Flexible Geothermal Power: An Economic Assessment

FY14 Final Report

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Executive Summary

State renewable portfolio standards requiring more intermittent wind and solar generation will substantially increase uncertainty and variability in grid operations. Geothermal power plant operators could help mitigate variability and uncertainty by operating plants in a more flexible mode. Plant operators would be compensated for flexibility through payments for ancillary services such as frequency regulation, load following, and spinning reserve.

This study explores economic incentives for geothermal plant operators to provide such flexibility. Historical and forecast ancillary service prices are compared to operator compensation for only energy under firm contracts at fixed prices. Power purchase agreements that provide flexibility when needed are proposed and evaluated.

In general, ancillary service prices for the years 2011 through 2013 were too low to provide sufficient economic incentive to geothermal plant operators to provide flexibility. Ancillary service prices in the year 2020, when California is projected to meet a 33% renewable portfolio standard, are significantly higher. Forecast hourly prices for load following ancillary services in the California Independent System Operator (CAISO) market are shown in **Figure ES.1**. As shown in the figure, *load following up* ancillary service prices around the morning and evening peaks exceed $60/MW throughout the year, and exceed $100/MW during the summer peak. *Load following down* prices are roughly half of the load following up prices (note change of scale in the second figure). Load following down prices are generally higher during the late evening and early morning hours when load is dropping. *Frequency regulation up* and *down* prices are similar in magnitude to load following and follow a similar temporal pattern.

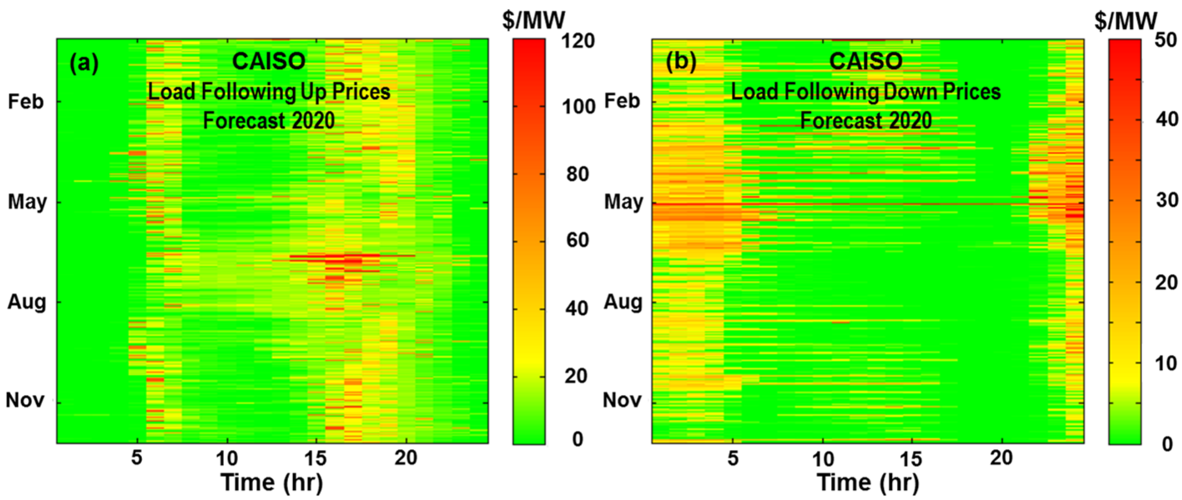

Figure ES.1. Load following ancillary service price forecast for 2020 Hourly prices are shown for the California Independent System Operator's market in the year 2020. Load following up prices are higher during the ramp up to meet morning and evening peaks. Load following down prices are higher during late evening and early morning hours when load is falling. Note the different scales indicating lower values for load following down ancillary services.

Power purchase agreements recently executed by geothermal operators typically provide energy-only payments at prescribed energy prices and escalation rates. For example, energy prices of four contracts reviewed range from $70/MWh to $99/MWh with escalation rates ranging from 1% to 2.75% per year.

Although current contracts and business practices do not provide incentives for flexible geothermal plant operations, we postulate new contract structures that would allow a geothermal plant operator to switch from providing energy-only to providing flexibility to the grid operator when it is advantageous to the plant operator to do so. This would allow additional revenues to be earned through ancillary service payments. The magnitudes of these payments, parameterized in terms of the firm contract energy prices, are shown in **Figure ES.2**.

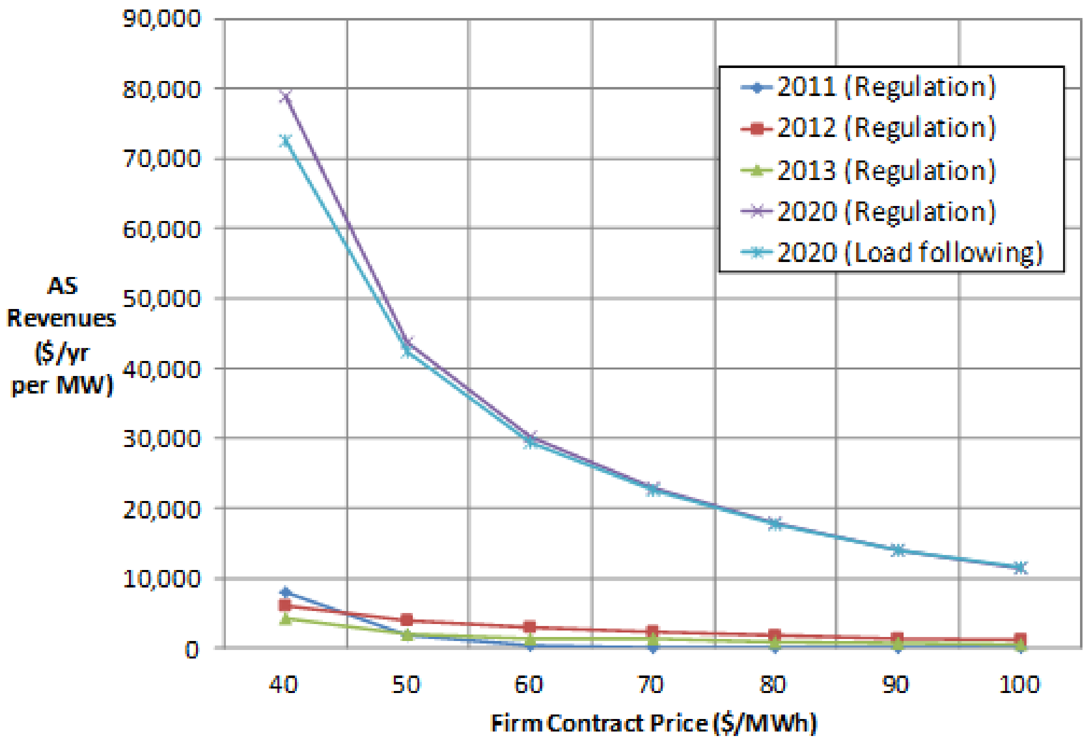

Figure ES.2. Potential ancillary service revenues from flexible contracts Historical and forecast regulation and load following ancillary service (AS) revenues from flexible contracts in the California market are shown. Note that year 2020 AS revenues are significantly higher than revenues that could be earned at historical prices.

The data in the figure show the annual revenues that a plant operator would receive from sale of one MW of ancillary services in those hours when it is advantageous to do so. Note that annual AS revenues decline as the firm contract price increases because there are fewer hours in the year when it is advantageous to switch from providing firm energy to providing ancillary services.

Even in the year 2020 when AS prices are much higher, the relative contributions from AS sales can be small. For example, consider a contract to provide energy at a firm contract price of $70/MWh. Assuming a 90% capacity factor for 1 MW of capacity, annual revenues from energy-only sales would be 8760 hours x $70/MWh x 0.9 = $552,000 per year. At this contract price, the figure indicates that an additional $22,000 per year can be earned from the sale of regulation services and another $22,000 per year for sale of load following services. This $44,000 per year revenue stream is only 8% of the $552,000 per year earned from energy sales. It is unlikely that the generator would be allowed to also provide spinning or non-spinning reserve services with the same MW of capacity under market rules likely to be in effect in the year 2020.

Compared to continuous operation at rated MW capacity, flexible geothermal plant operations would reduce average heat extraction rates from the underlying geothermal reservoir. These reduced heat extraction rates would extend well lifetime so that lower revenues could be earned over a longer period. A simple analysis of production at the Geysers field in California indicates that the present value of the energy revenues would be reduced by about 9% under flexible geothermal operations. The 8% additional revenues from providing ancillary services approximately compensates for the delay in energy revenues due to flexible operations. Hence, geothermal plant operators at this field would be capable of providing flexibility without incurring a net financial penalty.

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1 Introduction

Many states are adopting renewable portfolio standards that require procurement of wind, solar, and other intermittent renewable generators to meet goals within a given timeframe. For example, California is requiring 33 percent renewable energy generation by the year 2020 [California 2011]. Increased contributions from intermittent generators will substantially increase the variability and uncertainty in generation resources available to grid operators. Accordingly, the California Independent System Operator (CAISO) and others have undertaken several studies to estimate the impacts of this increase in variability and uncertainty [CAISO 2010; Rothleder 2011].

An estimate of these impacts in California for a spring day in the year 2020 is shown in **Figure 1.1** [Liu 2012]. The figure shows gross load, solar generation, wind generation, and the resulting net load when wind and solar generation are subtracted from the gross load. As indicated in the figure, very high ramp rates are observed in net load around the morning and evening peak load periods. Although wind generation is fairly constant on this particular day, in general it can be highly variable and uncertain.

