Thermo-economic evaluation of CSP technologies for their application in Uruguay

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Abstract

In the last decade the Uruguayan energy matrix has experimented substantial changes migrating to renewable energy sources. However, this process was carried forward mainly by wind and biomass projects. It was not until 2014 when solar technologies (photovoltaic) started to play a more significant role in the electricity generation sector. In this context, the current work focus on the feasibility of installing Concentrating Solar Power (CSP) technologies in Uruguay. The analysis consists in the performance and Levelized Cost of Energy (LCOE) evaluation for Power Tower and Parabolic Trough plants, considering various configurations and locations within the country.

Keywords: CSP, Thermoeconomic evaluation, Uruguay.

1. Introduction

Concentrating Solar Power (CSP) technology is gaining importance around the world. Actually there are 7567 MWe installed of which 5079 MWe are operational and the rest is under construction. In addition, there are 1260 MWe under development [Aso,2018]. In the last couple of years the majority of the projects that are being developed and constructed are based on Tower technology due to its higher efficiency. This can be explained since higher working temperatures can be achieved (up to 565°C in Tower versus 393°C in Parabolic Trough) and less heat exchangers are necessary since the working fluid is also the storage fluid. These technologies are being widely investigated all around the world leading to a rise in available information of working plants and its applicability on different countries [Ling et al, 2018, Yang et al ,2018, Aly et al, 2018]. Considering the Uruguayan scenario only one previous study was found [SOL, 2015] predicting LCOE values of 181.7 €/MWh and 142.0 €/MWh for 50 MWe Paraboloc Trough and 100MWe tower technologies respectively. In the current study, both Power Tower (Tower) and Parabolic Trough (PT) plants, of 100 Mwe and 50 Mwe, respectively, are evaluated for their installation in Uruguay. One-year performance evaluations are carried out, for five different locations in Uruguay, for which Typical Meteorological Year (TMY) are available [LES]. Furthermore, economic evaluation is performed and LCOE is calculated. Finally, design optimization —by varying solar field and thermal storage sizes— is performed for each location, obtaining lowest values of LCOE.

2. Background

CSP technologies are based on the utilization of reflective surfaces to focus the solar energy in either line (Parabolic Trough and Fresnel) or point (Power Tower and Dish stirling) collectors. The absorbed energy heat a fluid (HTF) that is used to generate superheated steam that is finally expanded in a turbine, commonly considering a Rankine cycle.

The Uruguayan energy matrix is extremely unusual since 63% of the total primary energy supply (TPES) is based on renewable resources. Moreover, in the last couple of years only 3% of the total electricity production was based on fossil fuels. However, the majority of non traditional energy production is based on wind and biomass energy, leading to a solar participation of approximately 5% (as shown in Fig. 1).

