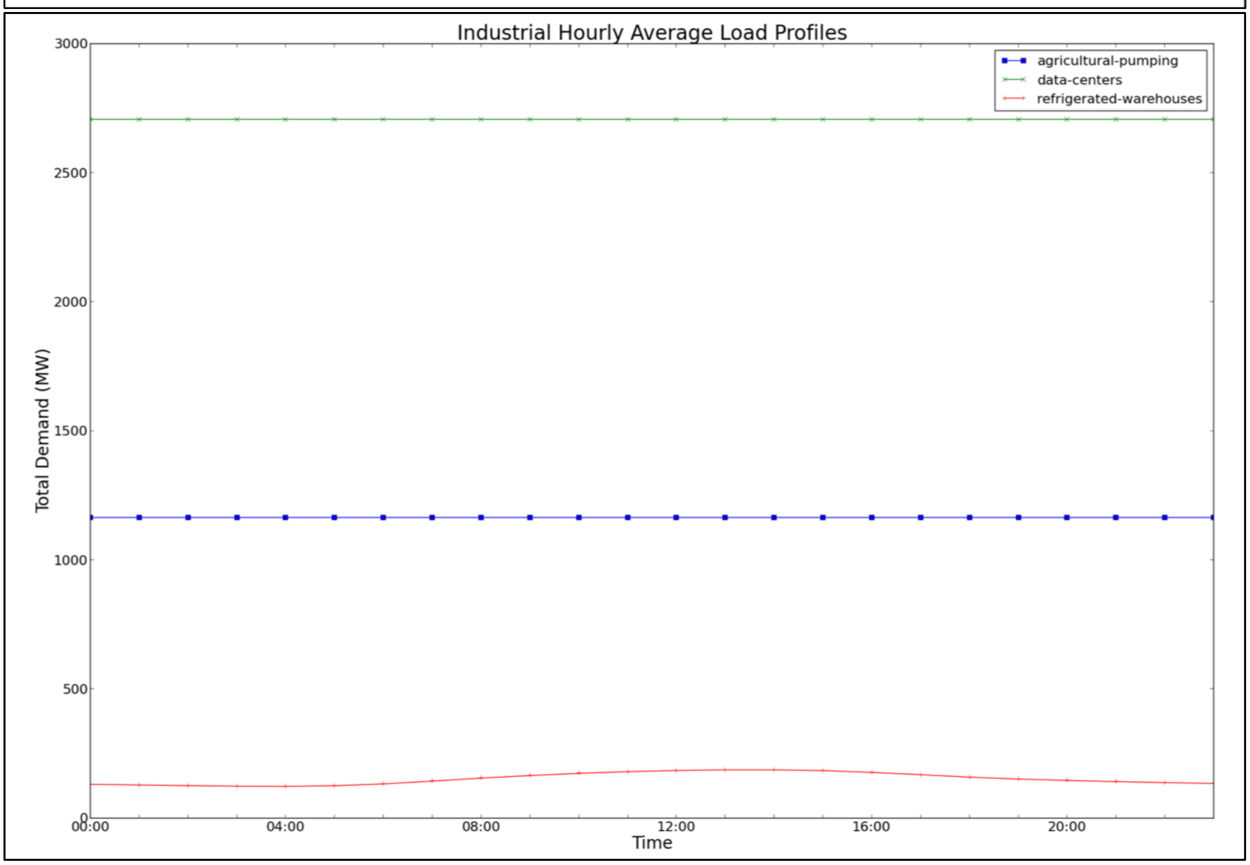

Projected Theoretical Availability of Capacity from Demand Response Resources - Relative to Total Load
Time
00:00
04:00
08:00
12:00
16:00
20:00
Date
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Max, 26.8 %
Min, 7.1 %
Hourly Availability (%)
0
3
6
9
12
15
18
21
24
27
Number of hours
0
500
1000
1500
2000
2500
3000
3500

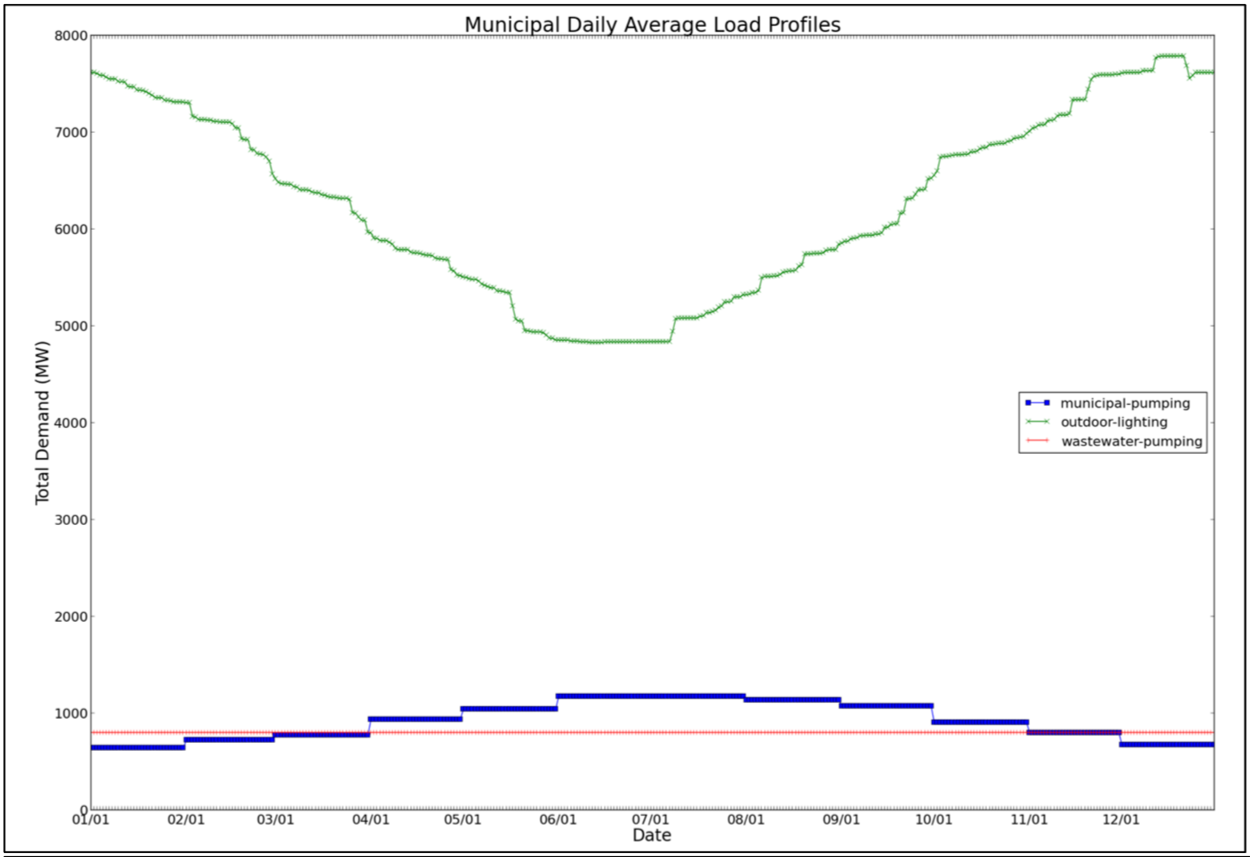
# Appendix D – Resource Load Profiles

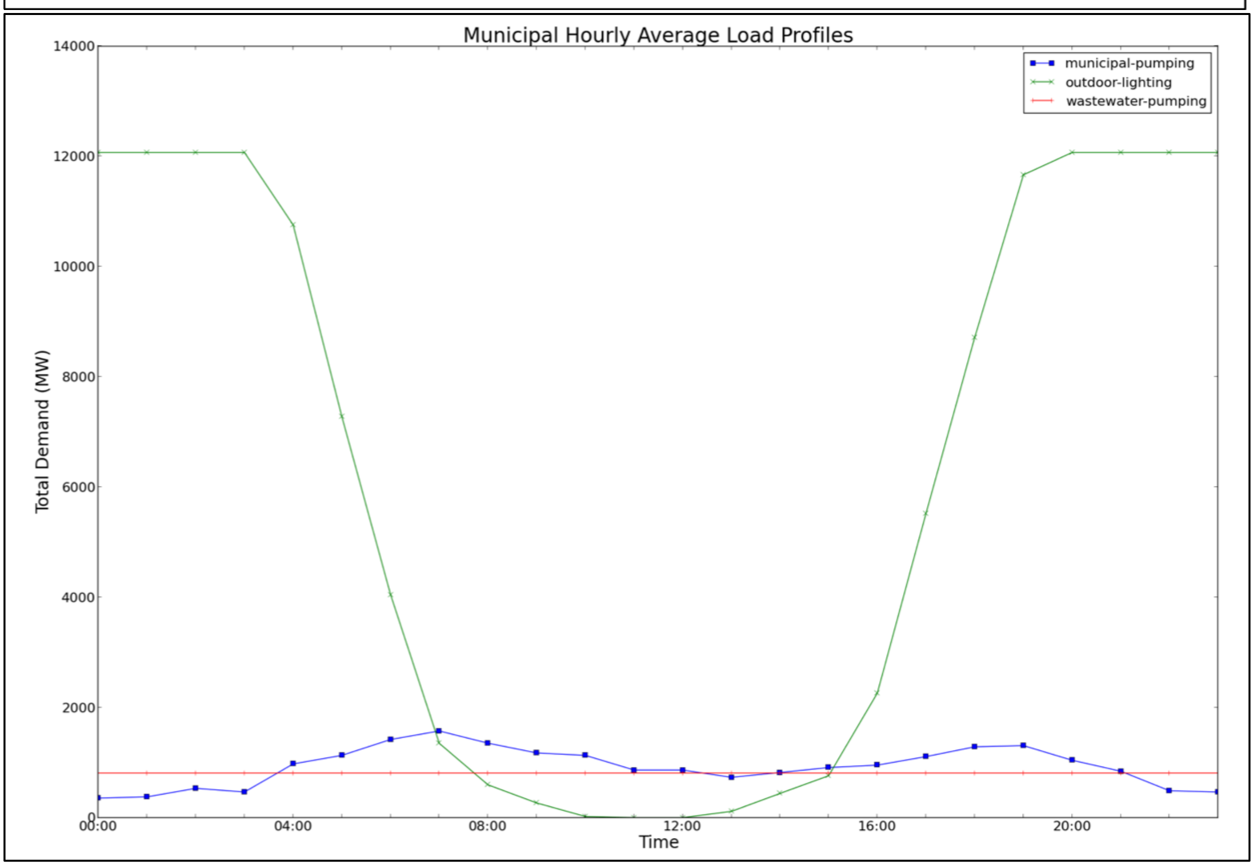

Commercial Daily Average Load Profiles
Total Demand (MW)
Date
commercial-cooling
commercial-heating
commercial-lighting
commercial-ventilation
0
2000
4000
6000
8000
10000
12000
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

