System Advisor Model (SAM) Case Study:

Gemasolar

Fuentes De Andalucía, Spain

The SAM team is compiling a series of case studies to provide specific examples with the view to guide users in constructing their own SAM analyses. These case studies describe the process of acquiring data, generating a SAM file with explicit inputs, and analyzing the salient results. Each case study is accompanied by the SAM file (v2012.11.30) that has been used to model the case.

<u>Abstract</u>

Gemasolar, located in Fuentes de Andalucía, Spain, about 40 miles east of Sevilla, is the first commercial-scale plant in the world to apply central tower receiver and molten salt heat storage technology. The plant has a capacity of 19.9 MWe (gross) and covers slightly less than 200 hectares. It is owned and operated by Torresol Energy, a joint venture between SENER and Masdar. Performance data from the plant is proprietary but even without a very accurate weather file the SAM model predicts an annual energy output proportional to the values reported in the media. In this case study we do not estimate the economics of the plant due to the lack of reliable data.

Figure 1: Gemasolar solar power tower plant

System Description

The Gemasolar power plant consists of 2,650 heliostats distributed in concentric rings around the tower, with a total reflective area of 304,750 m², in an immense 185-hectare circle. The 115 m² heliostats developed by SENER use proprietary technology to track the sun's location in order to maximize the collection of thermal energy, and their location was established by the SENSOL software. These heliostats reflect and concentrate sun radiation on a 120 MWth solar receiver located on the upper part of 140 m tower. Molten salt is pumped from a cold storage tank through the receiver where is heated and then stored into a hot tank. From the hot tank the salt is pumped to a steam generation system. The superheated steam produced drives a 19.9 MWe (gross) Siemens SST-600 two-cylinder reheat steam turbine, which is connected to a generator that produces electricity. The plant uses a wet-cooling system to condense the steam back to liquid. The Gemasolar power plant has a thermal storage system which stores part of the heat produced in the solar field during the day in a molten salt mixture of 60% sodium nitrate and 40% potassium nitrate. A full storage tank can be used to operate the turbine for about 15 hours at full-load when the sky is overcast or after sunset. The plant also utilizes a 15% fossil fuel back-up from a natural gas heater. Ground-breaking for Gemasolar plant began in February 2009 and after 26 months of construction, it went online in May 2011.

Figure 2: Aerial view of Gemasolar

Data Acquisition

This study used the Sevilla EPW climate file from the SAM database as the best representation of Fuentes de Andalucía due to the two locations being only 40 miles apart. The system specifications were primarily sourced from the NREL/ SolarPACES website [1] and from the Gemasolar plant fact sheet [2]. Torresol Energy released an estimated annual energy output for the plant in its website [3].

SAM Inputs

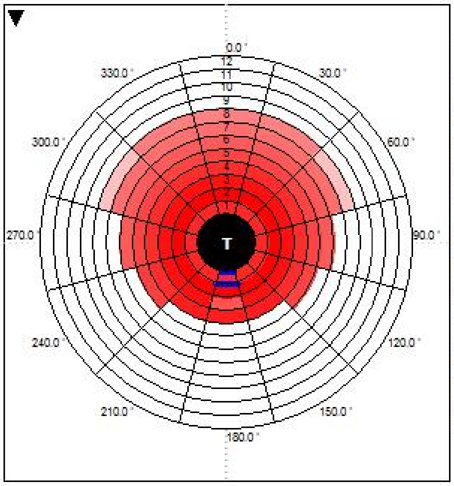
The SAM technology chosen for this system is CSP molten salt power tower. The market is Independent Power Producer since Torresol Energy sells the electricity to ENDESA at a price negotiated through a PPA that was established with the Spanish feed-in tariff. Table 1 shows all the changes from the default values based on the system description.

Table 1: SAM performance inputs for Gemasolar that differ from default values

Page	Variable	Default Value	Gemasolar
Climate	Location	CA Dagget (TMY2)	Sevilla (EPW)
Heliostat Field	Heliostat width	12.2 m	10.9 m
	Heliostat height	12.2 m	10.9 m
	Max heliostat distance to tower	7.5	8
	Solar field land area multiplier	1.3	1.4
Tower and Receiver	Receiver height	20.41 m	14.22 m
	Receiver diameter	17.67 m	8.89 m
	Number of panels	20	16
	Required HTF outlet temp.	574 ºC	565 ºC
	Solar multiple	2.4	2.5
	Tower height	203.33 m	140 m
Power Cycle	Design turbine gross output	115 MW	19.9 MW
	Estimated gross to net conv.	0.87	0.875
	Design HTF inlet temperature	574 ºC	565 ºC
	Aux heater outlet set temp.	594 ºC	570 ºC
	Min turbine operation	0.25	0.20
	Condenser type	Air cooled	Evaporative
	Ambient temp at design	43 ºC	20 ºC
Thermal Storage	Full load hours of TES	10	15
	Initial hot HTF temp.	574 ºC	565 ºC
	Current dispatch schedule	Summer peak	Uniform dispatch
	Fossil fill fraction (Period 1)	0	0.27
Parasitics	Piping loss coefficient	10,200 Wt/m	8,000 Wt/m

The Royal decree 661/2007 set an allowance for solar thermal plants to contain up to 12-15% natural gas back up. This increases the reliability of the plants, since natural gas can be used both to maintain the temperature of the heat storage during periods of interruption in solar thermal electricity generation and to continue generation during cloudy conditions or after sunset. We have adjusted the fossil fill fraction value in order to reach a 15% fossil fuel back up without specific criteria. Further research should be done in order to clarify how Gemasolar uses the 15% fossil fuel back up allowed.

