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Demand Response Availability Profiles for California in the Year 2020

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Energy Research and Development Division
Final Report

Demand Response Availability Profiles for California in the Year 2020

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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- Renewable Energy Technologies
- Transportation

Demand Response Availability Profiles for California in the Year 2020 is the final report for the Pier project (contract number 500-03-026, work authorization number 3 conducted by the Demand Response Research Center. The information from this project contributes to Energy Research and Development Division's For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

Demand response (DR) is being considered as a valuable resource for keeping the electrical grid stable and efficient, and deferring upgrades to generation, transmission, and distribution systems. However, simulations to determine how much infrastructure upgrades can be deferred are necessary in order to plan optimally. Production cost modeling is a technique, which simulates the dispatch of generators to meet demand and reserves in each hour of the year, at minimal cost. By integrating demand response resources into a production cost model (PCM), their value to the grid can be estimated and used to inform operations and infrastructure planning.

DR availability profiles and constraints for 13 end-uses in California for the year 2020 were developed by Lawrence Berkeley National Laboratory (LBNL), and integrated into a production cost model by Lawrence Livermore National Laboratory (LLNL), for the California Energy Commission's Value of Energy Storage and Demand Response for Renewable Integration in California Study. This report summarizes the process for developing the DR availability profiles for California, and their aggregate capabilities. While LBNL provided potential DR hourly profiles for regulation product in the ancillary services market and five-minute load following product in the energy market for LLNL's study, additional results in contingency reserves and an assumed flexible product are also defined. These additional products are included in the analysis for managing high ramps associated with renewable generation and capacity products and they are also presented in this report.

Keywords: Demand response, automation, smart grid, demand response costs, grid integration, production cost model.

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Introduction

Demand response (DR) is being considered as a valuable resource for keeping the electrical grid stable and efficient, and deferring upgrades to generation, transmission, and distribution systems. However, simulations to determine how long infrastructure upgrades can be deferred are necessary in order to plan optimally.

Project Purpose

While LBNL's initial scope was to support LLNL with their analysis by providing DR hourly profiles for regulation product in the ancillary services market and five-minute load following product in the energy market, we received additional funding from the Department of Energy to include additional results in contingency reserves, an assumed flexible product that can be used for managing high ramps and capacity products.

Project Results

DR availability profiles and constraints for 13 end-uses in California for the year 2020 were developed by Lawrence Berkeley National Laboratory (LBNL), and integrated into a production cost model by Lawrence Livermore National Laboratory (LLNL), for the California Energy Commission's Value of Energy Storage and Demand Response for Renewable Integration in California Study. This report summarizes the process for developing the DR availability profiles for California, and their aggregate capabilities. 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.

Project Benefits

By integrating demand response resources into a production cost model (PCM, a simulation technique that simulates the dispatch of generators to meet demand and reserves in each hour of the year at minimal cost), their value to the grid can be estimated and used to inform operations and infrastructure planning. Therefore, in this report, we included results of our analysis of the contingency and capacity products as well.

CHAPTER 1: Introduction

Demand response (DR) is being considered as a valuable resource for keeping the electrical grid stable and efficient, and deferring upgrades to generation, transmission, and distribution systems. However, simulations to determine how long infrastructure upgrades can be deferred are necessary in order to plan optimally. Production cost modeling is a simulation technique, which simulates the dispatch of generators to meet demand and reserves in each hour of the year at minimal cost. By integrating demand response resources into a production cost model (PCM), their value to the grid can be estimated and used to inform operations and infrastructure planning. To do this accurately, time- and location-varying DR availability profiles are needed for each service (energy, capacity, operating reserves, etc.) in which DR can participate. Additionally, constraints are needed to represent the level of DR participation likely to be accepted by the customers.

DR availability profiles and constraints for 13 end-uses in California for the year 2020 were developed by Lawrence Berkeley National Laboratory (LBNL), and integrated into a production cost model by Lawrence Livermore National Laboratory (LLNL), for the California Energy Commission's Value of Energy Storage and Demand Response for Renewable Integration in California Study. This report summarizes the process for developing the DR availability profiles for California, and their aggregate capabilities. 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. While LBNL's initial scope was to support LLNL with their analysis by providing DR hourly profiles for regulation product in the ancillary services market and five-minute load following product in the energy market, we received additional funding from the Department of Energy to include additional results in contingency reserves, an assumed flexible product that can be used for managing high ramps and capacity products. Therefore, in this report, we included results of our analysis of the contingency and capacity products as well.

CHAPTER 2: Methodology

2.1 End Use Categories Chosen

Sector-specific end-uses were selected for inclusion in the study based on the magnitude of their electrical demand and their ability to control their demand in response to the needs of the electrical grid. Ultimately, we selected 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 1.

Table 1: The 13 end uses considered

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

For each resource, an hourly load profile was developed, incorporating available information on the magnitude, distribution, and timing of energy consumption in the year 2020. The magnitude of energy used for each Balancing Authority Area (BAA) was estimated using the Transmission Expansion Planning Policy Committee (TEPPC) PC1 reference case, and the magnitude energy used by each sector within BAAs was estimated using Itron's predictions of monthly energy use by sector. Commercial end-use load profiles were obtained from the California Commercial End-use Survey (CEUS), conducted by the California Energy Commission (California Energy Commission 2006). For residential loads, residential end-use forecast data from the California Energy Commission for the year 2020 are used (California Energy Commission 2012). Agricultural irrigation pumping loads were estimated using the data from the USDA on operating pumps, crop distributions, historical weather patterns, and typical planting/harvest dates (United States Department of Agriculture 2009 & 2010, National Oceanographic and Atmospheric Administration 1982). Data center load magnitude of 3% of each BAA was assumed, based on data from the EPA (Environmental Protection Agency 2007). Municipal lighting magnitudes are based on a DOE study into the benefits of LED lighting conversions, and timing is estimated using sunrise/sunset times from the US Naval Observatory (Department of Energy 2011, United States Naval Observatory 2012). Municipal pumping and wastewater pumping loads were estimated on a per-capita basis, and load profiles were estimated based on previous studies into California water use (House 2007, Department of Water Resources 1994). Refrigerated warehouse loads were based on storage volume and seasonal weather patterns (United States Department of Agriculture 2012).

We identified five products, to which we assumed DR resources could contribute (Table 2). In addition to the regulation and energy products that were used by LLNL for their California study, additional products were considered for a separate study with DOE and the National

Renewable Energy Laboratory for a Western Electricity Coordinating Council (WECC)-wide production cost modeling (PCM) implementation. We mapped the DR resources to the products, based on product requirements, and summarized it in Table 3.Resource response capabilities were estimated based on a literature review, previous experience with field studies, and filings by utilities, independent system operators(ISOs), and public utilities commissions. **To determine what fraction of these loads could respond to each of the products in each hour of the year, three flexibility filters were 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.

Table 2: 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			

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 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” or “pre-charged”, the end-uses are modeled as storage and the timing and magnitude of the energy re-charge/pre-charge are specified. These generator profile parameters are shown graphically in Figure 1. The maximum “generation” at each hour is specified using the demand response availability profiles.

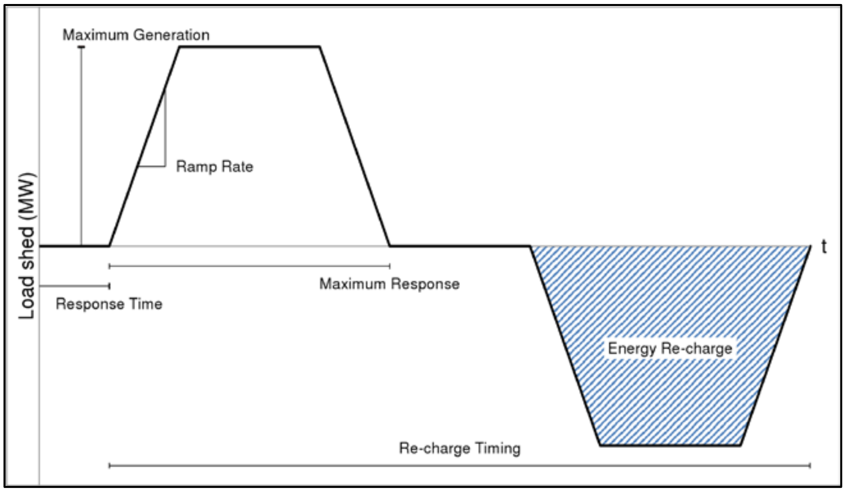

Figure 1: Demand response generator profile for energy shifting end uses.

Further details of the load profiles, flexibility filters, and generator profiles are provided in the full report on the Western Interconnection (Olsen et al. 2013).

2.2 Flexibility Assumptions

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 hourAs 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.

The determination of the demand response available for ancillary services by hour is shown in Equation 1.

$$DR(hour, BAA, enduse, product) = Load * Participationrate * ShedRate \tag{1}$$

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 (also termed 'sheddability') is the proportion of the responding load that is shedin 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.

$$Participationrate(hour, BAA, enduse, product) = \min(Acceptability, Controllability) \tag{2}$$

In this equation, the Controllability is a static value representing the share of the loads that 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 value issued for the Participation rate.

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 acceptabilitythroughout the day and through the year, the peak 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 service, energy and capacity product flexibility factors (sheddability, controllability and availability) were 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 were 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 factors 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 were weighted by building type-specific end-use annual energy usage (GWh) data from CEUS, the Northwest Power and Conservation Council (NPCC) and the Commercial Building Energy Consumption Survey (CBECS), to obtain weighted end-use specific sheddability and controllability values for each state. "Current controllability" values were used to estimate controllability for Energy and Capacity products in 2020, while 2020 ancillary services controllability penetration would be equivalent to these "technical potential" controllability values.

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. Acceptability values for each region were determined based on current utility programs and pilots and on projections as to what 2020 programs and related participation may be. As such, California could 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 is not targeted by California utilities, and customers are not comfortable with heating DR). Low levels of minimum acceptability (~2%) for all commercial end-uses were assumed for the rest of the Western Interconnect 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

	Energy and Capacity			Ancillary Services				
	Sheddability	Controllability	Acceptability	Sheddability	Controllability	Acceptability		
						Regulation	Flexibility	Contingency
Heating	46 – 51%	10 – 25%	*Default* Daily min: 0% Daily max:75-77% *Northwest* Daily min: 3% Daily max: 75-77%	53 – 64%	7-16%	Daily min: 0% Daily max:0.6%	Daily min: 0% Daily max:1.8%	Daily min: 0% Daily max:1.8%
Cooling	41 – 49%	15-25%	*Default* Daily min: 3% Daily max: 75-77% *California* Daily min: 35% Daily max: 75-77%	50 – 58%	7-16%	*Default* Daily min: 0% Daily max: 2% *California* Daily min: 3% Daily max: 7%	*Default* Daily min: 0% Daily max: 2% *California* Daily min: 10% Daily max: 21%	*Default* Daily min: 0% Daily max: 2% *California* Daily min: 3% Daily max: 77%
Ventilation	46-49%	17-25%	Daily min: 3% Daily max: 75-77%	53 – 59%	8-16%	*Default* Daily min: 0% Daily max: 2% *California* Daily min: 3% Daily max: 7%	*Default* Daily min: 0% Daily max: 2% *California* Daily min: 10% Daily max: 21%	*Default* Daily min: 0% Daily max: 2% *California* Daily min: 10% Daily max: 21%
Indoor Lighting	26 – 28%	15-17%	Daily min: 3% Daily max:75-77%	26 – 28%	7-11%	*Default* Daily min: 0% Daily max: 2% *California* Daily min: 3% Daily max: 7%	*Default* Daily min: 0% Daily max: 2% *California* Daily min: 10% Daily max: 21%	*Default* Daily min: 0% Daily max: 2% *California* Daily min: 10% Daily max: 21%

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. See Table 5 for the range in flexibility factors for residential heating and cooling.

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 programmable communicating thermostats. 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 Interconnect (26% DLC in Utah).

Acceptability. The prevalence of current utility programs and pilots in residential heating and cooling issued as a guide to determine the corresponding 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.

Table 5. Residential Cooling and Heating Values

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

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* Daily min: 13% Daily max: 19%	5%	0%	0%
		Utah: 26%	*Utah* Daily min: 26% Daily max: 39%			

2.3.3 Industrial 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 end-uses are included here based on the DRRC'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 Auto-DR 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 Capacity and Contingency, and a participation rate of 10% is assumed for Energy.

Data Centers: Given that data center loads are relatively flat throughout the day and year, a flat rate of 3% is assumed for all products, with a 100% participation rate. Mixed use data centers exhibit a diurnal load profile peaking during daytime, but the variability is due to conventional office 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.

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 Energy.

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, min/max duration, and constraints on call frequency. For loads which respond by shifting load rather than shedding it, an energy payback is required, and the timing and magnitude of this payback are also parameters of a generator model (in this case the generation model is based on pumped storage hydro). The speed of energy payback is constrained as well. For end-uses with a constant load profile, payback occurs at the same rate as the daily availability, while for variable end-uses, payback is constrained to the difference between scheduled availability during payback hours and peak daily availability (precluding the creation of a new peak due to payback). These parameters are listed for all resources in Tables 7 and 8. The 'faster' response times were used for Regulation, Flexibility, and Contingency, while the 'slower' ramp times were used for Energy and Capacity.

For thermal end-uses, this energy payback can occur before an event, 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 3-7am and 8am-12pm, respectively; these times were selected as immediately preceding the peak load hours for these resources. Ideally, energy payback via pre- and post-cooling would be constrained to occur adjacent to an energy shift, whenever it occurred, but due to limitations in PLEXOS they were modeled on a 24-hour cycle with restricted hours of payback.

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 and cost per-hour are specified for the Energy and Capacity products.

Figure 4shows these parameters graphically in the context of a single response event with associated energy payback. 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 payback requirements behave as an energy storage medium, such as pumped hydro-generation, without losses.

Table 7: Product constraints

Resource	Minimum Duration	Maximum Duration	Call Limits	Energy Payback
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 8am-12am
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
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

Based on the assumptions made about the magnitude, behavior, and abilities of the selected end-uses within California to respond, the demand response resources can contribute as much as 1,621 MW of the capacity product, 1,006 MW of the energy product, 1,252 MW of contingency reserves, 1,117 MW of flexibility reserves, and 818 MW of regulation reserves. Expressed as a fraction of total predicted California load in each hour, these values represent up to 2.2% of load for regulation reserves, 2.8% for flexibility reserves, 3.2% for contingency reserves, 2.4% for the energy product, and 3.9% for the capacity product.

The interpretation of the availability values for the energy and capacity products differs from the interpretation of the ancillary services values. For each balancing authority area (BAA) in California, 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.

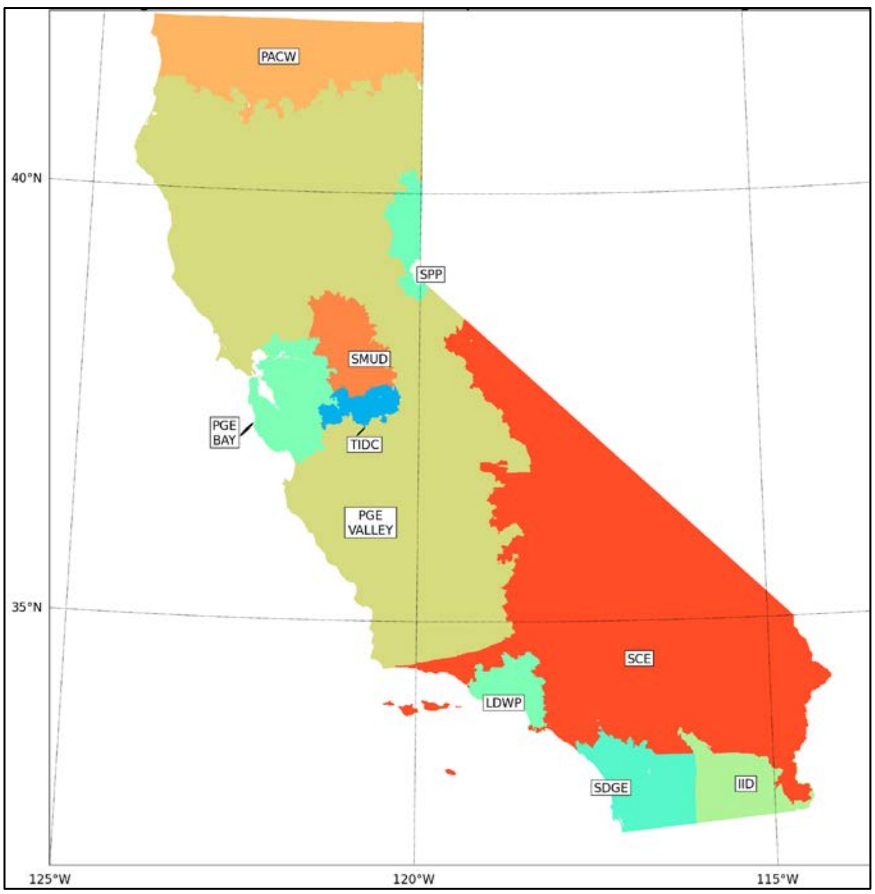

Figure 2: Approximate BAA boundaries, as implemented in model

The range of values for each product is shown in Figure 3. For each product, the range of total product availability within California 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.

