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Estimating Project LCOE – an Analysis of Geothermal PPA Data

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ABSTRACT

The geothermal power industry (globally) faces the challenge of not having access to quality economic data. With the current effort to implement more renewable energy in the United States and abroad, policy makers need dependable data to make informed energy decisions. Levelized cost of energy (LCOE) is a common metric used when considering energy solutions. However, because of the unique relationship of surface and subsurface variables required to make each geothermal project economically viable, it is difficult to estimate the cost of installing new projects. The best known pricing data is in the form of power purchase agreements (PPAs) between geothermal companies and public power providers; PPAs outline an initial purchase price, a price escalation rate, the duration of the agreement, and capacity of energy purchased. This paper presents an analysis that can estimate a range of LCOE values for existing geothermal power plants based upon both publicly available information and direct industry data for individual PPAs. This economic data was collected from a variety of primary, secondary, and tertiary sources. The applied basis for this analysis is borrowed from the National Renewable Energy Laboratory's (NREL's) System Advisory Model (SAM) that establishes a direct and calculable relationship between a known PPA and the subsequent LCOE estimate. The formula equates the LCOE of a project by dividing the sum of annual discounted income, found in the PPA, by the sum of annual discounted energy output. As reported, the formula was intended to find a minimum PPA that would cover a known LCOE and balance the project economics. Using the same quantitative theory as used in NREL's SAM, this analysis assumes that the average lifetime PPA price is only equal to the project LCOE when a profit margin is built into the calculation delta. The goal of this analysis is to provide an alternate method of estimating LCOE for decision makers and to validate cost calculation in conjunction with traditional methods of LCOE analysis such as the Geothermal Electric Technology Evaluation Model (GETEM) used by the Department of Energy (DOE).

1. INTRODUCTION

The geothermal sector, like many other energy technologies, values data and analytics in assessing the performance of the industry in general. Unlike many other energy technologies, the scale of geothermal project development and the frequency of successful projects creates a very limited data pool to analyze. As a result, the sector has approached costs over time in one of two distinct ways: 1) model the theoretical yields of a power plant over time or 2) use publicly available data to ascertain trends and behaviors. This study is intended to be a dualistic approach, harnessing publicly available information to model trends using a theoretical techno-economic tool for LCOE, and then validate the accuracy using the DOE's GETEM. The latter is a direct result of years of federal investment in structured testing of power plant dynamics under defined conditions.

2. METHODS AND PROCEEDURES

In order to implement the model discussed in this paper and estimate LCOE, PPA data for geothermal power plants in the United States was collected from primary, secondary, and tertiary sources of information. The crucial metrics used in the analysis are the initial PPA price, an escalation rate (if one exists), the net capacity of the geothermal facility, and the duration of the agreement. The duration of the agreement is likely much less than the expected lifetime of the power plant. Online searches of websites from both private companies and independent geothermal interest groups provided the bulk of the data that was collected. A typical search for "PPA contract" or "PPA news" at one of these sites would often lead to a link to a press release about a recently signed PPA. The Ormat Technologies website, for example, provides regular press releases about company projects that usually report the desired PPA information whenever the company signs a new PPA. In total, this study found useful PPA data on 24 geothermal facilities. Other public documents include annual reports or filings with the Securities and Exchange Commission (SEC).

The LCOE is defined as the total discounted lifetime cost of an energy project divided by the total discounted amount of energy it either produces or saves in its lifetime (Short et. al. 1995). The importance of the LCOE as a metric comes from its ability to simplify the complex and diverse variables among multiple forms of energy production and energy efficiency in order to make them comparable to each other in a rudimentary way. The basis for estimating the LCOE of the geothermal facilities described in this paper is derived from NREL's SAM (Gelman 2013). The intended purpose of the SAM is to provide a potential energy seller with a way to estimate the minimum PPA price needed to cover a known LCOE for his or her facility. In this analysis, the objective is to estimate the LCOE using the known PPA information that has been collected. With the PPA data, it is possible to predict the total income over the life of the project and the total energy output of the project. With these two values, an income per megawatt-hour ($/MWh) value can be stated for any given project, whether geothermal or another means of energy production. Understanding that these power-supplying businesses are looking to do more than just cover costs, the $/MWh value that is derived from the PPA data has a profit margin and subsidies built into it. By comparing the expected $/MWh to a range of profit margins, it is possible to establish a curve of potential LCOE values from which to select. This allows users of the model to narrow down the range of LCOE values based upon aggregated profit data for many of the listed companies. Subsequent sections discuss the findings of this approach in more detail.

