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Comparative Analysis of Designing Solar and Geothermal Power Plants: A Case Study

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Abstract- Geothermal and solar thermal are renewable, clean energy sources with immense potential for electricity generation. Concentrating Solar Power can achieve very high temperatures and high efficiencies compared to geothermal power plants. However, it is intermittent and must be coupled with thermal storage or another source for continuous power generation. Geothermal resources exist in varying temperatures but are too small for economic power production; however, it is not intermittent. This paper briefly summarizes the location-specific design considerations for geothermal and solar thermal plants. The performance of both these types of power plants is analysed in terms of capacity factor, thermal energy storage hours, solar multiple, area requirement, and levelized cost of energy for a given set of environmental conditions at two separate locations, Las Cruces, US and Aydin, Turkey. Electricity consumption for an example airport at Aydin is provided by DHMI Airport authority administration, which was used as load profile for Aydin. This analysis is performed using the System Advisor Model. Simulation of parabolic trough, power tower, linear Fresnel, dish Stirling, and geothermal energy conversion systems are performed and the results are compared.

Keywords Concentrating solar power, Geothermal power generation, System Advisor Model, economic analysis, case study.

1. Introduction

By the end of 2013, ~22.1% of the global energy consumption is supplied by renewable energy sources [1]. Concentrating solar power (CSP) was the fastest growing electricity generation technology in the United States in 2013, It was estimated that the cumulative installed capacity increased by 410 MW compared to 2012 [2]. In case of geothermal energy conversion systems, a decrease in instalments occurred in 2013 (85 MW) when compared 148 MW in 2012 [3]. Both these energy sources can use Rankine cycle and allow for 24-hour electricity generation. In addition, thermal storage has also been proposed for CSP during night times and is an active research field [4-8]. Since the temperature of geothermal sources is much lower than CSP, organic fluids are typically employed for use in the Rankine cycle operated on geothermal sources [9-12].

Selecting the right source for power generation at a location depends on many factors. For example, presence of a geothermal well is the main criteria for choosing whether a geothermal power plant can be used at a location. There are many other factors that must be considered when choosing a renewable energy power option at a location. This paper briefly discusses the design requirements for choosing CSP and geothermal power plants for a site location. In the present work, utilization of both these technologies at two different locations; Las Cruces, US and Aydin, Turkey, that have existing energy resources is studied by comparing the economic feasibility using a performance and financial analysis software. Few studies exist in literature that studied the economic feasibility of different renewable options, including geothermal, solar and solar-geothermal hybrid, however, there are no studies that compare geothermal and solar thermal options individually for a site [13-34]. These systems analyzed the effect of design and operational parameters on the different types of CSP and geothermal plants. Ref [13] compared the economics and cost of electricity of the parabolic trough (PT) and linear Fresnel (LF) technologies. Ref. [14] compared both these technologies and found that the optical efficiency of PT technology is more than LF technology. Refs. [15] and [16] studied the suitability of using weighted average incident solar radiation and economic optimization of the solar multiple of a solar only PT plants. In Ref. [8] effect of solar multiple, capacity factor and storage capacity on a direct steam generation plant is studied. Levelized cost of energy (LCOE) analysis of PT, LF and power tower was performed in Ref. [19]. Ref [22] discusses the optimum design when design DNI, solar multiple and thermal storage hours are considered. Ref [23] studied the optimum parameters for PT and LFR power plants for eight different locations in India.

