GRC Transactions, Vol. 42, 2018

Geothermal selection in California resource planning:

Preliminary results from the CPUC's IRP tools and recommendations for future development and analysis

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Keywords

Geothermal, Integrated Resource Planning, Capacity Expansion, Value, Utility Procurement, California, California Public Utilities Commission (CPUC), Western Grid, Wind, Solar, Batteries, Baseload

ABSTRACT

Integrated Resource Planning (IRP) is an important component of utility and state electric power planning processes. Under state legislation adopted in 2015, all California load-serving entities above a minimum size are required to conduct IRPs. In 2017, the California Public Utilities Commission (CPUC) provided a publicly available capacity expansion model "to identify optimal portfolios of resources that will achieve electric sector GHG reductions, reliability needs, and other policy goals at least-cost under a variety of possible future conditions." That model made cost assumptions regarding geothermal generation which were not consistent with recently executed geothermal PPAs. A modest reduction in the cost assumptions reflecting recent Ormat contracts resulted in a significant increase in geothermal being selected. Subsequently, in 2018, the CPUC updated the model assumptions, notably increasing forecast load, which again greatly improved geothermal selection and resulted in over 2 GW of additional geothermal being selected by 2030 when geothermal costs are in the range of \$76 - \$82/MWh. When regional geothermal resource potential caps are removed, the model selects almost 3 GW of new geothermal. The model also shows that more geothermal is selected in higher renewable penetration scenarios. This paper examines the data and assumptions driving geothermal selection, explaining the methodology used, and identifying resource planning modeling issues which should be addressed through further research and modeling tool development.

1. Introduction

Integrated Resource Planning (IRP) is an important component of utility and state electric power planning processes as new technologies are rapidly transforming utility and regional power systems. As the models and methods used for IRP development proliferate and are adapted to represent new types of resource portfolios[1], certain technologies may encounter both advantages

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[1] Notably, those incorporating very high renewable penetration.

and disadvantages due to the assumptions and model structures being developed. This paper provides a preliminary assessment of some of the factors which are affecting selection of geothermal in California's IRP process and makes recommendations for further analysis and research.

1.1 Recent developments in California IRPs

In 2015, the California legislature established new requirements that Integrated Resource Planning (IRP) apply to all California load-serving entities (LSEs) above a certain size.[2] Some California utilities have already been conducting some form of resource planning, but many others will need to establish a more formal process to comply. In 2016, the California Public Utilities Commission (CPUC) began an IRP proceeding to provide guidance to its jurisdictional entities. In 2017, it released proposed assumptions and scenarios to comprise a Reference System Plan (RSP) to achieve greenhouse gas (GHG) reductions in 2030 to meet legislative policy targets. It also provided a capacity expansion model called RESOLVE for public use in the proceeding.[3] Following stakeholder comments and other adjustments, in February 2018, the CPUC updated and finalized the RESOLVE model assumptions for the RSP, for use by jurisdictional LSEs when filing their IRPs (CPUC 2018). The adopted RSP scenario targets the reduction to 42 million metric tons (MMT) of greenhouse gas (GHG) emissions by 2030. Generally, the resulting generation portfolio requires about 60% renewable energy, along with other resources such as energy storage, to achieve this objective.

1.2 Key findings

In this paper, both the 2017 and the 2018 versions of the CPUC assumptions, scenarios, and public models are used for a more extensive examination for the selection of geothermal resources in future resource portfolios and to provide recommendations to regulatory agencies, utilities, and geothermal developers.

In 2017, we began such testing and submitted stakeholder comments (Ormat 2017). We found that the model selected only 202 MW of new geothermal for all CPUC-jurisdictional entities in the proposed 42 MMT scenario with a geothermal levelized cost of energy (LCOE) in the range of $88.56 - $91.63/MWh and solar PV and battery costs in the CPUC's "mid" range (see discussion in Section 4 below).[4] We modified the model to use geothermal costs used in actual contracts, with contract prices around $76 - $82/MWh, and found that the model selected 424 - 734 MW of new geothermal, with additional geothermal selected if solar PV and energy storage costs were higher than forecast (Ormat 2017). Some of these results are shown in Figure 2 below.

Under the revised 2018 CPUC assumptions, the geothermal component of the RSP portfolio has greatly increased due to several factors, notably increased load forecasts and higher behind-the-meter PV forecasts. The model now selects 1,700 MW of new geothermal in the 42 MMT scenario when costs are in the $88.56 - $91.63/MWh range, but up to 2,020 MW of new geothermal when

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[2] See http://www.cpuc.ca.gov/sb350/.

[3] All model versions and supporting documentation can be found at http://www.cpuc.ca.gov/General.aspx?id=6442451195.

[4] These cost ranges are dependent on geographical location; see tables in Section 4.

modeling Ormat's recently executed PPA costs,[5] which are in the range of \$76 - \$82/MWh. Moreover, the model builds 2.5 GW to around 3 GW of new geothermal if there was greater regional geothermal resource potential available in the model, suggesting that further attention to issues related to resource development and transmission access is warranted.

These findings are amplified further in our testing of the CPUC's 2017 30 MMT scenario, which results in lower GHG emissions and results in greater renewable penetration, up to 75%. In this case, geothermal expansion quickly reaches regional resource potential and doubles when greater resource potential is assumed. This suggests that geothermal resources will only *increase* in comparative value as California attempts to achieve greater decarbonization of its economy.

1.3 Organization of paper

The paper begins with a brief background on IRP methods and models, along with a description of the CPUC IRP proceeding and associated assumptions, scenarios and modeling tools. Sections 4-5 examine a range of sensitivity analyses using the RESOLVE tool under alternative assumptions, both pre-loaded within the model and making adjustments to the pre-loaded assumptions. Section 6 provides conclusions and recommendations.