This study will take account of publicly available data on PPAs specifically for geothermal projects in the United States. Contractually, a PPA represents the revenue expected from power plant operations over a given period of time, usually between 10 and 20 years. Using a discounted cash flow method, the PPA is reduced to an average per unit value, and accounts for contract terms such as escalation rates and seasonal adjustments. The average PPA price is simply then taken from those annual values for the term of the contract. Furthermore, to ensure that a direct comparison could be made with the LCOE, the authors also calculated the discounted average revenue/unit for each data point to note any differences between the average and the levelized values. In these examples, the only differences were noted in the plants with annual variations due to escalation rates or seasonal terms. The levelized revenue value is based upon a price for one unit of power, megawatt-hour (MWh), for each year, and thus, does not need to reflect any effects from capacity and/or availability factors at each plant.

Detail to this point is merely to set up the point for which the LCOE is estimated. Specially, the authors found that solar photovoltaic (PV) analysis has already made a connection between a levelized revenue per unit value and LCOE, as shown in Equation 1. A direct, although not always linear, relationship can be established between the levelized PPA price and the LCOE for the power plant during the same timeframe. Where Q is energy in kilowatt-hour (kWh), P is PPA price in income per kilowatt-hour (\$/kWh), n is year, N is analysis period in years, and d is annual discount rate.

I. $$Levelized\ Revenue = \frac{\sum_{n=1}^{N} \frac{Pn*Qn}{(1+d)^n}}{\sum_{n=1}^{N} \frac{Qn}{(1+d)^n}};$$

II. $$Levelized\ Revenue = Levelized\ Cost;$$

III. $$Levelized\ Cost = \frac{\sum_{n=1}^{N} \frac{Pn*Qn}{(1+d)^n}}{\sum_{n=1}^{N} \frac{Qn}{(1+d)^n}}.$$

Equation 1: SAM LCOE Formula (Gelman 2013)

In the equations above, the relationship between levelized revenue is a function of the PPA. By equating the levelized revenue (\$/MWh) to the levelized cost, the assumption in the SAM model is that this price now becomes the minimum breakeven price for the project. The authors contend that, in reality, there is a need for those stakeholders incurring the development cost to also include overhead and profit in order to make cost and revenue directly comparable. By doing so, the financial incentive improves and helps to fundamentally mitigate project risk and secure capital. Alternatively, the authors put forward an alternative equation to include a per unit profit margin. The value definitions remain the same; profit margin (PM) is written as a percentage. Neither formulas include financial subsidies.

$$\frac{Levelized\ Cost}{(1-PM)} = \frac{\sum_{n=1}^{N} \frac{P_n * Q_n}{(1+d)^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1+d)^n}}$$

Equation 2: Modified LCOE Formula

2.1 Data Sources and Collection

Table 1 provides a list of each of the data points used in the analysis. This list does not reflect every known PPA contract collected in the study, but given some incomplete data sets, it is a list of those that are complete. In order for a data point to be used, it is important to know the following: initial price, escalation rate, seasonal conditions, term length, capacity, and date of service. Data was further parsed by state to identify variations by location. Off-taker categorization is also possible, however, the latter is not included in this writing.

Select data points did need to be assessed further and distributed by plant. This was the case with the contract between Southern California Edison and Terra-Gen at Coso Clean Power I and II. The former consists of both the Navy I and Navy II facilities, while the latter represents solely the U.S. Department of the Interior's Bureau of Land Management (BLM) property. Looking just at the Navy properties, the price is consistent annually at \$90/MWh over a 20-year term (Terra-Gen 2015). By separating the net plant capacities to 81 megawatts (MW) and 83MW (U.S. Energy Information Administration 2016), respectively, the authors also found that the in-service dates for each property varied. Navy II began producing power under contract in January 2010, and Navy I began the following year. This difference does impact the valuation and later analysis, albeit only in a superficial manner.