None of the studies analyzed and compared solar only and geothermal only power plants for a location. A conference paper using a condensed form of the same model with limited parameters was submitted by the authors [35]. However, it only analyzed one site location, Las Cruces, NM, USA. The current manuscript discusses the full model with more parameters and an additional site location (Aydin, Turkey), the corresponding new findings, and a site comparison analysis. Factors such as plant capacity, annual energy production, land required, system dimensions and cost are considered while performing the comparative analysis. The economic analysis is performed using the system advisor model (SAM) software [36]. This software allows modeling of detailed hourly energy production at any location and couple it to compute the levelized cost of energy for both the technologies that are being considered. It also allows optimization of thermal energy storage (TES) hours and solar multiple (SM) for CSP plants. In case of CSP plants, all the four power generation technologies, linear Fresnel, parabolic trough, dish Stirling, and power tower were considered and the electricity generation costs were compared. This work is performed to design and compare both the energy sources to facilitate a renewable energy based airport (or an airport that receives electricity generated by only renewable energy source) at Aydin. This airport is a small training facility and, the power plant capacity requirements for this location are smaller (1.1 MW_e to 3 MW_e) compared to typical plant capacities for which solar thermal power plants (~tens to hundreds of MW) are analyzed. Though the location of the airport is in Aydin, Las Cruces was chosen to understand the effect of site location mainly by using the direct normal irradiation (DNI) specific to the site. Based on the analysis, both the sources are compared for the two locations considered. Though the analysis considers only two sites, results from this analysis can be considered while selecting the renewable source at any location.

1.1 Geothermal Power Plants

Geothermal resource technologies utilize the thermal energy from the ground (fluids of different temperatures and forms can be extracted) to generate power. As the heat is directly extracted in the form of hot fluids, these power plants do not require burning of fossil fuels and do not require transportation and storage of fuels. In general, three types of geothermal energy conversion systems exist, direct dry steam (direct steam from the geothermal site is used to run a turbine), flash and double flash (fluid is extracted at around 180 °C – 200 ºC) and binary (where a separate working fluid will be used). Geothermal resources are known to be more favourable in the western part of the United States [29]. During 2013, Geothermal power plants accounted for ~ 530 MW of power around the world. The total installed capacity is ~ 12,000 MW, and indicates an international growth at a stable 4% to 5% per year [3]. Table 1 below shows the main requirements that must be satisfied before choosing a geothermal power generation option at a certain location [38].

Table 1. Geothermal Power Plant Requirements reproduced from Ref. [35]

Geography and topography	"Slope of the site is one of the main factors to be considered. Slope < 8% indicates slight limitation, 8-15% indicates moderate limitation and severe if >15% [38]."
Availability of water	"Should avoid river banks and the surroundings due to flooding potential [38]."
Faults	"Analyze a plane for fractures and faults [39]."
Population	"A 500 m separation of population centers, access roads and lands was used as research parameter by Ref. [38], so these population centers do not affect the GPP."
Road	"An access road in good condition is important."
Anomaly zone	"Since it is economical only if the geothermal fluid is transported by pipelines over short distances, power plant must be located near (~ tens of km) geothermal anomaly zone [38]."
Wells locations	"Selection near well pads must be avoided. A 200 meter radial separation from wells was used by Ref. [38]."
Hot springs	"Hot springs are potential areas for a GPP as it is assumed that the probability of the occurrence of a geothermal resource is higher than that in the surrounding area."

1.2 Concentrating Solar Thermal Power Plants

CSP is variable like wind and photovoltaics; however, they can be coupled with conventional fuels to generate electricity, or with a thermal energy storage (TES) system that can store the heat when sun is available and can provide that heat later to drive a heat engine. From ref. [35], “A typical CSP plant consists of a collector, a receiver/absorber, a storage system (if possible), steam turbine/Stirling engine, generator and steam condenser (if applicable). The types of concentrating solar power systems are, linear Fresnel, parabolic trough, power tower systems, and dish/Stirling engine [5]. Just as geothermal resources, solar resources are known to be more favourable in the western part of the United States [40]. CSP had reached about 918 MW, adding about 410 MW of power during that same year representing an increase in cumulative capacity of 81% by the end of 2013 [2]. CSP systems increased by almost 0.9 GW to make a total of 3.4 GW (36% increase) around the globe in 2013. A record growth of almost 1 GW was reported in 2012 [2]. Table 2 includes key requirements for suitable site selection for a CSP plant and is reproduced from Ref. [35].”