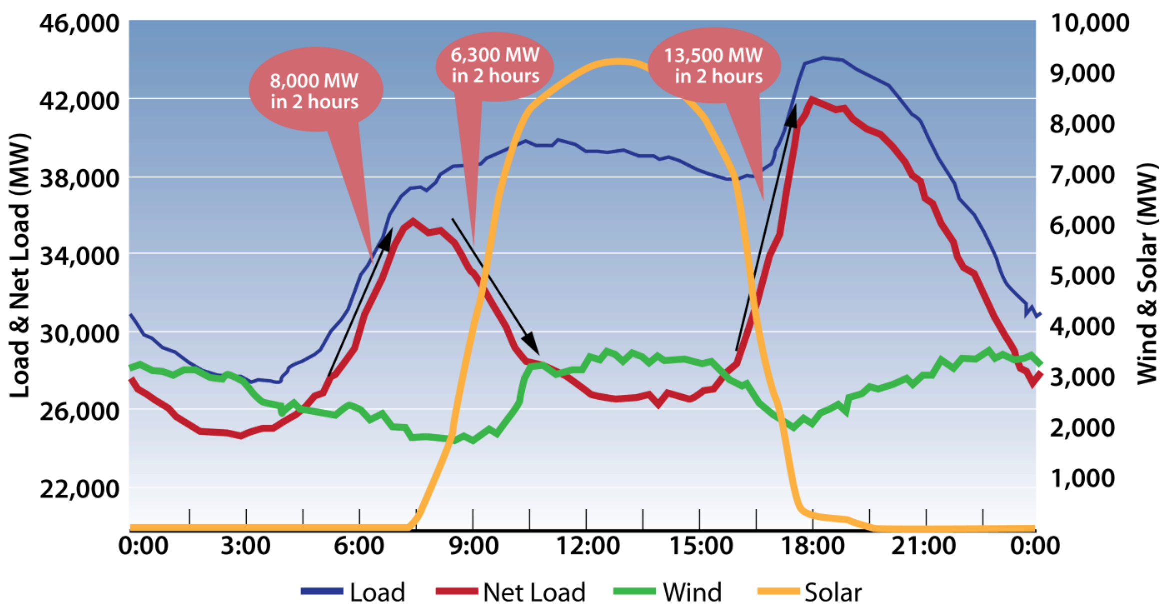

Figure 1.1. Forecasts of gross load, renewable generation, and net load in 2020
Forecast for the California market in the year 2020 is shown. The gross load (blue line) is reduced by solar power generation (yellow line) and wind generation (green line) resulting in a net load (red line) that is highly variable. Note the rapid ramps up and down associated with the morning and evening peaks during this spring day.

Independent system operators must manage this increase in variability and uncertainty with flexible and dispatchable generation, storage, and demand response resources. This study conducts a system level economic analysis to quantify additional revenue streams that geothermal energy systems could receive by providing operational flexibility to independent system operators in the western U.S. Changes in the structure of power purchase agreements and geothermal power plant operating policies are analyzed using historical price data for the years 2011–2013 and results from a prospective integrated weather, renewable generation, and production simulation model of the year 2020

[Edmunds 2014]. In particular, the value of providing ancillary services (frequency regulation services at sub-second time intervals, load following services at five-minute time intervals, spinning reserve, and non-spinning reserve) are examined. Parametric studies of geothermal system operating policies are conducted to help identify optimal courses of action.

2 Energy and Ancillary Service Prices

This section provides an overview of historical and forecast of future energy and ancillary service prices. There are six types of ancillary service products: regulation up, regulation down, load following up, load following down, spinning reserve, and non-spinning reserve. Regulation is used to control system frequency that can vary as generation and load vary, and must be maintained very narrowly around 60 hertz. Units and system resources providing regulation are certified by the ISO and must respond to "automatic generation control" (AGC) signals to increase or decrease their operating levels depending upon the service being provided, regulation up or regulation down. Resources providing load following services must respond to the system operator's economic dispatch signals every five or fifteen minutes. Markets for load following ancillary services are currently being introduced by several independent system operators. Spinning reserve is the portion of unloaded capacity from units already connected or synchronized to the grid that can deliver their energy in 10 minutes. Non-spinning reserve is capacity that can be synchronized and ramped to a specified load within 10 minutes[1].

2.1 Historical Prices

Historical and prospective price patterns are used to evaluate the revenue potential of providing ancillary services, and the opportunity costs of reductions in energy deliveries required to permit delivery of ancillary services. Historical prices for frequency regulation, spinning reserves, and non-spinning reserves were obtained from the California Independent System Operator (CAISO) OASIS database [OASIS 2014]. Market for load following ancillary services had not yet been established during the historical periods discussed in this section.

Marginal hourly energy prices for each hour in the year 2013 are shown in **Figure 2.1**. Horizontal lines in the figure correspond to days of the year and vertical lines correspond to hours of the day. Marginal hourly energy prices in $/MWh in California are color coded according to the scale at the right of the figure. Note that peak prices of $180/MWh occur during a few hours of the summer peak. Peak prices during other times of the year are $60-80/MWh in the mornings and evenings. Off peak prices are less than $40/MWh. One exception to this pattern is a period of several days in November when prices are in the $60-80/MWh range throughout the day.

[1] http://www.caiso.com/Documents/SpinningReserveandNonSpinningReserve.pdf

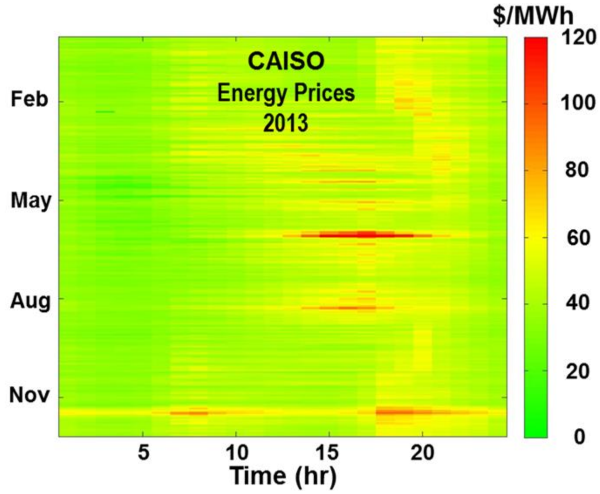

Figure 2.1. CAISO energy prices ($/MWh) in 2013 Energy prices over $100/MWh are observed during evening peak loads in the summer and during morning and evening peak loads in the fall.

Prices for the frequency regulation up ancillary service in each hour of the year 2013 are shown in **Figure 2.2a**. As indicated in the figure, prices of approximately $100/MW were observed during summer peak loads in August. As was the case with energy prices, slightly higher (lighter green) prices are observed during the morning and evening peaks. Prices for frequency regulation down are shown in **Figure 2.2b**. Prices of approximately $20/MW (yellow) were observed in the early morning from late April to May. Prices during other hours in the year are in the $5-10/MW range. Although not apparent in **Figure 2.2b**, low regulation-down prices occur after the August afternoon peak load shown in **Figure 2.1**. Prices during other hours in the year are in the $0-20/MW range.

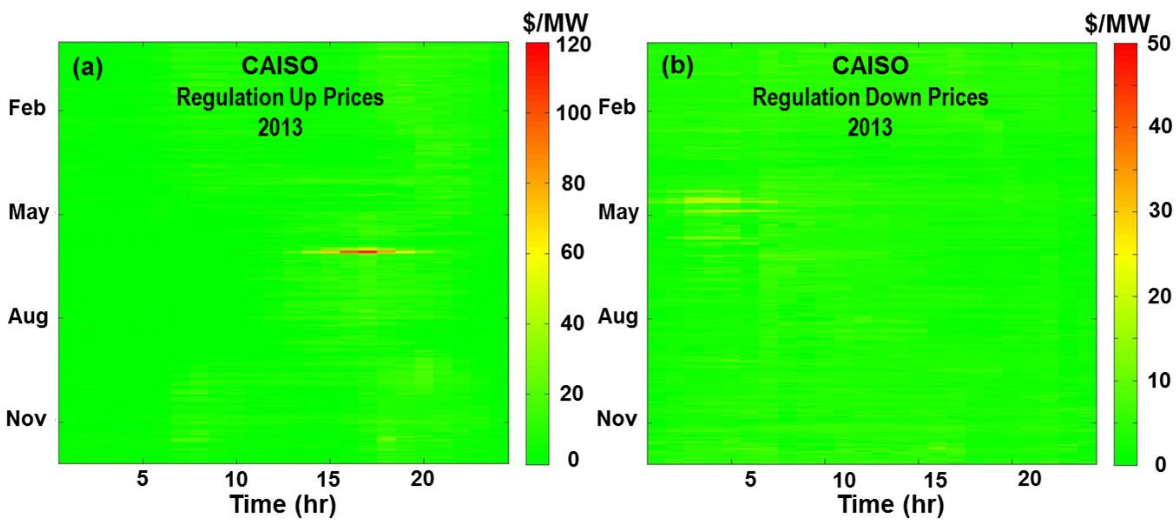

Figure 2.2. CAISO prices ($/MW) in 2013 for regulation ancillary services Prices for regulation up were over $100/MW during summer peak load. Regulation down prices exceeded $25/MW during one period in the spring. Note the different color scales indicating that regulation down prices are much lower than regulation up prices.

Prices for spinning reserve are shown in **Figure 2.3a**. As indicated in the figure, prices of approximately $100/MW were observed during summer peak loads in June and July. Prices during other hours in the year are in the $0-30/MW range. Prices for non-spinning reserve are shown in **Figure 2.3b**. Price patterns are similar to the spinning reserve prices, although the duration of the high price periods observed during the summer peaks are shorter. Energy and ancillary service prices at CAISO for the years 2011 and 2012 are shown in **Appendix A**. A general increasing trend in prices can be observed over this three-year period.

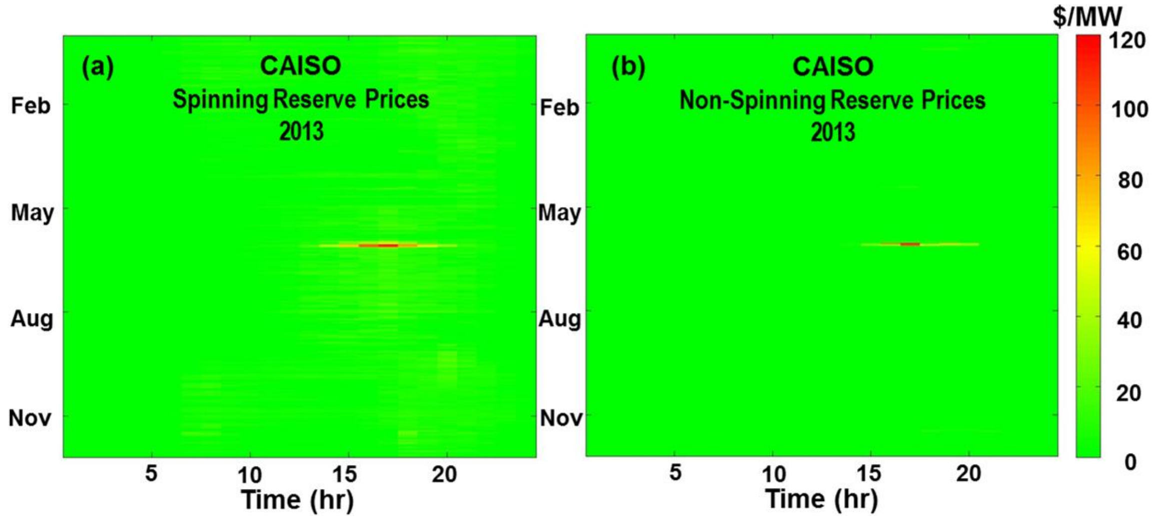

Figure 2.3. CAISO prices ($/MW) in 2013 for spinning and non-spinning reserve Prices were over $100/MW during summer peak loads.