In Figure 1, the states provide the initial PPA price. Note that California and Nevada both have multiple examples while each of the other states provides only one. Thus, assessing the distribution by state is subject only to California and Nevada. Beginning with Nevada, the distribution of values is reasonably consistent with the average falling at \$74.41/MWh. California, however, is less evenly distributed with a key outlier being identified as the PPA contract between Southern California Edison and Calpine Corporation for power at The Geysers at \$17.76/MWh (Southern California Edison 2011). This is an extremely low contract price by comparison, which is shown by the average California PPA contract starting at \$75.10/MWh. Other states do vary, with the highest values being represented in New Mexico and the lowest in Idaho. Raft River in Idaho, however, does have one of the highest annual escalation rates at 2.1% allowing revenues to start low and grow faster annually.

Power Purchaser	Company	Plant	Location (State)	Initial Price $/MWh	Escalation Rate	Length (Years)	Capacity Delivered (MW)	Contract Date Signed	Start Year
NV Energy	Ormat Technologies	Galena 1	Nevada	$ 58.83	1.0%	20	17.15	NA	2006
NV Energy	Ormat Technologies	Desert Peak 2	Nevada	$ 49.50	0.0%	20	8.41	2007	2007
NV Energy	Ormat Technologies	Galena 2	Nevada	$ 47.50	0.0%	20	5.29	NA	2007
Southern California Edison	Calpine	Geysers	California	$ 17.76	0.0%	10	225	11/16/2007	2007
Pacific Gas and Electric Company	Bottle Rock LLC	Bottle Rock	California	$ 68.50	0.0%	15	17	5/2/2006	2007
Idaho Power Company	U.S. Geothermal	Raft River	Idaho	$ 53.61	2.1%	25	9.61	1/12/2008	2008
Southern California Edison	Ormat Technologies	Heber & Gould 2	California	$ 84.49	1.0%	20	14	NA	2008
Sierra Pacific Power Company	Ormat Technologies	ORNI 14 Galena No.3	Nevada	$ 62.07	1.0%	20	20	2/21/2008	2008
Southern California Edison	Ormat Technologies	ORNI 18 North Brawley	California	$ 85.00	0.0%	20	50	3/13/2008	2009
NV Energy	Baseload Clean Energy Partners	Blue Mountain	Nevada	$ 77.30	1.0%	20	23	8/18/2006	2009
Southern California Edison	Terra Gen	Navy II	California	$ 90.00	0.0%	19	83	5/24/2007	2010
Southern California Edison	Terra Gen	BLM	California	$ 81.76	0.0%	11	74	11/15/2006	2010
Southern California Edison	Terra Gen	Navy I	California	$ 90.00	0.0%	20	81	5/24/2007	2011
NV Energy	Ormat Technologies	Jersey Valley	Nevada	$ 66.16	1.0%	20	10	NA	2012
Idaho Power Company	U.S. Geothermal	Neal Hot Springs	Oregon	$ 96.00	6% 1.33%	25	30	NA	2012
NV Energy	U.S. Geothermal	San Emidio	Nevada	$ 89.37	1.0%	25	8.6	1/3/2012	2012
Public Service Co. of New Mexico	Cyrq Energy	Lightning Dock	New Mexico	$ 97.97	2.8%	20	10	5/2/2012	2013
Salt River Project	Enel Green Power NA	Cove Fort	Utah	$ 79.00	2.0%	20	25	4/23/2012	2013
Southern California Public Power Authority	Ormat Technologies	Don A. Cappbell Phase I	Nevada	$ 99.00	0.0%	20	16.2	4/29/2013	2014
NV Energy	Ormat Technologies	McGinness Hills 1 & 2	Nevada	$ 85.58	1.0%	20	63.7	11/14/2013	2015
Southern California Public Power Authority	Ormat Technologies	Don A. Cappbell Phase II	Nevada	$ 81.30	0.0%	20	19	3/24/2015	2015
Southern California Public Power Authority	Ormat Technologies	Heber 1	California	$ 85.62	0.0%	10	46	9/6/2013	2015
City of Riverside	CalEnergy	Salton Sea	California	$ 72.75	1.5%	26	33	7/1/2013	2016
Southern California Edison	Ormat Technologies	Caithness Dixie Valley	Nevada	$ 101.95	0.0%	12	50	3/13/2008	2018