2. Model

The SAM software was used for performing the comparative analysis. This software provides scope to analyze different models of both geothermal and solar thermal power plants.

2.1 Geothermal Power Plant System

SAM software has the capability to model flash and binary conversion plants with hydrothermal resources and also enhanced geothermal systems [47]. To describe the energy available at the site, resource characterization inputs such as resource temperature, depth, distance from injection wells and potential are required by the software. In case of EGS systems, where water is pumped (either as liquid or steam) to collect the heat stored in underground rocks by fracturing the rocks, the cost of new fracturing is included in the software as recapitalization cost. The plant’s performance is done over its lifetime in the software and it is assumed that changes in the resource and electrical output occur monthly over a period of years. In the current work a reservoir lifetime of 25 years was assumed.

2.2 Solar Thermal Power Plant System

The software can model different CSP technologies. In case of parabolic trough, two different models, physical and empirical are available [40, 41]. “The physical trough model uses principles of heat transfer and thermodynamics to characterize the components of the system, instead of empirical measurements as in the empirical trough system model. The physical model suits most system but the empirical model can be accurately used in designs located in the southwestern United States. The physical trough model is more flexible than the empirical trough model, but it adds more uncertainty to performance predictions than the empirical model. Both models use the same set of inputs for location, resource and system costs. Two types of power tower systems, molten salt and direct steam can be modeled in SAM. In the direct steam model, the steam flowing through the tower is both the HTF that transfer energy from the receiver and the working fluid of the power cycle. Also, the direct system is composed of three individual receivers: a boiler, superheater, and reheater; this means additional changes to the control strategy. The molten salt model uses molten salt as the HTF, and steam as the working fluid. The receiver only heats the HTF. The power cycle can use either an evaporative cooling system for wet cooling, or an air-cooled system for dry cooling. The power cycle model for the SAM physical trough model is the same as that used for the power tower model.”

Table 2. "Concentrating Solar Power Requirements: This table summarizes the requirements for a concentrating solar power plant. All the characteristics covered were assumed to be ideal. Dry cooling and non-hybrid power plants were considered.”

Solar resource assessment	“The solar resource should has a minimum Direct Normal Irradiance (DNI) of 5 kWh/m^2/day according to the US DOE [41].”
Availability of water and cooling modes	“For Rankine cycle usage in the design of a CSP plant, water or air is needed for cooling. For wet cooling, CSP plants in California consume 3.4 m^3 of water per MWh of electricity produced [42]. For dry cooling, CSP can deliver approximately 5% less energy than the annual electric energy that wet cooling would (based on a parabolic trough plant located in the Mojave desert [43]).”
Soil structure and geology	“Loose and sandy soils have to be avoided, while local rocks or sands could be used in constructing storage systems, thus reducing costs [44].”
Hybrid thermal plant options	“Hybrid CSP/Diesel thermal plant guaranties continuous production of electricity. Oil deposits availability is needed so this could be implemented. This implementation can avoid the need of building fossil-fired power plants in parallel with 100% CSP to have seasonal and diurnal storage systems [45].”
Land issues	“The area requirements for a parabolic trough CSP is approximately 1 km 2 per 50 MW of electric capacity [46].”
Geography and topography of the CSP site	“Higher altitude leads to higher DNI. Due to the need of big areas, a small land slope of less than 5%, which ideally would be less than 1% for central systems, or up to 10% for distributed generation, is desired [44].”
Energy demand profile and grid connected system	“For transmission cost reduction and lessening power losses, availability of transmission lines (69–345 kV) and access road/rail within 80 km is key criterion [46].”