2. Integrated Resource Planning

Integrated Resource Plans (IRPs) generally look ahead over 10-20 years to examine a wide range of possible resource solutions – including generation, demand modification, storage, and transmission – to meet future load growth and policy requirements in a least-cost portfolio. To do so, IRPs generally simplify system operational requirements, transmission network constraints, and local reliability requirements to examine many different resource portfolios.[6] As the changes to the resource mix become more complex, many IRPs have attempted to introduce some dispatch capabilities within the modeling structure. This can be done in part by simplifying the model further to examine a few selected days (this is part of the approach in the CPUC's version of the RESOLVE model).

2.1 Legislative requirements for IRP

The recent phase of California IRPs began with the Clean Energy and Pollution Reduction Act of 2015[7] (SB 350), which requires that the state energy agencies coordinate to establish a process by which each load-serving entity would file an IRP on approved timelines, as discussed below. The statutory objective is to facilitate a 40 percent reduction in greenhouse gas (GHG) emissions from 1990 levels by 2030.

2.2 CPUC IRP proceeding

The CPUC has jurisdiction over the California investor-owned utilities as well as community choice aggregators (CCAs) and some other classes of load-serving entities. The CPUC has expanded its role in resource planning since 2004, when it was legislatively required to establish

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[5] See http://investor.ormat.com/file/Index?KeyFile=2000842054

[6] For a survey of western US utility IRP methods, see Wilkerson et al., 2014.

[7] See http://www.cpuc.ca.gov/sb350/

a Resource Adequacy requirement, and continuing in 2007, when it began the long-term planning proceeding (LTPP) as an umbrella proceeding to identify resource needs related to state policy objectives, in particular the renewable portfolio standard (RPS). With the enactment of SB 350, the CPUC began an IRP proceeding in 2016 and allowed stakeholders to comment on assumptions and scenarios, as well as provided tools, as discussed below, to facilitate stakeholder engagement.

In February 2018, the CPUC adopted a decision which established a two-year process for load-serving entities to file IRPs, beginning in 2018 (CPUC 2018). We will not review this decision in detail here, but want to note that, with respect to the role of the modeling analyzed in this paper, it clarifies that "the purpose of this analysis is to inform a directional GHG goal-setting framework for planning purposes, and the modeling does not lead to a direct compliance obligation for any LSEs at this stage" (CPUC 2018, pg. 52). However, while the tools and assumptions are not at this time required for LSEs, they are instructed to do the following (CPUC 2018, Att. A, pgs. 6-7):

> Name all modeling software used by LSE to develop its IRP, if any, and include the vendor and version number. Provide an explanation of differences between the LSE's modeling tool and RESOLVE, and an explanation of how those differences should be considered during evaluation of the LSE's portfolio(s).
>
> Describe any inputs or assumptions used by the LSE that differ from the corresponding assumption used by the Commission to prepare the Reference System Plan. Each differing assumption must include a rationale for use of this assumption and any intermediate calculations used to develop the assumption and source data with citations. Include a side-by-side comparison of the original assumption data from the Reference System Plan and the LSE's differing assumption data. Report data according to the requirements in the Data section below.

Hence, the sensitivity analysis and methods shown in this paper may have direct relevance to actual CPUC-jurisdictional LSE IRP methods for analysis of geothermal and future evolution of these methods.[8]

2.3 POU IRPs

While this paper focuses on the CPUC proceeding and associated tools, the California Publicly-Owned Utilities (POUs) are major buyers of geothermal energy and the State will need to coordinate its resource planning among the different entities. SB 350 also requires California POUs with greater than 700 MWh average load to file IRPs with the CEC by mid-2019 (CEC 2018). Currently, these IRPs are intended to be required on a 5-year cycle. Some of the POUs are already conducting IRPs or other types of resource planning functions.

The Los Angeles Department of Water and Power (LADWP) is the POU with the largest current and forecast geothermal portfolio. LADWP conducts an annual IRP (see, e.g., LADWP 2017, 2016, 2015), using a range of different tools, including methods to create future resource portfolios and production cost modeling, to establish the operational flexibility and reliability of those portfolios. Many of the input assumptions used in the LADWP IRPs are provided, but the tools

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[8] We note that in late August 2018, the IRPs from CPUC-jurisdictional LSEs were submitted to the CPUC. Many of them select significant geothermal resources, including Southern California Edison (SCE).

are not freely available for public use; hence, we can only comment on the final modeled results but cannot alter any input assumptions.

Table 1 shows that in recent years, the LADWP IRPs have significantly increased their forecast procurement of geothermal. This paper will not examine these results in detail. However, we note here that these quantities are significantly more than the CPUC assumes the non-jurisdictional CPUC LSEs will require.

Table 1 – LADWP geothermal portfolios in recent IRPs

IRP year	Existing geothermal capacity in starting year	Assumed existing geothermal capacity in final planning year (20 year target date)	New geothermal capacity in final planning year (20 year target date)	Total geothermal capacity in final planning year
2017	106	0	445	445
2016	108	18	480	498
2015	69	0	293	293

Sources: LADWP (2017), (2016), (2015)

3. The CPUC modeling assumptions and RESOLVE tool

The remainder of this paper focuses on aspects of geothermal modeling within the CPUC's IRP proceeding and system modeling to date.

Continuing from the prior CPUC LTPP proceeding, each phase of the IRP proceeding begins with a release of standardized assumptions and scenarios to be used in the IRP proceeding as well as in the CAISO's transmission planning process. We will not review these in detail here, but note that due to the legislative requirements for California IRPs, each scenario is developed around a greenhouse gas (GHG) emissions reduction target measured in million metric tons (MMT) of avoided carbon emissions. As noted, a 2018 CPUC decision established a Reference System Plan (RSP) based on an aggregate electric power emissions target in 2030 of 42 MMT, which results in a renewable portfolio equivalent to approximately a 60% RPS (for perspective, based on current procurement, the California IOUs are forecast to achieve a 50% RPS by 2020).[9] The model scenarios also included higher emissions reductions scenarios, including a 30 MMT scenario which resulted in renewable portfolios of around 73%.