The distribution of the heliostats in the solar field, receiver height and receiver diameter were calculated with the wizard. Once the wizard populated the zonal grid we adjusted the number of the heliostat to make them coincident with the 2,650 heliostat of the Gemasolar plant. Figure 3 (below) shows the final distribution of the heliostats in the solar field.



Span Angle: 360 Radial Zones: 12 Azimuthal Zones: 12

	0.0	30.0	60.0	90.0	120.0	150.0	180.0	210.0	240.0	270.0	300.0	330.0
Rad.1	11	11	11	11	11	11	11	11	11	11	11	11
Rad.2	31	31	31	31	31	31	31	31	31	31	31	31
Rad.3	39	39	39	39	39	39	28	39	39	39	39	39
Rad.4	43	43	43	43	43	46	46	46	43	43	43	43
Rad.5	46	46	46	46	46	0	0	0	47	46	46	46
Rad.6	47	47	47	47	0	0	0	0	0	47	47	47
Rad.7	47	47	47	0	0	0	0	0	0	0	47	47
Rad.8	46	46	23	0	0	0	0	0	0	0	23	47
Rad.9	0	0	0	0	0	0	0	0	0	0	0	0
Rad.10	0	0	0	0	0	0	0	0	0	0	0	0
Rad.11	0	0	0	0	0	0	0	0	0	0	0	0
Rad.12	0	0	0	0	0	0	0	0	0	0	0	0

Import Export

Figure 3: Location of the heliostats in the solar field

Results and Discussion

Table 3 shows the key SAM metrics for the performance of the system along with reported values (when available) and the percent difference between the SAM estimates and the media reports.

Table 3: SAM metrics table

Metric	SAM value	Reported Value	Difference (%)
Annual Energy	107,356,960 kWh	110,000,000 kWh	2.4%
Capacity Factor	70.4%	74%	3.6%
Gross to Net Conv. Factor	0.88		
Total Land Area	438.18 acres	457.00 acres	4.1%
Annual Water Usage	368,347 m^3		

The simulation gave an energy output of approximately 107.4 GWh/year. The reported annual output for Gemasolar is estimated at 110 GWh/year, giving a 2.4% difference in the actual and simulated values. There was also a 4.1% difference between the simulated and reported values for the total land of the plant.

There are many practical graphs for the performance side of the model. Figure 4 (below) shows the annual energy flow. From this, we can see the energy losses associated with certain processes throughout the system. For example, we can see the inefficiency of converting thermal energy to electricity during the power cycle. We can also obtain a more precise picture of the system's output using DView, SAM's hourly time series data viewer. To launch DView, click on Time Series in the Results menu. Figure 5 (below) shows the gross power output of the plant at different times of the day and different days of the year. This is useful in determining peak output hours throughout the year and could be used to make a comparison between peak output and peak demand hours or to compare time series outputs in different locations.