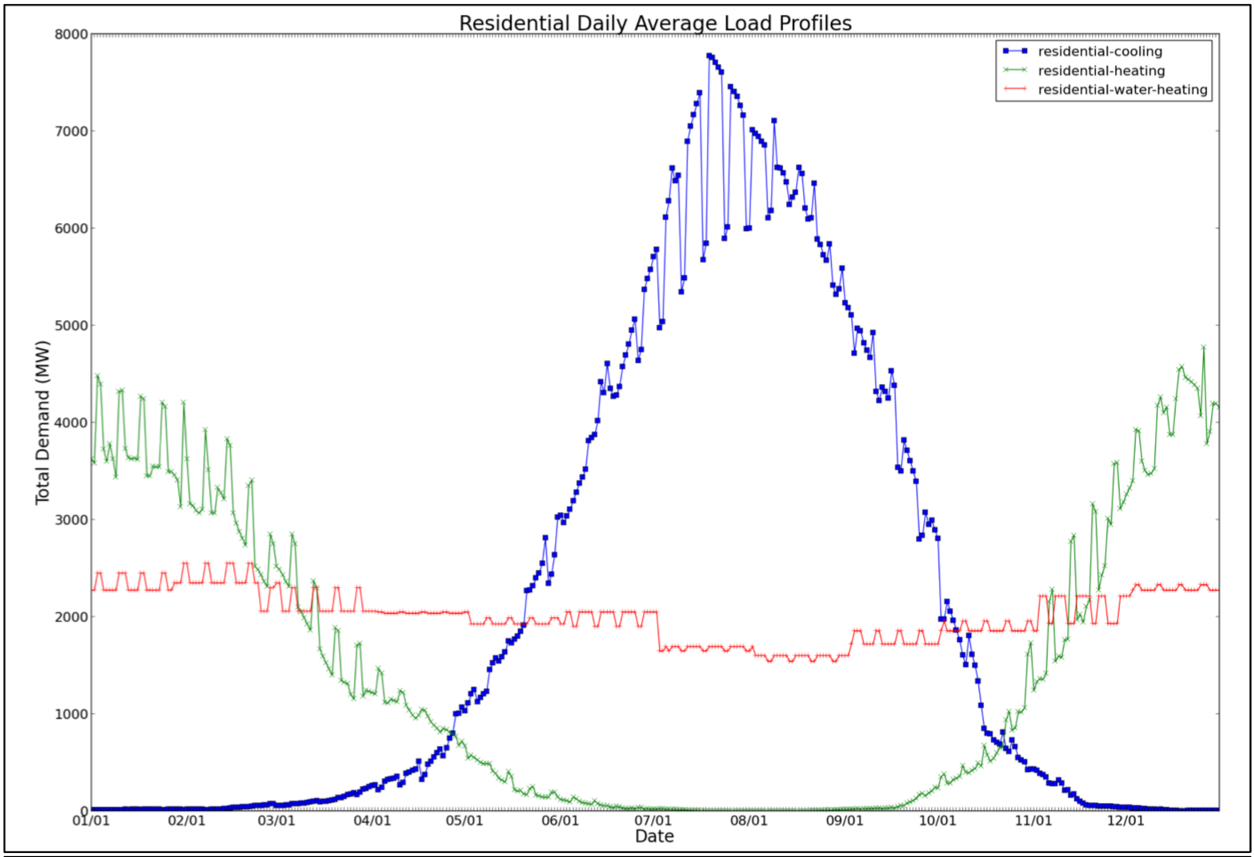

Commercial Hourly Average Load Profiles
Total Demand (MW)
Time
commercial-cooling
commercial-heating
commercial-lighting
commercial-ventilation
0
2000
4000
6000
8000
10000
12000
14000
00:00
04:00
08:00
12:00
16:00
20:00

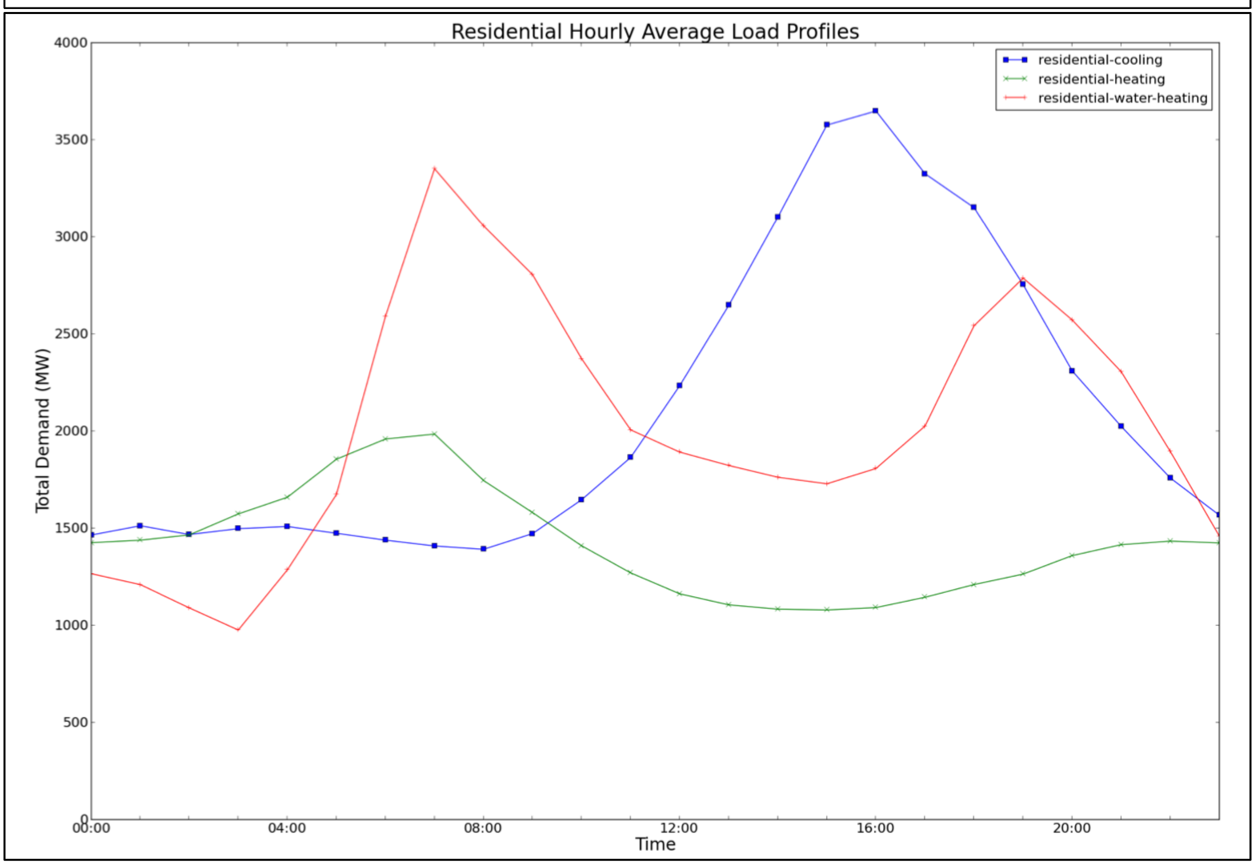

Industrial Daily Average Load Profiles
agricultural-pumping
data-centers
refrigerated-warehouses
Total Demand (MW)
Date
3000
2500
2000
1500
1000
500
0
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01


Industrial Hourly Average Load Profiles
agricultural-pumping
data-centers
refrigerated-warehouses
Total Demand (MW)
Time
3000
2500
2000
1500
1000
500
0
00:00
04:00
08:00
12:00
16:00
20:00

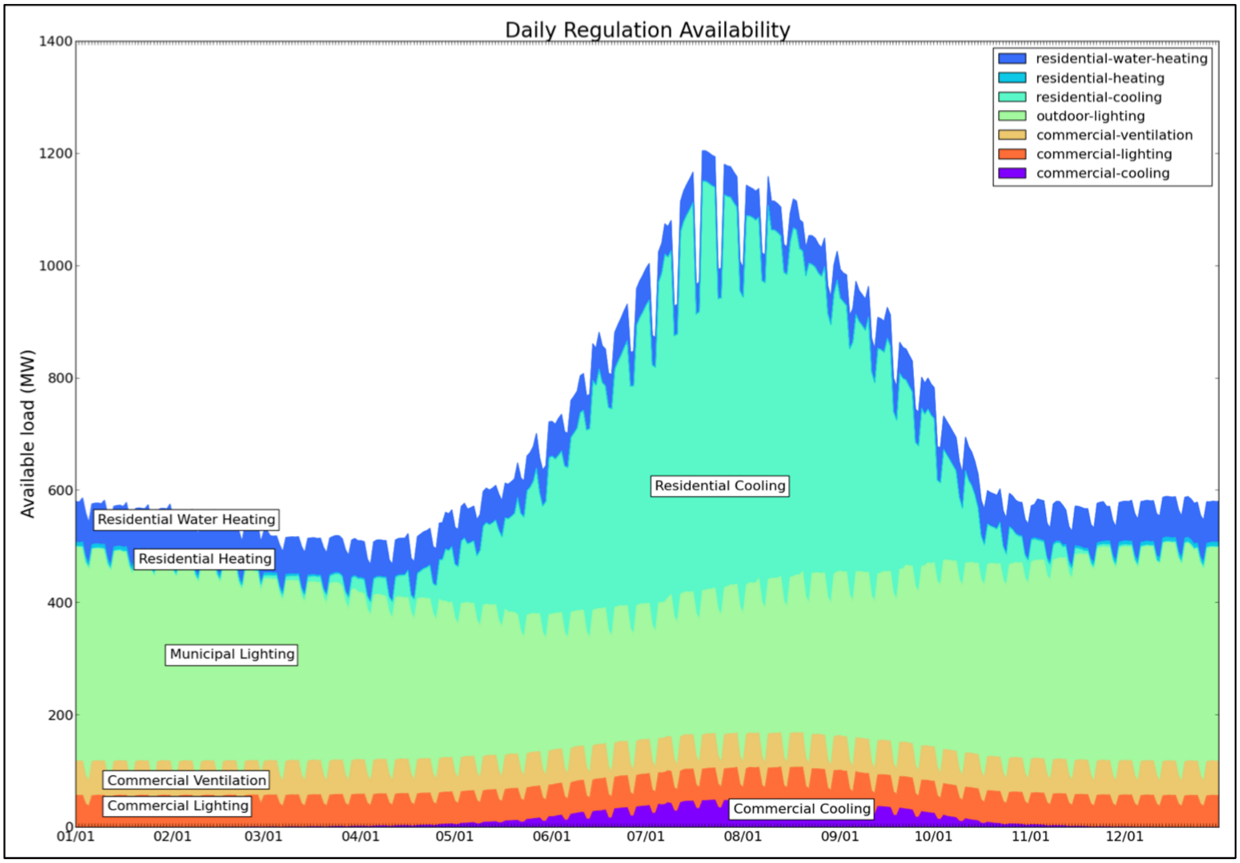

Municipal Daily Average Load Profiles
Total Demand (MW)
Date
0
1000
2000
3000
4000
5000
6000
7000
8000
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
municipal-pumping
outdoor-lighting
wastewater-pumping