Associated with the assumptions and scenarios, the CPUC has made publicly available a spreadsheet-based optimization model called RESOLVE which packages the various Commission assumptions. The model can be downloaded and modified by any user. It comes pre-loaded with

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[9] Current renewable procurement and forecasts are available here: http://www.cpuc.ca.gov/RPS_Homepage/.

a large number of scenarios. The stated purpose of RESOLVE is "to identify optimal portfolios of resources that will achieve electric sector GHG reductions, reliability needs, and other policy goals at least-cost under a variety of possible future conditions."

4. Geothermal resource assumptions in the CPUC IRP modeling

The 2018 assumptions on cost, performance and development potential of renewable resources in the IRP proceeding are the result of a number of stakeholder processes and consultant reports.

The CPUC is currently using geothermal assumptions developed in 2016 for RPS modeling (Black & Veatch, 2016) and then re-evaluated in the subsequent IRP proceeding in 2017. In this section, we briefly review these assumptions before considering sensitivity analysis on those assumptions in the next sections; Appendix D provides additional background.

4.1 Geothermal resource location and capacity factors

The CPUC models two types of renewable resource capacity: the existing capacity assumed to be in the resource baseline over the modeling period, and potential new resources to meet policy goals. Table 2 shows the existing geothermal capacity in the IRP baseline assumptions; these resources are removed from service in a particular time period based on their existing contracts. Potential new geothermal resources are modeled by the CPUC in four zones. Two zones are for in-state resources located in the Greater Imperial zone and the Northern California zone. As shown in Table 3, there are 1,808 MW of in-state geothermal resource potential presumably at or below the cost assumed in the model. In addition, there are 1,152 MW of geothermal resource potential in two out-of-state zones: Southern Nevada and the Pacific Northwest. Of these zones, the Nevada locations are assumed to be able to utilize existing transmission capacity, while the Pacific Northwest locations would need new transmission capacity, which adds costs to resource selection (as discussed further below). Hence, there are a total of 2,128 MW available, using existing transmission capacity.

Table 2 – Regional baseline geothermal capacity (MW) in RESOLVE, 2018-2030

Zone of projects	Contracted to entities in zone	2018	2022	2026	2030
CAISO	CAISO	1,182	1,232	1,232	1,232
Imperial Irrigation District (IID)	CAISO	455	271	235	235
Pacific NW	CAISO	15	15	15	15

The California RPS rules give priority to resources located in-state or otherwise able to be delivered to a California balancing authority as renewable energy,[10] and there are contractual reasons for these resources to be selected first, which are reflected in the model structure. As shown in Table 3, geothermal resources in the Greater Imperial zone are expected to have the highest capacity factors in the Western region, while those in the Northern California and Nevada region have the lowest, although the numbers used are not entirely consistent with industry assumptions. Ormat does not agree with these assumptions but has not yet conducted sensitivity

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[10] See discussion here: http://www.cpuc.ca.gov/RPS_Procurement_Rules_33/.

analysis using better assumptions (however, see our analysis when resource potential constraints are removed, below).

For CPUC purposes, 108 MW of in-state geothermal resources is assumed to be assigned to non-CPUC-jurisdictional LSEs, notably the non-CAISO POUs.[11] In other words, there is 1,808 MW – 108 MW = 1,700 MW of in-state geothermal resource potential for development to meet the requirements of CPUC-jurisdictional LSEs. Similarly, there is 2,128 MW – 108 MW = 2,020 MW available to those LSEs in the combined California and Nevada region. As noted above, this is not consistent with LADWP's recent IRPs, which identify 450 MW or more of new geothermal for potential contracts over this period (LADWP 2016, 2017); hence, this may be an over-estimate of the remaining geothermal capacity for CPUC-jurisdictional LSEs or indicate the need for other adjustments to the modeling.

Table 3 – Regional geothermal capacity factor and resource potential defaults in the RESOLVE model, 2018

			Resource potential (MW)		
Region		**Capacity factor**	**Resource potential with existing transmission**	**Resource potential with new transmission**	**Total**
In-state	Greater Imperial	88%	1,384	-	1,384
	Northern California	80%	424	-	424
Out-of-state	Pacific Northwest	84%	-	832	832
	Southern Nevada	80%	320	-	320

Sources: RESOLVE Documentation: CPUC 2017 IRP Inputs & Assumptions (DRAFT), July 2017, Tables 20 and 21.

4.2 Geothermal costs

The geothermal costs used in the CPUC IRP proceeding to date were developed for RPS planning purposes over the previous several years.

Table 4 summarizes the default geothermal installed costs and capacity factors within the model by region; note that the model assumes that these costs are not subject to any reductions in the period modeled (that is, the costs are the same in each modeled interval from 2018-2030).[12]

Table 4 – Regional geothermal installed cost defaults in the RESOLVE model, 2018

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[11] This number is extracted from the 2018 version of the RESOLVE model, and is also discussed in E3 (2017), pgs. 22 and 32.

[12] Within the downloaded version of the 2018 RESOLVE User Interface model, the "generic" installed cost of geothermal is $5,063/kW, as found in the tab "COSTS_Resource_Char," cell L22.

Region	**Capacity factor**	**Installed cost, 2018-2030**
Greater Imperial	88%	$5,349
Northern California	80%	$5,011
Pacific Northwest	84%	$4,952
Southern Nevada	80%	$6,259

Source: RESOLVE Documentation: CPUC 2017 IRP Inputs & Assumptions (DRAFT), July 2017, Table 21.