2.2 Short-term price spikes in 2013-2014

The prices shown in the previous figures are *hourly* average prices. Shorter-term price spikes up to $1,000/MWh and down to $-500/MWh have been observed in the major markets in 2013. Some examples are shown in **Figure 2.4** [LCG 2014]. As indicated by the data in the figure, the price spikes occur throughout the year. These positive and negative price spikes typically last for five or ten minutes. However, on October 15, 2014 a $1,017/MWh price was observed for at 9:15 pm for five minutes followed at 9:55 pm by a price of $-157/MWh that persisted for 75 minutes. Because the price spikes are generally unpredictable exploiting them would be difficult. In addition, CAISO business practices include provisions to modify prices *ex post* under prescribed circumstances.

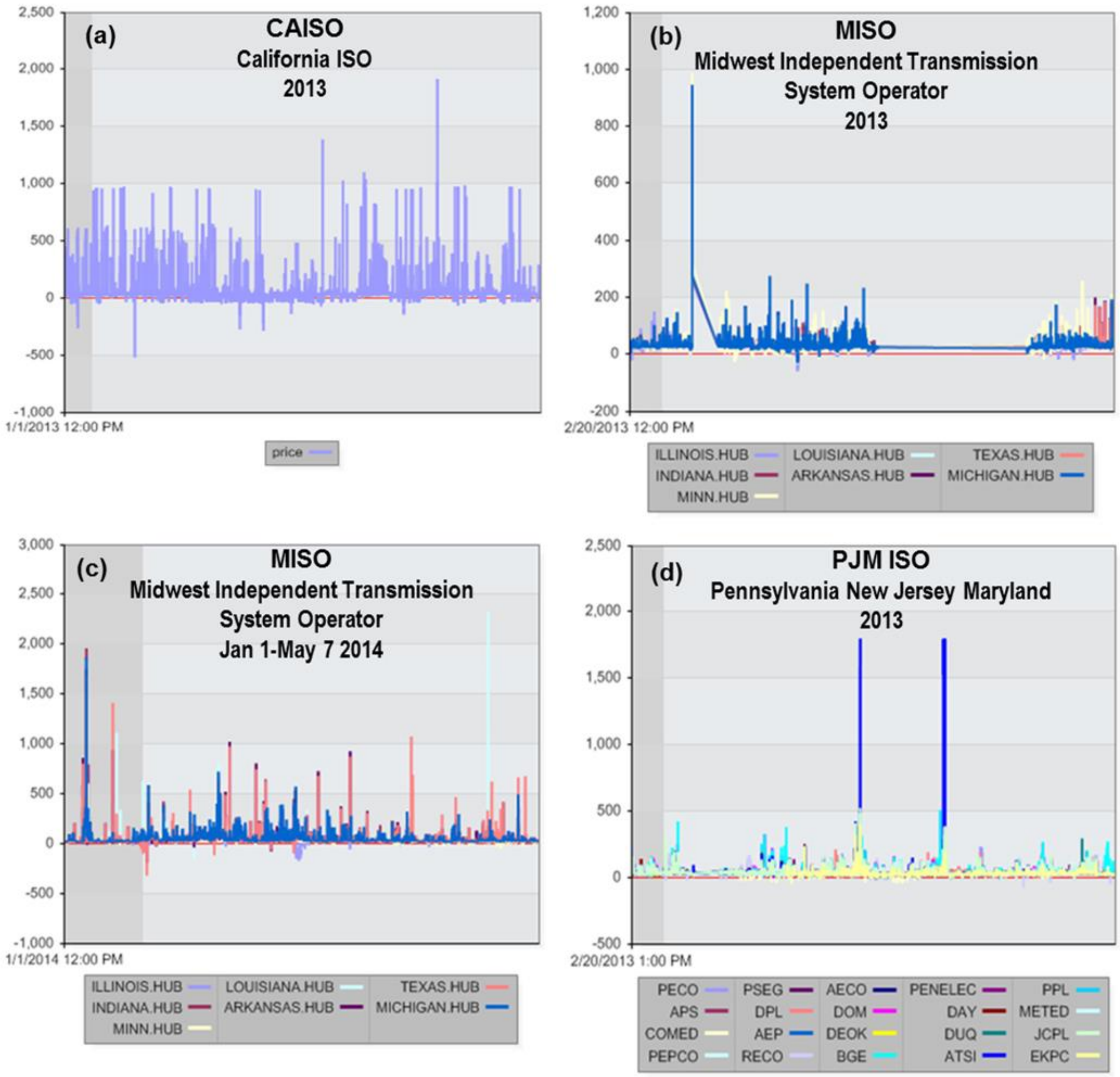

Figure 2.4. Energy prices ($/MWh) in markets Prices in California ISO market in 2013, Midwest ISO market in 2013, Midwest ISO market from Jan. 1 to May 7, 2014, and PJM ISO market in 2013 are shown [LCG 2014]. In general, prices were significantly more volatile in the California energy markets. Prices reached $1000/MWh during many hours in 2013 and were less than $-100/MWh on some days.

Energy prices in the California ISO market for the year 2013 are shown in **Figure 2.4a**. As indicated by the data in the figure, Prices exceed $500/MWh approximately sixty times during 2013. The price is $2,000/MWh during one period in September. Prices are less than -$100/MWh during six periods, when over-generation conditions are experienced. Similar patterns can be observed for the first four months of 2014.

In general, prices in other markets were less volatile than California prices during 2013 – positive price spikes were less frequent and few negative price spikes were observed. This may be due to more efficient market implementation, more aggressive demand response programs, or less intermittent renewable generation in these other markets.

Energy prices in the Midwest ISO market for the year 2013 are shown in **Figure 2.4b**. Except for one $900/MWh price spike in February, prices are less than $300/MWh. There is a period of missing data in the source's database. The prices during the first four months of 2014 shown in **Figure 2.4c** indicate higher volatility in the Midwest for the year 2014.

Energy prices in the Pennsylvania-New Jersey-Maryland (PJM) market are shown in **Figure 2.4d**. As indicated by the data in the figure, prices reached $1800/MWh twice during 2013. There appear to be more price spikes in the Baltimore Gas and Electric (BGE) service territory that the other utilities. Prices in the PJM market are rarely negative.

2.2 Prices in 2020

As discussed previously, California's 33 percent renewable energy goal by 2020 is expected to increase ancillary service prices in that year. LLNL has completed a study of energy markets in the Western U.S., including forecasts of energy and ancillary service prices [Edmunds 2014].

Forecasts of marginal energy prices in California are shown in **Figure 2.5**. As indicated by the data in the figure, prices exceed $100/MWh during the evening peak load. Higher prices are also observed during the morning peak load.

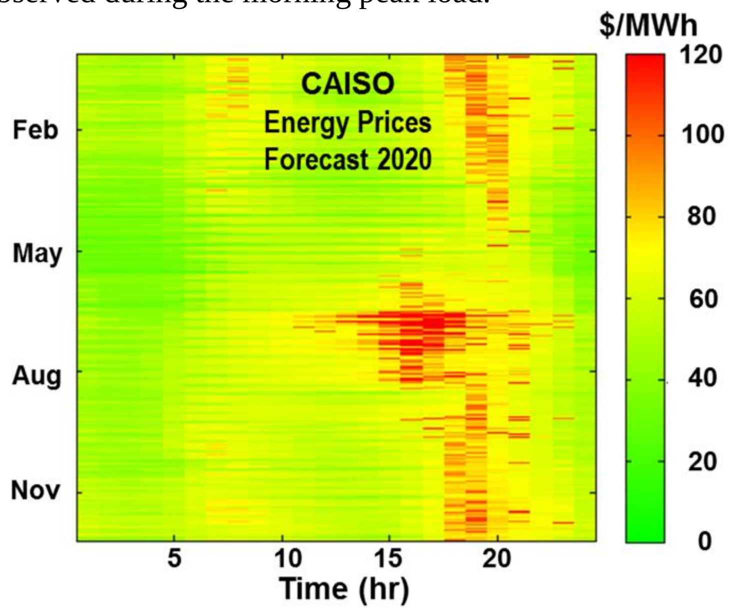

Figure 2.5. Energy price forecast for the California ISO market in 2020 ($/MWh) Prices are forecast to exceed $100/MWh during winter and summer peak load hours.

The California ISO is in the process of defining flexibility products to provide load following capabilities to be traded in the five minute real time market [CAISO 2014]. These load-following products require flexibility of dispatch in the real-time market. For the LLNL study, it was assumed that these products would be in place and dispatch would occur at five-minute intervals in the year 2020. The prices for load following up ancillary service are shown in **Figure 2.6a**. Price patterns for this ancillary service generally follow energy price patterns. Prices for load following down ancillary services are shown in **Figure 2.6b**. Load following down prices are high late at night and early in the morning when load is falling to a daily minimum. Load following down prices are also high just before noon in the winter, spring, and fall. This is due to a combination of low gross load and high solar generation rates which decrease the net load during this time period. Over-generation conditions may sometimes exist.