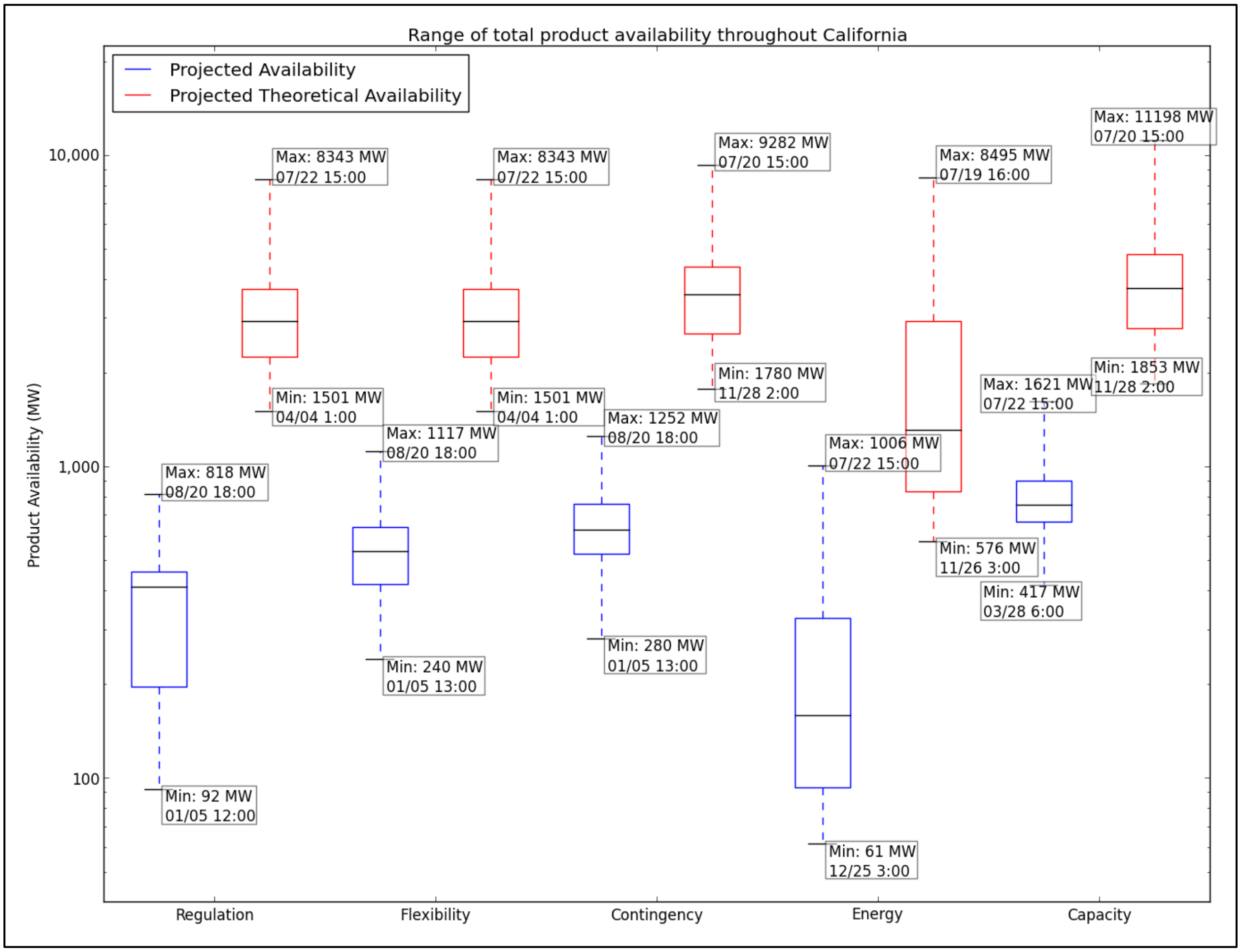

Figure 3: Product availability ranges with maximum and minimum hours

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 4.Availability patterns for all products are shown in Appendix C.

In Figure 4, the total availability of regulation reserves throughout California for each hour is calculated by summing the availability for each resource in each BAA. The availability value 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.

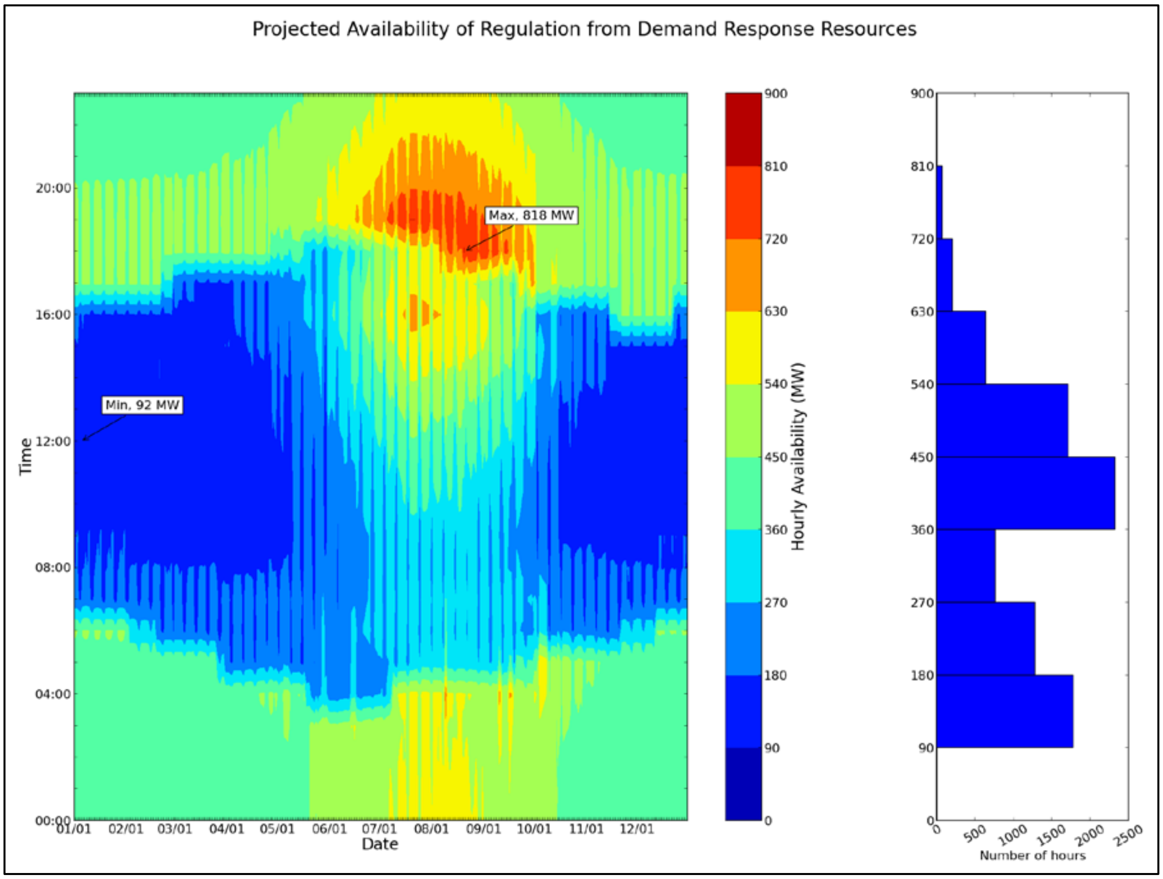

Figure 4: Regulation reserves availability pattern

DR availability profiles typically vary by end-use, be time-of-day, day-of-the week, month or season of the year. These availability profiles can be disaggregated in several ways: one example is by resource. Over the course of a day, the availabilities from the individual resources vary, and reach their maximums at different times:

- Commercial lighting and ventilation peak during the hours of 8am to 6pm.
- Commercial heating peaks 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.

Maximum availability times were consistent across the balancing authority areas in California due to similarities in underlying load compositions, but differ from availability profiles in areas with significant electric heating, which are winter- or dual-peaking. The availability of each resource for contingency reserves across California is shown in Figures5a and 5b, and the contribution from each BAA for the capacity product availability is shown in Figures 6a and 6b.