These assumed costs are not consistent with recent geothermal project costs. In 2017, Ormat Technologies disclosed that its average geothermal installed cost range is between $4,000/kW - $4,500/kW. Within the RESOLVE model, the $4,500/kW installed cost is converted into levelized costs of energy of between $82.00 - $85.22/MWh, depending on location, while the $4,000/kW installed cost results in levelized costs of energy of between $76.22 - $79.57/MWh. On June 1, 2017, the Los Angeles Department of Water and Power (LADWP) announced it had entered into a new, 26-year power sales agreement for approximately 150 MW of power to be generated by a portfolio of new and existing binary geothermal power plants. The portfolio PPA contract capacity is 150 MW, with a minimum capacity of 135 MW and maximum potential capacity of 185 MW. The portfolio PPA is for a term of approximately 26 years, expiring on December 31, 2043, and has a fixed price of $75.50/MWh.[13]

In 2017, Ormat conveyed this cost information to the CPUC and conducted sensitivities using RESOLVE on the lower costs (Ormat 2017), but the 2018 updated assumptions in the RESOLVE tool do not modify this assumption. Nevertheless, as discussed in Section 5, other assumptions adjusted in the model have driven a significant increase in geothermal selection, and additional lower cost sensitivities lead to even higher geothermal selection.

4.3 Other key assumptions

As geothermal is primarily competing with solar PV and lithium-ion battery storage in the model, largely as a function of the costs of those resources, we briefly note what those assumed costs are. For each technology, the CPUC has used "Low," "Mid," and "High" cost cases, which are shown in the matrix below. For ease of reference, we include these factors here, as many of the scenarios we model in Section 6 utilize the full range of solar and storage cost cases against each of our geothermal cost cases.

There are ten in-state zones for utility-scale PV and four out-of-state zones. PV costs are denominated in 2016 dollars ($), and in the "High" cost case, in-state costs range from $45/MWh (utility-scale) to $104/MWh (distributed) in 2018 (E3, 2017, pg. 36). Out-of-state, utility-scale PV costs are slightly lower, as little as $39/MWh in 2018. The "Mid cost range utilizes the multipliers shown in the matrix below to reduce the base cost by 2% in 2018 and an increasing amount after that; the RSP scenario uses the "Mid" costs.

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[13] See https://www.publicpower.org/periodical/article/ladwp-enters-agreement-150-mw-geothermal-project

The “Low” PV cost scenario assumes further cost reductions in each modeling interval, although they do not get as low as the most recent solar PPAs signed in Nevada, which are in the range of $25/MWh.

RESOLVE Scenario Setting	**2018**	**2022**	**2026**	**2030**
High	100%	100%	100%	100%
Mid	98%	94%	91%	87%
Low	88%	77%	72%	68%

For lithium-ion batteries, the cost cases are shown in the following matrix:

Cost Component	**Case**	**2018**	**2022**	**2026**	**2030**
Capital Cost – Power ($/kW)	Low	$345	$225	$175	$164
	Mid	$485	$343	$280	$265
	High	$637	$487	$416	$399
Capital Cost – Energy ($/kWh)	Low	$290	$189	$147	$137
	Mid	$523	$370	$302	$286
	High	$777	$594	$508	$487

Ormat believes that the "Low" cost case is lower than commercially available for the periods in the table but did not modify as it is the CPUC assumption.

In this paper, we conduct sensitivities on geothermal costs against all of these solar PV and lithium-ion battery cost cases, leading to 27 different simulated cases in each of the scenarios we test (3 different geothermal costs, each modeled against all nine combinations of solar PV and battery costs).

5. Geothermal selection in the CPUC IRP scenarios and sensitivity analysis

As noted above, RESOLVE selects all resources by creating a supply stack based on the LCOEs of each resource to minimize total resource costs needed to meet load and reserve requirements and subject to the constraints in the model. For geothermal, each resource is modeled as a flat block or baseload resource.

5.1 Baseline results in the CPUC scenarios

Table 5, based on a table from a CPUC presentation, summarizes key results from the RESOLVE model under different scenarios, including the 2017 version of the 42 MMT scenario, the 2018 version of the 42 MMT scenario, and the 2017 version of the 30 MMT scenario. These scenario results are under the baseline assumptions in the model, which we modify in the subsequent tables. The shaded row labeled "Geothermal" shows that in the 2017 42 MMT scenario, the model only selected 202 MW of new geothermal by 2030; in response, Ormat conducted the cost sensitivity analysis shown below. However, the subsequent 2018 42 MMT scenario, which was accepted as the RSP, selected 1,700 MW of new geothermal, and it selected 2,020 MW of new geothermal in the 2017 30 MMT reference scenario. These two latter scenarios are the basis for the analysis which follows.

5.2 Sensitivity on geothermal, solar and battery costs in the CPUC 2018 42 MMT scenarios

This section shows results of additional sensitivities conducted with RESOLVE on the CPUC's 2018 42 MMT scenario.

In addition to geothermal costs, geothermal expansion in RESOLVE is also highly sensitive to assumed future solar and lithium-ion battery costs. While Ormat is also a developer of projects which utilize these technologies,[14,15] when evaluating geothermal, it is important for utilities to be able to form reasonable expectations about future costs of these alternative technologies given international trade issues and other possible competing uses (e.g., transportation) which could constrain supply.

Table 5 – Comparison of key results by scenario

Category	Metric	Unit	42 MMT Reference – 2030 (2017 proceeding)	Reference System Plan 42 MMT Reference Updated – 2030 (2018 proceeding)	30 MMT Reference – 2030 (2017 proceeding)
Load Forecast	Net Energy for Load	*GWh*	242,474	255,038	242,474
	Behind The Meter PV	*MW*	15,941	19,992	15,941
Selected (New) Resources	Geothermal	*MW*	202	1,700	2,020
	Wind	*MW*	1,145	1,670	4,775
	Solar	*MW*	8,828	7,122	11,121
	Battery Storage	*MW*	1,992	2,219	3,792
	Pumped Storage	*MW*	0	0	1,209
Cost	Total Resource Cost	*$MM*	$46,394	$47,619	$48,098
	GHG Shadow Price + Cap & Trade	*$/tCO2*	$150	$194	$254
PRM	1-in-2 Peak Load	*MW*	45,624	50,778	45,624
	Actual Reserve Margin	*%*	31%	22%	42%

Sources: RESOLVE results and CPUC presentations

Ormat has tested these results over several months. First, we demonstrated that in the 2017 42 MMT scenario, sensitivities on costs of new geothermal resources measured against different solar and battery costs demonstrated significantly higher selection of geothermal resources. These initial results are shown graphically in Figure 2 (below on pg. 17).