Table 1. PPA Data[1]

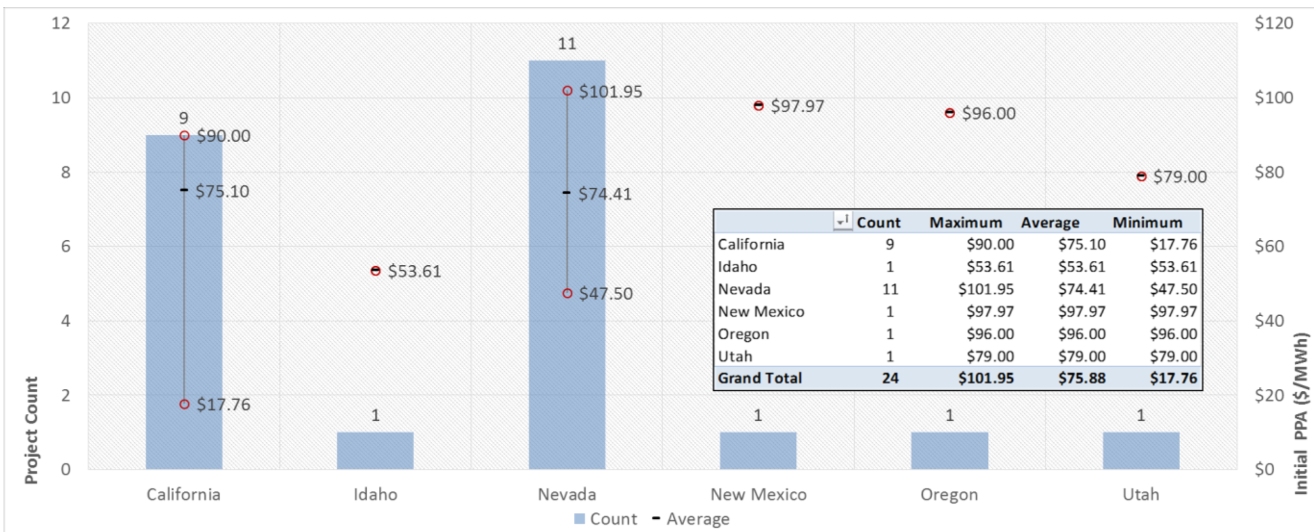

Figure 1. PPA Distribution by State (2006–2015)

2.2 Applied Assumptions

In order to conduct this study, it was necessary to include a series of assumptions. These assumptions are valuable in understanding the nature of available data and the dynamics for which it is usable.

I. Producer Price Index (PPI) is applied against 2006 value for calculating real values, based upon the electric generation category (Bureau of Labor Statistics 2016).
II. Future subsidies and tax credits are not explicitly considered but are assumed to be part of the negotiated contract price and all tax treatments are included.
III. The calculation does not factor in output decline as the impact affects both the revenues and output.
IV. The discount rate is 7% (Ruegg et. al. 2014).

[1] (California Public Utilities Commission 2008)(City of Riverside 2013)(Matek, B. 2015)(Nordquist, J. 2015)(Ormat Technologies Inc. 2015)(Pacific Gas and Electric Company 2007)(Southern California Edison 2011)(US Geothermal LLC 2015)

V. The calculations include only contracts with initial price, escalation rate, contract start date, and capacity.
VI. The publically reported profit margins are used as a proxy for those contracts involving publicly traded companies (e.g., Ormat Technologies Inc., Calpine Corporation, Enel Green Power NA, U.S. Geothermal Inc.).
VII. Gross margin is applied only to Ormat contracts to include both development and equipment sales in returns.