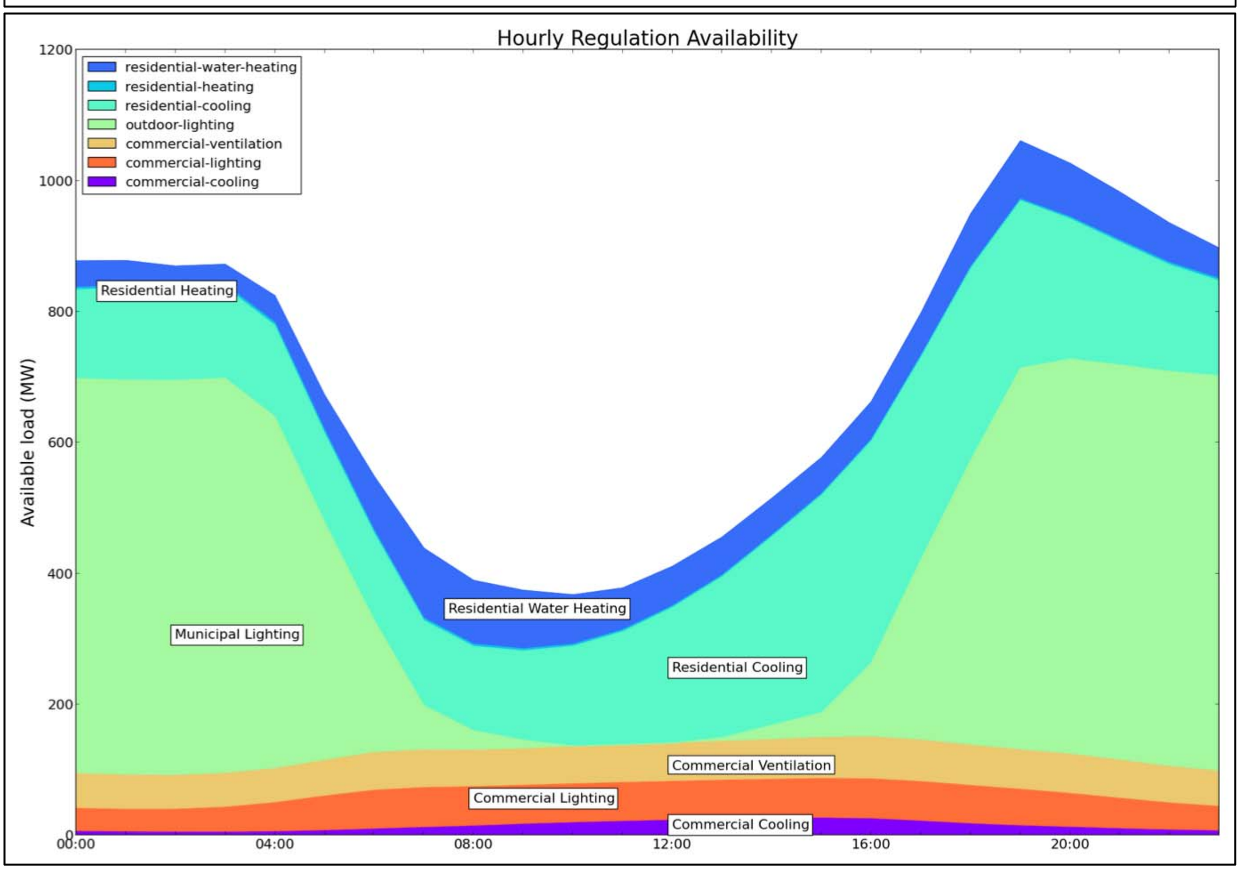

Municipal Hourly Average Load Profiles
Total Demand (MW)
Time
0
2000
4000
6000
8000
10000
12000
14000
00:00
04:00
08:00
12:00
16:00
20:00
municipal-pumping
outdoor-lighting
wastewater-pumping

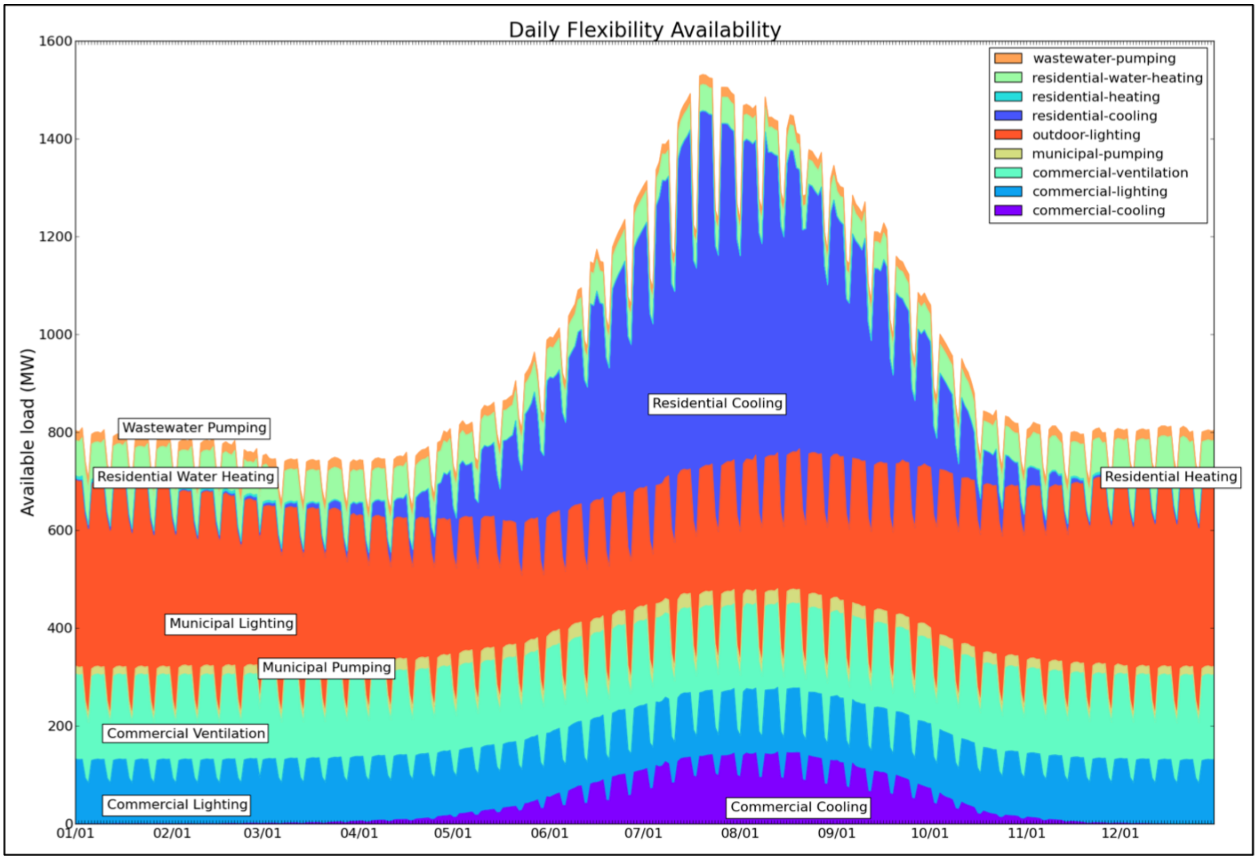

Residential Daily Average Load Profiles
residential-cooling
residential-heating
residential-water-heating
Total Demand (MW)
0
1000
2000
3000
4000
5000
6000
7000
8000
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
Date