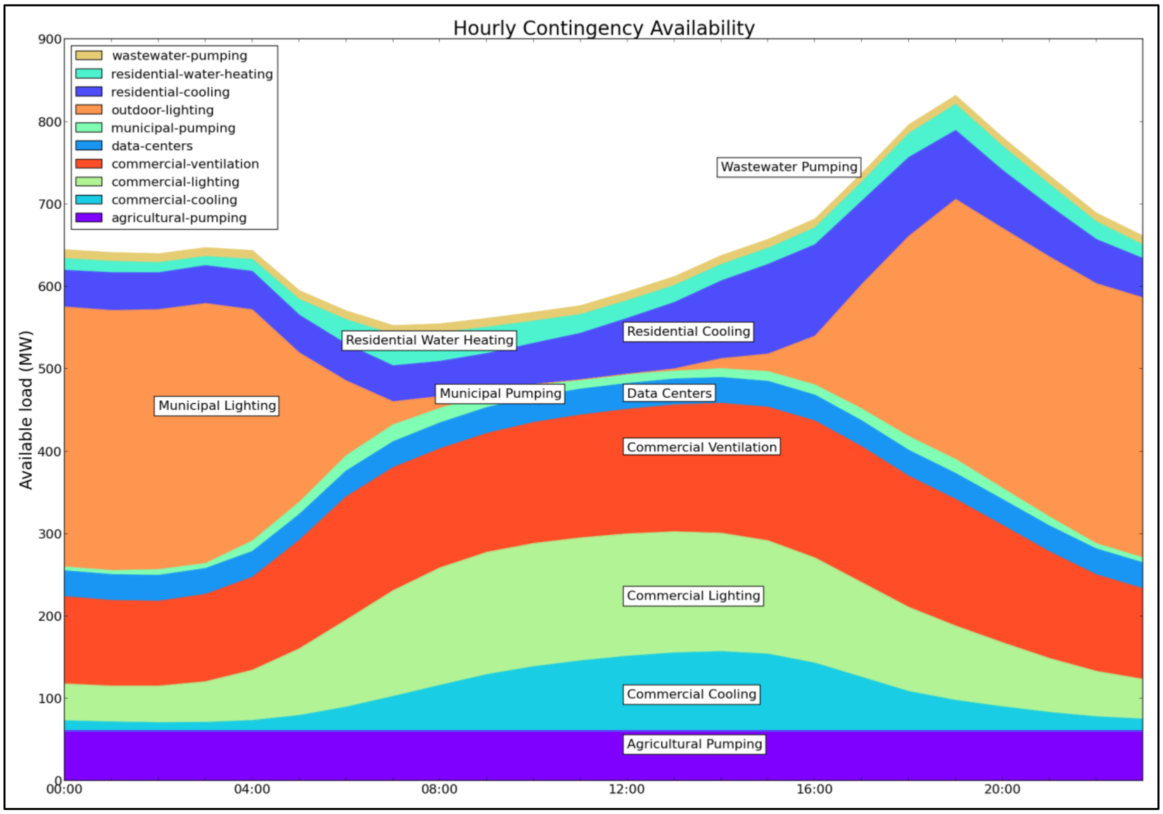

Figure 5a: Contribution of each resource to contingency reserves, hourly average

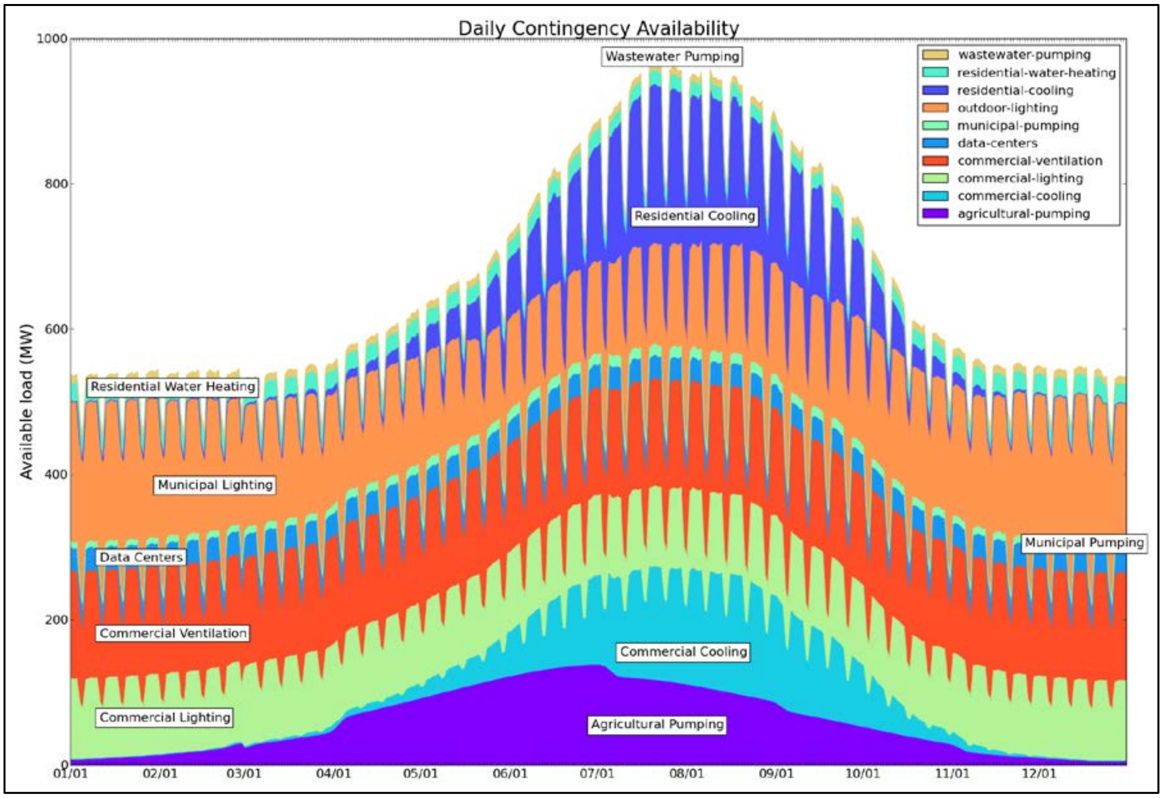

Figure 5b: Contribution of each resource to contingency reserves, daily average

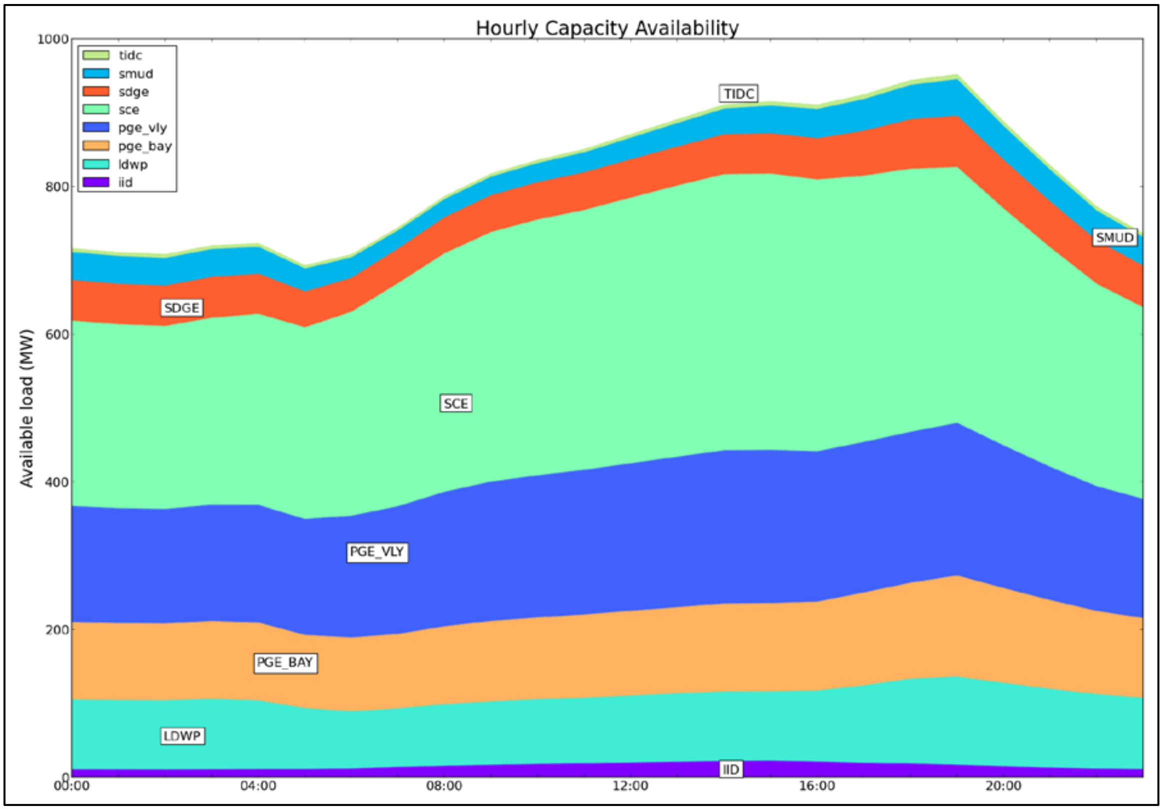

Figure 6a: Contribution of each BAA to the capacity product, hourly average

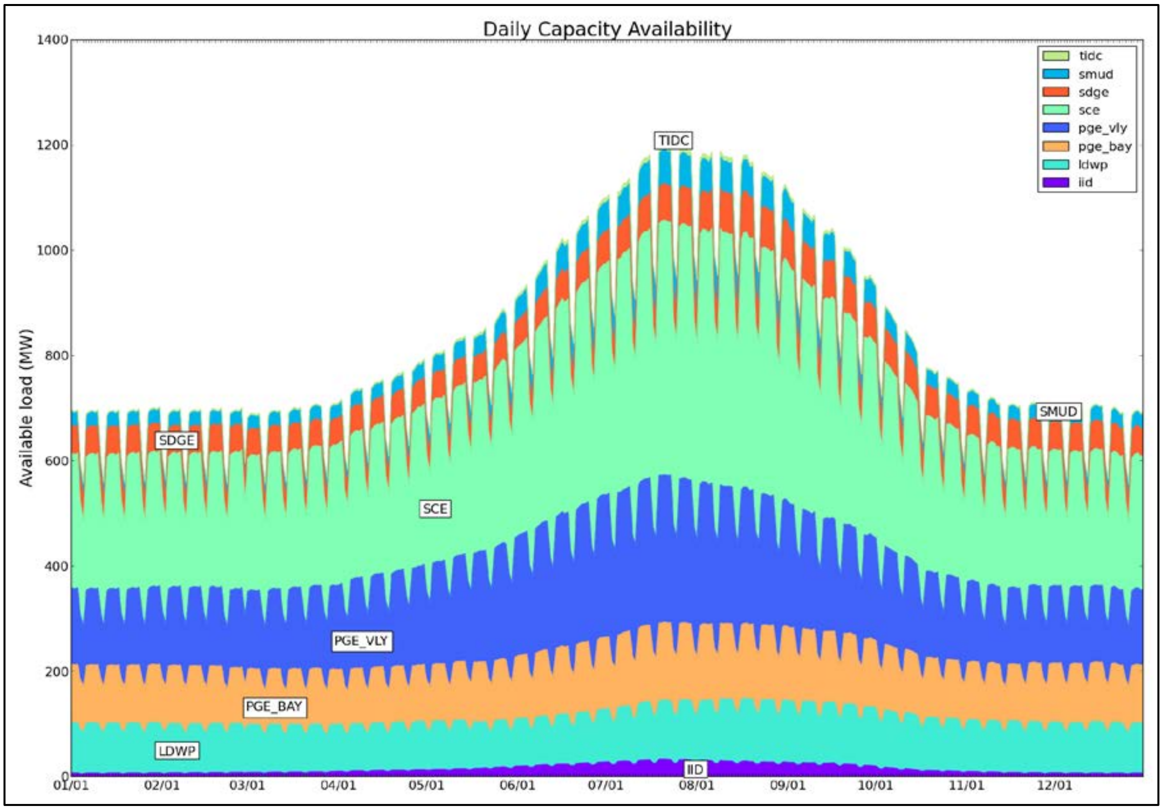

Figure 6b: Contribution of each BAA to the capacity product, daily average

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.

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, or the fraction of load shed in typical DR strategies. In this case, there is a maximum of 8.3 GW available for regulation and flexibility reserves, 9.3 GW available for contingency reserves, 8.5 GW available for the energy product, and 11.2 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 9.

Table 9: Total California 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	0.09 – 0.8 GW (0.3-2.2%)	1.5 – 8.3 GW (5-20%)
Flexibility	0.24 – 1.1 GW (0.7-2.8%)	1.5 – 8.3 GW (5-20%)
Contingency	0.28 – 1.3 GW (0.9-3.2%)	1.8 – 9.3 GW (6-22%)
Energy	0.06 – 1.0 GW (0.2-2.4%)	0.6 – 8.5 GW (2-20%)
Capacity	0.42 – 1.6 GW (1.3-3.9%)	1.8 – 11.2 GW (6-26%)

CHAPTER 4: Conclusions and Discussion

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 in California. 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 and were used to build load availability profiles for the Western Interconection.

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
- Expansion to evaluate additional end uses not included in this analysis
- 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.

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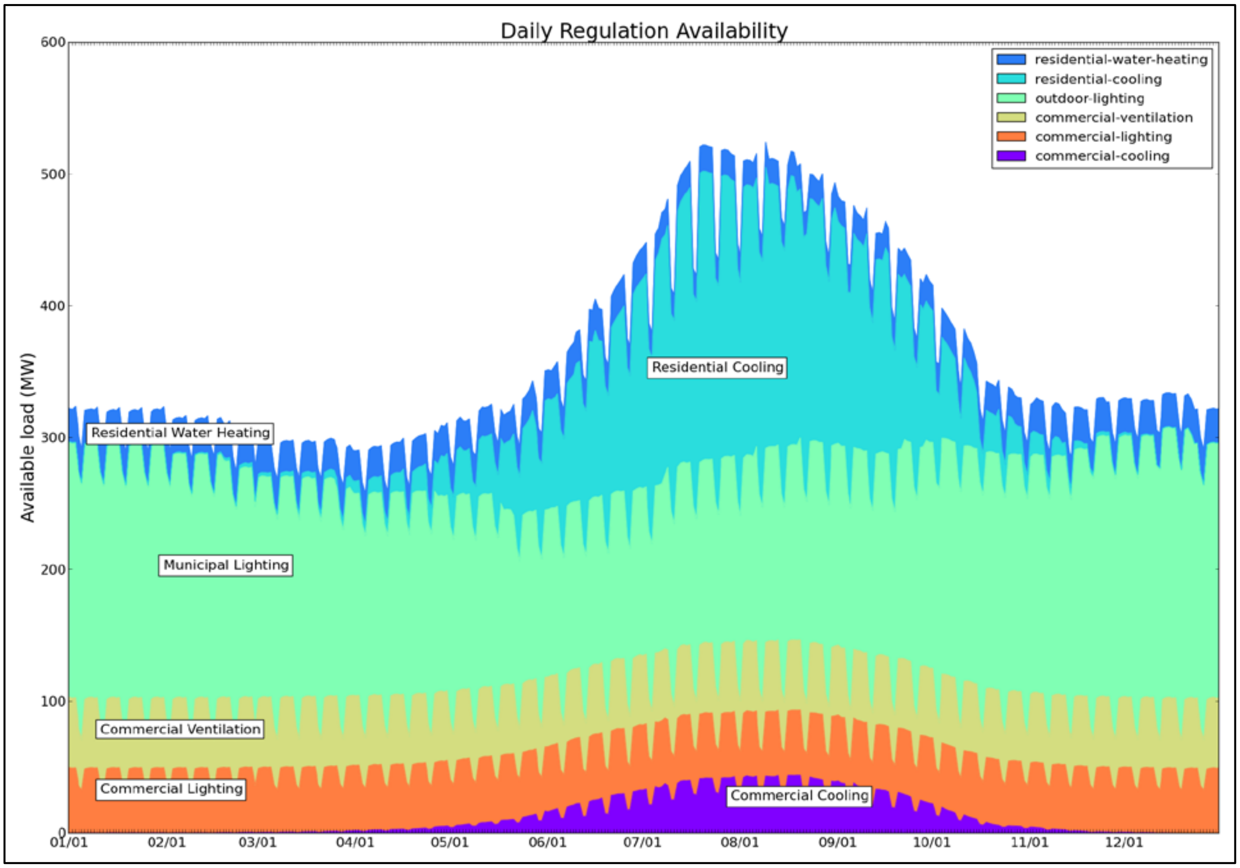
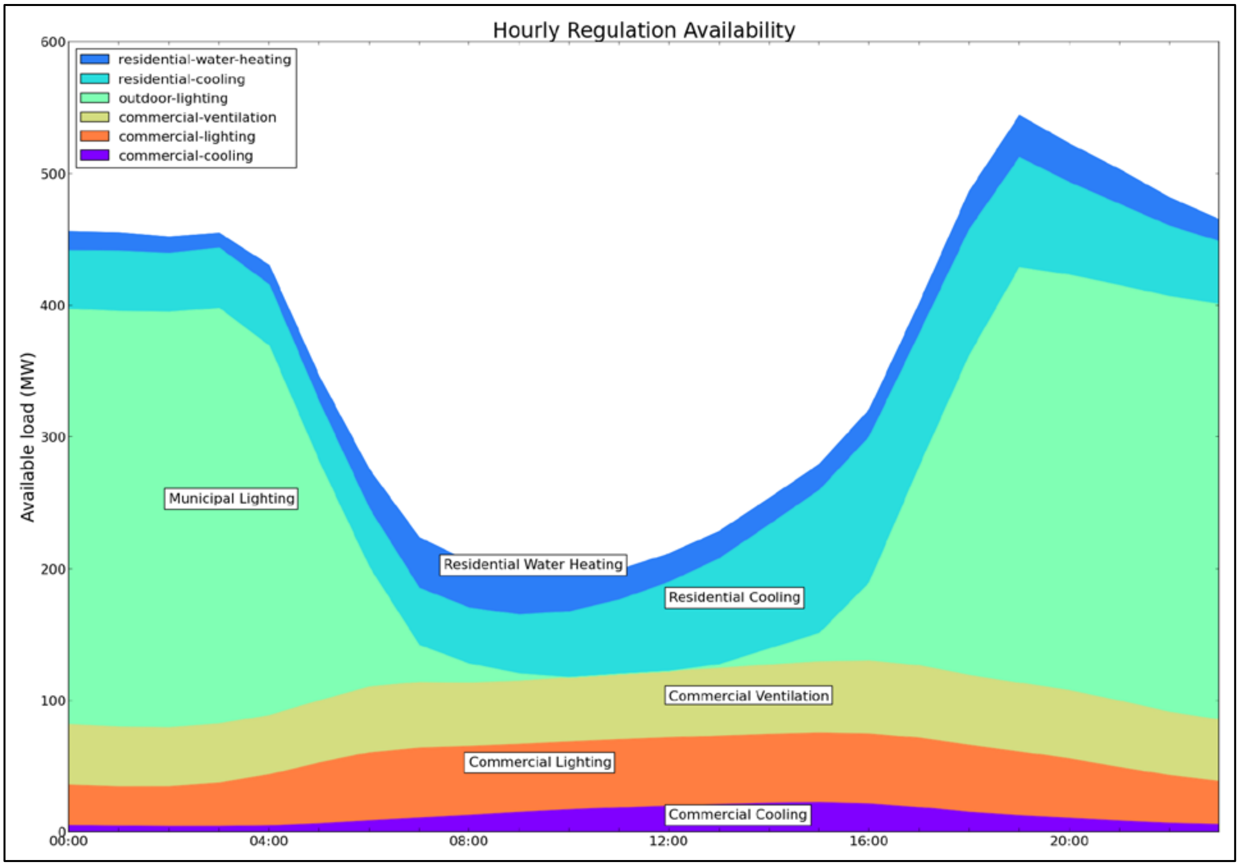
Appendix A
Resource Contributions to Products