Table 6 shows the same range of sensitivities on assumed cost of new geothermal resources along with sensitivities on solar and battery costs in the 2018 42 MMT scenario. The key capacity expansion numbers in the table are reflective of the resource potential as shown in Section 5. In

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[14] See http://investor.ormat.com/File/Index?KeyFile=22888659.

[15] See https://viridityenergy.com/.

that section, 1,700 MW is the maximum in-state resource potential available in the model to CPUC-jurisdictional utilities. Beyond that level, the model has to access what it sees as higher cost, lower capacity factor geothermal in Nevada. The 2,020 MW number includes all geothermal within California and Nevada included in the model. However, in none of these cases does the model build transmission to access geothermal in the Pacific Northwest.

These results suggest a few conclusions. First, as shown in the table, the 2018 CPUC IRP assumptions show that in all but the very lowest forecasts of solar PV and battery costs (LS, LB), the model builds significant new geothermal capacity. This is important because in utility procurement, new geothermal is often competing with declining cost forecasts for these alternative resources. The model confirms that when all other factors are taken into consideration, there is still geothermal selection.

Table 6 - Sensitivity of new geothermal capacity (MW) results in the 2018 42 MMT Reference Case to changes in geothermal, solar and battery costs

Geothermal avg. LCOE in model	**Geothermal resource capacity (MW) in 2030**								
	Solar and Battery cost scenarios ***H – High, M – Mid, L – Low, S – Solar, B – Battery***								
	HS, HB	HS, MB	HS, LB	MS, HB	MS, MB	MS, LB	LS, HB	LS, MB	LS, LB
$86.56/MWh	1,700	1,700	1,269	1,700	1,700	303	1,700	1,618	0
$82.00/MWh	2,020	2,020	1,700	2,020	2,020	1,700	1,700	1,700	0
$76.22/MWh	2,020	2,020	1,767	2,020	2,020	1,700	2,020	1,716	424

5.2.1 Impact of additional geothermal resource potential in the 42 MMT scenario

As noted above, the CPUC has utilized earlier assessments by Black & Veatch to determine the geothermal resource potential in each region modeled. While Ormat does not have alternative estimates to propose at this time, there is clearly more resource potential available at different costs, and if California expands its procurement of geothermal, a larger potential resource could be tapped at lower cost. To test the *economic potential* if the resource potential could be increased at different comparative resource costs, we allowed the model to access unlimited geothermal resource potential (at the same resource costs) and re-ran the cases. As shown in Table 7, as expected, the model builds more geothermal in almost every case. We note that these results are indicative; if this level of geothermal expansion were considered desirable, we need additional research given that the actual geothermal supply curve in the region will be more differentiated by cost than we were able to represent using this model without significant modification. But the results demonstrate that geothermal could, in principle, serve an even greater proportion of California renewable resource needs than currently shown in RESOLVE.

5.2.2 Impact of geothermal selection on renewable curtailment

Prior high RPS studies of California have found that when a high solar portfolio is diversified to include other resources and less solar, the overall quantity of renewable energy curtailment can decline (e.g., Brinkman et al, 2016) In our testing of RESOLVE, we found that as geothermal is added to the portfolio through cost reductions, largely substituting for solar, there is some degree of corresponding reduction in curtailed energy. However, this result is more significant in scenarios in which there are large changes in the quantity of geothermal; in the 2018 42 MMT scenario, as shown above, the model selects most of the available geothermal in all scenarios and hence there is little impact on curtailment between sensitivities. When we removed all the geothermal from the 2018 42 MMT, as described in more detail in Section 6.4 below, and then added it back in at the costs and results shown in Table 5, we found that the curtailment rate in 2030 was reduced from 6.9% to 5.9% of total annual energy, a change of about 1,200 GWh of energy per year. This is because the model largely only builds solar and batteries to substitute for geothermal and this leads to the higher curtailment rate.

Table 7 - Sensitivity of new geothermal capacity (MW) results in the 2018 42 MMT Reference Case with unlimited geothermal resource potential to changes in geothermal, solar and battery costs

Geothermal avg. LCOE in model	Geothermal resource capacity (MW) in 2030								
	<u>Solar and Battery cost scenarios</u> ***H – High, M – Mid, L – Low, S – Solar, B – Battery***								
	HS, HB	HS, MB	HS, LB	MS, HB	MS, MB	MS, LB	LS, HB	LS, MB	LS, LB
$86.56/MWh	2,885	2,713	1,994	2,690	2,593	303	2,360	1,886	0
$82.00/MWh	3,163	2,880	2,464	3,044	2,764	2,319	2,791	2,438	0
$76.22/MWh	3,592	3,213	2,869	3,255	2,985	2,704	3,000	2,738	1,567

5.3 Sensitivity on geothermal, solar and battery costs in the CPUC 30 MMT scenarios

Based on prior renewable integration studies, we anticipate that additional geothermal resources will be selected as renewable penetration increases beyond the levels modeled in the 42 MMT scenario. This is primarily because the curtailment rates of marginal solar PV resources will continue to increase, requiring either significant mitigating measures (notably, shifts in retail load and substantially greater energy storage capacity) or substitution by other resources, such as wind and geothermal. The comparative economic value of geothermal has been shown previously to increase under such scenarios (e.g., Mills and Wiser, 2012). The CPUC included several lower greenhouse gas emissions scenarios with the 2017 version of RESOLVE, including a 30 MMT scenario which has an effective 75% RPS in 2030.