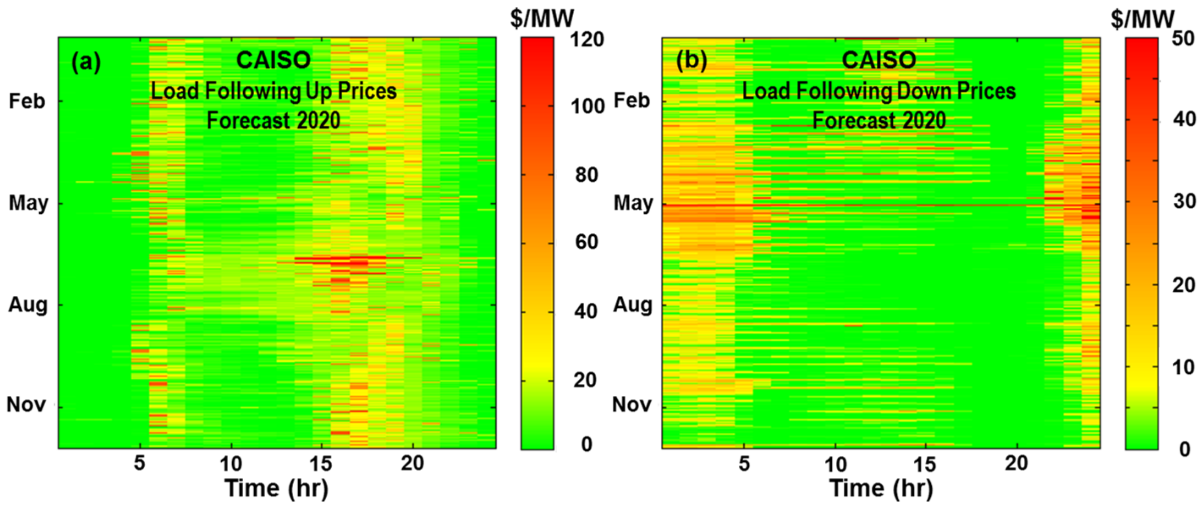

Figure 2.6. Load following up and down ancillary service price ($/MW) forecasts Prices for the California ISO market in 2020. Load following up prices exceed $100/MWh during ramp ups to meet the morning and evening peak loads. Load following down prices exceed $40/MWh when load is falling in the late evening and early morning hours. Note the different color scales indicating that load following down prices are less than half of the load following up prices.

Frequency regulation up and regulation down ancillary service prices are shown in **Figures 2.7a** and **2.7b**, respectively. The regulation-up price patterns generally mirror energy and load following up prices. Regulation-down prices are high late at night and early in the morning when load is falling to a daily minimum. Different color scales are used in **Figure 2.7** because regulation-down prices are generally less than half of the regulation-up prices.

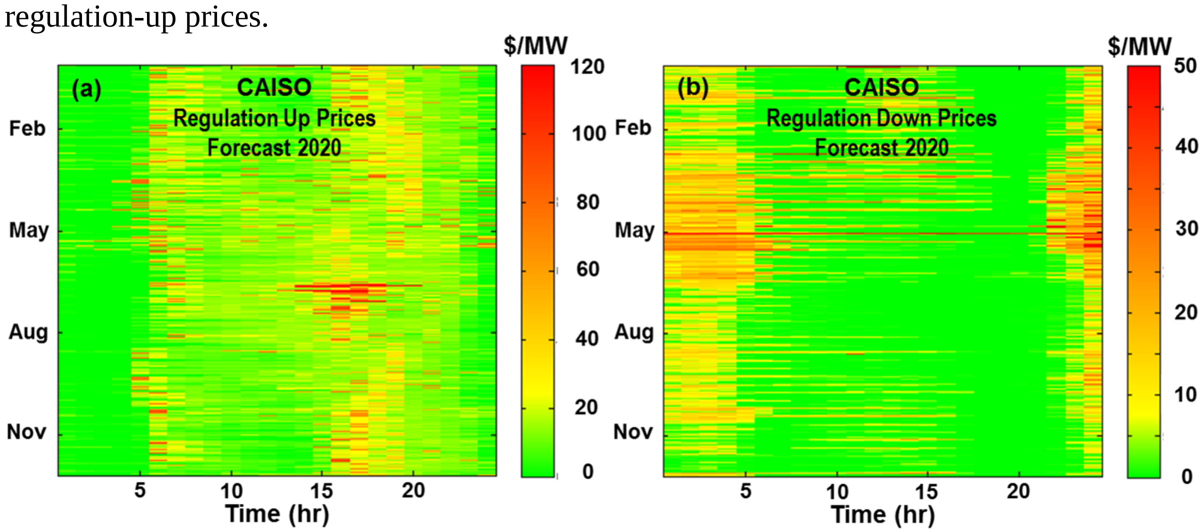

Figure 2.7. Ancillary service price ($/MW) forecast Prices for the California ISO market in 2020 for regulation up and down. Regulation prices follow the same general patterns as load following prices.

Finally, hourly prices for spinning and non-spinning ancillary services are shown in **Figures 2.8a** and **2.8b**, respectively. Spinning reserve services provide significantly more revenue potential than non-spinning reserve.

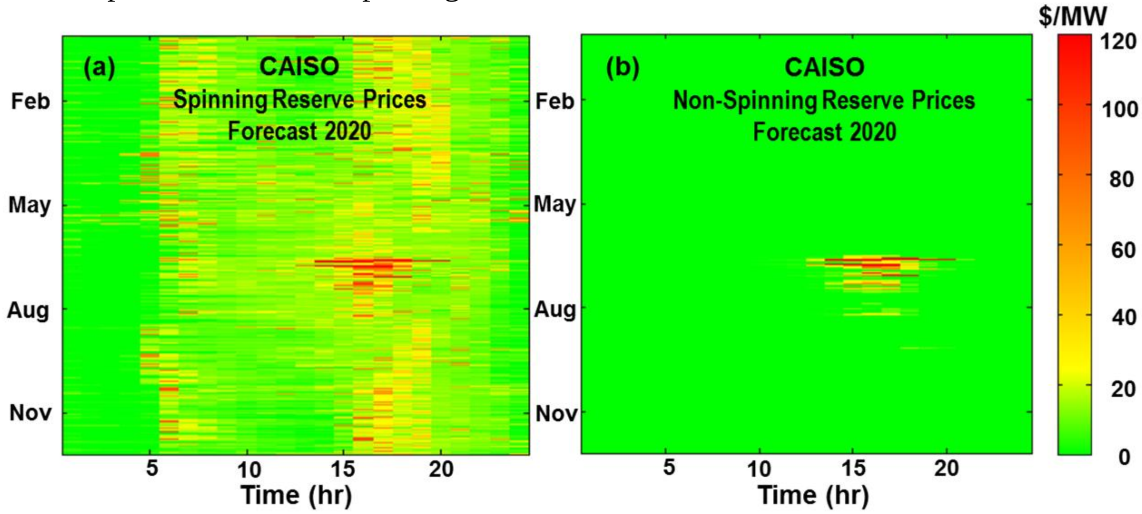

Figure 2.8. Spinning and non-spinning reserve price ($/MW) forecast Prices for the California ISO market in 2020 for spinning reserve and non-spinning reserve. In comparison to year 2013 prices that are shown in **Figure 2.3**, spinning and non-spinning reserve prices for the year 2020 are forecast to be over $100/MWh for many more hours of the year.

3 Economics of Flexible Operations

3.1 Current Business Models for Geothermal Projects

From an engineering perspective, geothermal projects are technically capable of providing a range of ancillary services. For example, Ormat Corporation's 38 MW Puna geothermal plant in Hawaii provides 8 MW of capacity that is controlled by Hawaii Electric Company. The plant provides regulation and ramping services to the utility [AltEnergy 2014]. In addition, some plant operators at the Geysers geothermal field in California are operating in operating in a flexible manner to provide peaking capacity [Sanyal 2011]. Geothermal plants could capture some of the ancillary service revenues described previously.

However, the economic incentives associated with the sale of ancillary services may not warrant deviation from an operating strategy of producing as much energy as possible. Due to high energy prices negotiated in recent geothermal power purchase agreements (PPAs), a reduction in energy generation needed to support provision of ancillary services (AS) will incur an economic penalty if AS prices are below energy prices. For example, Ormat recently executed a contract with the Southern California Public Power Authority to provide energy at $99/MWh from its 16 MW Don A. Campbell geothermal plant in Nevada [EBR 2014]. Revenues from the contract are driven solely by the number of MWh delivered. Other contracts include[2]:

- Cyrg Energy plant in New Mexico at $98/MWh with a 2.75 percent per year price escalation over 20 years
- Trans Alta-Mid American Energy plant in Riverside, California at $70/MWh with a 1.5 percent price escalation over 24 years
- U.S. Geothermal plant in Nevada at $90/MWh with a 1 percent price escalation rate over 25 years

If contracts were written to provide some measure of flexibility with regard to the services they are providing (energy vs. ancillary services), a plant operator could shift from providing only MWh of energy to providing an ancillary service. This contract switching could only occur if sufficient MW capacity were available on the system. The plant could provide regulation, load following, spinning, or non-spinning reserve ancillary services in those hours in which the price of the ancillary services exceeded the contractual energy price. However, at the energy prices in these recently-executed PPAs, there are few hours in the year when ancillary service prices exceed these energy prices. The short-duration price spikes in 2013 described in Subsection 2.2 are not frequent enough and of sufficient duration to provide enough incentive to deviate from an energy-only PPA at high energy prices. Accordingly, there would be few hours in the year when geothermal operators would be willing to reduce energy deliveries in order to provide ancillary services. Geothermal power generators would have more incentive to provide ancillary services if PPAs included a capacity payment and a lower energy price. Under such PPA structures, there would be more hours in the year when AS prices would exceed energy prices and operators would be willing to switch and deliver AS products.

[2] http://www.utilitydive.com/news/the-forgotten-renewable-a-users-guide-to-geothermal/218374/

Industry, state energy policy staffs, and other stakeholders should consider promoting such contract structures in the future.

In addition, some ancillary service markets may not be sufficiently large to impact the overall economics of the geothermal industry. Only a few hundred MW of capacity are needed for regulation services in the California ISO. The size of the market for load following ancillary services in California has yet to be determined because this product is currently under development by CAISO.