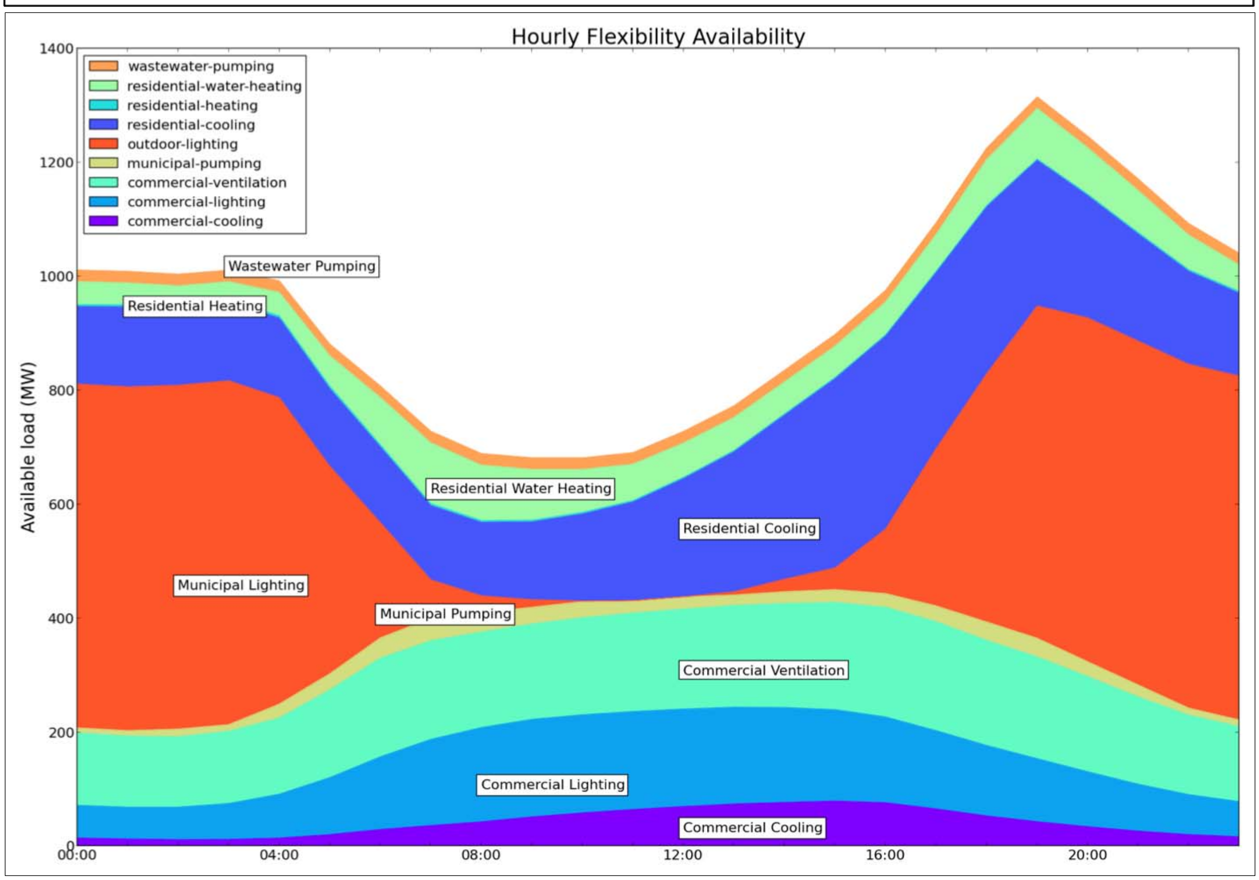

Residential Hourly Average Load Profiles
residential-cooling
residential-heating
residential-water-heating
Total Demand (MW)
0
500
1000
1500
2000
2500
3000
3500
4000
00:00
04:00
08:00
12:00
16:00
20:00
Time

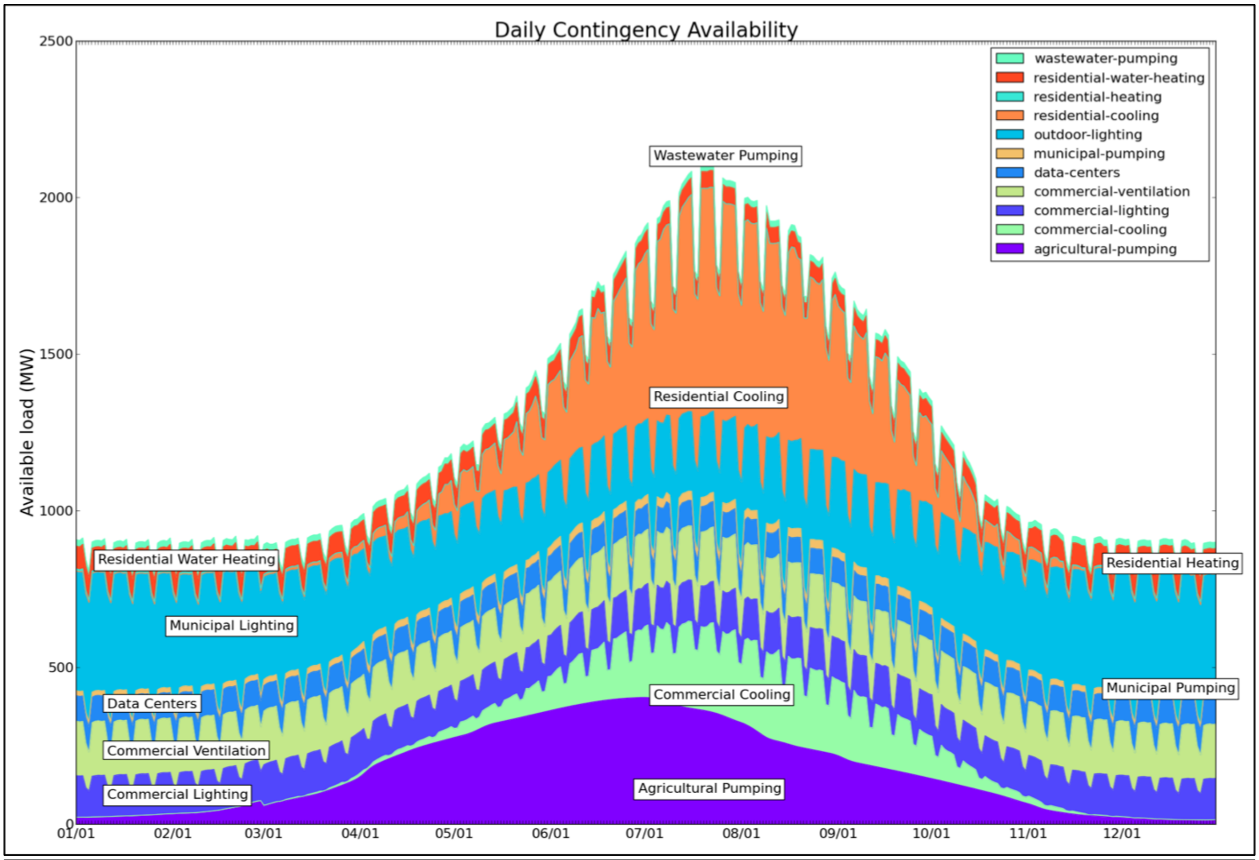
# Appendix E – Resource Contributions to Products


Daily Regulation Availability
Available load (MW)
1400
1200
1000
800
600
400
200
0
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
residential-water-heating
residential-heating
residential-cooling
outdoor-lighting
commercial-ventilation
commercial-lighting
commercial-cooling
Residential Water Heating
Residential Heating
Residential Cooling
Municipal Lighting
Commercial Ventilation
Commercial Lighting
Commercial Cooling

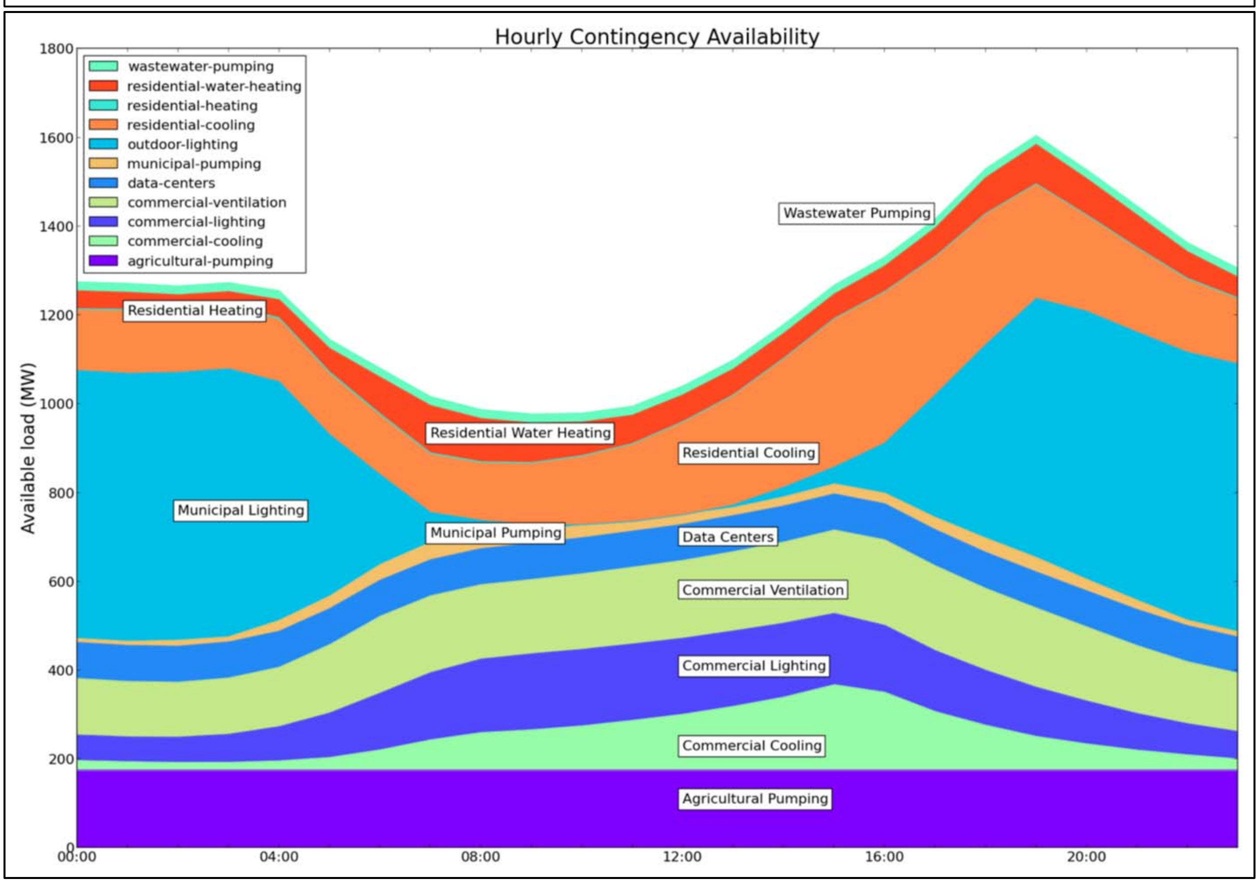

Hourly Regulation Availability
Available load (MW)
1200
1000
800
600
400
200
0
00:00
04:00
08:00
12:00
16:00
20:00
residential-water-heating
residential-heating
residential-cooling
outdoor-lighting
commercial-ventilation
commercial-lighting
commercial-cooling
Residential Heating
Residential Water Heating
Municipal Lighting
Residential Cooling
Commercial Ventilation
Commercial Lighting
Commercial Cooling