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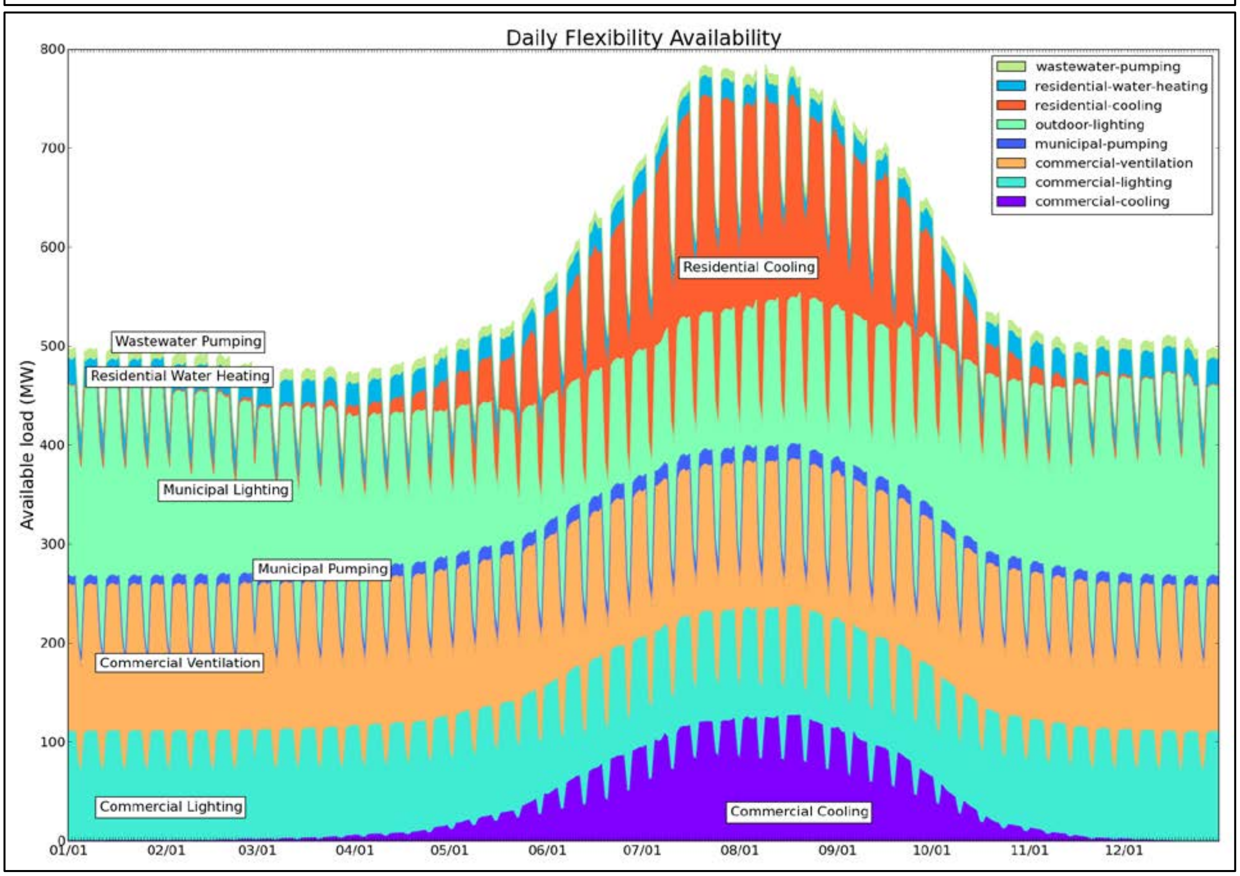
residential-cooling
outdoor-lighting
commercial-ventilation
commercial-lighting
commercial-cooling
Available load (MW)
Municipal Lighting
Residential Water Heating
Residential Cooling
Commercial Ventilation
Commercial Lighting
Commercial Cooling
00:00
04:00
08:00
12:00
16:00
20:00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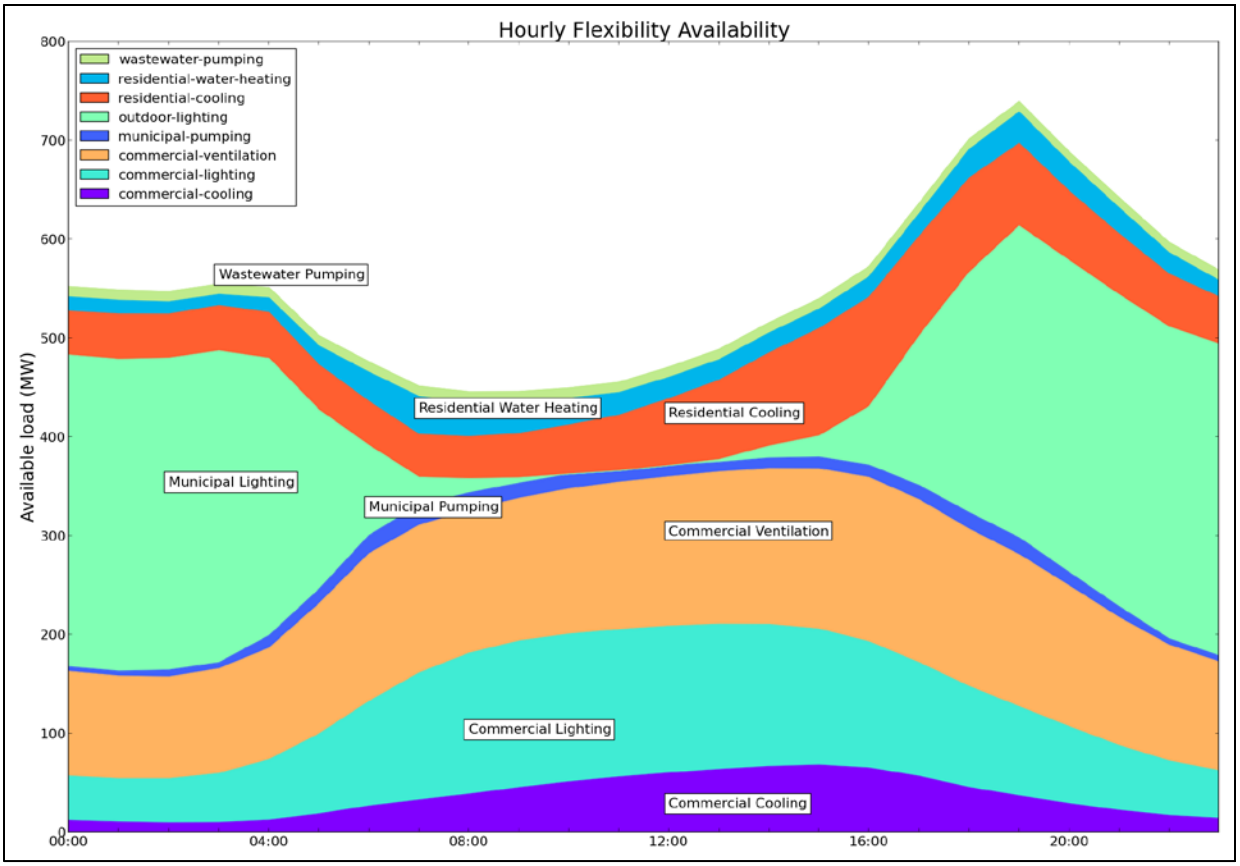
residential-water-heating
residential-cooling
outdoor-lighting
municipal-pumping
commercial-ventilation
commercial-lighting
commercial-cooling
Available load (MW)
Residential Cooling
Wastewater Pumping
Residential Water Heating
Municipal Lighting
Municipal Pumping
Commercial Ventilation
Commercial Lighting
Commercial Cooling
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01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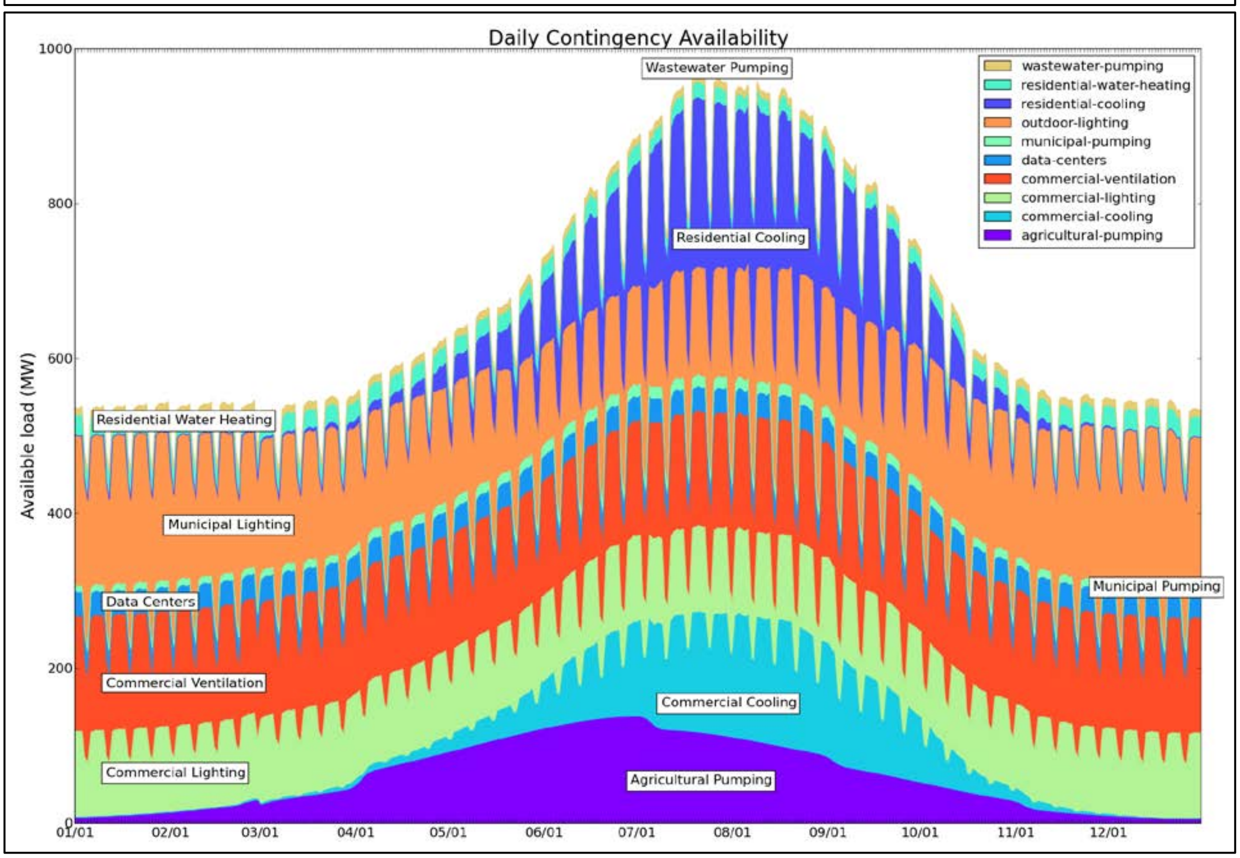
residential-water-heating
residential-cooling
outdoor-lighting
municipal-pumping
commercial-ventilation
commercial-lighting
commercial-cooling
Wastewater Pumping
Residential Water Heating
Residential Cooling
Municipal Lighting
Municipal Pumping
Commercial Ventilation
Commercial Lighting
Commercial Cooling
Available load (MW)
00:00
04:00
08:00
12:00
16:00
20:00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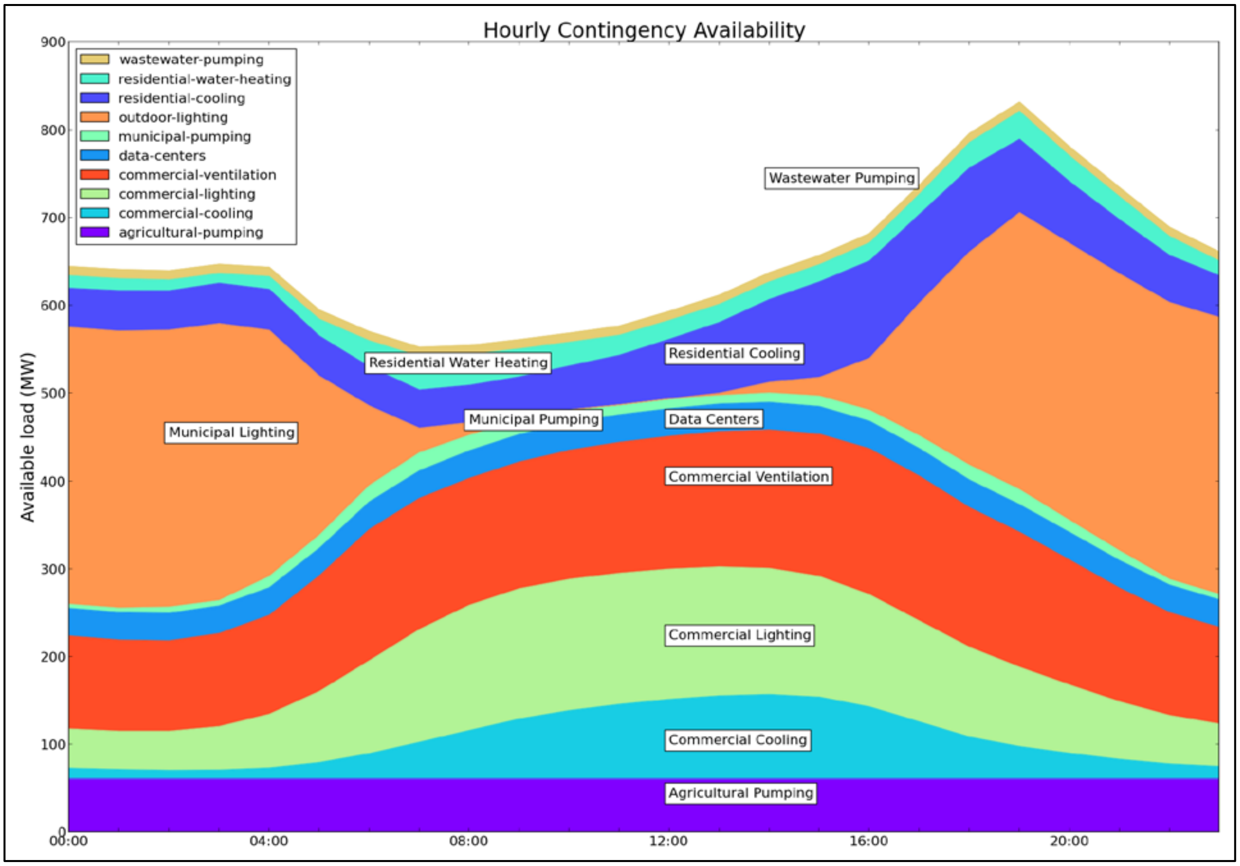
residential-water-heating
residential-cooling
outdoor-lighting
municipal-pumping
data-centers
commercial-ventilation
commercial-lighting
commercial-cooling
agricultural-pumping
Wastewater Pumping
Residential Cooling
Residential Water Heating
Municipal Lighting
Data Centers
Municipal Pumping
Commercial Ventilation
Commercial Cooling
Commercial Lighting
Agricultural Pumping
Available load (MW)
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 Contingency Availability
Available load (MW)
wastewater-pumping
residential-water-heating
residential-cooling
outdoor-lighting
municipal-pumping
data-centers
commercial-ventilation
commercial-lighting
commercial-cooling
agricultural-pumping
Wastewater Pumping
Residential Water Heating
Residential Cooling
Municipal Lighting
Municipal Pumping
Data Centers
Commercial Ventilation
Commercial Lighting
Commercial Cooling
Agricultural Pumping
00:00
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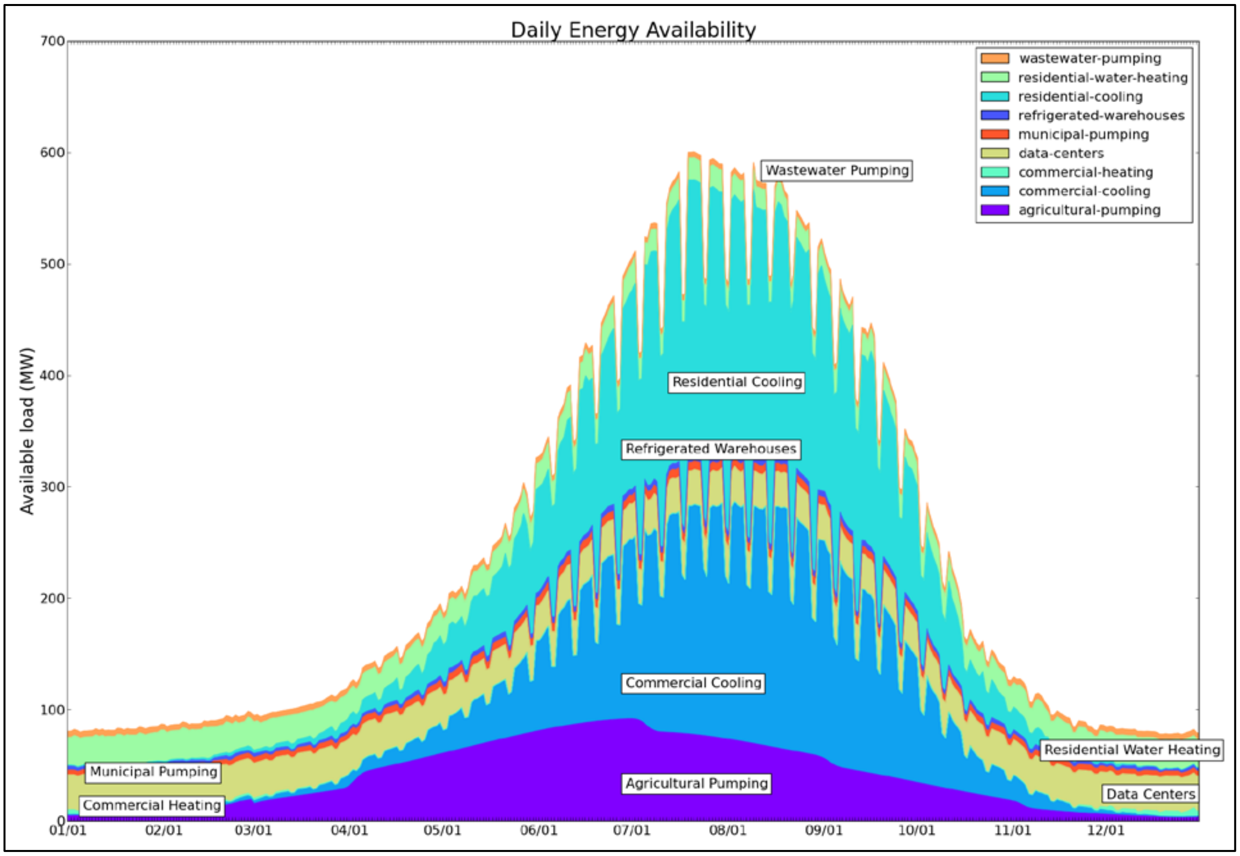
12:00
16:00
20:00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Available load (MW)
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residential-water-heating
residential-cooling
refrigerated-warehouses
municipal-pumping
data-centers
commercial-heating
commercial-cooling
agricultural-pumping
Wastewater Pumping
Residential Cooling
Refrigerated Warehouses
Commercial Cooling
Residential Water Heating
Municipal Pumping
Agricultural Pumping
Data Centers
Commercial Heating
01/01
02/01
03/01
04/01
05/01
06/01
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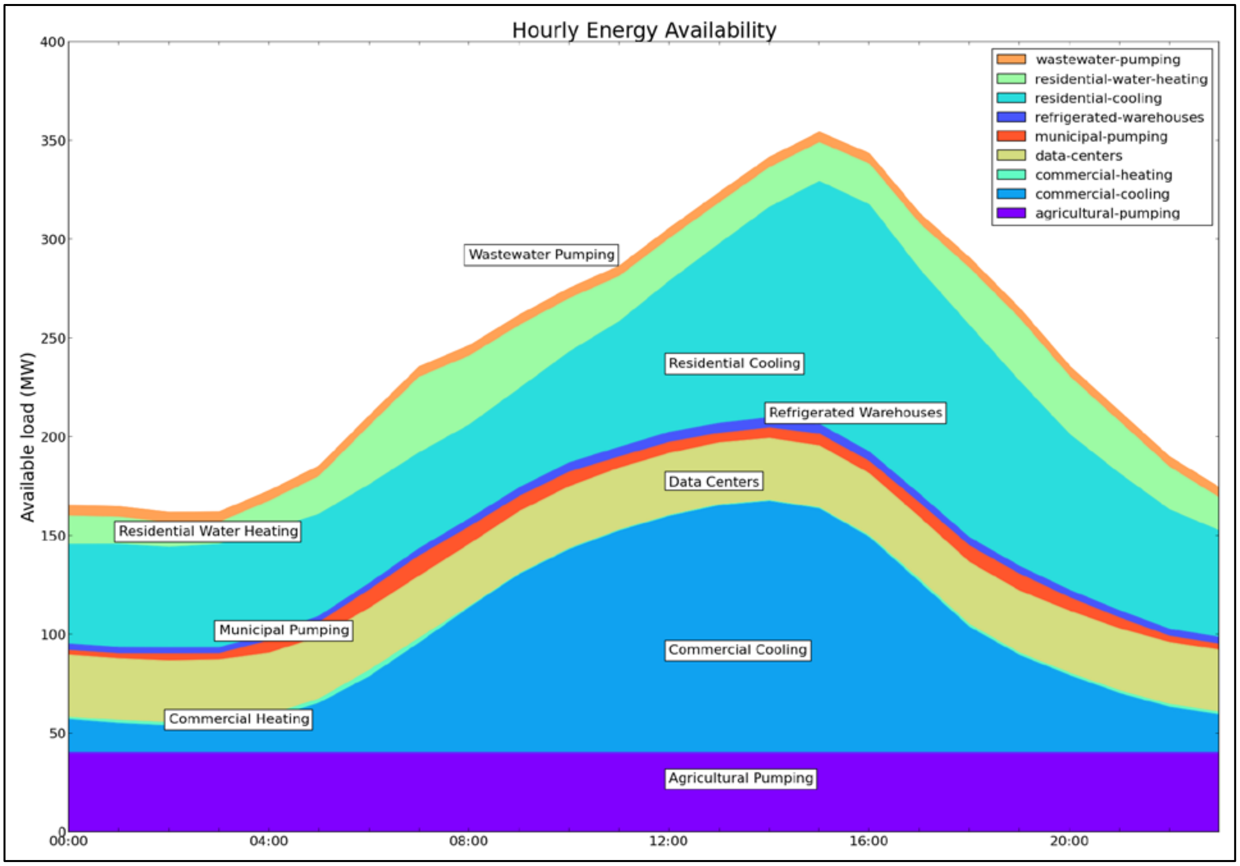
10/01
11/01
12/01