3.2 Revenue Estimates for Ancillary Service Sales with Flexible Contracts

In this section, we assume new business models could be negotiated that allow geothermal operators to moderate output and sell ancillary services when it is advantageous to do so. For each hour of the year, we assume the operator can switch from providing energy at a firm contract price to providing ancillary services during that hour. The opportunity cost of switching is the price of energy not delivered under the energy-only contract. The operator would receive the current market price for each MW of ancillary services provided in that hour. In addition, we assume the operator would receive compensation for incidental energy provided in conjunction with the ancillary service. For example, if the operator provided one MW of load following up ancillary service in a given hour, the plant would ramp up by one MW in accordance with five-minute economic dispatch signals sent by the ISO. During this period, we assume that, on average, 0.5 MWh of energy would be provided. We further assume that the geothermal plant operator would be compensated for this energy provided at the prevailing market price for energy in that hour.

A code was written to search hourly ancillary service prices depicted in the previous section in order to identify those hours in which it would be advantageous for the operator to switch from providing energy at the firm contract price to providing an ancillary service and the incidental energy described previously. Results are shown in **Figure 3.1**.

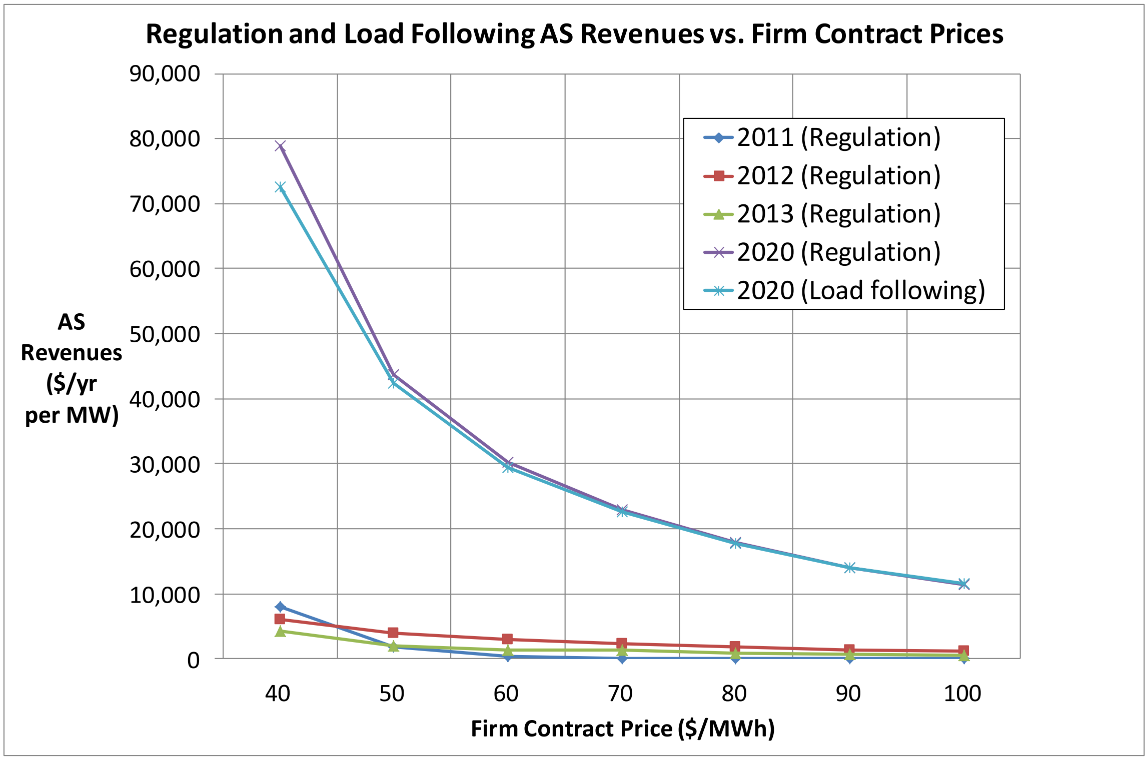

Figure 3.1. **Ancillary serve revenues under assumed flexible contract** Historical and forecast regulation and load following ancillary service (AS) revenues from flexible contracts in California market. Flexible contracts assume plant operator can switch from providing energy at a firm contract price to providing AS during any hour when it is advantageous for the operator to do so. Note that year 2020 forecast AS prices are significantly higher than historical prices.

The data in the figure show the annual revenues that a plant operator would receive from sale of one MW of ancillary services in those hours when the AS and incidental energy price exceeds the firm contract price for energy. As indicated by the data in the figure, regulation and load following AS revenues in the year 2020 are much larger than during the years 2011 through 2013. Further, annual AS revenues decline as the firm contract price increases because there are fewer hours in the year when it is advantageous to switch from providing firm energy to providing AS.

Even in the year 2020 when AS prices are much higher, the relative contributions from AS sales can be small. For example, consider a contract to provide energy at a firm contract price of $70/MWh. Assuming a 90% capacity factor for 1 MW of capacity, annual revenues from energy-only sales would be 8760 hours x $70/MWh x 0.9 = $552,000 per year. At this contract price, analysis indicates that an additional $22,000 per year can be earned from the sale of regulation services and another $22,000 per year for sale of load following services. This $44,000 per year revenue stream is only 8% of the $552,000 per year earned from energy sales. Finally, it is unlikely that the generator would be allowed to also provide spinning or non-spinning reserve services with the same MW of capacity under market rules in effect in the year 2020.

3.3 Revenue Results from Simulation Modeling

An integrated, stochastic weather and production simulation model of the year 2020 was developed in a previous study of renewable resources for the California Energy Commission [Edmunds 2014]. This model included existing geothermal power plants in the Pacific Gas and Electric, Southern California Edison, Imperial Irrigation District service territories as well as out-of-state facilities. Some of the out-of-state facilities were designated as providing load following and regulation services. Ten additional geothermal generation facilities were forecast to be built by the year 2020 and included in the model: six in California, one in New Mexico, one in Nevada, and two in Utah. The energy and ancillary service prices shown in Section 2 were generated with this model. The model was built using the Plexos production simulation software [Plexos 2012].

To conduct the analysis in this section, the production simulation model was updated to reflect plant retirements that have been announced since the model used in the previous study was built (during 2010-2012). These plant retirements are shown in **Table 3.1**.

Table 3.1. Update of production simulation model Plants removed from the production simulation model developed in 2010-2012 due to subsequently announced retirements[3].

	Plant retirement	Capacity (MW)	Comments
1	San Onofre Nuclear Generating Station Units 2 and 3 (SONGS)	2,254	Announced in 2013 will not restart after failed steam generator tube replacement
2	Contra Costa Units 6 and 7	680	Retired April 30, 2013
3	Humboldt Bay Units 1 and 2	15	Retired September 30, 2010
4	Morro Bay Units 3 and 4	676	Plans to close facility on February 28, 2014
5	Redondo Units 6 and 8	661	Plans to retire by December 31, 2018
6	South Bay	0.6	Retired December 31, 2010
	Total	4,287	

The previous study used statistical clustering techniques to identify a subset of the days that were most representative of conditions throughout the year[4]. The updated simulation model, including the geothermal generators, was run for these representative days. **Figure 3.2** and **Figure 3.3** show daily revenues from regulation and load following ancillary services (AS) for days under the same set of assumptions about flexible contracts described in the previous section.

[3] http://www.energyalmanac.ca.gov/powerplants/

[4] The 365 days in a year were partitioned into 24 clusters using a k-means clustering algorithm. The day closest to the centroid of the cluster was selected as the representative day. The weight assigned to that representative day was equal to the number of days in the cluster divided by 365. Days had weights ranging from 1/365 to 50/365. See [Edmunds 2014].

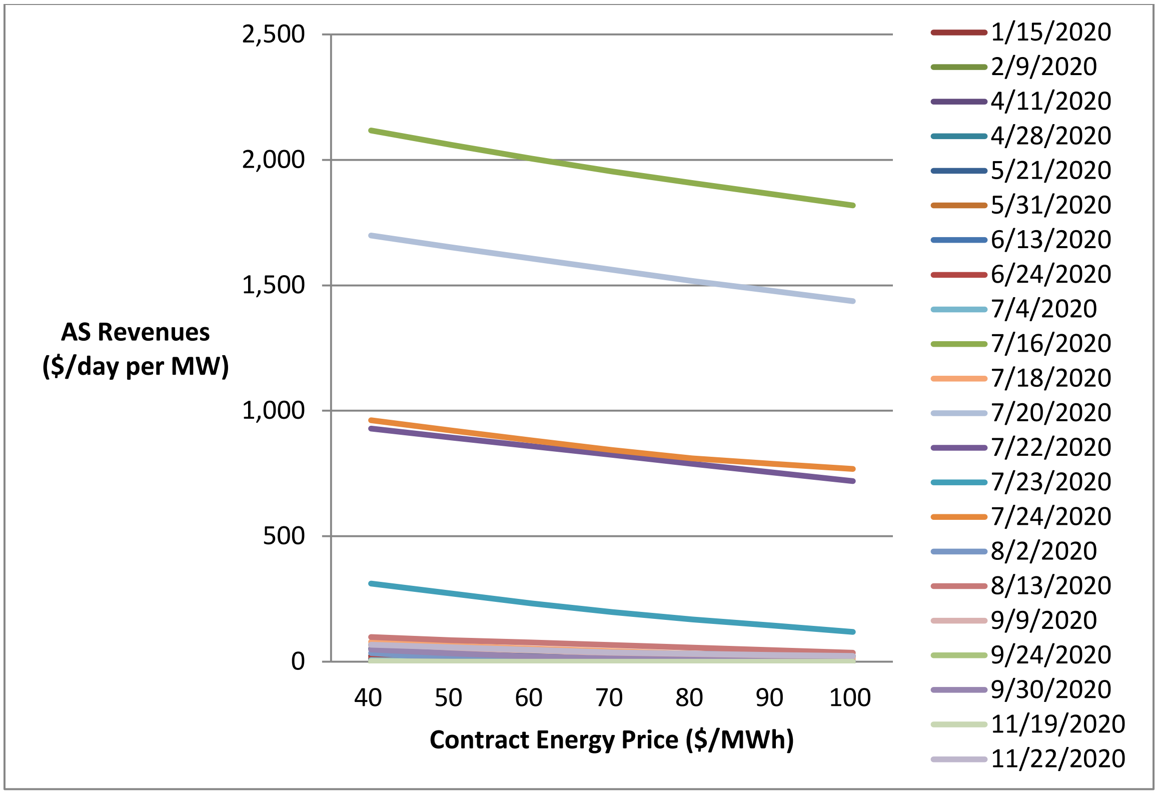

Figure 3.2. Regulation revenues from flexible contract Forecast regulation ancillary service (AS) revenues from flexible contract in CAISO market in year 2020 are shown. Revenues during on February 9, July 16, July 22, and July 24 are more than ten times the revenues for most other days in the year.