Daily Flexibility Availability
Available load (MW)
wastewater-pumping
residential-water-heating
residential-heating
residential-cooling
outdoor-lighting
municipal-pumping
commercial-ventilation
commercial-lighting
commercial-cooling
Wastewater Pumping
Residential Water Heating
Residential Cooling
Residential Heating
Municipal Lighting
Municipal Pumping
Commercial Ventilation
Commercial Lighting
Commercial Cooling
0
200
400
600
800
1000
1200
1400
1600
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

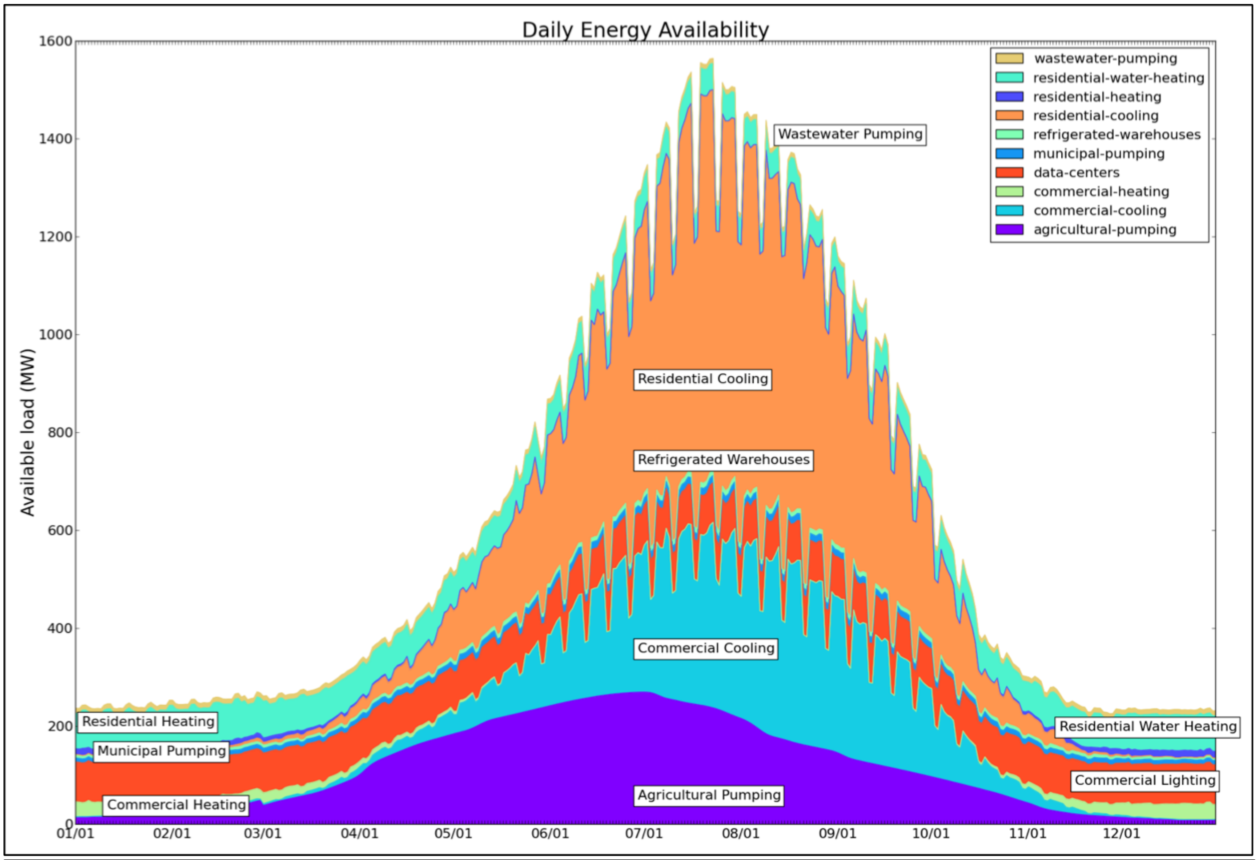

Hourly Flexibility Availability
Available load (MW)
wastewater-pumping
residential-water-heating
residential-heating
residential-cooling
outdoor-lighting
municipal-pumping
commercial-ventilation
commercial-lighting
commercial-cooling
Wastewater Pumping
Residential Heating
Residential Water Heating
Residential Cooling
Municipal Lighting
Municipal Pumping
Commercial Ventilation
Commercial Lighting
Commercial Cooling
0
200
400
600
800
1000
1200
1400
00:00
04:00
08:00
12:00
16:00
20:00

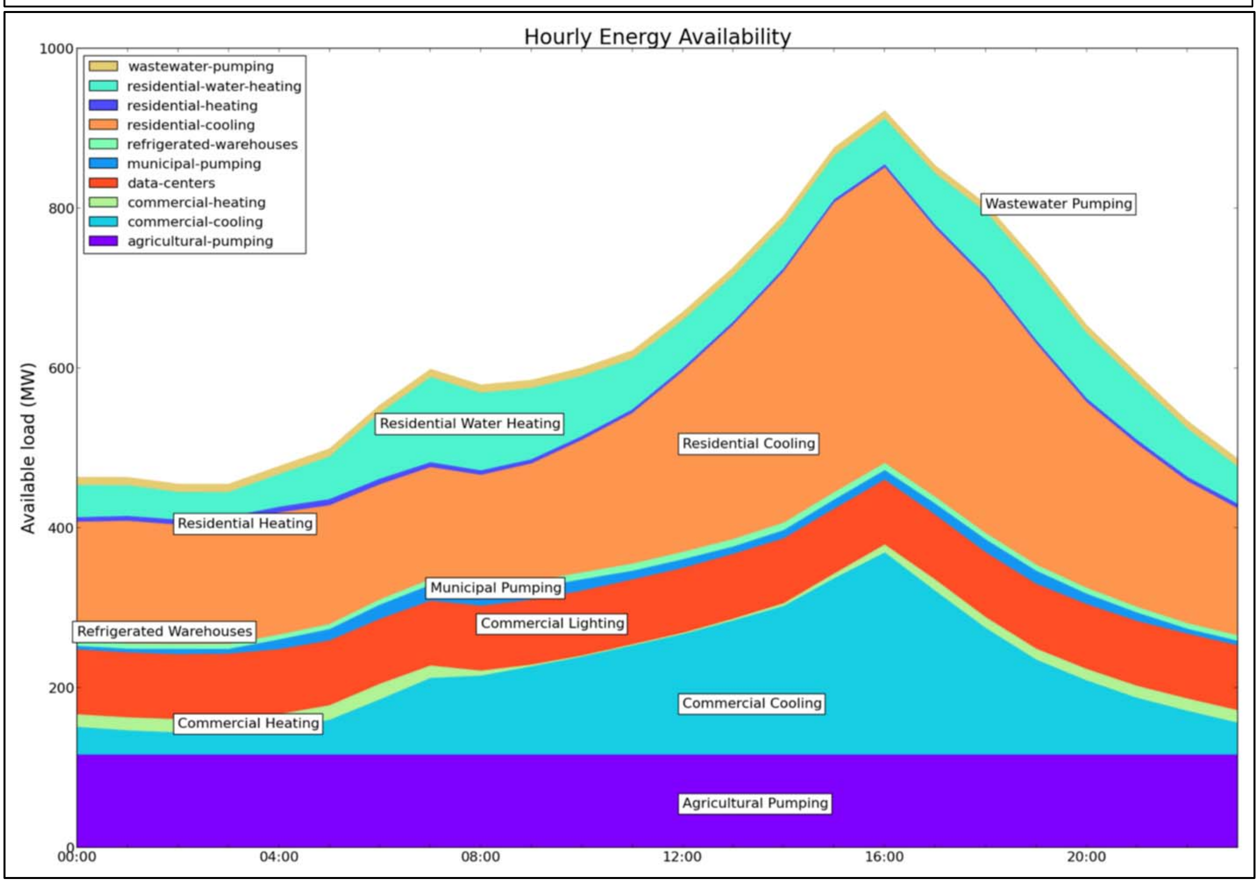


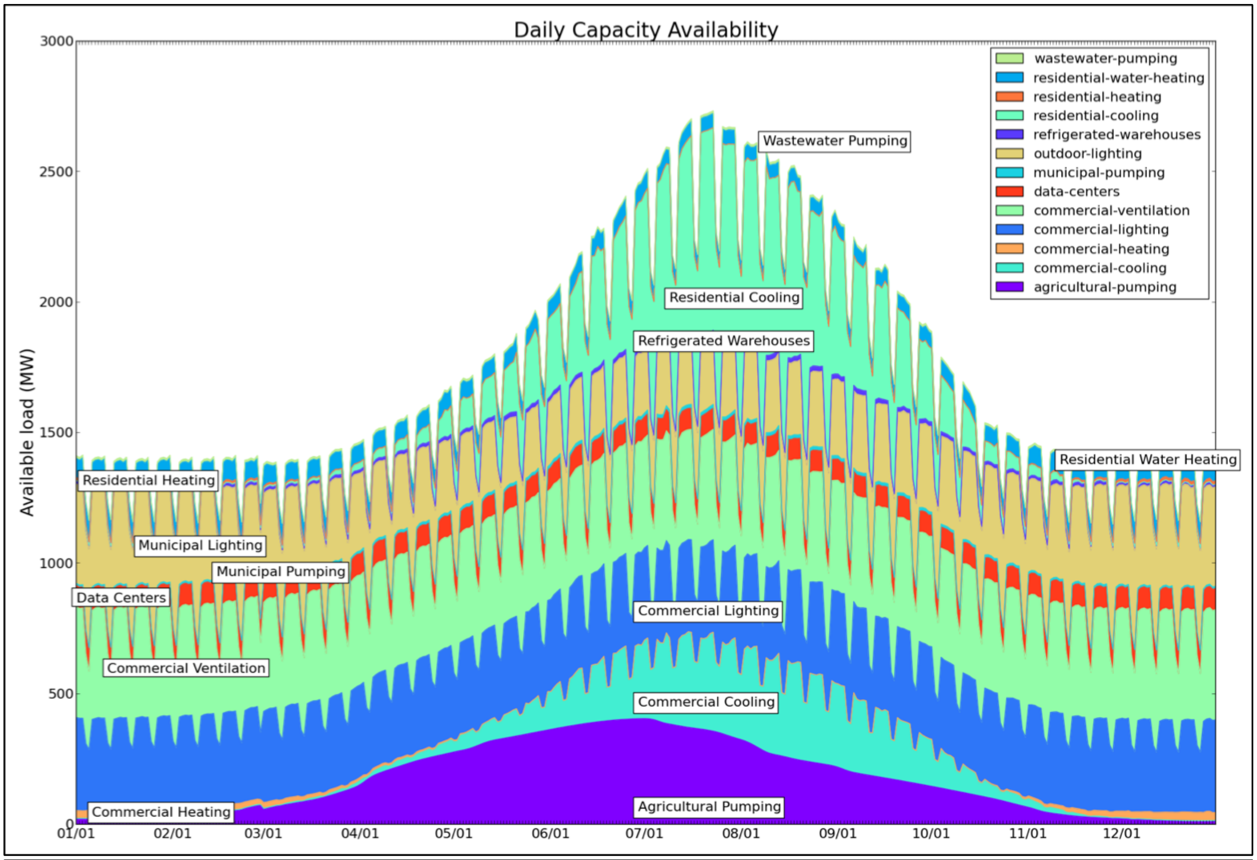
Daily Contingency Availability
Available load (MW)
2500
2000
1500
1000
500
0
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
wastewater-pumping
residential-water-heating
residential-heating
residential-cooling
outdoor-lighting
municipal-pumping
data-centers
commercial-ventilation
commercial-lighting
commercial-cooling
agricultural-pumping
Wastewater Pumping
Residential Cooling
Residential Water Heating
Residential Heating
Municipal Lighting
Municipal Pumping
Data Centers
Commercial Cooling
Commercial Ventilation
Commercial Lighting
Agricultural Pumping