2.3 Thermal energy storage for CSP

A thermal energy storage system (TES) can be included for three of the four solar thermal technologies. A TES system simply stores heat from the solar field in a storage medium during the periods of solar insolation. "This heat from the storage system can drive the power block during periods of low or no sunlight, which were considered as 16 hours a day for the models presented in this paper (except for the geothermal and dish/Stirling). Collection of solar energy for thermal storage in a CSP system can be separated from the operation of the power block. There are direct and indirect storage systems, and the main difference is that in direct systems, the HTF in the power block serves also as the storage medium. In indirect systems, the storage fluid and the power block fluid are physically separated, and heat will be transferred from the solar field's HTF to the storage fluid through heat exchangers. The thermal storage systems considered in SAM consist of one or more tank pairs, pumps and heat exchangers (if indirect system). For the tank pairs, there is a hot tank and a cold tank. The heat from the solar field is stored in the hot tank, while the cold tank is used to store the storage medium after its usable energy has been extracted by the power block. SAM describes the thermal energy storage system through the system variables, and dispatch control variables are also included to determine the energy dispatch from the storage and from the fossil-fired backup if it is included in the system."

2.4 Levelized Cost of Energy (LCOE)

"LCOE is the total cost (total) of the installation and operation of a power-generating system over its lifetime divided by the total power output of the system over that lifetime. It is expressed in cents per kilowatt-hour of the generated electricity over the system's life. The following parameters are included in SAM to calculate the LCOE [50].

- Installation costs
- Financing costs
- Taxes
- Operation and maintenance costs
- Salvage value
- Incentives
- Quantity of electricity the system generates over its life

SAM calculates the LCOE assuming the power generation projects are installed on the utility side of the consumer power meters where the electricity is sold at a price negotiated by the project and the electricity purchaser. The real and nominal discount rates are applied to calculate the present worth of future costs. The real and nominal LCOEs are calculated as shown in equations (1) and (2):

$$\text{real LCOE} = \frac{\sum_{n=1}^{N} \frac{R_n}{(1+d_{\text{nominal}})^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1+d_{\text{real}})^n}} \quad (1)$$

$$\text{nominal LCOE} = \frac{\sum_{n=1}^{N} \frac{R_n}{(1+d_{\text{nominal}})^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1+d_{\text{nominal}})^n}} \quad (2)$$

where

Q_n (kWh)	Electricity generated by the project in year *n*. This is calculated by the performance model using the weather data and system performance parameters.
N	Analysis period in years.
R_n	Project revenue from electricity sales in year *n*, which is the system's annual electric output multiplied by the annual price purchase agreement (PPA) price.
d_{real}	The real discount rate without inflation.
d_{nominal}	The nominal discount rate with inflation." [35]

3. Input Parameters

A comparative study was performed using SAM to compare the potential of both the geothermal and solar power generation systems for two locations under the same environmental conditions. Different assumptions were made for both locations. Location 1 was used for performing initial parametric study to test the various options in the software and understand the impact of different systems. In the SAM software, weather files can be imported in the Typical Meteorological Year (TMY) format that has hourly values of solar radiation and other parameters for any desired location [49]. This was readily available for Las Cruces. Similarly, the geothermal parameters are also available in SAM for this location. For Aydin, variability and magnitude of solar irradiance, wind, and temperature at the Cildir Airport project site located in Turkey (Latitude: 37.815446_N, Longitude: 27.886678_E) was obtained from 3TIER [51]. The report provides a retrospective analysis of the past 16+ years of solar irradiance, wind, and temperature data. This data was included in a TMY3 file, which was used in SAM to fulfil all the requirements in the Location and Resource portion of the analysis. The parameters used for the analysis for both locations are shown below:

3.1 Location 1: Las Cruces, US

Geothermal Parameters: For analysis of geothermal power plant at Las Cruces, US, the following assumptions were made.

- Binary: Two resource options, EGS and hydrothermal resource.
- Resource temperature: 150 ˚C.
- Resource depth: 2000 m.
- Plant Efficiency: 95%.
- "Temperature decline parameters: Constant at a rate of 3%/year, with a maximum temperature decline of 20 ˚C before the reservoir is replaced. Enables the designer to

determine when and how often the project will require new wells to be drilled.