Hourly Energy Availability
Available load (MW)
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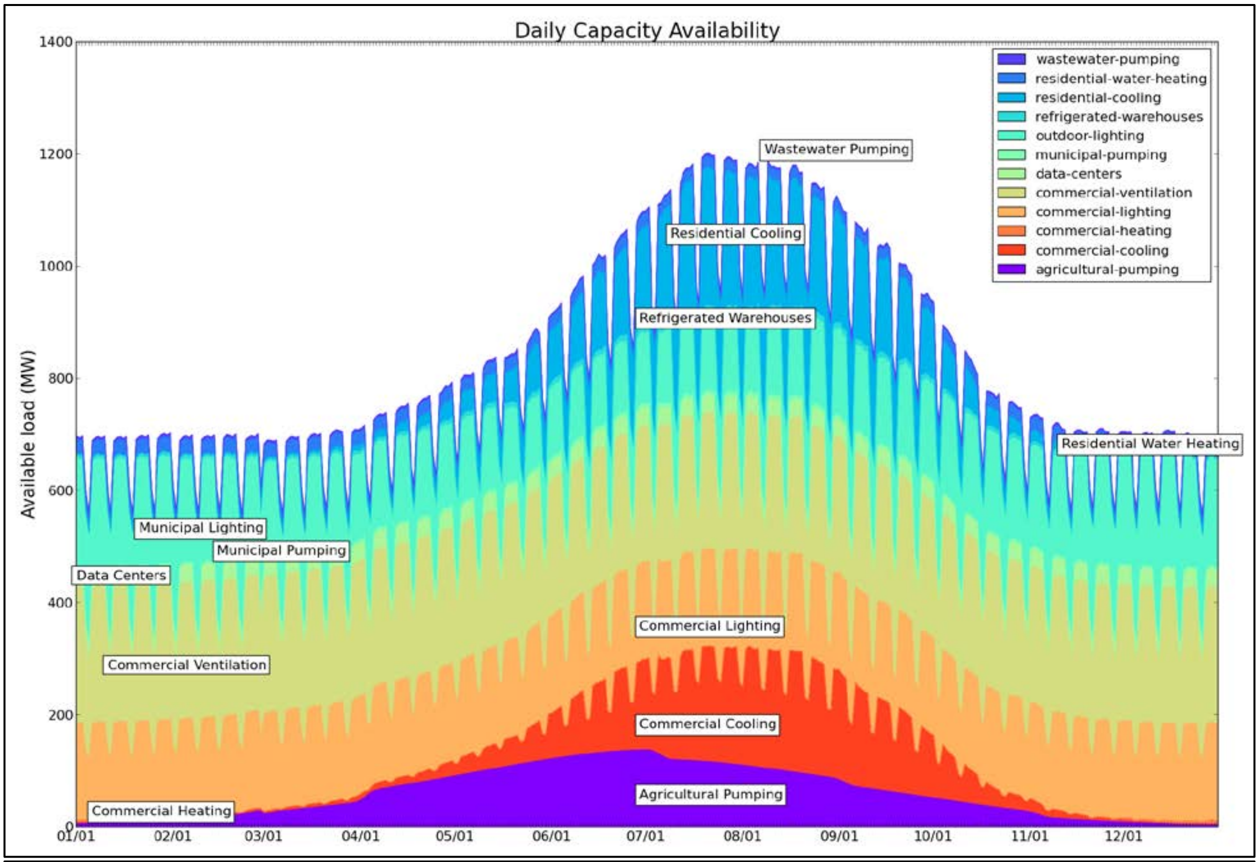
350
300
250
200
150
100
50
0
00:00
04:00
08:00
12:00
16:00
20:00
wastewater-pumping
residential-water-heating
residential-cooling
refrigerated-warehouses
municipal-pumping
data-centers
commercial-heating
commercial-cooling
agricultural-pumping
Wastewater Pumping
Residential Cooling
Refrigerated Warehouses
Data Centers
Residential Water Heating
Municipal Pumping
Commercial Cooling
Commercial Heating
Agricultural Pumping


Daily Capacity Availability
Available load (MW)
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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
wastewater-pumping
residential-water-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
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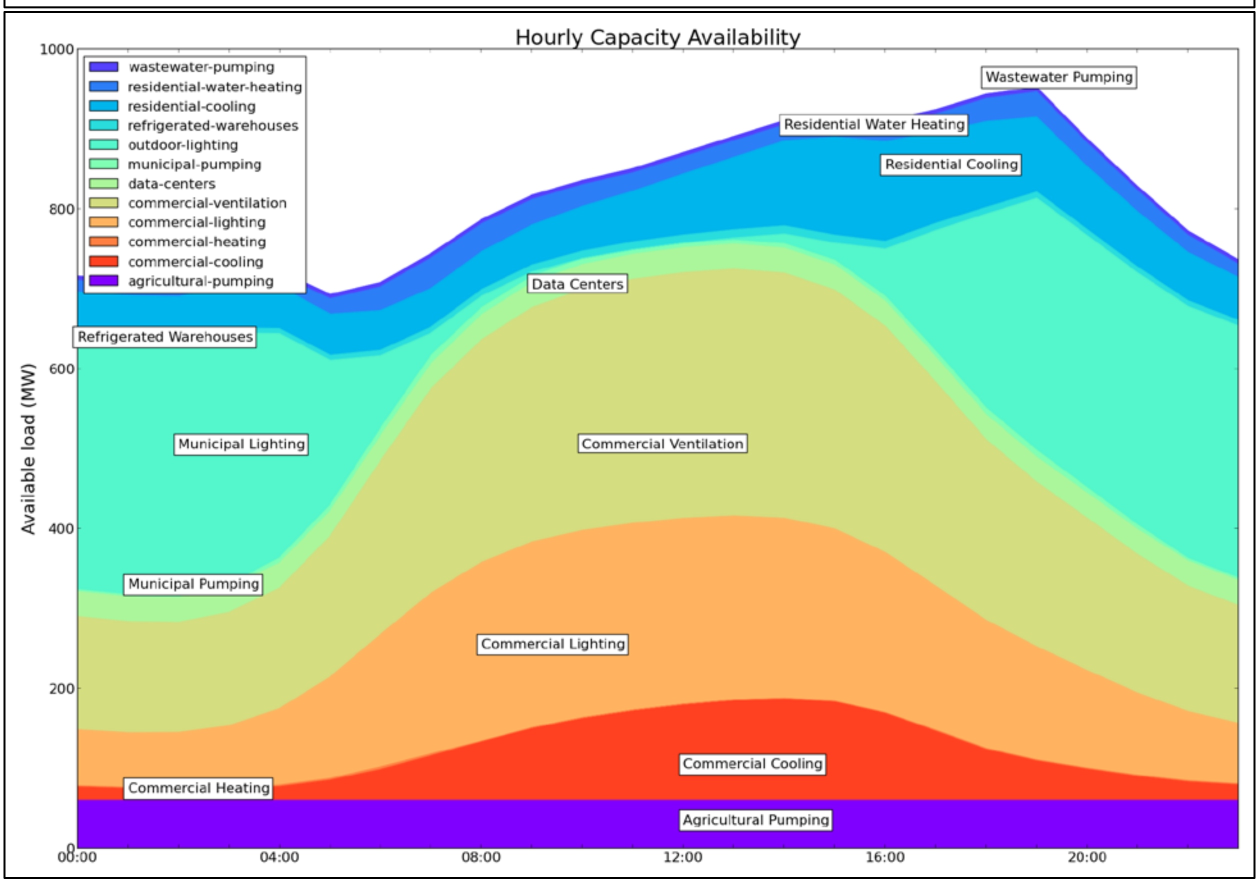
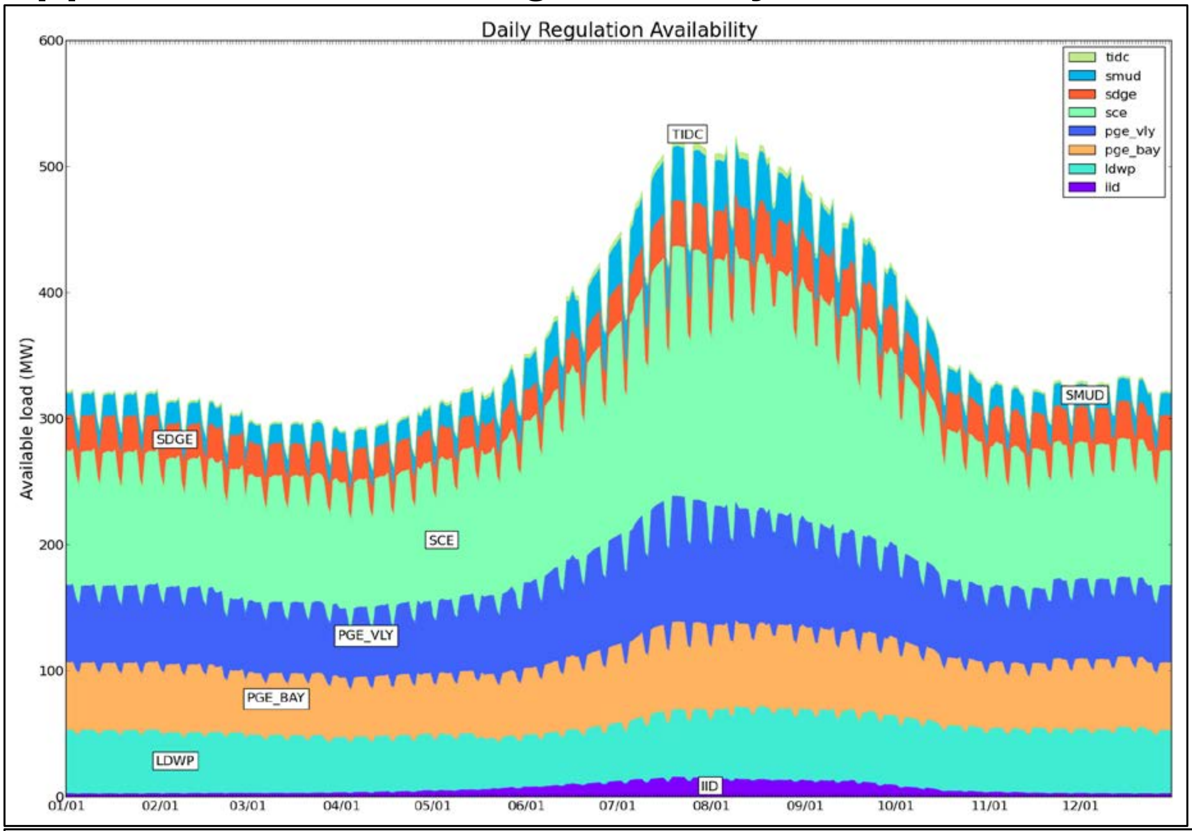
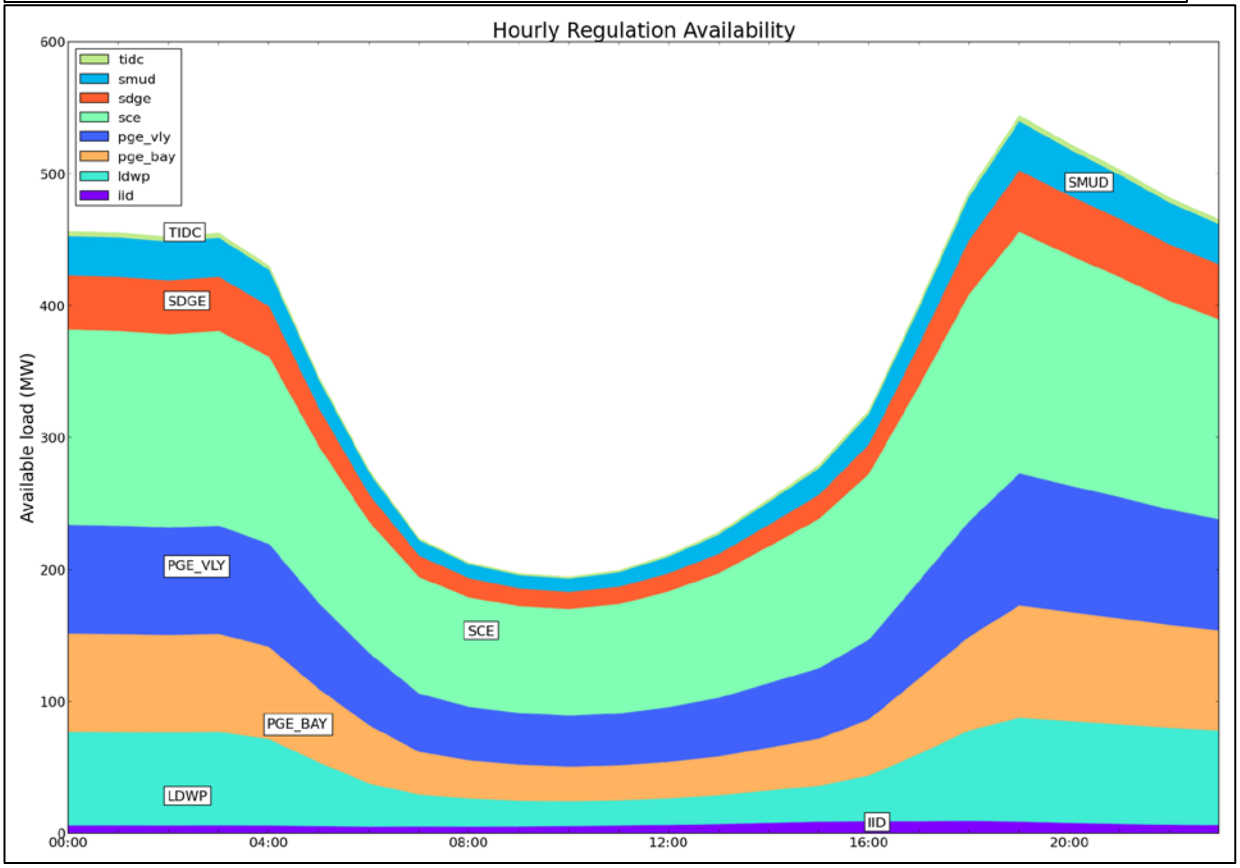
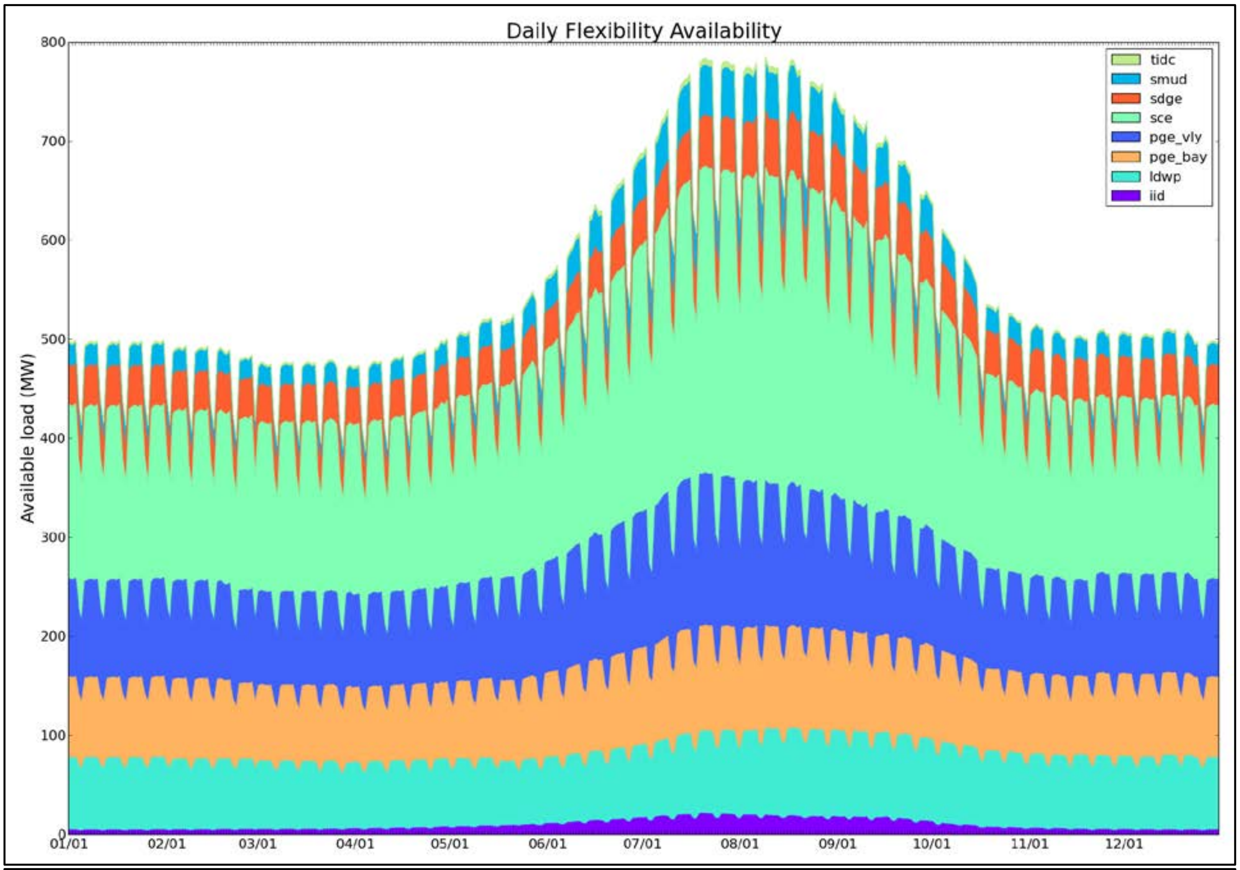
Agricultural Pumping
Commercial Heating