As indicated by the regulation ancillary service revenues shown in **Figure 3.2**, revenues from switching from an energy-only service to regulation ancillary services are more than ten times higher during a four days in July (16, 20, 22, and 24) than most other days in the year. During these particular days, energy as well as regulation up, spinning reserve, and non-spinning reserve ancillary service prices exceeded $1,000 during several peak load hours of that day due to a combination of high temperatures, high air conditioning load, and low renewable generation. However, these days are unique so the weight applied to each of them is only 1/365 when computing annual revenues.

Potential revenues for load following ancillary services in the year 2020 are shown in **Figure 3.3**. Very high load following revenues are observed on these same four July days (16, 20, 22, and 24).

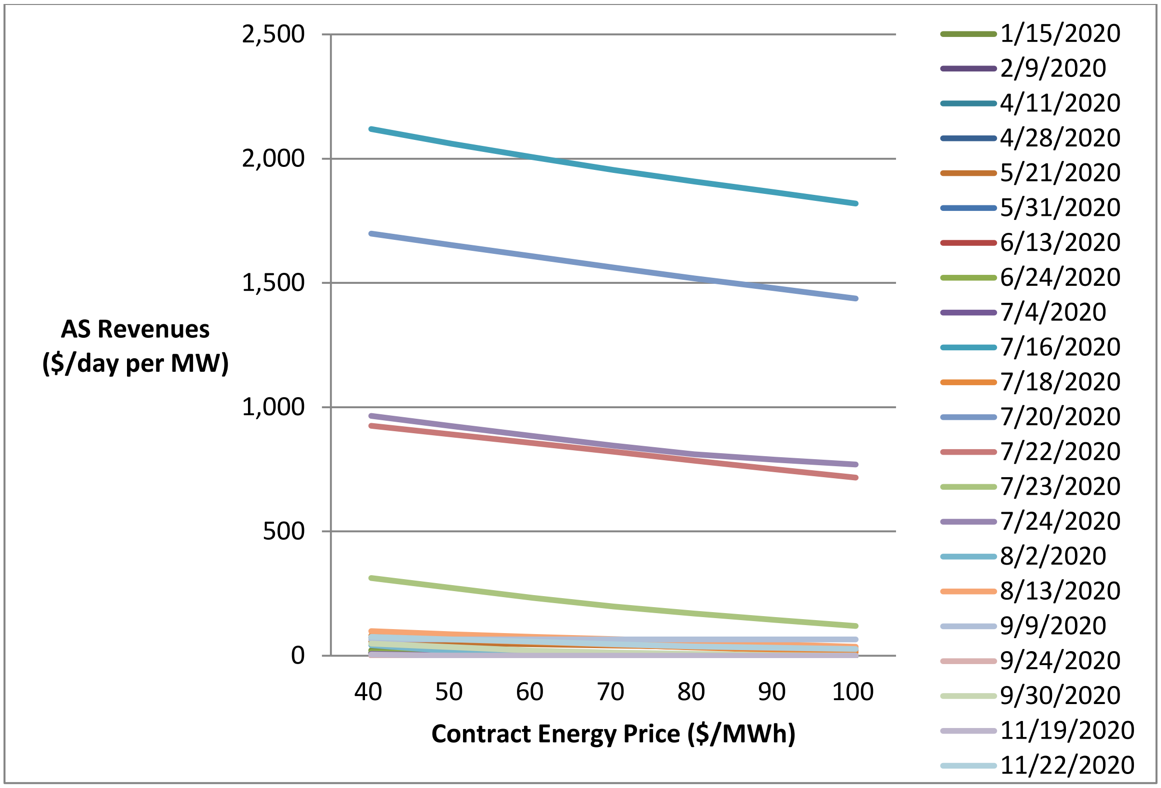

Figure 3.3. **Load following revenues from flexible contract** Forecast load following ancillary service (AS) revenues from flexible contract in CAISO market for the year 2020. Revenues on July 16, 20, 22, and 24 are more than ten times the revenues for most other days in the year.

Revenues on selected days from spinning reserves sales are shown in **Figure 3.4**. Spinning reserve prices follow the same pattern as regulation and load following revenues on the modeled days. As indicated previously, revenues from non-spinning reserve ancillary services are zero for most of the hours of the year. We conclude that it is fundamentally not economical for geothermal power plants to remain offline (non-spinning) and ready to provide power when non-spinning reserve is dispatched by the system operator.

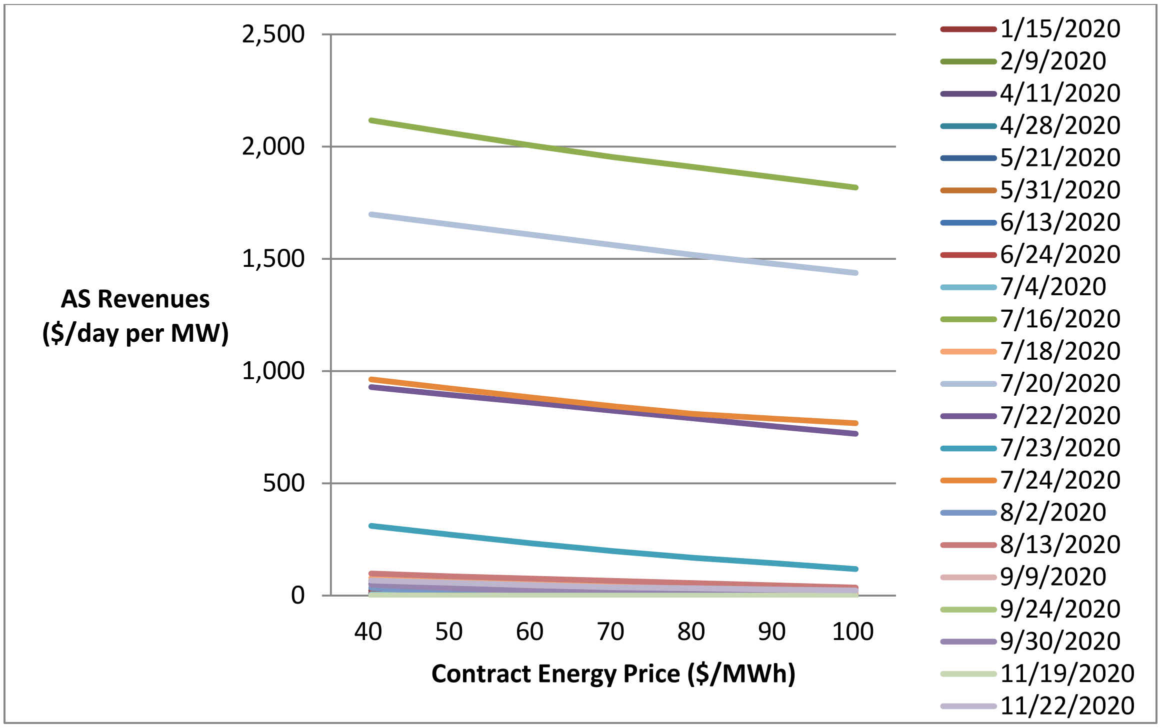

Figure 3.4. **Spinning reserve revenues under flexible contract** Spinning reserve revenues from flexible contract in CAISO market for the year 2020. Revenues during on July 16, 20, 22, and 24 are more than ten times the revenues for most other days in the year.

Forecasts of annual revenues from the sale of all ancillary services in the year 2020 are shown in **Figure 3.5**. Revenues are shown for contract energy prices of $50, $70, and $90 per MWh. As indicated in the figure, approximately $15,000 per year per MW of capacity can be earned by providing either load following or spinning reserve ancillary services if the energy price specified in the flexible contract is $70 per MWh. Approximately, $7,500 per year per MW can be earned by providing frequency regulation.

In these simulations conducted with the updated model, potential annual revenues from providing regulation services are approximately half of those from providing either load following or spinning reserve. This *revenue* relationship is in apparent contrast to the *price* relationships produced with the older simulation model that are shown in Section 2, where the prices for load following and regulation services were approximately the same. Because the updated model involved the removal of 4,287 MW of nuclear and fossil capacity with high inertia, one would expect the need for and potential revenues from frequency regulation to increase.

The loss of fossil units that were providing load following and spinning reserve services, but not regulation, may have increased load following and spinning reserve revenues that could be earned by the remaining units. The relatively lower revenues from frequency regulation may also arise from the switching behavior associated with the flexible contract. It may be that energy prices are always high when regulation prices are high so the switch from providing energy to providing ancillary services is not triggered. Energy prices may not be as highly correlated with load following and spinning reserve prices, so the contractual switch between energy and these ancillary services is triggered more often. This would explain the ability to earn higher revenues from providing load following and spinning reserve services.