As the 30 MMT scenario was not updated in the CPUC 2018 release on assumptions and scenarios, to test our hypothesis we had to start with the prior 2017 version of this scenario.[16] Table 8 shows that the model builds 2,020 MW of geothermal by 2030 under CPUC Reference case assumptions

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[16] As observed above, the 2018 42 MMT scenario includes a number of updated assumptions which in themselves lead to higher geothermal selection when compared to the 2017 version of the same scenario, and presumably the 30 MMT scenario will show this effect when updated.

under almost all cost sensitivities, and unlike the 42 MMT cases we tested (Table 6), the minimum build, in this case, is 424 MW under the lowest CPUC forecasts for solar and battery costs.

Since the 2,020 MW result is simply the maximum available geothermal in the California and Nevada regions, we also repeated the "economic potential" sensitivities described in the prior section. Table 9 shows that, without the resource potential constraint, the model finds a significant increase in economic potential compared to the 42 MMT scenario, now selecting 5-6 GW of new geothermal in the MS, MB cases. This outcome appears to confirm that geothermal comparative benefits will increase substantially over coming years, even when competing with declining cost solar PV and batteries.

Table 8 - Sensitivity of new geothermal capacity (MW) results in the 30 MMT Reference Case to changes in geothermal, solar and battery costs

Geothermal avg.LCOE in model	**Geothermal resource capacity (MW) in 2030**								
	Solar and Battery cost scenarios ***H- High, M – Mid, L – Low, S – Solar, B - Battery***								
	HS, HB	HS, MB	HS, LB	MS, HB	MS, MB	MS, LB	LS, HB	LS, MB	LS, LB
$86.56/MWh	2020	2020	1700	2020	2020	1700	2020	2020	424
$82.00/MWh	2020	2020	2020	2020	2020	1700	2020	2020	1626
$76.22/MWh	2020	2020	2020	2020	2020	2020	2020	2020	1700

Table 9 - Sensitivity of new geothermal capacity (MW) results in the 2017 30 MMT Reference Case with unlimited geothermal resource potential to changes in geothermal, solar and battery costs

Geothermal avg.LCOE in model	**Geothermal resource capacity (MW) in 2030**								
	Solar and Battery cost scenarios ***H – High, M – Mid, L – Low, S – Solar, B – Battery***								
	HS, HB	HS, MB	HS, LB	MS, HB	MS, MB	MS, LB	LS, HB	LS, MB	LS, LB
$86.56/MWh	5627	5321	3537	5467	5154	3153	5060	4859	1119
$82.00/MWh	5941	5576	4029	5727	5446	3820	5318	4999	2180
$76.22/MWh	6400	6115	5284	6163	5965	4699	5838	5462	3635

5.4 Impact of geothermal availability on composition of renewable portfolio and costs

Geothermal can displace other resources on a cost basis, but this displacement may also have physical impacts in that the geothermal production profile allows for less installed capacity of other resources and hence lower spatial requirements.

In this sensitivity, we removed the *potential* geothermal resource entirely from the model supply function (baseline geothermal resources were left in) and examined the attributes and costs of the resulting portfolios.[17] This establishes a more accurate method for evaluating the contributions of geothermal when it is priced to be selected in the model.

In the RESOLVE scenarios, geothermal primarily displaces utility-scale solar PV and battery storage from the resource mix. In the case where solar and battery costs are in the “mid” range (MS, MB), when geothermal is priced out of the market, the model builds 9,409 MW of solar PV and 2,996 MW of batteries to compensate for the missing geothermal. When geothermal is added into the model, in the mid- and low- geothermal cost ranges which we modeled, the model builds 2,020 MW of geothermal in both cases, and reduces the quantity of the other resources to 5,619 MW of solar PV and 2,083 MW of batteries. We then divide the solar and battery displaced MW by the added geothermal MW. In the “MS, MB” cost cases, this results in a ratio of each 1 MW of geothermal displacing almost 2 MW of solar and about 0.5 MW of batteries, hence about 2.5 MW of alternative resources.

Figure 1 shows the results of this MW displacement effect for cases where geothermal is priced in the mid-range and low range. The results in the figure are organized from the cases with the highest solar displacement case on the left to those with the lowest on the right; the displaced battery capacity is also shown for each case. In the “low” cost scenarios for solar and batteries, the model builds more of those resources when geothermal is removed, and hence there can be a higher displacement effect when the geothermal is added back in, with the highest displacement being 1 MW of geothermal displacing 4.2 MW of combined solar and battery capacity in the “MS, LB” case.

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[17] This could be done by either removing the geothermal resource potential MW from the model or increasing geothermal cost so that it wasn’t selected. We increased geothermal cost.