- Pumping parameters: Flow rate - 70 kg/s per well, pump efficiency - 60%.
- Condenser: Air-cooled.
- Plant capacity: 3 MW_e.
- Distance from the injection to production wells: varied

Solar Parameters:

- Solar Multiple: To compare the different solar field aperture size that it is required to generate the same amount of energy with different systems, solar multiples were varied to find the optimum solar multiple for each CSP technology.
- Thermal storage: 0, 6, 12, and 16 hours, when technology allows it.
- Solar Resource: A weather file can be input directly into the Location and Resource page. The same TMY2 file (for Las Cruces [49]) was used in all technologies to compare them under the same environmental conditions [35]". A reference number was defined using the maximum field collector DNI-cosine product (796 W/m^2) and was used for simulating the solar field.

3.2 Location 2: Aydin, Turkey

The goal of the project under which this work is done is to find the suitable renewable energy option for an airport at Aydin, Turkey. A load profile as shown in Fig. 1 is used, which represents the average hourly energy used by the airport on a single month, August. This load profile is provided as percentage of the maximum peak energy. Two different plant capacities, 1.1 MW_e or 3 MW_e are modeled for analysis at this location, which were estimated to be the requirements for the Aydin airport.

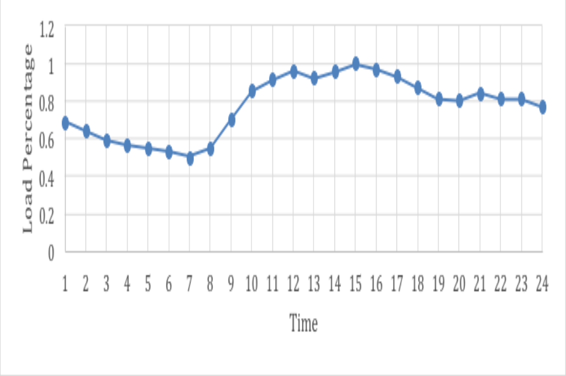

Fig. 1. Load Profile for used for plant design comparison at Aydin

Geothermal Parameters: According to Basel et al. [52], resource in Sultanhisar-Salavatli /Aydin is considered as one of the major geothermal fields in Turkey. This resource data was used for the simulations, along with the same environmental conditions obtained from 3TIER [42]. The assumptions made for location 2 are as follows:

- Temperature decline parameters: 3% per year with a maximum decline of 20 ˚C before the reservoir replacement.
- Pumping parameters: Flow rate - 70 kg/s per well, pump efficiency - 60%.
- Condenser: Air-cooled
- Plant efficiency: 95%.
- Total resource potential: 210 MW
- Resource temperature: 200 ^{0}C
- Resource depth: 2000 m
- Distance from the injection to production wells: 1500 m

Solar Parameters: Solar Resource for Aydin, Turkey: Variability and magnitude of solar irradiance, wind, and temperature at the Cildir Airport project site located in Turkey was obtained from 3TIER [51]. Assumptions such as plant efficiency, solar multiple, TES materials, HTF materials is shown in Table 3. For the solar multiple, the tradeoff between a larger solar field that maximizes the system's electrical output and project revenue, and a smaller field that minimizes installation and operating costs were considered.

Table 3. Assumptions for solar energy conversion system for Aydin

	Parabolic trough	**Power tower**	**Linear fresnel**
Rated cycle conversion efficiency	0.3774	0.412	0.38
Solar multiple	3.1	3.5	2.5
TES	Indirect- two tank - solar salt	Direct - two tank - solar salt	Direct- two tank - Hitec XL
HTF	Therminol VP-1	Solar salt	Hitec XL