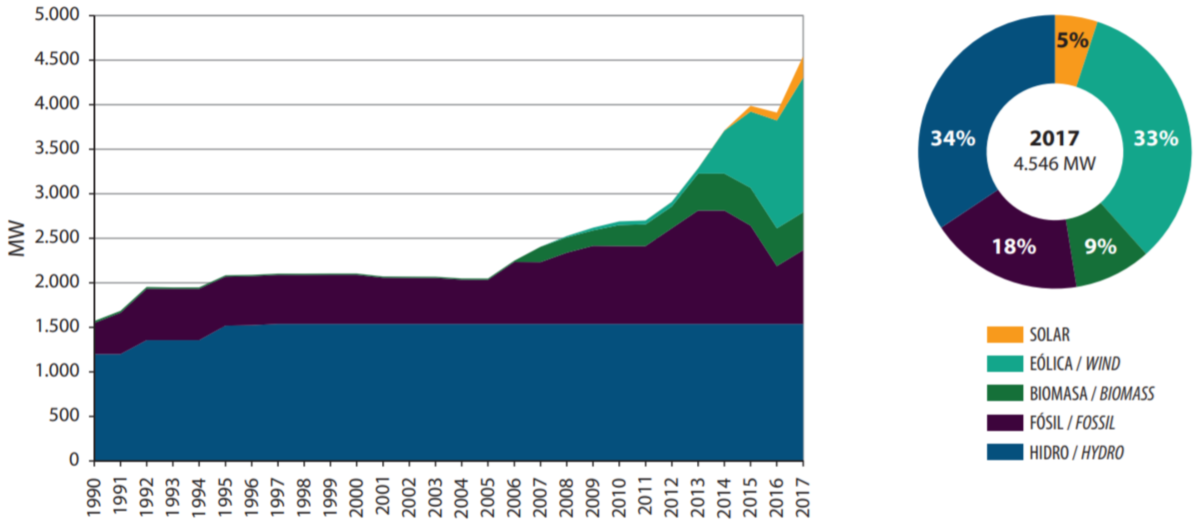


Figure 1: Installed capacity evolution in Uruguay. Source: Mie 2017.

Neither wind nor solar (photovoltaic) energy installed allow storage, making the coupling of electricity demand and offer a critical issue in the matrix optimization. This is one of the aspects that makes concentrating solar power technologies interesting since thermal storage can be easily implemented. A previous study of this technology was developed by SOLIDA Energías Renovables [SOL,2015] leading to LCOE values of 142 (€/MWht) and 181.7 (€/Mwht) for Power Tower and Prabolic Trough respectively.

3. Irradiation data

Uruguay has been working in the last years in creating a reliable database, this effort led to the elaboration of typical meteorological years for five different locations [LES] including hourly Direct Normal Irradiance (DNI), ambient temperature and wind velocity data. A brief summary of the information available is exposed in table 2.

Table 2: Meteorological data. Source: Own elaboration.

	DNI (kWh/year)	Mean ambient temperature (°C)	Mean wind velocity (m/s)
Salto	1897.5	19.3	4.0
Rivera	1779.7	18.4	3.0
Montevideo	1862.5	16.5	4.8
Colonia	1890.3	16.6	6.3
Rocha	1740.6	16.2	2.4

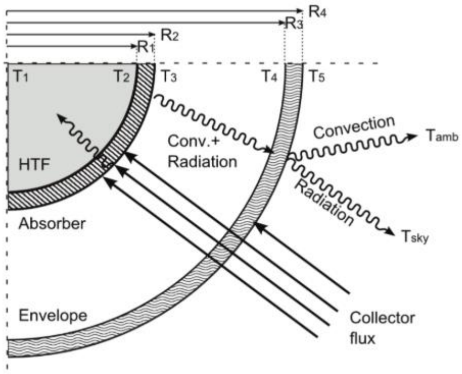
It can be deduced from table 2 that the best location for this kind of project should be Salto. However in the present work other locations are studied varying the field size and hours of storage in order to minimize the Levelized cost of energy (LCOE) for each place. It is expected that lower DNI values leads to greater solar fields and storage sizes.

4. Analysis methodology

Physical model

After analyzing several available software [Clifford,2008] the System Advisor Model (SAM) developed by National Renewable Energy Laboratory (NREL) was selected. Performance analysis for both technologies can be implemented. Hourly data of Direct Normal Irradiance, diffuse radiation, ambient temperature, dew point, pressure, wind direction and wind speed is required.

The Physical Model employed for Parabolic Trough is described in [Wagner,2011] while the Power Tower model is exposed in [Wagner,2008]. The Parabolic Trough model consists in solving the electric-equivalent diagram presented in figure 2.



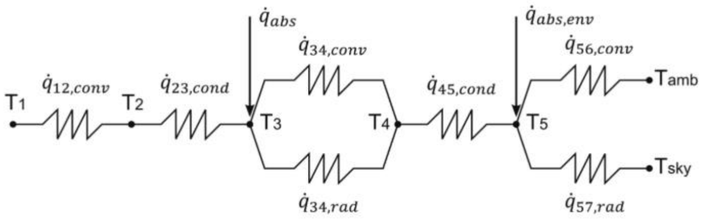


Figure 2: Parabolic Trough scheme and electric diagram. Source: Wagner,2011.