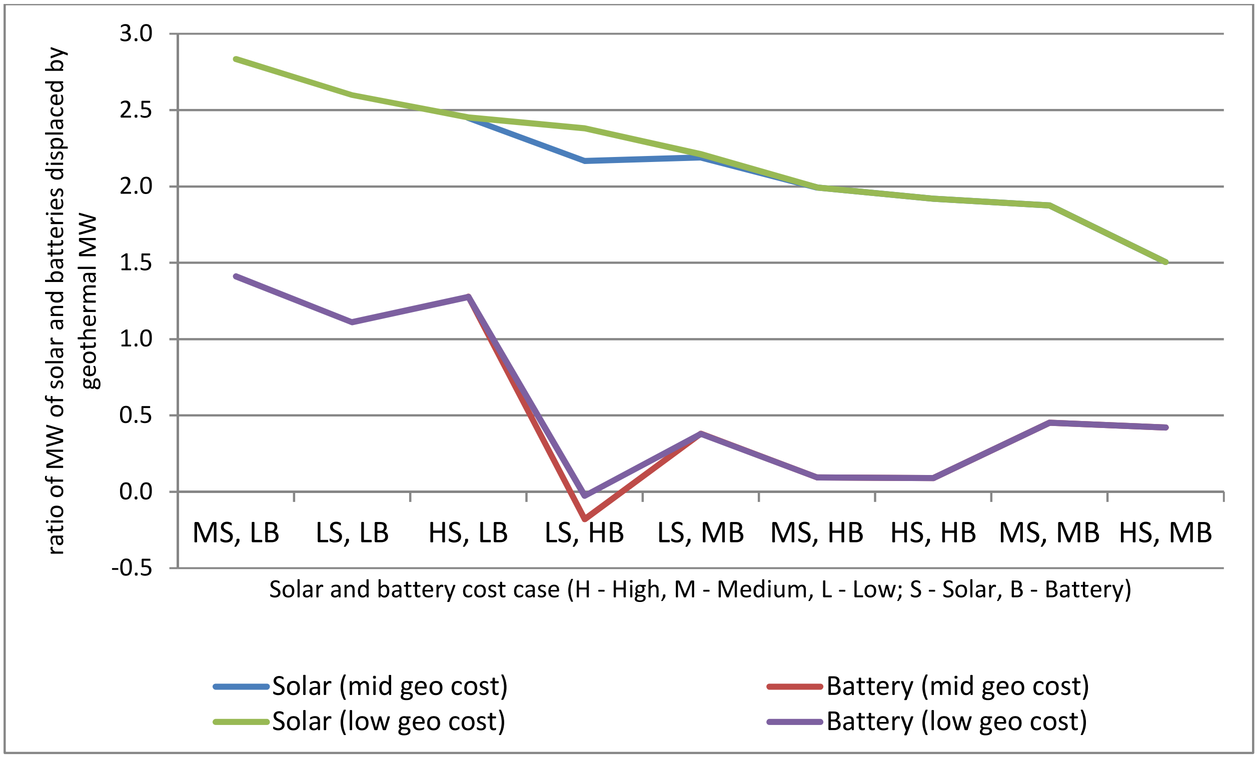

Figure 1 – Displacement of solar PV and lithium-ion battery capacity (MW) by geothermal under different cost cases, 2018 42 MMT scenario

We expected that introducing geothermal into a portfolio comprised primarily of new solar PV and batteries could also reduce total resource costs, simply because of the way geothermal displaces these other resources. The RESOLVE model finds a significant difference. As shown in Table 9, total resource costs in 2030 are reduced by up to $372 million when lower cost geothermal is introduced, and about $200 million at the higher cost geothermal. Again, as noted above, this is an indicative calculation based on all new geothermal resources being at the same cost, which would have to be adjusted in more detailed resource planning. However, it is important that this benefit of geothermal is considered in future IRPs.

Table 9 – Change in total resource costs ($ million) in 2030 when geothermal is added to the portfolio

Average geothermal cost ($/MWh)	Total resource costs in 2030 ($ million)	Difference from no geothermal case ($ million)
No geothermal	$47,168.28	
$86.56/MWh	$46,966.00	$202.27
$82.00/MWh	$46,885.47	$282.80
$76.22/MWh	$46,796.05	$372.22

6. Conclusions and Research Needs

With utilities and policymakers increasingly turning to IRP and related planning methods to establish resource requirements and set directions for utility procurement, geothermal developers must be proactive in analyzing models and ensuring that geothermal resources are appropriately valued both quantitatively and qualitatively. Over the next few years, Ormat and other geothermal companies and trade associations need to demonstrate comprehensive understanding of IRP tools in the relevant regions; as found in the CPUC's IRP proceeding, this will be a multi-year effort, but one which we believe will only continue to highlight the long-term benefits of clean, reliable geothermal resources.

We consider this paper a starting point for both further analysis of the RESOLVE model and for a more comprehensive research agenda on how geothermal is modeled in other resource planning tools and methods. In addition, the CPUC has required that LSEs explain in their 2018 IRP filings how assumptions and tools which they use for IRP reflect differences from what is found in the RESOLVE model. Hence, the preliminary analysis here, as well as any subsequent contributions, could have a material impact on those methods in the future.

6.1 Key results of RESOLVE model assessment

We found that RESOLVE was able to conduct sensitivity analysis with fairly consistent results, and that, after some testing, we were able to modify inputs in ways that led to expected outcomes. However, apart from internal consistency, we did not attempt to validate through other methods or research any of the model assumptions or results.

The first and key finding is that due to both changes in the CPUC assumptions and scenarios between 2017 and 2018, as well as the Ormat sensitivity analysis on new geothermal costs discussed in this paper and across all pre-packaged solar and battery cost cases, RESOLVE shows much greater selection of geothermal in 2030 scenarios.

Changes to the CPUC's RSP assumptions led to significant increases in geothermal selection between the 2017 and 2018 42 MMT scenarios, under "reference case" assumptions, from 202 MW to 1,700 MW. The drivers of higher geothermal selection include, most notably, higher forecasts of load and behind-the-meter PV for 2030. Similarly, additional geothermal is selected in the 2017 30 MMT scenario, of 2020 MW at the reference cost. This shows that additional renewable penetration will increase the potential for geothermal selection.

Second, the use of lower geothermal costs more reflective of recent Ormat geothermal contract prices in the RESOLVE model led to even higher selection of new geothermal resources. In both the 2018 42 MMT and 2017 30 MMT scenarios, lower assumed geothermal costs largely utilized all the geothermal resource potential in the model. Figure 2 shows the selection of geothermal at $76/MWh in the three scenarios; in each case, the additional geothermal selected over the previous scenario is shown (that is, the sum of the segments is the total selected in the scenario with the highest selection). As discussed above, in each case except for the "low solar, low battery" cost case, the full regional potential in California and Nevada is selected.