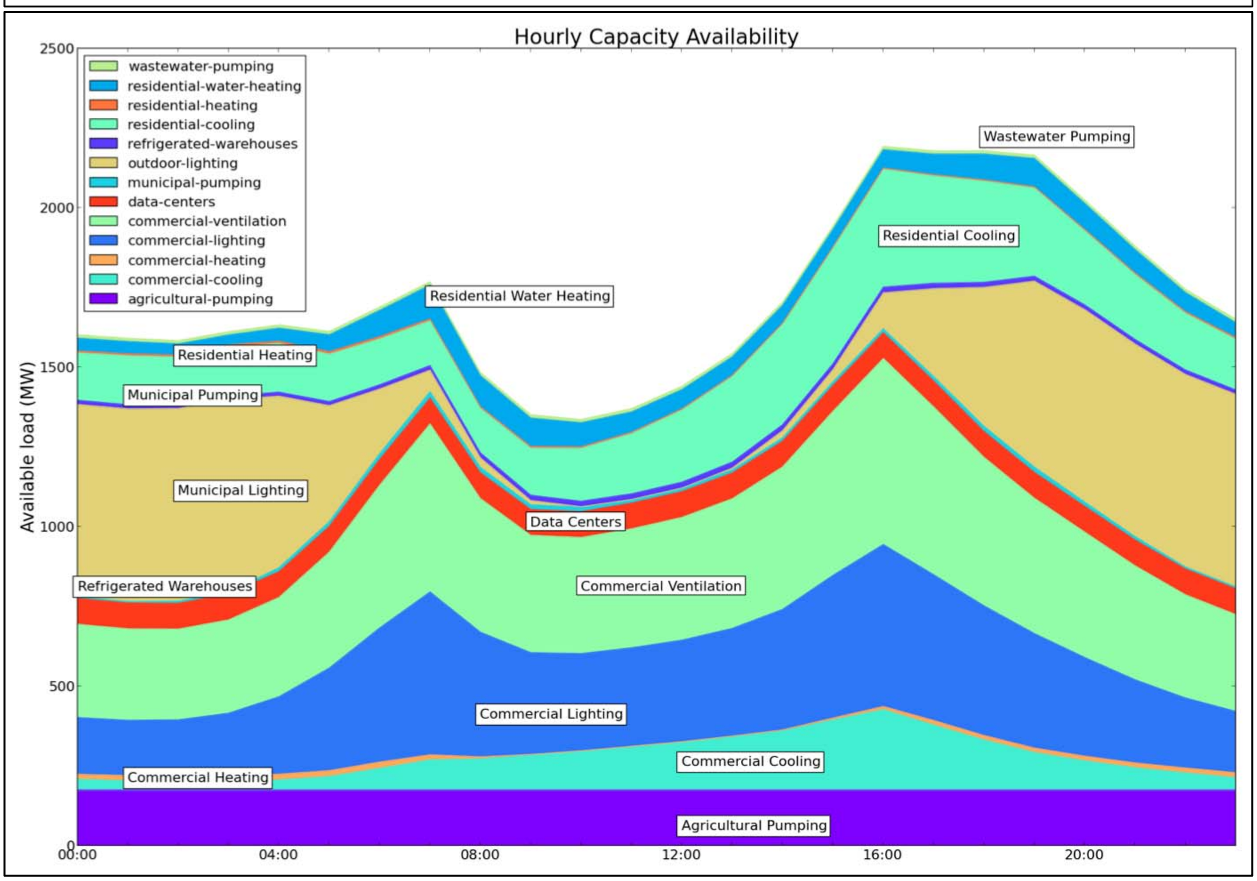



Hourly Contingency Availability
Available load (MW)
1800
1600
1400
1200
1000
800
600
400
200
0
00:00
04:00
08:00
12:00
16:00
20:00
wastewater-pumping
residential-water-heating
residential-heating
residential-cooling
outdoor-lighting
municipal-pumping
data-centers
commercial-ventilation
commercial-lighting
commercial-cooling
agricultural-pumping
Wastewater Pumping
Residential Heating
Residential Water Heating
Residential Cooling
Municipal Lighting
Municipal Pumping
Data Centers
Commercial Ventilation
Commercial Lighting
Commercial Cooling
Agricultural Pumping

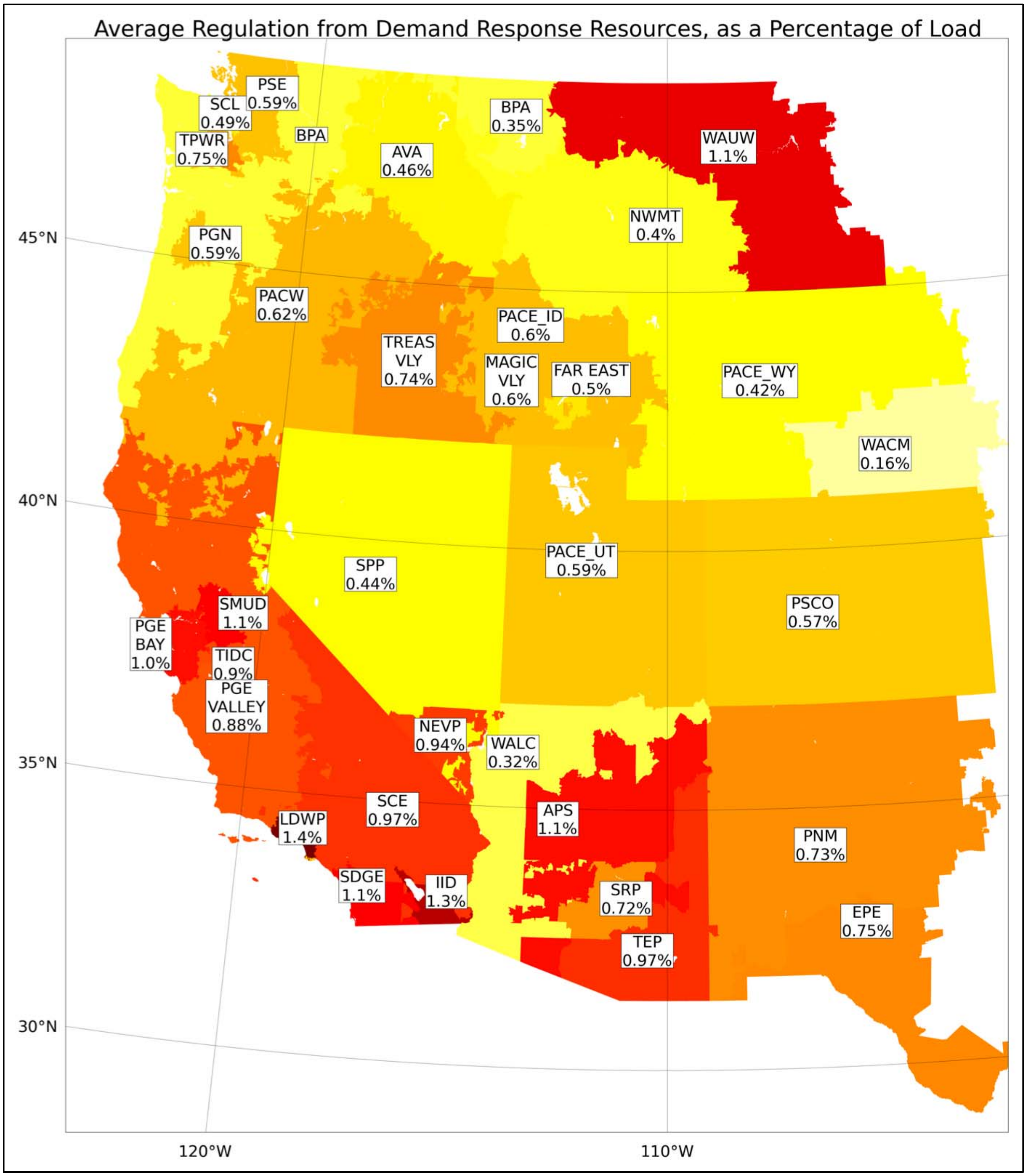

Daily Energy Availability
Available load (MW)
wastewater-pumping
residential-water-heating
residential-heating
residential-cooling
refrigerated-warehouses
municipal-pumping
data-centers
commercial-heating
commercial-cooling
agricultural-pumping
Wastewater Pumping
Residential Cooling
Refrigerated Warehouses
Commercial Cooling
Residential Heating
Municipal Pumping
Commercial Heating
Agricultural Pumping
Residential Water Heating
Commercial Lighting
01/01 02/01 03/01 04/01 05/01 06/01 07/01 08/01 09/01 10/01 11/01 12/01