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

Appendix B – Balancing Authority Area Contributions






Daily Flexibility Availability
Available load (MW)
tidc
smud
sdge
sce
pge_vly
pge_bay
ldwp
iid
0
100
200
300
400
500
600
700
800
01/01
02/01
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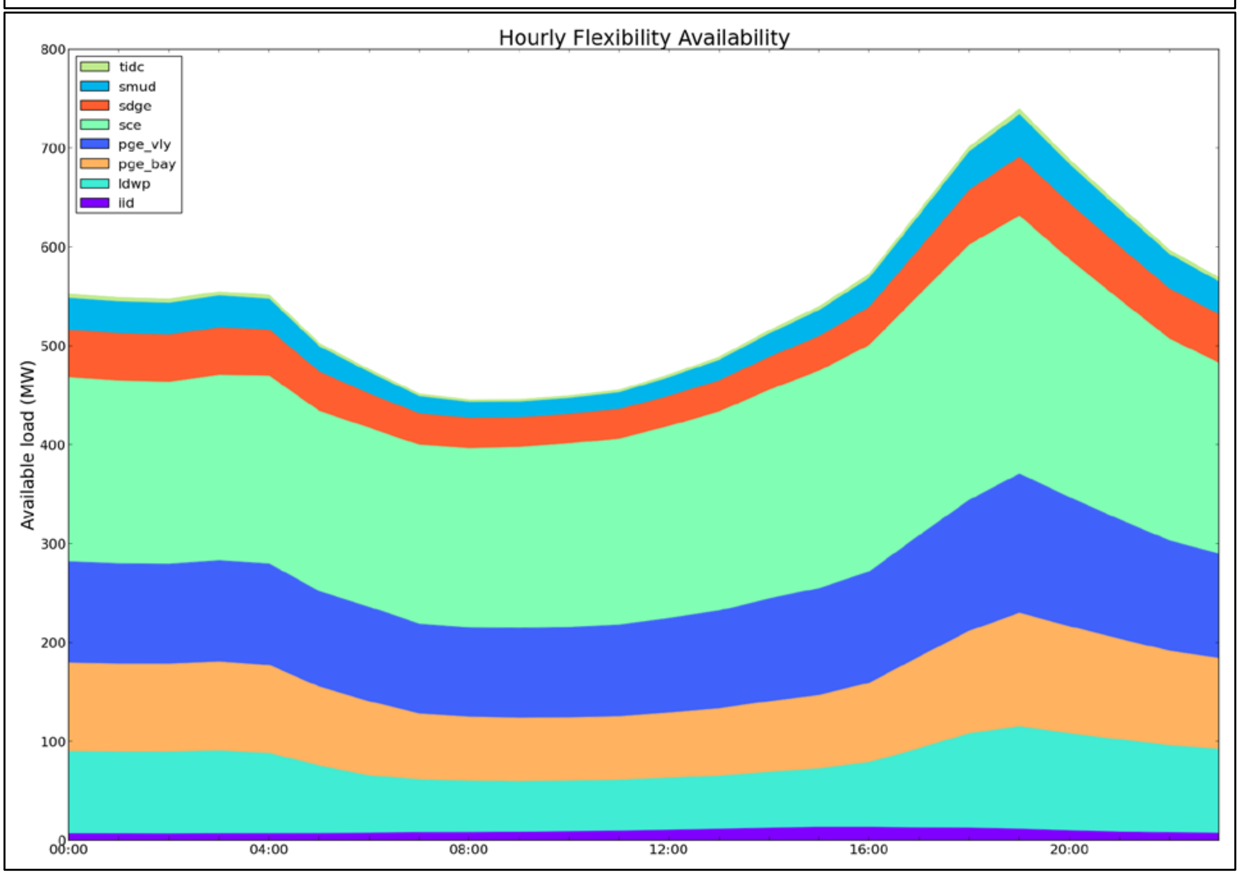
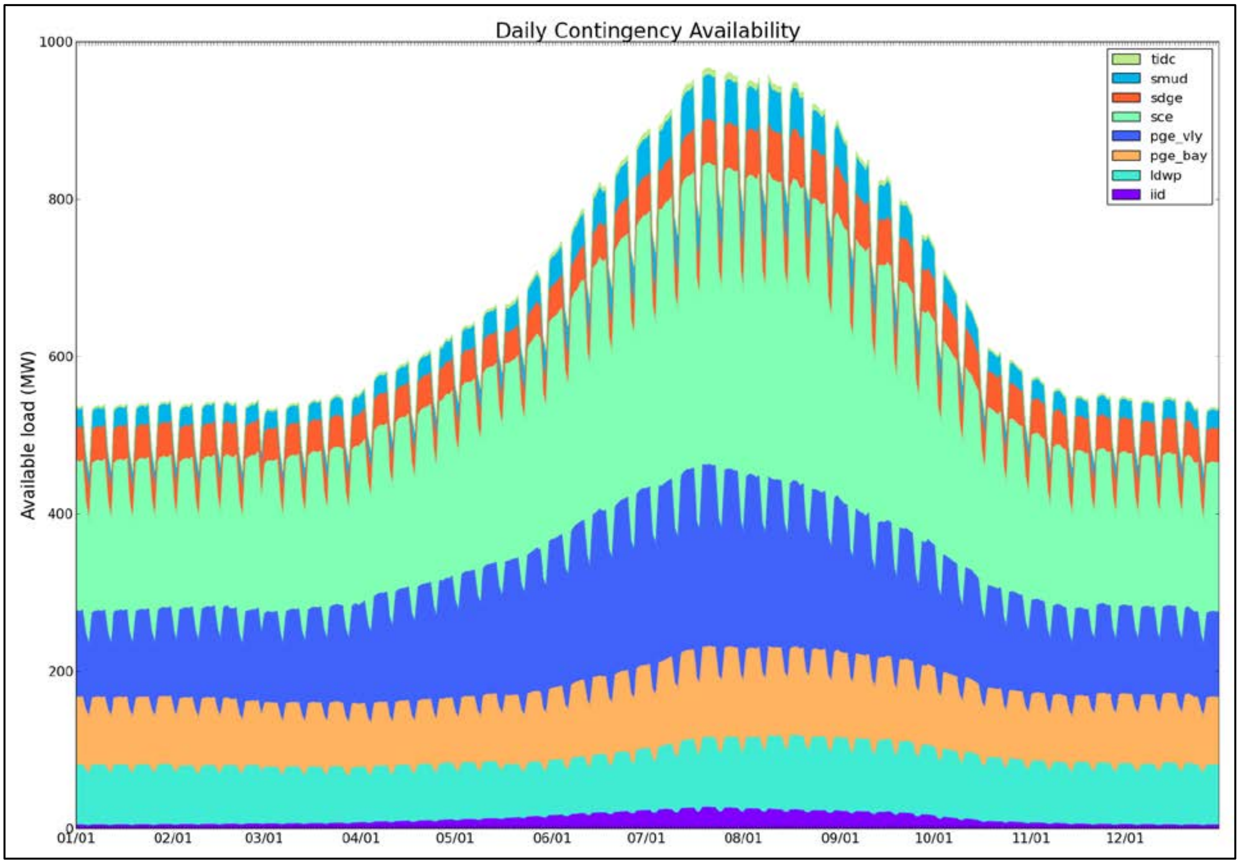
10/01
11/01
12/01


Hourly Flexibility Availability
Available load (MW)
tidc
smud
sdge
sce
pge_vly
pge_bay
ldwp
iid
0
100
200
300
400
500
600
700
800
00:00
04:00
08:00
12:00
16:00
20:00



Daily Contingency Availability
Available load (MW)
0
200
400
600
800
1000
01/01
02/01
03/01
04/01
05/01
06/01
07/01
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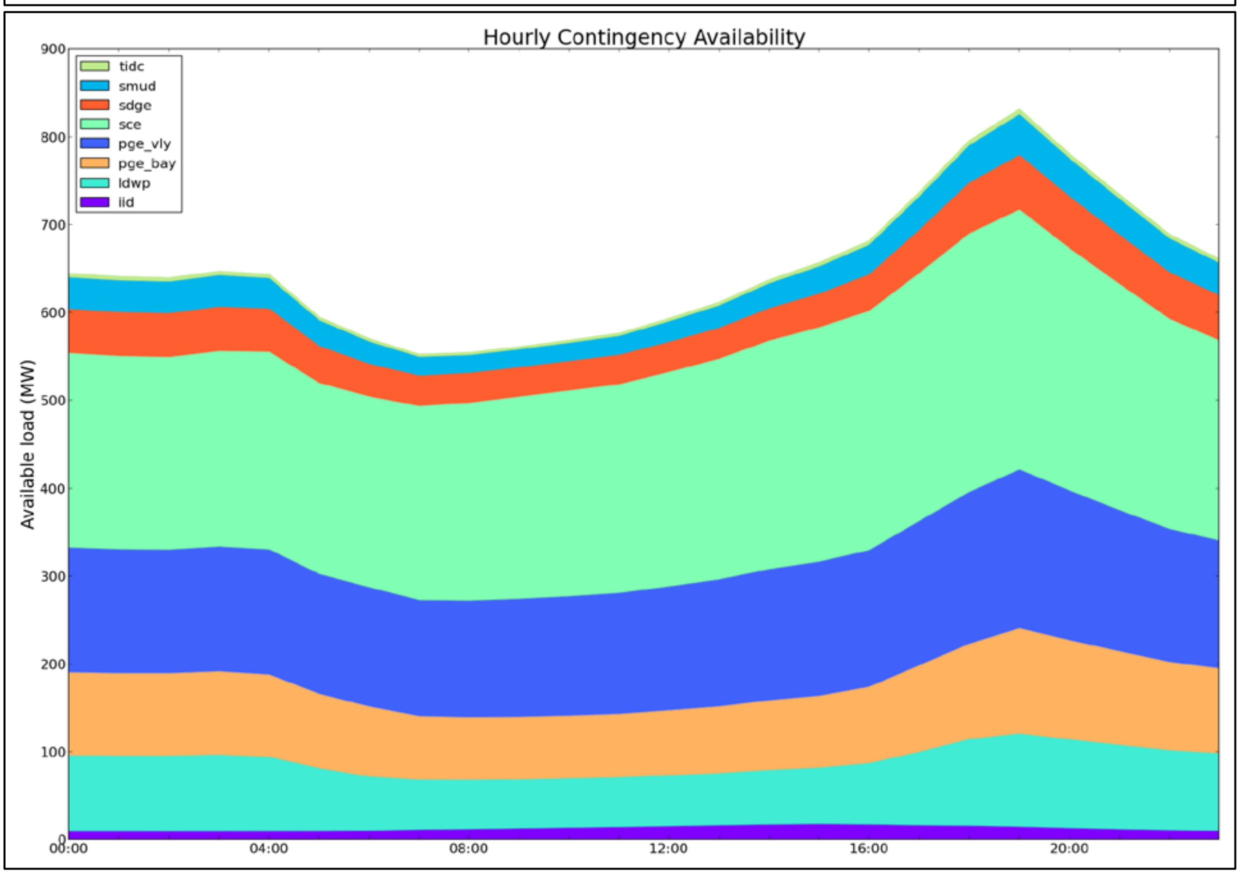
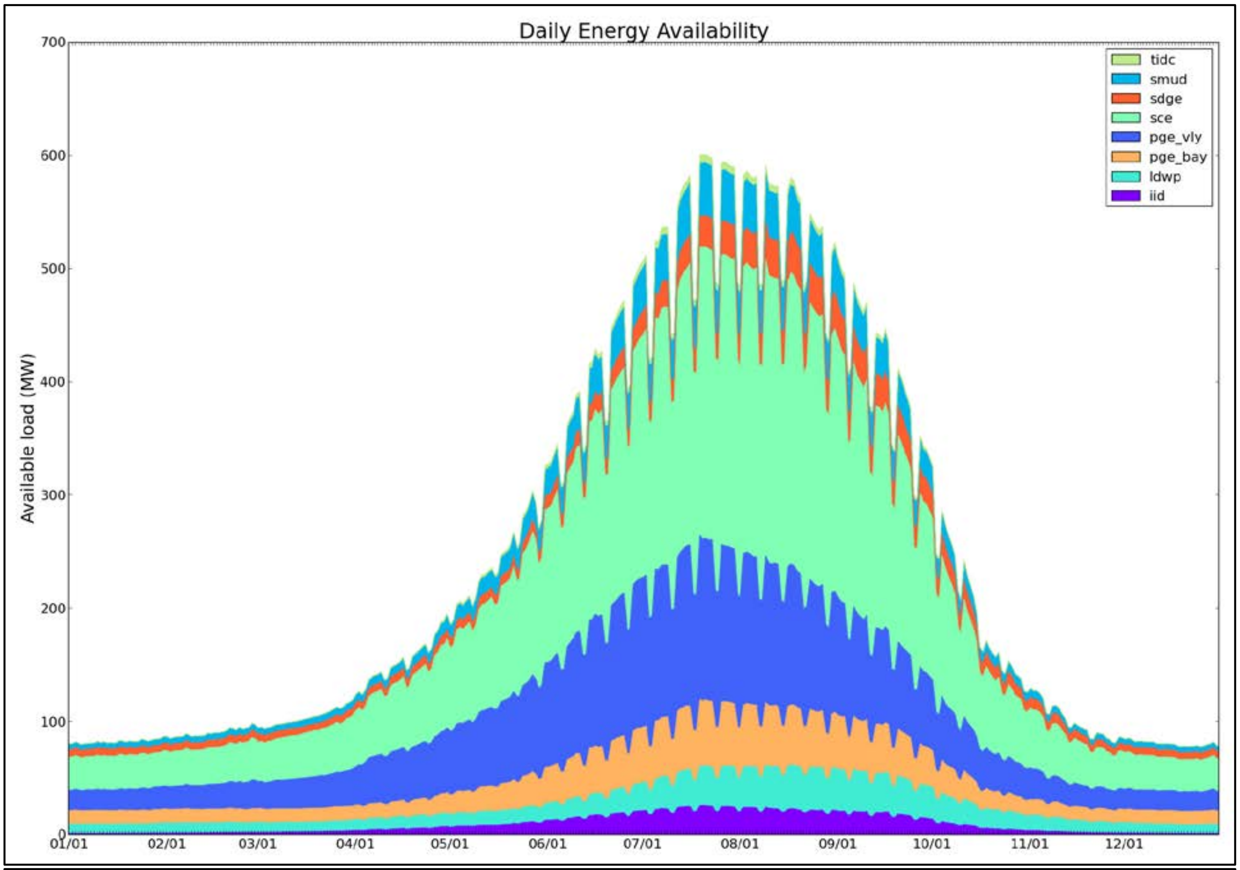
ldwp
iid