4. Results and Discussion

The above-mentioned methodology was used to find the values of LCOE delivered by both the plant types. All the four CSP plants were analyzed at Las Cruces and since thermal storage could not be used for Stirling Dish technology, it was not analyzed for Aydin. Solar multiple and TES hours were varied for all the CSP plants. A summary of typical results and a brief discussion on the same is presented in the following paragraphs:

4.1 System Design for Las Cruces, US

Table 4 shows the results obtained for both the sources in Las Cruces. For CSP technologies, it can be observed that the LCOE for the dish Stirling is the lowest, however, since this technology cannot be coupled with thermal storage (but only battery storage that is less efficient than thermal storage), it was not considered for further analysis. It can be observed from the table that for the same conditions, linear Fresnel and power tower are costlier than parabolic trough.

This implies that for a 24 hour per day operation, parabolic trough is the most suitable technology for this location. Higher installation cost for a lower energy output increases the LCOE for the power tower. It can also be observed that the annual energy production is higher for power tower compared to parabolic trough and linear Fresnel, whereas, the area requirement is also the highest.

Table 4. CSP and Geothermal Results [27]

CSP Technology	TES hours	Solar Multiple	Annual Energy (kW)	LCOE (nominal, ¢/kWh)	Area (acres)
Parabolic Trough	0	1	3,595,013	41.18	20
	6	1.6	5,402,230	34.25	27
	12	2.4	8,037,056	30.49	41
	16	2.4	8,537,237	29.78	41
Power Tower	0	1	3,744,830	69.17	23
	6	3	9,865,414	41.31	82
	12	3	12,769,465	33.24	82
	16	3	14,193,327	30.32	82
Linear Fresnel	0	1	3,832,756	32.39	8
	6	1.8	4,778,967	34.74	13
	12	2.5	6,014,741	34.57	18
	16	2.7	6,400,874	36.14	21
Dish Stirling	na	Na	46,000,000	3.39	56
Geothermal	na	Na	17,100,000	9.17	na

It can also be observed from the table increasing the number of hours of thermal storage and solar multiple aids in drastically decreasing the LCOE for power tower, however, it still seems unsuitable for such small loads even though it has higher thermal efficiency due to higher operating temperatures compared to parabolic and linear Fresnel technologies. It can also be observed from the table that for same solar multiple, increasing the number of thermal storage hours decreases the LCOE and this decrease is higher for power tower. "In terms of land area, a solar multiple (SM) of one represents the solar field aperture area that, when exposed to solar radiation equal to the design radiation value (irradiation at design), generates the quantity of thermal energy required to drive the power block at its rated capacity (3 MW_e), accounting for thermal and optical losses. Under the condition of using a SM = 1, the amount of heat generated rarely drives the power block at its rated capacity because the number of hours in a year that the actual solar resource is equal or more than the design radiation value is small. Increasing the solar multiple (SM>1), results in a solar field that operates at its design point for more hours of the year and generates more electricity, as noted in Table 4. It can also be observed that area requirement under the considered conditions favors the linear Fresnel technology and depending on the requirements could substantiate for its high LCOE."

When compared to the all the solar technologies except for Stirling dish, geothermal power plant seem to have lower LCOE. These results are obtained assuming a geothermal well that is less than 1500m away from the power plant and 2000 m underground. If such resource is available, geothermal option may represent a good investment in Las Cruces. Further analysis was done to estimate the effect of distance between injection and production wells. Table 5 shows the results resource parameters, type (R_{type}), temperature (R_{temp}), depth (R_{depth}) and separation distance between injection and production wells ($R_{distance}$) are varied. It can be observed that increasing $R_{distance}$ by 500 m (33.33%), LCOE drastically increases. It can also be observed that the cost is higher for low temperature reservoirs and the cost increases with R_{depth} and $R_{distance}$. When the LCOE of EGS and hydrothermal (that has higher permeability than EGS system) systems are considered it can be concluded that LCOE decreases as permeability increases.