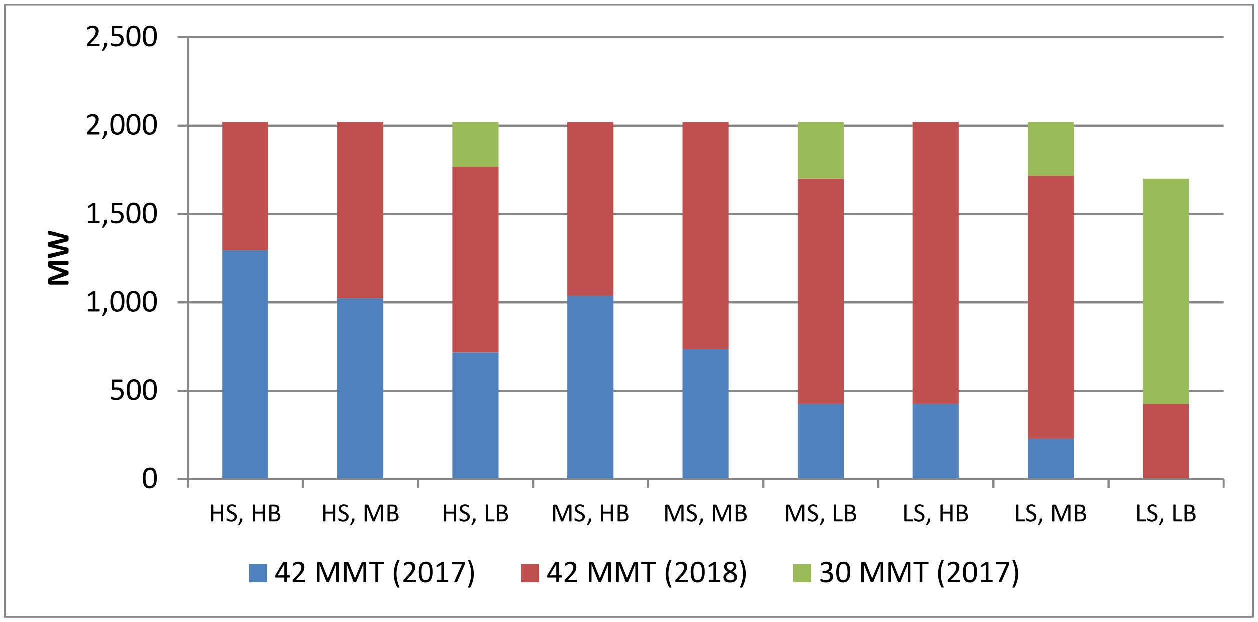

Figure 2 – Comparison of geothermal selection in 3 CPUC scenarios, with geothermal average costs of $76/MWh

Finally, we were able to then determine that if the limits on geothermal resource potential were removed in the model, what we called the "economic potential" at each price point found that between 2.5 GW and about 3 GW of new geothermal were selected in the 42 MMT mid-cost scenarios for PV and lithium-ion batteries, and double that in the 30 MMT scenario. As noted, this type of analysis is indicative, as we did not provide any further information on whether additional low-cost geothermal could be developed.

6.2 General recommendations on IRP and capacity expansion models

Based on our experience with utilizing the RESOLVE model and review of other studies, we have the following general recommendations for the CPUC and all other regulatory agencies and utilities.

First, Ormat recommends that the CPUC and all other regulatory agencies and utilities conduct sensitivity studies on a range of geothermal levelized costs of energy between $75/MWh - $82/MWh for new projects. The impact of these cost sensitivities has been discussed in this paper, showing that they affect the portfolio of resources as well as other factors such as curtailment.

Second, unlike most solar PV plants, geothermal plants have a more significant development time and much greater limitations on locations. Capacity expansion models do not consider any development timelines or risks, and RESOLVE consistently only "builds" geothermal in the last planning period being modeled. For further geothermal development in the West to achieve opportunities for cost reductions, regulators must ensure that the positive results from capacity expansion models are not translated into a "wait and see" until the periods when these models actually deploy geothermal.

Third, while the cost reduction potential for geothermal is not as significant as for PV and lithium-ion batteries, there will be an economies of scale difference in whether the geothermal sector is attempting to develop 200 MW of additional resources or 2 GW. This factor is not examined in current LSE IRPs, and should thus be a strategic planning objective of state agencies.

Fourth, while we modeled all the solar PV and lithium-ion battery cost sensitivities pre-loaded in RESOLVE, these were not exactly reflective of current and forecast project costs. Notably, there are recent solar PV projects which are lower cost than the RESOLVE "low cost" assumptions, but the RESOLVE low battery costs are lower than current market results. These factors can make stakeholder analysis using RESOLVE problematic for third-party users.

Finally, we note that in this preliminary assessment, we did not consider a range of other operational factors which could benefit geothermal, such as inadequate representation of the true operational requirements associated with integration of variable energy resources at very high penetrations. These factors should be investigated in further research.

6.3 Additional California IRP planning assumptions

In addition to the general recommendations above, Ormat offers the following suggestions for the CPUC and other California entities conducting IRPs.

6.3.1 Coordination of state IRPs

The CPUC should evaluate the comprehensive forecast of California utilities for geothermal procurement; as we have observed, the CPUC currently assumes that only 108 MW of new geothermal resources will be allocated to non-CAISO POUs, whereas LADWP alone forecasts around four times that capacity in its most recent IRPs.

6.3.2 Technology and resource diversity

Technology and resource diversity are qualitative metrics for resource portfolio development, intended to ensure that California and neighboring power systems do not become reliant on a small number of renewable and storage technologies which could be vulnerable to climatic changes, lower capacity ratings than forecast, technology risks such as more rapid operating efficiency decreases, high land use requirements, and so on. The CPUC requires that LSEs address resource diversity in their proposed renewable resource procurement plans.[18] RESOLVE does not include any constraints intended to ensure technology diversity, and hence, as shown, under sufficiently low solar PV and lithium-ion battery cost assumptions, *these are the only two resources* built in the model. Ormat does not have any further specific recommendations on how to include technology and resource diversity, but suggests that further consideration of these metrics is required to support geothermal development.

Finally, with the submission of the California LSE 2018 IRPs underway and forthcoming, there will be opportunity for futher comparative analysis of model finding on geothermal selection. This should be a key focus of the geothermal sector and other energy analysts.

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[18] See, e.g., utility RPS procurement protocols and CPUC RPS orders linked here: http://cpuc.ca.gov/Utility_Scale_RFO/.

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