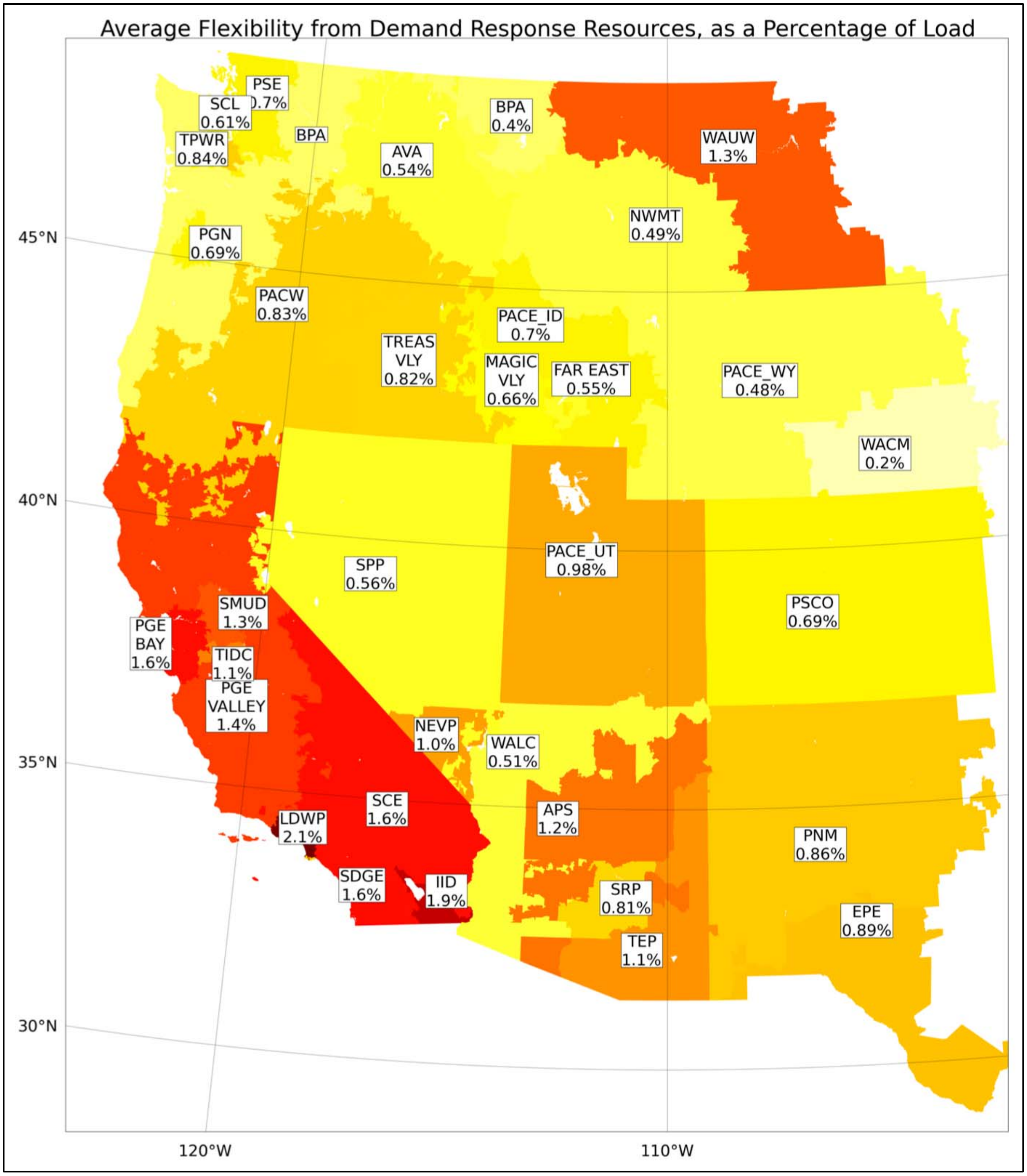

Hourly Energy Availability
Available load (MW)
wastewater-pumping
residential-water-heating
residential-heating
residential-cooling
refrigerated-warehouses
municipal-pumping
data-centers
commercial-heating
commercial-cooling
agricultural-pumping
Wastewater Pumping
Residential Water Heating
Residential Cooling
Residential Heating
Municipal Pumping
Refrigerated Warehouses
Commercial Lighting
Commercial Cooling
Commercial Heating
Agricultural Pumping
00:00 04:00 08:00 12:00 16:00 20:00

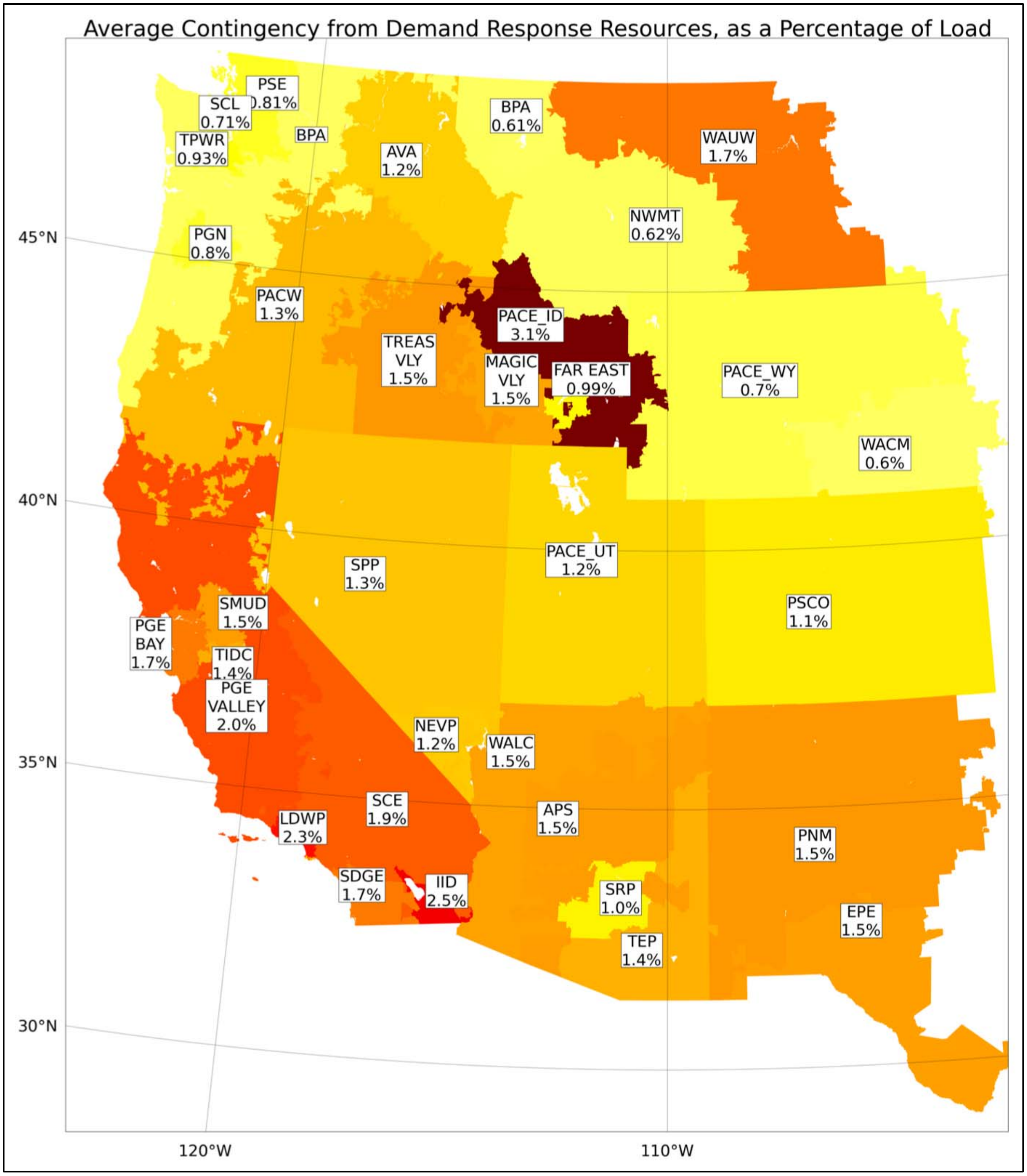

Daily Capacity Availability
Available load (MW)
3000
2500
2000
1500
1000
500
0
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01
wastewater-pumping
residential-water-heating
residential-heating
residential-cooling
refrigerated-warehouses
outdoor-lighting
municipal-pumping
data-centers
commercial-ventilation
commercial-lighting
commercial-heating
commercial-cooling
agricultural-pumping
Wastewater Pumping
Residential Cooling
Refrigerated Warehouses
Residential Water Heating
Residential Heating
Municipal Lighting
Municipal Pumping
Data Centers
Commercial Lighting
Commercial Ventilation
Commercial Cooling
Commercial Heating
Agricultural Pumping