Table 5. LCOE for GPP with varying parameters [27]

R_{type}	R_{temp} (°C)	R_{depth} (m)	$R_{distance}$ (m)	LCOE (¢/kWh)
Hydro-thermal	200	2000	1500	4.32
EGS	200	2000	1500	4.5
EGS	150	2000	1500	11.45
EGS	150	3000	1500	13.57
EGS	150	3000	2000	52.89

4.2 System Design for Aydin, Turkey

Two different plant capacities were used for the analysis at location 2. Comparison of parabolic trough, power tower, and linear Fresnel technologies was performed and is shown in Table 6. Stirling dish technology was not included because of its incapability of storing heat, which is advantageous for electricity production when there is no solar insolation. The results in Table 6 assumed a total 16 hours of thermal energy storage without fossil fuel backup. It can be observed that parabolic trough is still better option for the plant capacities used, when the annual energy and LCOE are compared with other technologies.

For the simulations performed, incorporating TES in CSP plants significantly increases their capacity value. While CSP plants without TES have capacity factors ranging between 19% and 21% of maximum capacity for 1.1 MW_e and 3MW_e capacity respectively, plants with TES can have capacity values between 38.4% and 46.6%. Increasing the TES hours also increases the land area by over 150% from 0 hours of TES to 16, as shown in Fig. 2.

Table 6. CSP Results for Aydin, Turkey

	Parabolic trough	Power tower	Linear Fresnel
Annual energy	13,414,700 kWh	13,618,100 kWh	8,541,060 kWh
Initial cost	$41,593,200	$53,707,300	$41,561,760
Installed cost per watt	$12.84	$16.18	$9.28
LCOE (nominal)	22.1099 cents/kWh	28.9311 cents/kWh	22.4244 cents/kWh
Site improvements	$1,308,000.00	$1,022,173.63	$902,975.94
Solar field	$11,772,000.00	Heliostat field- $12,266,083	$15,802,079.00
HTF system	$3,488,000.00	NA	$2,257,439.75
Storage	$11,328,033.00	$3,617,476.00	$11,250,560.00
Fossil backup	$0.00	$0.00	$0.00
Power plant	$2,772,200.00	$4,140,000.00	$2,939,200.00
Balance of plant	$367,400.00	$1,207,500.00	$0.00
Total tower cost	NA	$5,116,502.50	NA
Total receiver cost	NA	$11,078,252.00	NA
Contingency	7% - $2,172,494.25	7% - $ 2,691,359.00	10% - $2190169.5
Total direct cost	$33,208,128.00	$41,139,348.00	$35,342,424.00
Area required by the system	39 acres	126 acres	18 acres
Maxiumum system height	20m (reservoir tank)	43m (tower)	20m (reservoir tank)

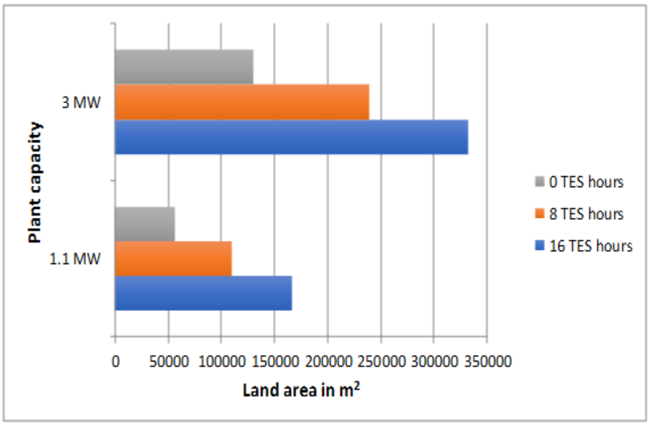

Figure 2. Land area requirement with increase in TES hours for different plant capacities