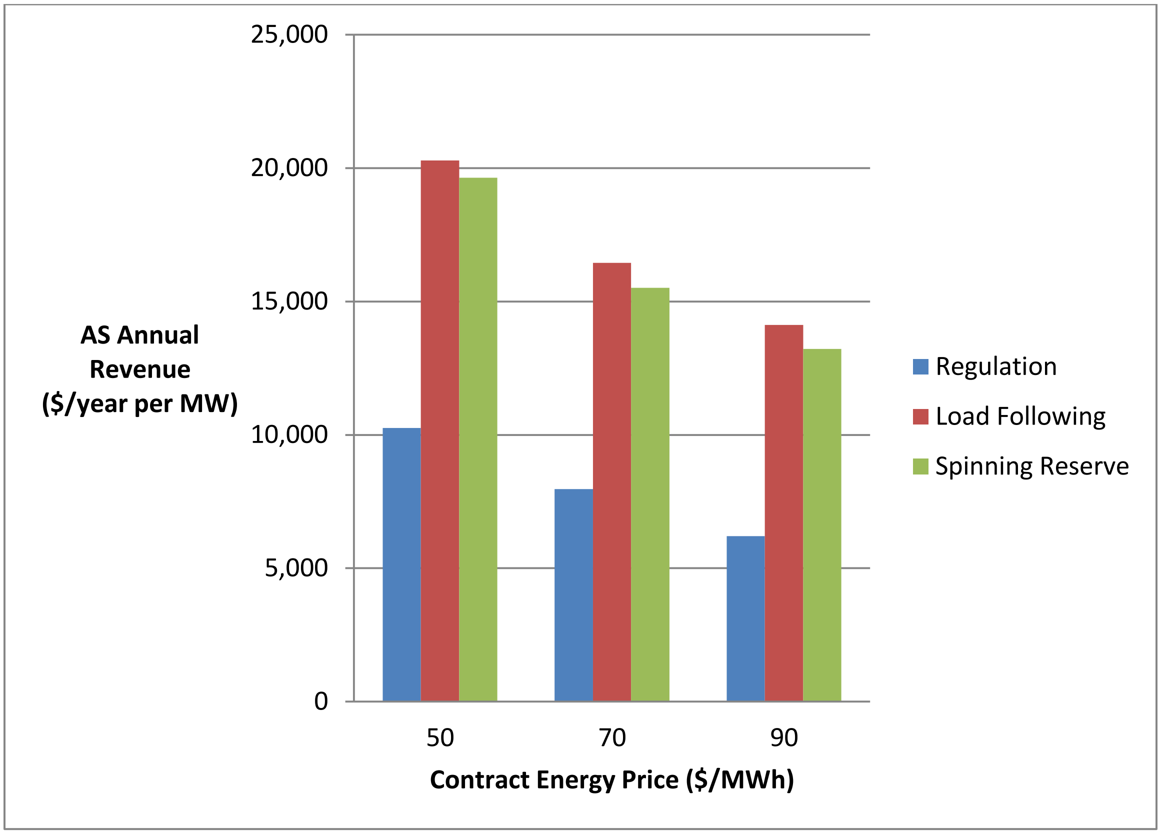

Figure 3.5. **Annual revenues from ancillary services under a flexible contract** Forecast revenues for the year 2020 are shown assuming energy prices of $50/MWh, $70/MWh, or $90/MWh under the contract. Note that potential revenues from regulation are approximately half of the

3.4 Recommendations for Flexible Geothermal Contracts

The previous analysis indicates that additional revenues could be realized if new contract structures could be negotiated between geothermal plant operators and load serving entities. These new contract structures could incorporate the following elements:

- Capacity payments – If generation expansion plans show a need for new capacity to meet peak loads, then new contracts with geothermal generators could be negotiated that include capacity payments based upon value of deferring construction of new capacity. Such payments could be justified for geothermal operators who could dispatch their plant to help meet peak load, but may not be fully justified for intermittent, non-dispatchable generators who may or may not be available during the system peak.

- Load following compensation – Contracts could be negotiated to include payments for load following in accordance with dispatch signals transmitted by the independent system operator or other load serving entity. This would require installation of additional communication and control hardware and software.
- Frequency regulation compensation – Contracts could also be negotiated to include payments for frequency regulation services. This would also require installation of additional communication and control hardware and software.
- Lower energy prices – Many of the contracts currently in place specify relatively high energy prices with no other compensation mechanisms. As a consequence, there may be little incentive to decrease output in order to provide flexibility to the system. Both parties to the contract may benefit if the geothermal generators are provided access to other revenue streams in exchange for concessions on contract energy prices.

4 Geothermal Reservoir Life Extension Due to Flexible Operations

4.1 Approximate Financial Impacts

To first order, extracting less geothermal energy from a reservoir today allows that same amount of energy to be extracted later. From a financial perspective, any lost revenue from operating the plant at a lower power output in order to provide flexibility could be partially recouped with future revenues associated with running the plant longer. The relative value of such future revenues can be measured by computing the net present values (NPVs) of revenue streams with and without a flexible operating policy.

To illustrate the effect, consider a geothermal power plant with a 40 year life time when operated at 100% of capacity. If the annual revenue stream is normalized to $1.0M and a discount rate of 10% is used, the NPV of the plant without flexible operations is $9.78M.

Now consider a plant with flexible operations so that only 90% of its full capacity is used for each of the first 40 years. Because less energy is extracted from the geothermal reservoir during this 40 year period, more energy will remain in the reservoir at the end of this period. Assuming equipment life is proportional to energy produced and not chronological age, an additional 4 years of plant life will remain. The NPV of 40 years of operation at 90% and 4 years of operation at 100% is $8.87M. Thus, the NPV for energy sales under a flexible operating policy is 9.28% less than the NPV of energy-only services provided under an inflexible contract.[5] Revenues from the sale of ancillary services would need to compensate for this loss of NPV from deferring energy sales.

The long plant life and discounting dramatically reduces the contribution of the remaining 4 years of operation to the total project NPV. The additional 4 years only contribute $0.07M, or less than 1% to the total NPV.

4.2 Change in Production Profile Due to Flexible Operations

Several functional forms have been developed to model the decline in production from geothermal wells over time. For this analysis, we use a hyperbolic rate-time equation described in [Ripperda 1987], and compute the increase in well life when annual production rates are decreased by 10 and 20%. The parameters in the rate-time equation were fit to a model of the Geysers field attributed to [Enedy 2010] and described in [Sanyal 2011]. Results are shown in **Figure 4.1**.

The 100% production profile in the figure corresponds to the historical and forecast production rate through 2020 from the Enedy model. The other two production profiles reflect reduced annual production rates due to flexible operations. The reduced annual production rates of 10% and 20% result in increased well lifetimes of 5 and 11 years, respectively. The total energy produced is the same for each of the three production profiles. At a 10% discount rate, the net present values of the revenue streams are reduced by 9% and 18% for a 10% and 20% reduction in production rate, respectively.

[5] Of course, this result is influenced by the choice of discount factor. The NPVs from flexible operations are 7.06% and 9.84% less using discount rates of 5% and 10%, respectively.

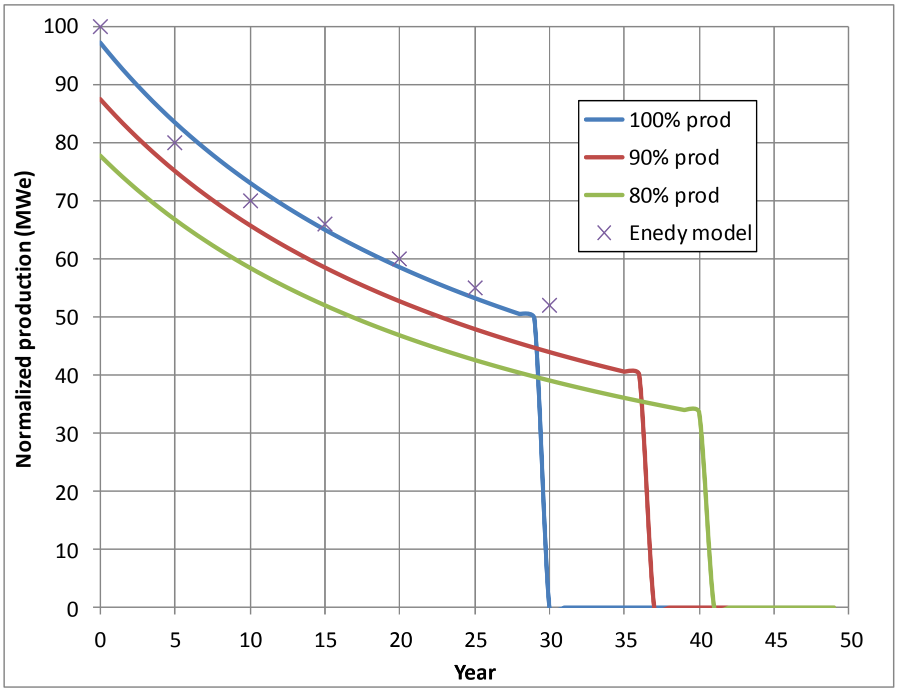

Figure 4.1. **Production rates from normal and flexible operations** The 90% and 80% annual production rates due to flexible operations lead to extended well lifetimes. All production curves yield the same total quantity of energy.

In the 100% production scenario shown in the figure, the geothermal generator is only earning revenues from energy sales. In the 90% and 80% production scenarios, the geothermal generator would be earning additional revenues due to sales of ancillary services under a the posited flexible contract described in Subsection 3.2. As indicated previously, ancillary services sales under such a contract could add approximately 8% to the revenues that would be realized under an energy-only contact. This 8% increase in net present value almost compensates for the 9% reduction in net present value caused by the deferral of revenues from energy sales under the 90% production scenario.

Under the 80% production scenario, the generator would presumably be selling about twice as much ancillary services and earn about 16% additional revenues from these sales. This 16% increase in revenues approximately compensates for the 18% reduction in net present value due to the delay in receipt of revenues from energy sales.

In summary, the increase in net present value of revenues that could be realized from sale of ancillary services under a flexible contract is approximately equal to the reduction in net present value caused by the delay in receipt of revenues that is caused by reduction in generator output necessary to provide flexibility.

5 Summary and Conclusions

State renewable portfolio standards are driving deep market penetration of intermittent wind and solar generation. This change in grid structure will substantially increase the uncertainty and variability in grid operations, and will increase the prices for ancillary services needed by operators to stabilize the grid. If ancillary service prices increase significantly above current levels for a sufficient number of hours during the year, geothermal power plant operators could capture additional revenues by operating plants in a flexible mode in order to provide these services. However, power purchase agreements reported in the recent press indicate that contracts are being configured to provide only energy sales. Energy prices under these contracts are significantly higher than current average ancillary service prices so there is insufficient incentive to reduce energy sales in order to provide ancillary services.

Regulation, load following, spinning reserve, and non-spinning reserve ancillary service prices for the years 2011 through 2013 in the California markets were too low to provide sufficient economic incentive to geothermal plant operators to provide flexibility. However, prices in the year 2020 are expected to be significantly higher due to an aggressive renewable portfolio standard of 33% in California and the retirement of over 2,000 MW of flexible generation capacity. Hourly prices for regulation up, load following up and spinning reserve ancillary services in 2020 are expected to periodically exceed $100/MW. Prices for load following down and regulation down are likely to be at half of these levels. Geothermal plant operators who secure flexible contracts that allow them to provide ancillary services could add to their annual revenue streams. For example, ancillary services could add 8% to the annual revenue stream under a flexible contract with an energy price of $70/MWh.