Power Tower technology is far more complex to be analyzed since every heliostat focus to a single receptor, making the distance between the mirror and the aim, variable. Moreover, the optical efficiency of each mirror varies not only with the distance to the tower but also with the position relative to the sun. SAM calculates each optical efficiency and employs specified data of the receiver to obtain the total energy produced.

Economic procedure

As mentioned above the optimization is carried on considering the LCOE. This parameter can be expressed as a function of the discount rate (i), OPEX and CAPEX costs (M and I respectively), the net energy produced (E) and the period of analysis (a) as follows

$$\boldsymbol{LCOE} = \frac{\sum_a \frac{I_a+M_a}{(1+i)^a}}{\sum_a \frac{E_a}{(1+i)^a}} \quad \text{(eq. 1)}$$

In the present work typical values of 8% and 20 years are considered as discount rate and analysis period. The correct determination of both CAPEX and OPEX cost is essential to obtain accurate results. The available information presents a wide range of variation for these values, depending mainly on the location considered. The National Renewable Energy Laboratory (NREL) offers detailed information for the different components of the central ([Turchi and Heath,2013] and [Kurup and Turchi,2015]). These values lead to a Total investment cost of 6.0 (USD/MWh) for Tower plants and 7.9 (USD/MWh) for Parabolic trough. However, it is observed that China presents more favorable scenarios with CAPEX costs that fall to 5.0 (USD/MWh) and 6.0 (USD/MWh) for SP and PT technologies respectively.

The OPEX cost include taxes that represent the 25% of the utility, however the Uruguayan legislation admit several exonerations for new ambient friendly technologies. The total exoneration represent the 80% of the total tax charge.

5. Results

Physical

Table 3 presents the net annual energy produced, net incident energy on the field, total efficiency and spilled energy for Salto and Rocha.

Table 3: Annual results considering optimal locations for Salto and Rocha. Solar field and storage sizes are shown in Table 4 and Table 5.

Technology	Net annual energy produced (GWh)	Net incident energy on field (GWh)	Total efficiency(%)	Spilled energy (GWht)
Salto				
Parabolic Trough 50 MWe	229.0	1668.5	13.7	93.6
Power Tower 100 MWe	442.5	2926.6	15.1	117.4
Rocha				
Parabolic Trough 50 MWe	206.1	1530.6	13.5	70.3
Power Tower 100 MWe	415.7	2862.4	14.5	85.3

The spilled energy is associated to the excess of incident energy when storage tanks are already at full capacity. In this situation, some reflecting surfaces are defocused in order to absorb the needed thermal power and not more. As expected plants located in Salto achieve better efficiencies, however the total energy produced difference is reduced due to the greater storage capacity of plants located in Rocha(See Table 4) that leads to less spilled energy.

Optimization

Several simulations were implemented in System Advisor Model (SAM) in order to reach the optimal configuration for each technology and location. The optimization method for Salto is presented in figure 3 considering 100 MWe power tower technology.