3. ANALYSIS AND FINDINGS

The data, as collected, represents a considerable number of the power contracts placed in service since 2006. Due to completeness of data sets and access, there are some data points that could not be modeled. From those that were, the authors applied a series of adjustments to the data by plant to estimate any resulting trends in the geothermal industry. Remember that these contracts include new build projects, as well as expansions and renewals. The analysis is therefore referenced as "contract additions" and not "capacity additions," which may be common in similar literature.

Each contract value is subject to multiple adjustments. The first of which is to identify a representative profit margin for each plant so as to narrow down the possible outcomes from the distribution curves. For this, the authors assessed the profit margins for all public companies acting as developers within the data set. The list of public companies includes: Ormat Technologies Inc., Calpine Corporation, Enel Green Power NA, and U.S. Geothermal Inc. Several other developers, such as CalEnergy, are subsidiaries of larger parent corporations, but for the purposes here, those associations would not be properly represented in the approach. For each of the public companies, the annually reported "operation margin" was averaged over the terms of the study (i.e., 2006–present) and then applied to each respective project. The only exception to this approach was Ormat Technologies, wherein the authors used the "gross margin" so as to reflect both the developer revenues and the embedded equipment sales. For those private developers on the list, this information is not publicly available, and the value was assumed at 20%. a conservative approach, used to limit the variability between average PPA and estimated LCOE.

Company	*Type (Avg.)*	*%*
Enel Green Power S.p.A.	Operating Margin	43.76
U.S. Geothermal Inc.	Operating Margin	28.98
Calpine Corporation	Operating Margin	15.01
Ormat Technologies Inc.	Gross Margin	33.20

Table 1: Reported Margins – Averages[2]

The second adjustment to the data was to apply a PPI value (normalized) to account for real valuation since 2006. This data was collected from the U.S. Bureau of Labor Statistics specifically on the electric generation annual average (Bureau of Labor Statistics 2016). This provides a more appropriate estimation of the cost trends over time, and it is determined by dividing the index value into the nominal LCOE. The year 2015 is the only year for which projected values are available and used in the average calculation. PPI averages are also not linear in nature and follow ebbs and flows as a result of market fluctuations for each commodity category. As a result, 2014 has the highest indexed value at 149.6, which is only marginally greater than the 145.5 in 2008.

Lastly, each estimated LCOE is weighted by the net capacity of the contract. Larger projects influence the average annual value more than smaller ones. Weighting the average net capacity makes it valuable in the calculations and distributes the value of each project more appropriately. Further distinctions could be made by state; however, the issue then hinges on the number of available data sets. Several states only have one data point. Although not accounted for here, it should not be overlooked that geographic influences on contract price are also subject to commonalities, or differences, among off-takers.

Figure 2 provides this analysis. Beginning with the annual capacity of contract additions, both the total and average are represented to indicate those years in which multiple contracts were initiated and for those that only had one. The LCOE data points, however, are more informative. Following the quantitative methods above the distribution over time can be fit to a fourth-order polynomial curve with an R-squared value of 0.92, which offers a reasonable level of statistical relevance. This curve is not intended to project or estimate future values but to identify the best-fit trend in prices over the given time scale. What is more important to recognize is the shape of the curve. Beginning in 2012, the shape of the curve plateaus and then subsequently begins to decline. The authors believe that there are two explanations for this market behavior: 1) the availability of renewable targeted PPAs, especially in California (Matek and Gawell 2014) and Nevada, are contingent on existing progress towards respective Renewable Portfolio Standards (RPS) and 2) steep decreases in cost for wind and solar PV projects are increasing the competiveness in the existing market for those PPAs (Bloomberg New Energy Finance 2014) (Fulton et. al. 2012). Only those projects that have competitive economics are able to secure contracts as the price is driven down, as is evident in a low cost bidding platform like the one used in California. Given that the only three contracts executed in 2015 include either repowering existing projects (Heber I) or Phase II projects (McGinness Hills II, Don A. Campbell) there is evidence to support such a conclusion. For example, at the same profit margin, the Phase I versus Phase II estimated LCOE for Don A. Campbell shows a 26% decline based on the model used in this study. The resulting trend carries further implications that are not fully expressed in the study.