In general, designs of both systems consider a power requirement that is sufficed by a 1.1 MW capacity power plant. The capacity implies a power plant which can produce the amount of annual energy (power requirement) by running under the actual environmental and resource conditions, and it is not the same as power plant size. As an example, a Parabolic Trough (PT) type power plant of 1.1 MW size running under actual environmental and resource conditions for Aydin, Turkey [51], can produce around 2,500 MWh of annual energy. Comparing that amount of energy with the energy produced by a 1.1 MW size power plant running for 24 hours 365 days a year (which gives around 9,636 MWh of energy) is less than 26% of the expected energy. Hence, a reference annual energy the amount of 9,636 MWh for a 1.1 MW capacity power plant for further simulations with both geothermal and PT plant. The parameters are adjusted to keep the plant capacity and annual design energy constant for both the power plants for 1.1 MW$_e$ and 3 MW$_e$.

Tables 7 and 8 show the results for geothermal and solar power plants. It can be observed that for the same annual capacity and system size, solar thermal power plant seems economical for a system capacity of 1.1 MWe. This is due to the reason that the geothermal plant is far from the site which increases the system costs tremendously as observed in Table 5. For large plant capacity, geothermal plant seems to have slightly lower LCOE. However, if land requirement is considered, geothermal plant requires smaller area for both the system capacities and has much higher capacity factor, which is typical to geothermal power plant due to invariability.

Table 7. Results for the Geothermal Energy System

Metric	Value	
System size (turbine size)	1.1 MW	3 MW
Design annual energy capacity	9,636,000kWh	26,280,000 kWh
Land area	14.3 acres	39 acres
Levelized COE (nominal)	53.12 ¢/kWh	21.42 ¢/kWh
Capacity factor	85.40%	85.40%
Maximum system height	Power plant height	

Table 8. Results for the CSP System

Metric	Value	
System size (turbine size)	1.1 MW	3 MW
Design annual energy capacity	9,636,000kWh	26,280,000 kWh
Land area	32 acres	68 acres
Levelized COE (nominal)	21.43 ¢/kWh	21.7 ¢/kWh
Capacity factor	41.5%	46.60%
Maximum system height	Storage tank height	

5. Conclusions

In this paper, solar and geothermal resource data for two new sites/locations, Las Cruces, US and Aydin, Turkey using the SAM software, have been considered which will add to the existing site database for renewable energy analysis. Feasibility study of solar and geothermal power generation was carried out for the first time for an active working site (a pilot training airport) for which the load profile is unique and different from other locations previously considered. Comparative analysis between the two specific renewable energy sources considered in this paper is performed for the first time, especially for small plant capacities.

It was found that parabolic trough power plant might be more suitable for a 3MW$_e$ size power plant, with 16 hours of thermal storage. A parametric study was performed by varying the thermal storage hours (except for Stirling dish) and solar multiple for all the CSP technologies and it was found that increasing both these parameters reduce the LCOE. The reduction is found to be higher for the power tower system. It was found that the linear Fresnel technology can be a competitor due to the small area requirement but it will depend on different parametric variations and assumptions. For geothermal technologies, it was found that the distance between injection and production wells significantly influences the LCOE. It was found that lesser the distance, lower are the costs. In addition, the area requirement was found to be lower for geothermal option compared to CSP option. Though these results are obtained for specific locations, it can be assumed that these results are generalized for any location. Site specific conclusions from the comparative study performed are:

(1) For Las Cruces, USA, the solar and geothermal data was obtained from SAM software and uniform load was assumed. For this location, geothermal option seems to be better choice if a geothermal well is available at a distance less than1500 m from the injection site.

(2) For Aydin, Turkey, both power plants were compared for same annual energy production and plant capacity. The load profile for the Turkish airport was used for the analysis at this location. It was found that solar thermal might be a better option for this location when the plant capacity is 1.1 MW$_e$ since the geothermal resource is far from the location.

(3) LCOE for geothermal power plant is slightly lower when the plant capacity is increased to 3 MW$_e$ for Aydin.

In summary, both generalized and site-specific conclusions were drawn from the comparative analysis performed. It can be concluded that several factors affect the choice of renewable source options for a location.

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