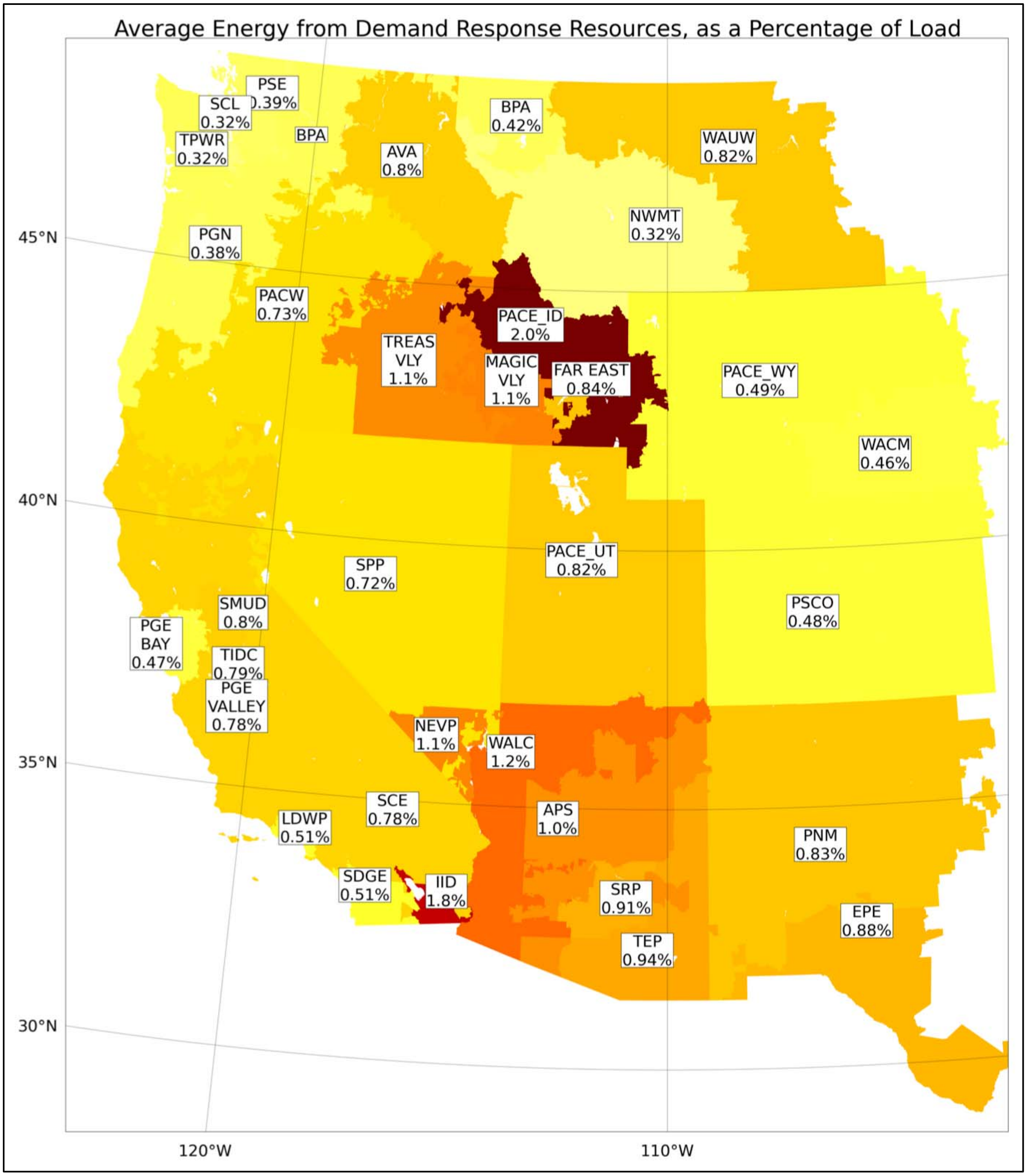

Hourly Capacity Availability
Available load (MW)
2500
2000
1500
1000
500
0
00:00
04:00
08:00
12:00
16:00
20:00
wastewater-pumping
residential-water-heating
residential-heating
residential-cooling
refrigerated-warehouses
outdoor-lighting
municipal-pumping
data-centers
commercial-ventilation
commercial-lighting
commercial-heating
commercial-cooling
agricultural-pumping
Wastewater Pumping
Residential Cooling
Residential Water Heating
Residential Heating
Municipal Pumping
Municipal Lighting
Data Centers
Refrigerated Warehouses
Commercial Ventilation
Commercial Lighting
Commercial Cooling
Commercial Heating
Agricultural Pumping

# Appendix F – Geographic Dispersion of Resource Availability

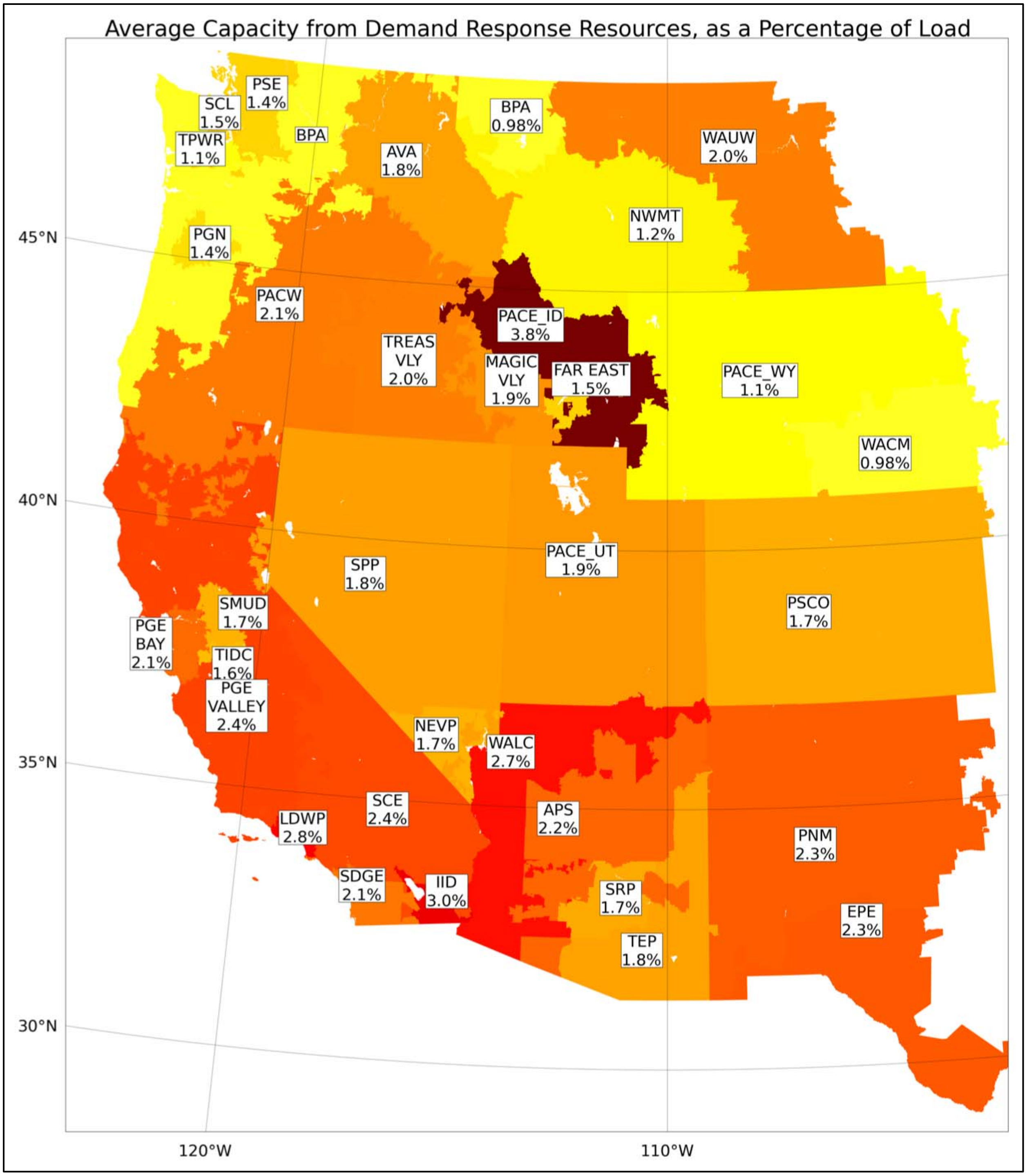



Average Flexibility from Demand Response Resources, as a Percentage of Load
PSE
0.7%
SCL
0.61%
BPA
0.4%
BPA
TPWR
0.84%
AVA
0.54%
WAUW
1.3%
NWMT
0.49%
PGN
0.69%
PACW
0.83%
PACE_ID
0.7%
TREAS
VLY
0.82%
MAGIC
VLY
0.66%
FAR EAST
0.55%
PACE_WY
0.48%
WACM
0.2%
PACE_UT
0.98%
SPP
0.56%
PSCO
0.69%
SMUD
1.3%
PGE
BAY
1.6%
TIDC
1.1%
PGE
VALLEY
1.4%
NEVP
1.0%
WALC
0.51%
SCE
1.6%
APS
1.2%
LDWP
2.1%
PNM
0.86%
SDGE
1.6%
IID
1.9%
SRP
0.81%
EPE
0.89%
TEP
1.1%
45°N
40°N
35°N
30°N
120°W
110°W


Average Contingency from Demand Response Resources, as a Percentage of Load
PSE 0.81%
SCL 0.71%
BPA
TPWR 0.93%
BPA 0.61%
AVA 1.2%
WAUW 1.7%
NWMT 0.62%
PGN 0.8%
PACW 1.3%
PACE_ID 3.1%
TREAS VLY 1.5%
MAGIC VLY 1.5%
FAR EAST 0.99%
PACE_WY 0.7%
WACM 0.6%
PACE_UT 1.2%
SPP 1.3%
SMUD 1.5%
PGE BAY 1.7%
TIDC 1.4%
PGE VALLEY 2.0%
PSCO 1.1%
NEVP 1.2%
WALC 1.5%
SCE 1.9%
APS 1.5%
LDWP 2.3%
PNM 1.5%
SDGE 1.7%
IID 2.5%
SRP 1.0%
EPE 1.5%
TEP 1.4%
45°N
40°N
35°N
30°N
120°W
110°W



Average Energy from Demand Response Resources, as a Percentage of Load
PSE 0.39%
SCL 0.32%
BPA
TPWR 0.32%
BPA 0.42%
AVA 0.8%
WAUW 0.82%
NWMT 0.32%
PGN 0.38%
PACW 0.73%
PACE_ID 2.0%
TREAS VLY 1.1%
MAGIC VLY 1.1%
FAR EAST 0.84%
PACE_WY 0.49%
WACM 0.46%
PACE_UT 0.82%
SPP 0.72%
SMUD 0.8%
PSCO 0.48%
PGE BAY 0.47%
TIDC 0.79%
PGE VALLEY 0.78%
NEVP 1.1%
WALC 1.2%
SCE 0.78%
APS 1.0%
LDWP 0.51%
PNM 0.83%
SDGE 0.51%
IID 1.8%
SRP 0.91%
EPE 0.88%
TEP 0.94%
45°N
40°N
35°N
30°N
120°W
110°W


Average Capacity from Demand Response Resources, as a Percentage of Load
PSE 1.4%
SCL 1.5%
BPA
TPWR 1.1%
BPA 0.98%
AVA 1.8%
WAUW 2.0%
NWMT 1.2%
PGN 1.4%
PACW 2.1%
PACE_ID 3.8%
TREAS VLY 2.0%
MAGIC VLY 1.9%
FAR EAST 1.5%
PACE_WY 1.1%
WACM 0.98%
SPP 1.8%
PACE_UT 1.9%
PSCO 1.7%
SMUD 1.7%
PGE BAY 2.1%
TIDC 1.6%
PGE VALLEY 2.4%
NEVP 1.7%
WALC 2.7%
SCE 2.4%
APS 2.2%
LDWP 2.8%
PNM 2.3%
SDGE 2.1%
IID 3.0%
SRP 1.7%
EPE 2.3%
TEP 1.8%
45°N
40°N
35°N
30°N
120°W
110°W