Hourly Contingency Availability
Available load (MW)
0
100
200
300
400
500
600
700
800
900
00:00
04:00
08:00
12:00
16:00
20:00
tidc
smud
sdge
sce
pge_vly
pge_bay
ldwp
iid



Daily Energy Availability
Available load (MW)
700
600
500
400
300
200
100
0
01/01
02/01
03/01
04/01
05/01
06/01
07/01
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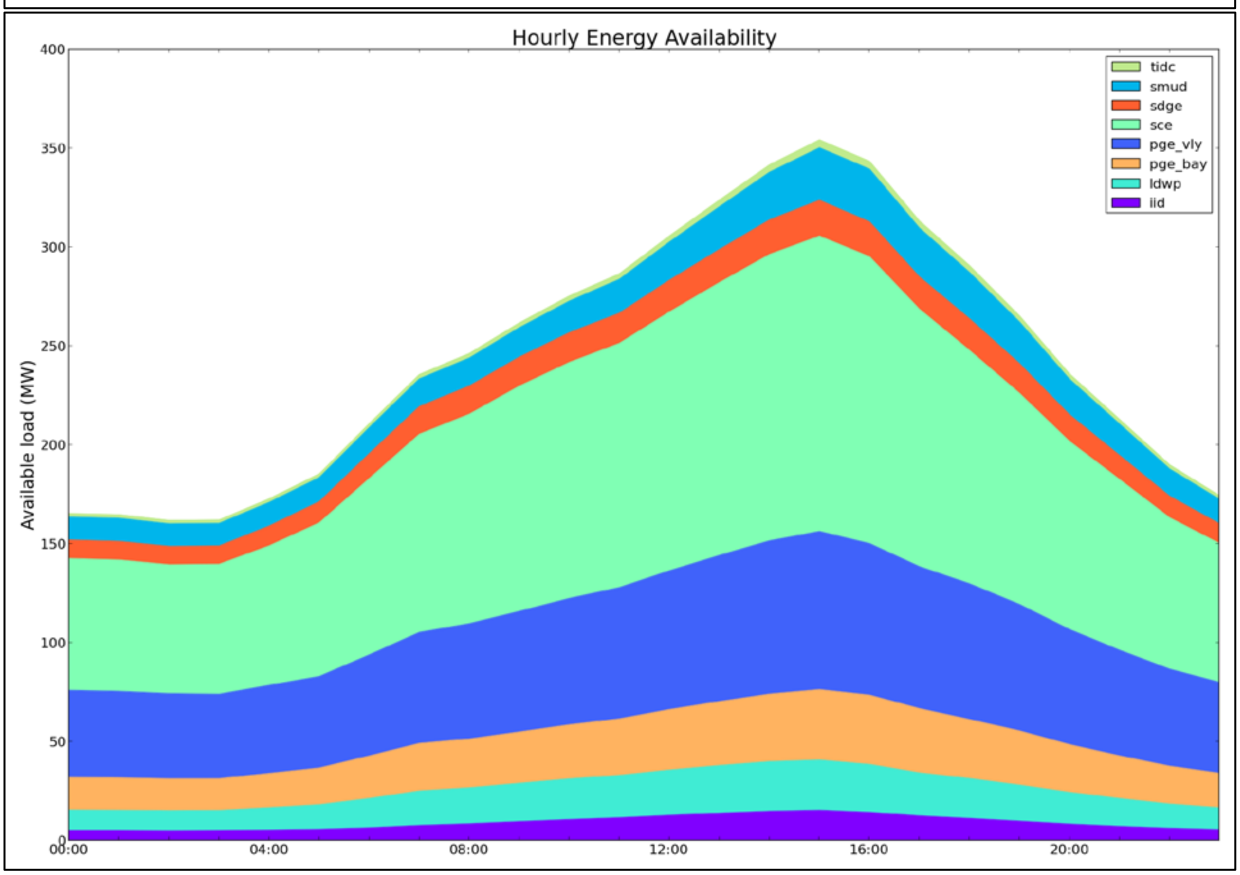
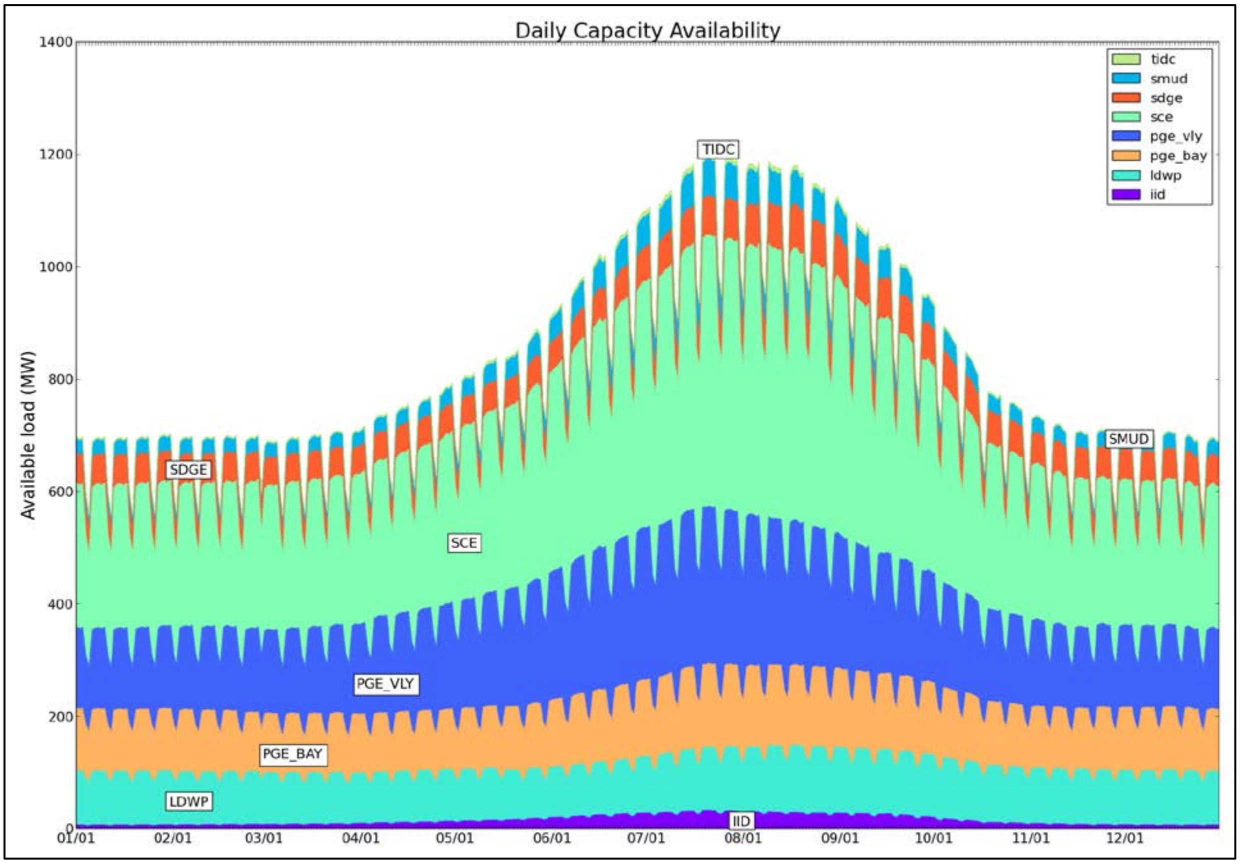
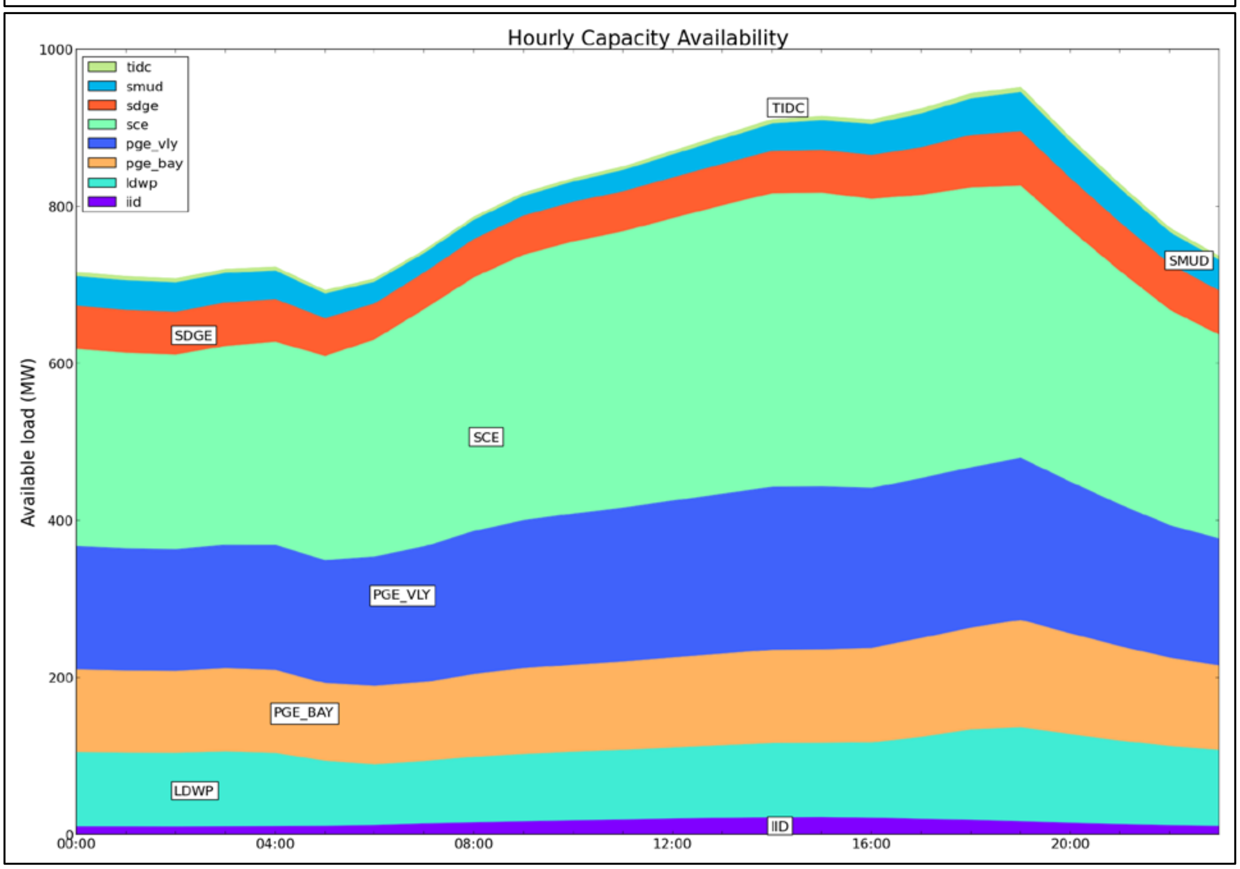
pge_bay
ldwp
iid