Geothermal plant operators who moderate power levels would extend the life of their respective thermal reservoirs. However, due to discounting of these future revenue streams, the impacts of project economics are minimal (less than 1% contribution to net present value).

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Appendix A: Energy and Ancillary Service Price Patterns

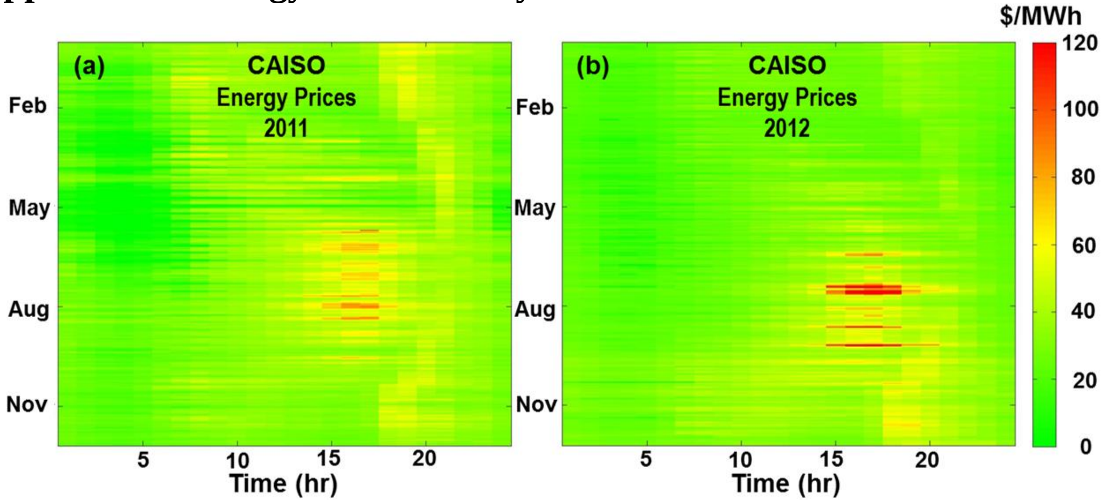

Figure A.1. CAISO energy prices ($/MWh) for 2011 and 2012

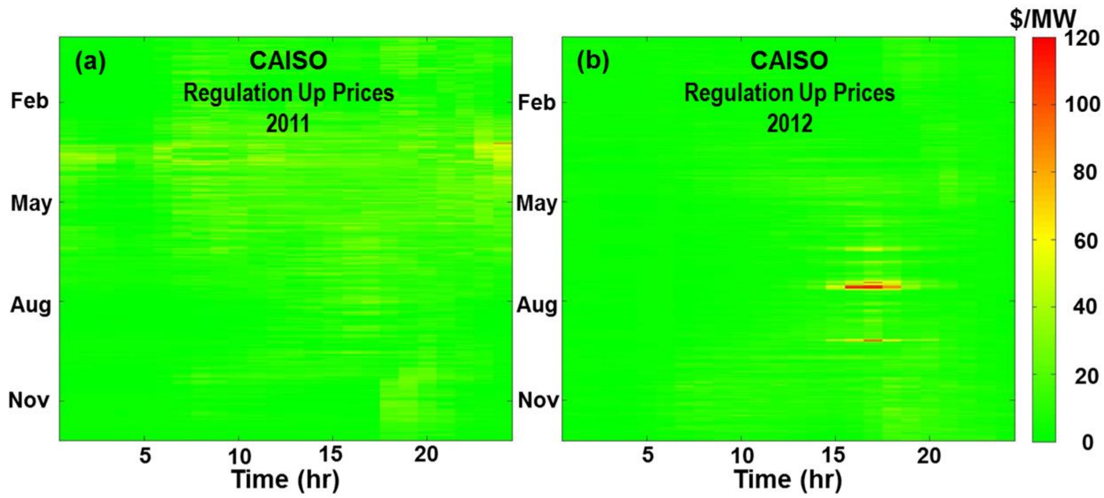

Figure A.2. CAISO ancillary service regulation-up prices ($/MW) for 2011 and 2012

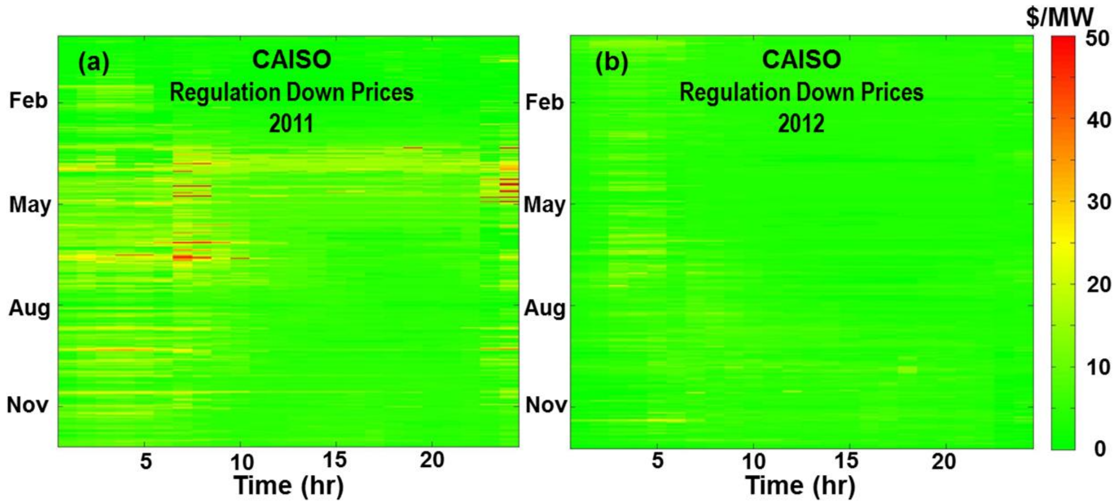

Figure A.3. CAISO ancillary service regulation-down prices ($/MW) for 2011 and 2012. Note that the color scale is different from the other figures in this appendix.

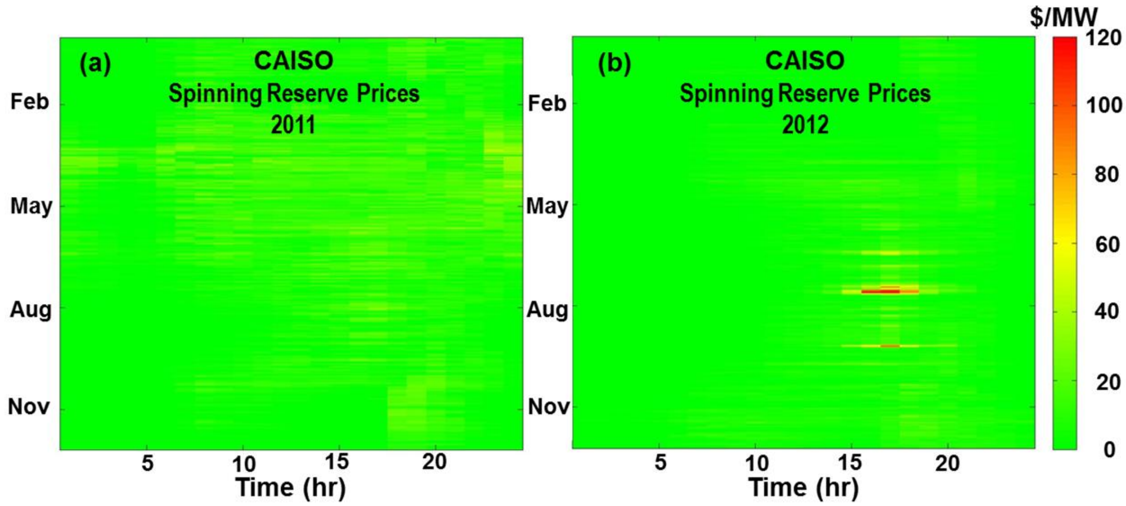

Figure A.4. CAISO ancillary service spinning reserve prices ($/MW) for 2011 and 2012.

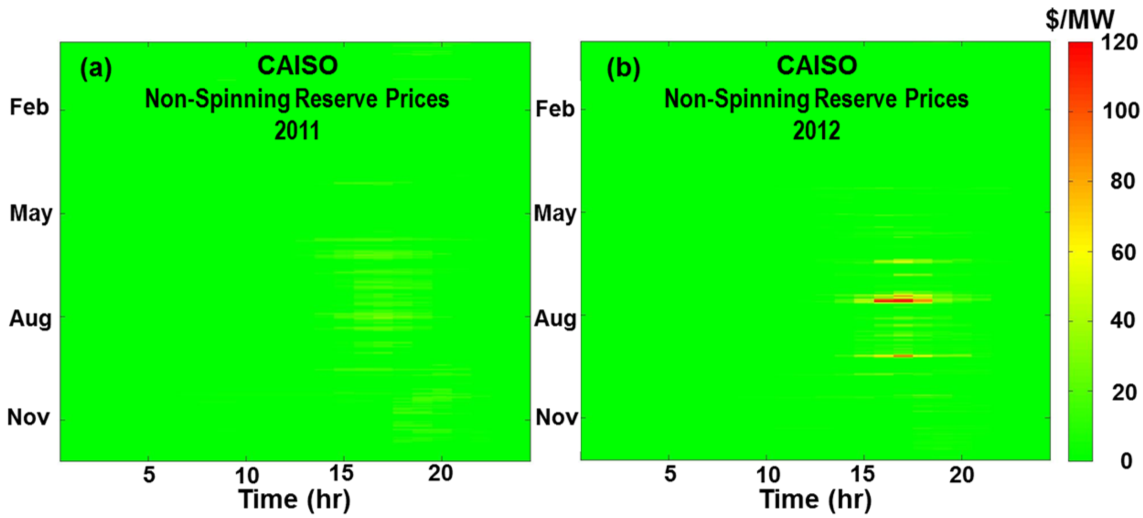

Figure A.5. CAISO ancillary service non-spinning reserve prices ($/MW) for 2011 and 2012