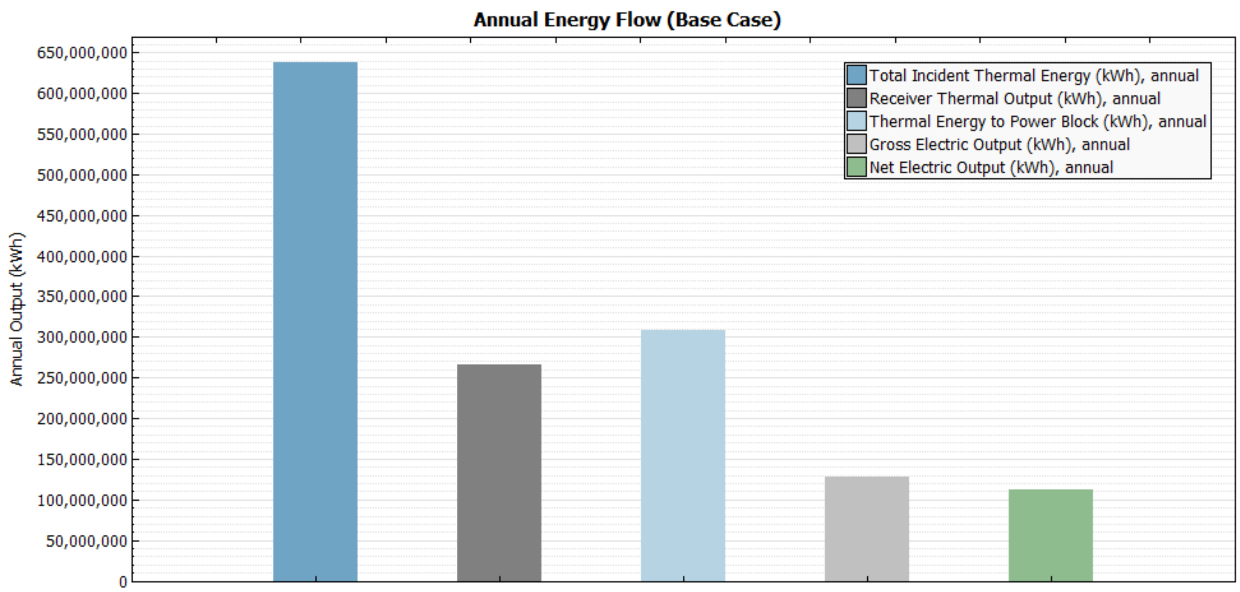


Figure 4: The annual energy flow shows the losses from different processes throughout the system

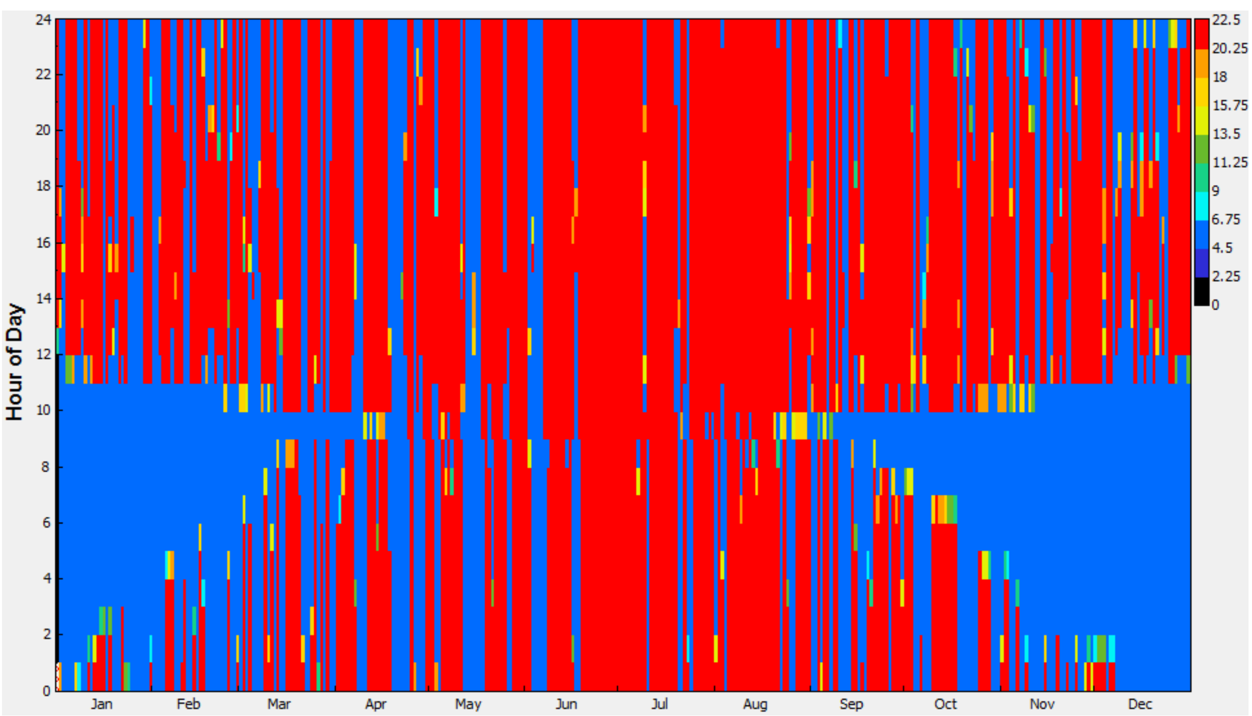


Figure 5: The gross power output of the system shows the peak times of year. Each pixel represents a single hour of the year.

Conclusion

Utilizing SAM's capabilities, we modeled Gemasolar, the first commercial-scale plant in the world to apply central tower receiver and molten salt heat storage technology. We were able to model the plant with minimal changes to the default values, using the limited information that has been made publicly available. Even with lacking performance data, we were able to get within 3% of the reported annual output. This case study is located in the SAM samples folder.

References

[1] "Gemasolar Thermosolar Plant" *SolarPACES. National Renewable Energy Laboratory.* <http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=40>

[2] "Gemasolar Plant (Solar-3)" *SENER Power and Process.* <http://www.sener-power- process.com/ENERGIA/ProjectsI/gemasolar/en>

[3] "Gemasolar" *Torresol Energy.* <http://www.torresolenergy.com/TORRESOL/gemasolar-plant/en>

[4] SAM templates available at: <https://www.nrel.gov/analysis/sam/templates.html>