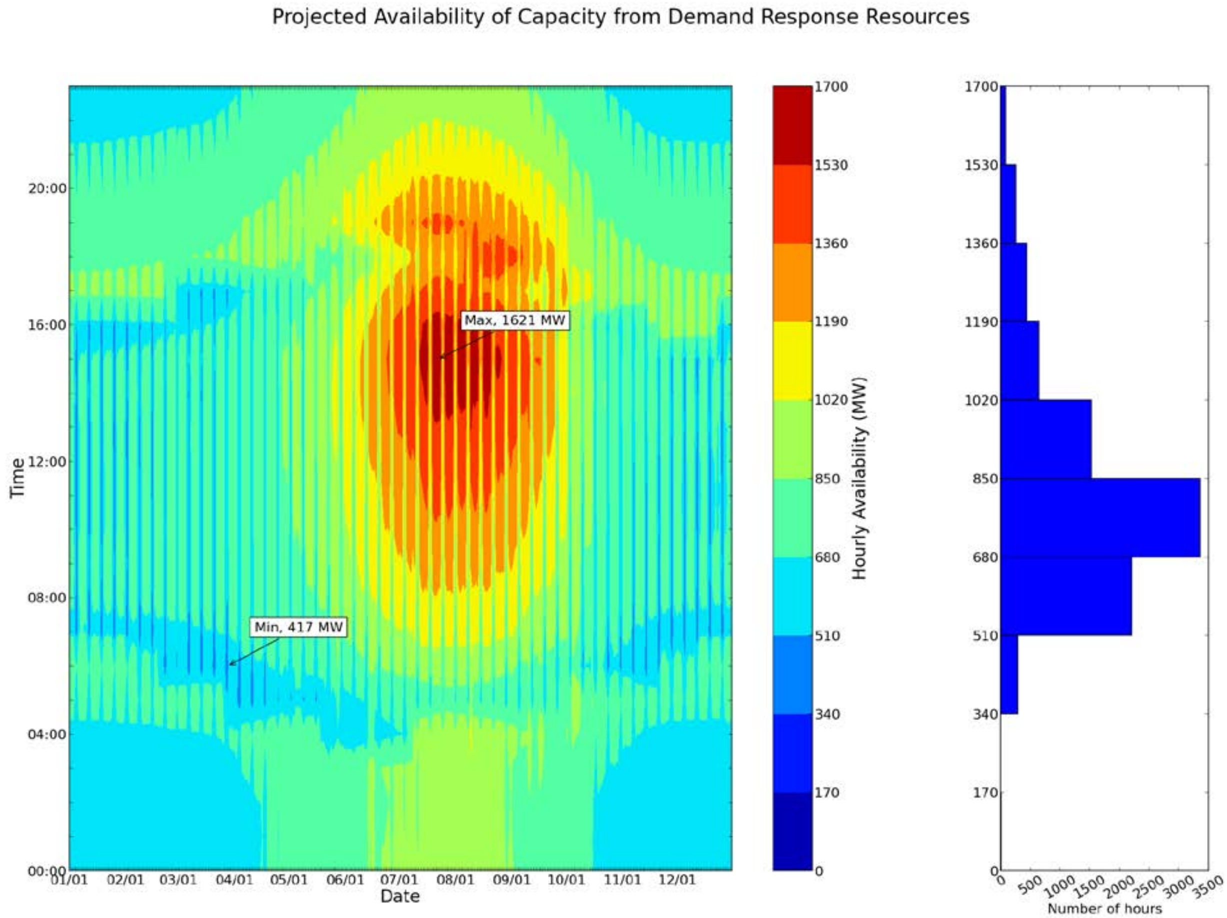


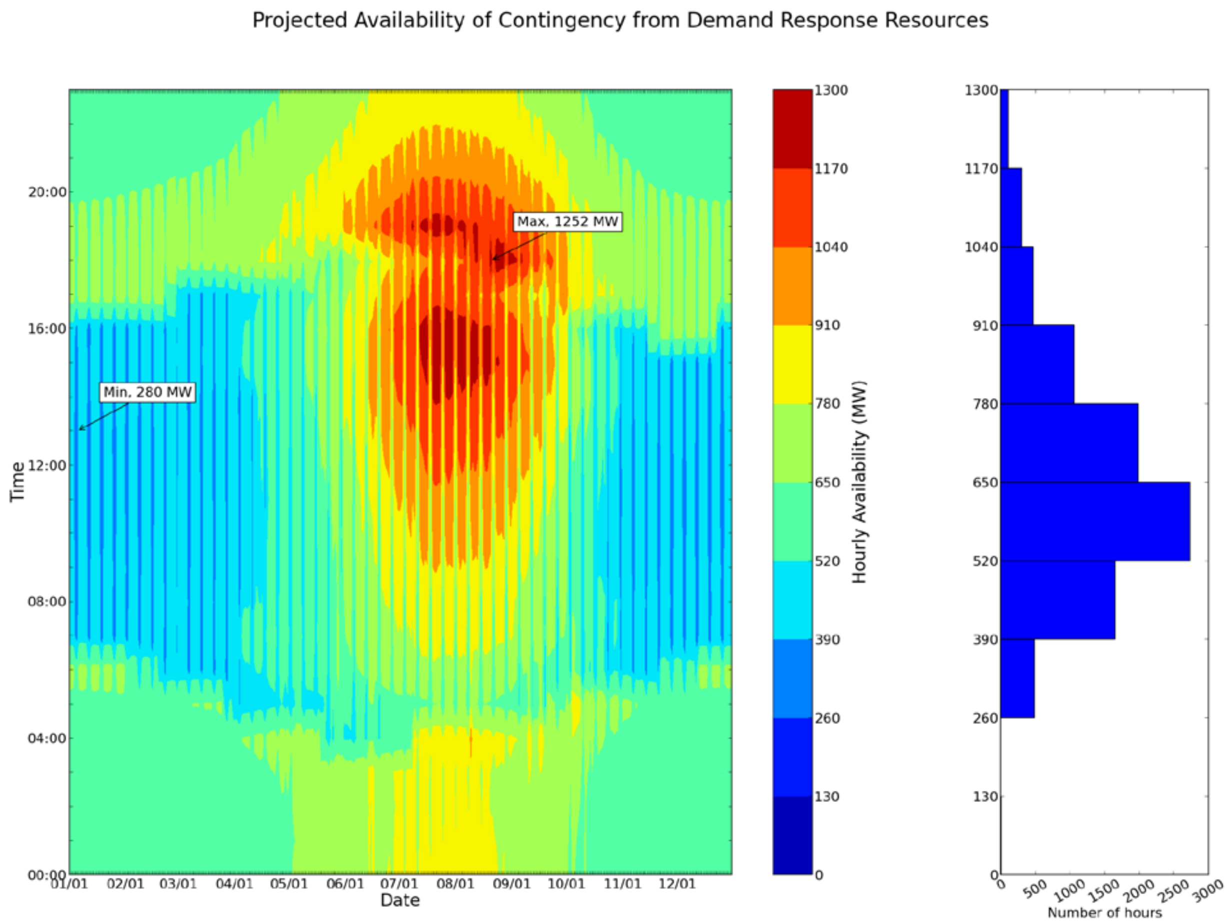
Hourly Energy Availability
Available load (MW)
400
350
300
250
200
150
100
50
0
00:00
04:00
08:00
12:00
16:00
20:00
tidc
smud
sdge
sce
pge_vly
pge_bay
ldwp
iid


Daily Capacity Availability
Available load (MW)
tidc
smud
sdge
sce
pge_vly
pge_bay
ldwp
iid
TIDC
SDGE
SMUD
SCE
PGE_VLY
PGE_BAY
LDWP
IID
0
200
400
600
800
1000
1200
1400
01/01
02/01
03/01
04/01
05/01
06/01
07/01
08/01
09/01
10/01
11/01
12/01

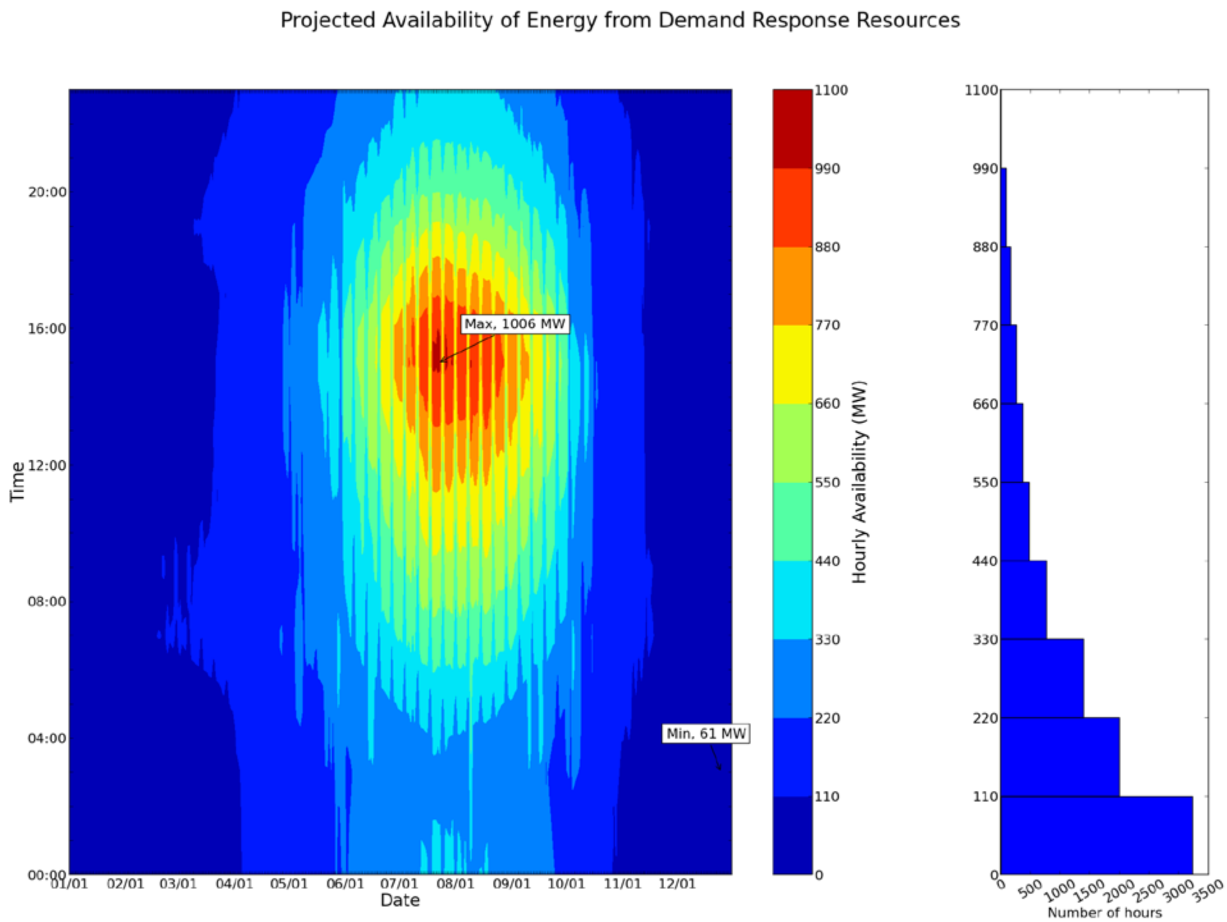

Hourly Capacity Availability
Available load (MW)
tidc
smud
sdge
sce
pge_vly
pge_bay
ldwp
iid
TIDC
SMUD
SDGE
SCE
PGE_VLY
PGE_BAY
LDWP
IID
0
200
400
600
800
1000
00:00
04:00
08:00
12:00
16:00
20:00

Appendix C
Demand Response Availability Patterns

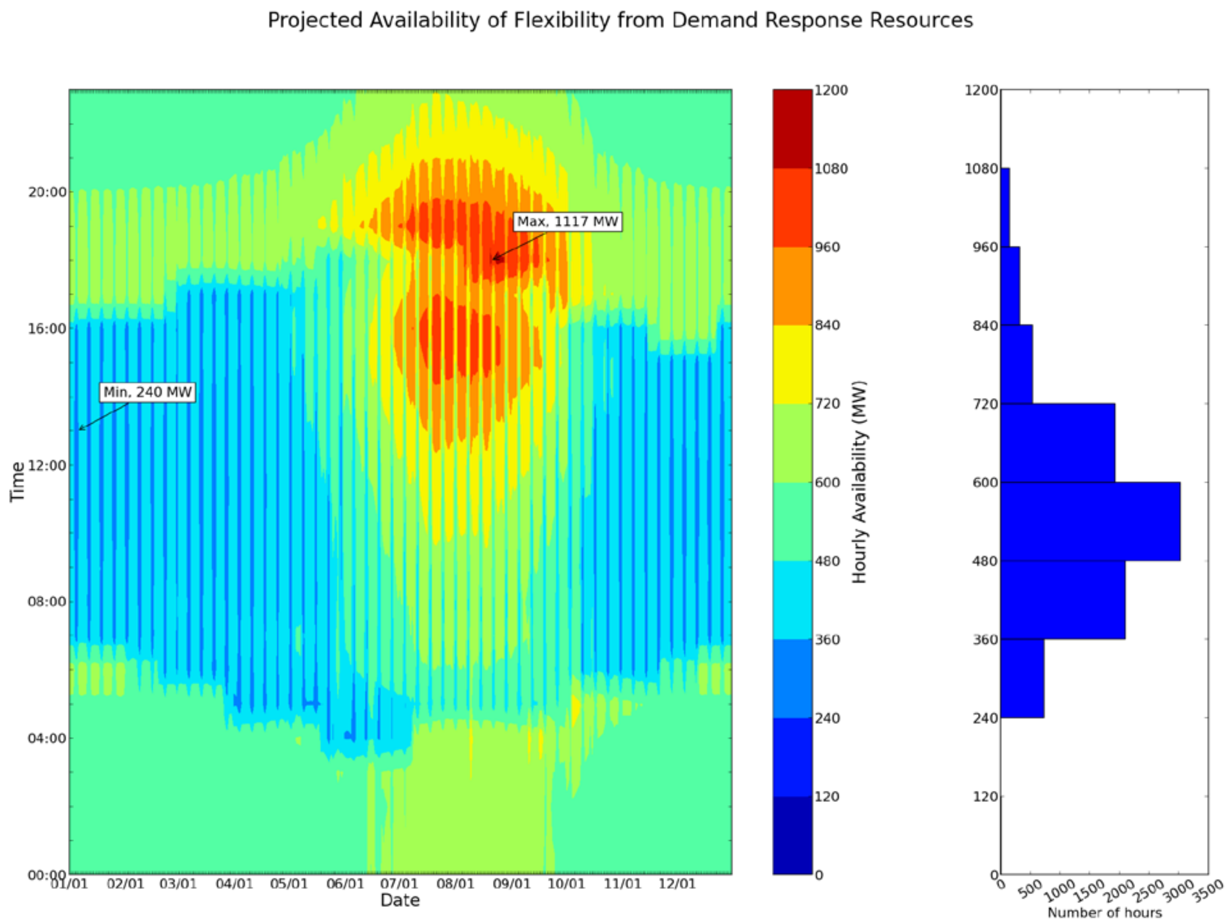


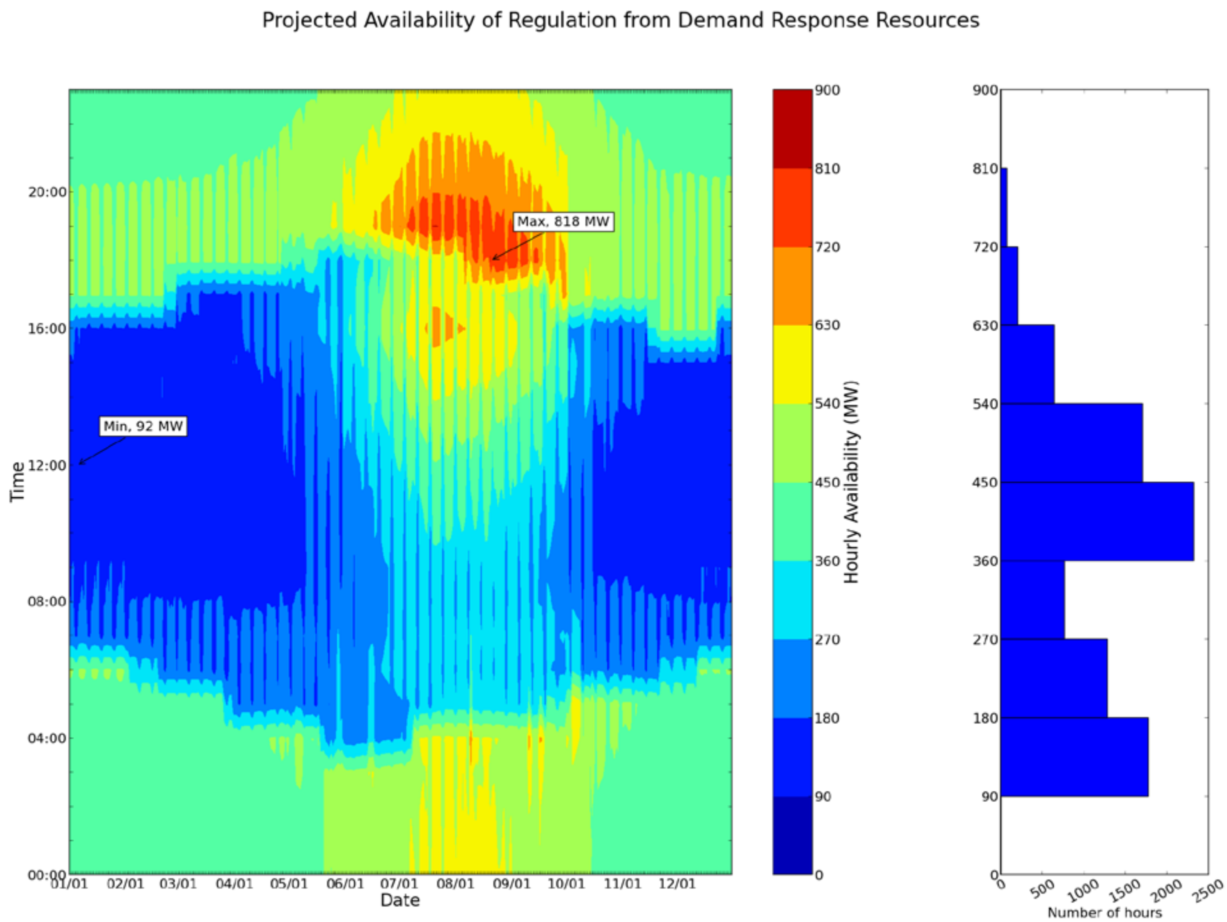


Projected Availability of Contingency from Demand Response Resources
Max, 1252 MW
Min, 280 MW
Time
Date
Hourly Availability (MW)
Number of hours



Projected Availability of Energy from Demand Response Resources
Max, 1006 MW
Min, 61 MW
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 (MW)
0
110
220
330
440
550
660
770
880
990
1100
Number of hours
0
500
1000
1500
2000
2500
3000
3500


Projected Availability of Flexibility from Demand Response Resources
Max, 1117 MW
Min, 240 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
120
240
360
480
600
720
840
960
1080
1200
0
500
1000
1500
2000
2500
3000
3500



Projected Availability of Regulation from Demand Response Resources
Max, 818 MW
Min, 92 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
90
180
270
360
450
540
630
720
810
900
500
1000
1500
2000
2500

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