[2] (GuruFocus 2016)

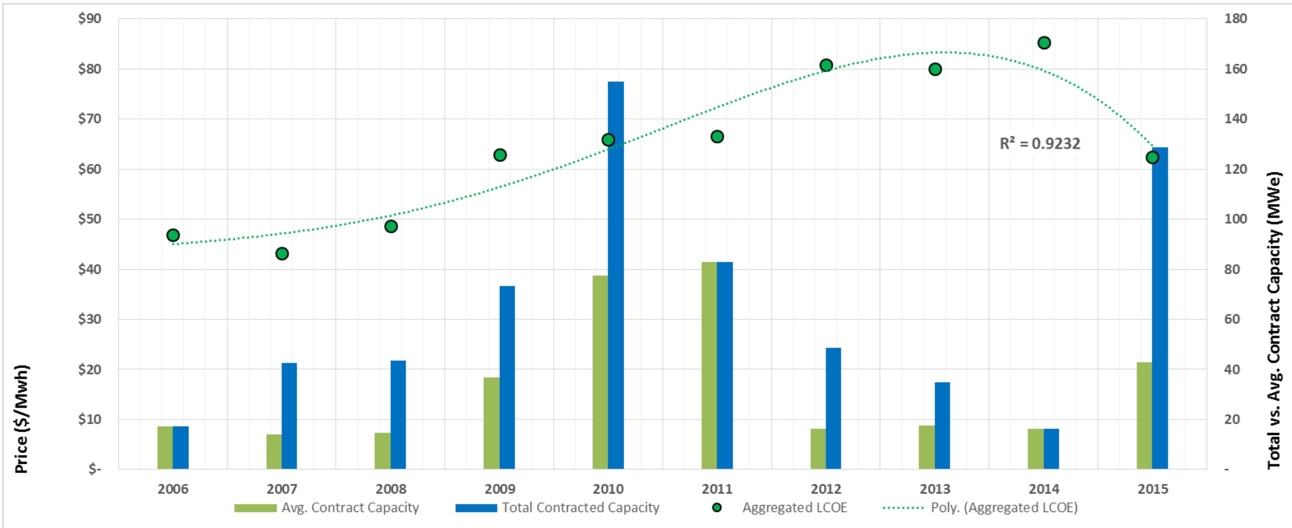

Figure 1. Weighted Average LCOE by Year (2006–2015)

Figure 2 provides the individual distribution of LCOE values given that the y-intercept is the average PPA price under the contract terms. Note that each curve shares a relatively similar shape, which lead the authors to test the curves to a normalization process to achieve the results shown in Figure 3.