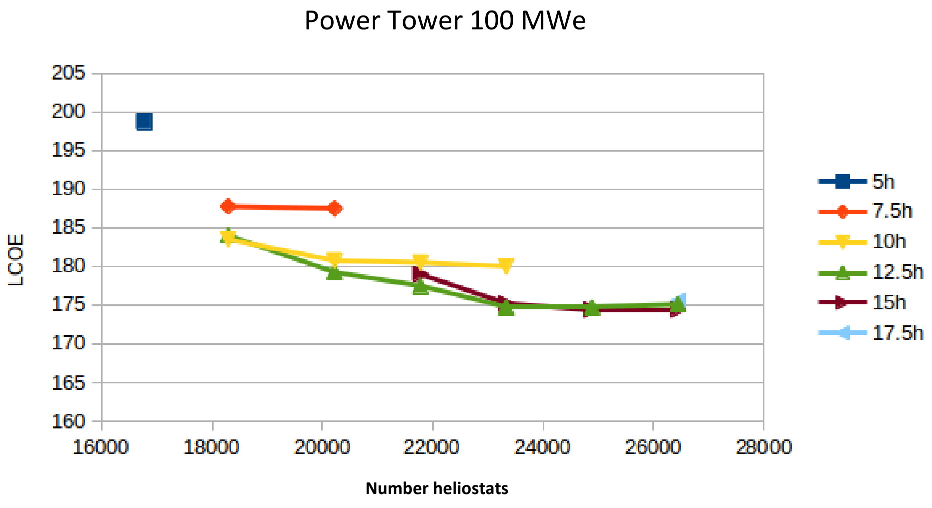


Figure 3: Solar Tower Optimization for Salto. Source: Own elaboration.

Figure 2 shows that over 23335 heliostats and 12.5 storage hours the LCOE remains constant, between these alternatives the option selected is the one that demand less capital expenditure. The same behavior can be observed for the parabolic trough technology. Best prices can be obtained in power tower technologies, this can be explained since higher temperatures can be achieved increasing the cycle efficiency and the installed capacity is higher. The optimal configuration for each location and technology is presented in table 4 and 5.

Table 4: Annual results for Power Tower technology.

Power Tower 100 MWe			
Location	Nº Heliostats	Storage Hours	LCOE(USD/MWh)
Salto	23335	12.5	174.7
Rocha	24891	15	194.7

Table 5: Annual results for Parabolic Trough technology.

Parabolic Trough MWe			
Location	Nº Loops	Storage Hours	LCOE(USD/MWh)
Salto	254	12.5	220.3
Rocha	254	12.5	243.7

It is observed that each technology present a 25% lower LCOE in Salto. In addition, the 100 MWe Solar Power technology LCOE is 10% lower than the 55MWe Parabolic Trough. However, the results obtained are far from being competitive to other renewable sources such as wind or PV.

Sensitivity analysis

A sensitivity analysis is performed, varying 5 % the parameter that generate greater impact in de final result (CAPEX cost and generated energy).

Table 6: Sensitivity analysis. Source: Own elaboration.

	Base case scenario	CAPEX cost		Generated energy	
Variation	-	+5%	-5%	+5%	-5%
Power Tower	174.7	182.6	167.7	166.5	183.7
Parabolic Trough	220.3	230.5	209.9	209.9	231.5
LCOE variation Power Tower (%)	-	-4.5	4.0	-4.7	5.2
LCOE variation Parabolic Trough (%)	-	-4.6	4.7	-4.7	5.0

Table 6 shows similar variation of LCOE with both CAPEX cost and generated energy, this shows both parameters are strongly attached to the final result. For completeness sake new simulations are implemented considering China CAPEX costs.

Table 7: LCOE considering China sceneario. Source: Own elaboration.

Technology	Investment cost (MUSD/MW)	Variation considering base case scenario (%)	LCOE (USD/MWh)	Variation considering base case scenario (%)
Power Tower	5.0	-16.7	148.4	-15.0
Parabolic Trough	6.0	-24.0	168.8	-23.3

Although this scenario is way more optimistic than the original it is still not competitive for the Uruguayan reality were wind generation reach values of around 60 USD/MWh.

6. Conclusions

In the present work a viability analysis was performed for CSP 100 MWe and 50 MWe power tower and parabolic trough technologies utilizing typical meteorological years for two locations. A solar field and storage size optimization was implemented obtaining different configurations for each location. Two main scenarios were considered varying the total investment due to the great variety of available information. The Tower technology presented LCOE values of 174.7 (USD/MWh) and 194.7 (USD/MWh) for Salto and Rocha respectively. On the other hand the LCOE for Parabolic Trough ascend to 220.3 (USD/MWh) and 243.7 (USD/MWh) for the same locations. Considering a more favorable scenario based on China lower investment cost, the LCOE descend to 148.4 (USD/MWh) and 168.8 (USD/MWh) for Tower and PT located in Salto. Even in the more favorable scenario considered these technologies are far for being competitive to wind a PV.Finally a sensitivity analysis was performed proving that the principal parameters that influence the final result are the initial cost and the energy produced.

7. Acknowledgments

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