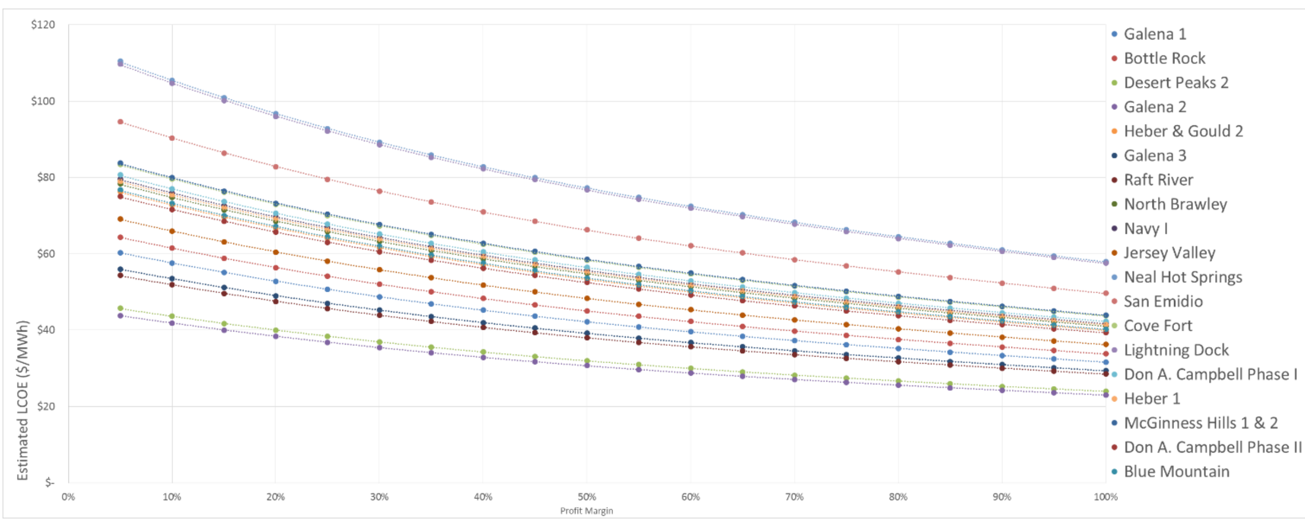

Figure 2. Distribution Curves by Plant

Figure 3, as show below, provides a normalized curve for each of the individual distribution curves by contract. Although each of the contracts begins at a different discounted PPA value (i.e., no profit margin), the rate of change across possible profit margins is the same. The result allows estimation of a respective LCOE once a suitable profit margin has been identified. This curve is represented by a third-order polynomial equation, where the y-intercept equals the index value and x equals the target profit margin (%). To achieve the corresponding LCOE, the resulting value must be multiplied by the levelized PPA price as calculated for each contract.

$$y = -0.209x^3 + 0.639x^2 - 0.9272x + 0.9958$$

Equation 3: Normalized Profit Margin Distribution Curve

The statistical fit of this curve is exceedingly high with an R-squared value of 1.0. The curve also represents a range of profit margins starting at 5% and continuing to 100%, although the probability of being realistic diminishes as the percentage exceeds 50%.

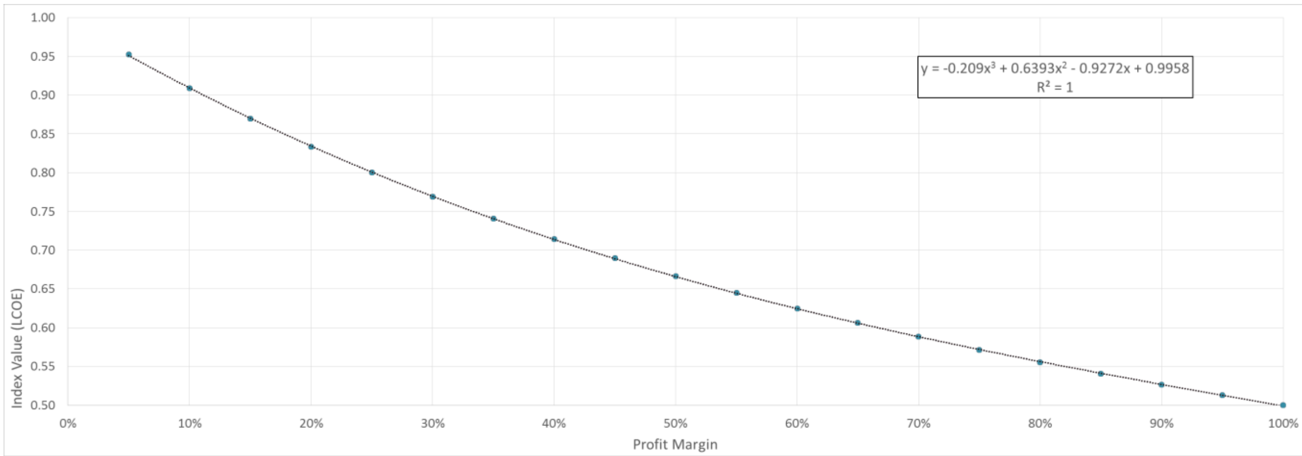

Figure 3: Normalized Distribution Curves by Plant

3.1 GETEM Validation

The secondary purpose of this study is to go beyond the analysis mentioned above and also provide a tool to aid in validating other techno-economic models used by geothermal professionals. Specifically, this tool was used in conjunction with the GETEM to assess the estimation of levelized cost for both the Don A. Campbell I and II plants in Nevada. Greg Mines at Idaho National Laboratory supervised the model runs represented in the data shown in Table 2; they use the latest version of GETEM. The model settings are subject to GETEM defaults and are adjustable for capacity, average resource temperature, and average resource depth for each plant. The recorded reservoir temperature for this field is 267° Farenehit (°F) according to Orenstein et al. (2015) and Orenstein and Delwiche (2014). Resource depth is also referenced in both papers by Orenstein et al.; the papers indicate that while drilling, the shallowest depth with sustained temperatures of 267°F was 200 feet (ft). The deepest point while drilling that encountered circulation loss at the average temperature was 1256 ft. Taking the average of these depths, the GETEM input variable for both plants is 956 ft. A summary of inputs and calculations from GETEM are in Table 2. Note that the profit margin is not calculated in GETEM but is unique to this study.

	Don A. Campbell I	Don A. Campbell II	
LEVELIZED COST OF ELECTRICITY	**80.21**	**63.71**	**$/MWh**
NET POWER SALES	**16,200**	**19,000**	**KW**
Do you wish to evaluate a Hydrothermal or EGS resource?	**Hydrothermal**	**Hydrothermal**	
What is the resource temperature?	267	267	**F**
What is the resource depth?	728.0	728.0	**ft**
Type of Conversion System to be Used?	**Binary**	**Binary**	
Power Sales	**16.2**	**19.0**	**MW**
Exploration	**$7,055,973**	**$23,403**	**overnight costs**
Drilling	**$10,817,482**	**$13,021,156**	**overnight costs**
Field Gathering System & Pumping	**$6,856,820**	**$8,486,602**	**overnight costs**
Reservoir Performance	**4.31**	**5.05**	**production wells required**
Operating & Maintenance	**$2,826,371**	**$2,513,867**	**per year**
Power Plant	**$48,837,619**	**$58,866,592**	**overnight costs**
CALCULATED PROFIT MARGIN	**23.55%**	**27.69%**	

Table 2. GETEM Inputs/Outputs

Reviewing the data collected earlier for the trend analysis, the gross margin for Ormat Technologies as a whole since 2006 ranges from 20.8% to 36.4%, with an annual average of 33.2%. Recognizing that a gross margin includes both operations and equipment sales, and that with each project there is a realistic range above and below the average, the results from GETEM are most certainly within reason at 23.55% and 27.69% based on the author's calculations for Phase I and Phase II respectively. Equation 3 was used to determine the profit margin values.

Although Phase II is larger in size, there are several considerations that must be accounted for given the lower calculated LCOE. First, as a Phase II project, most of the required exploration activities were assumed within Phase I, which significantly reduced the early development cost. Second, in order to meet the output requirements of the larger plant, Phase II did require additional production wells to support the necessary capacity, which also translates into higher power plant costs. Lastly, as was noted in Section 3, the most recent plants to come on line in the U.S. are expansion projects, including Don A. Campbell II. These expansion projects are able to assume some of the existing costs from parent projects making them much more competitive in the market when securing PPAs. As 2015 had three contracts of this nature executed, the downward trend referenced above shows, at least in part, sensitivity to this conclusion.

4. CONCLUSIONS

In conducting this study, the authors had multiple goals in mind. First was to provide a trend analysis of the cost of geothermal power as a function of known PPA terms, and second to provide co-validation of both this analysis and GETEM in modeling the Don A. Campbell I & II plants. Further use of this work should be expanded to refining the actual profit margins for each plant and adding additional contracts as data points. GETEM validation should also not rest solely on two projects but should be expanded to include other data as it is made available. Lastly, as it was not investigated in depth here, there are also implications that result from the findings expressed in Figure 2. If, in fact, the trend is reversing and costs are declining, is this a coincidence of contract timing or is there a market pressure forcing geothermal projects to become even more competitive on price? Further analysis is recommended.

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