
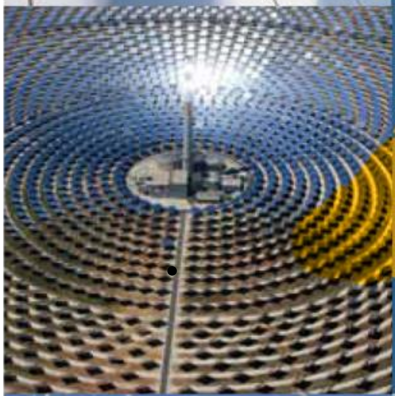




UNDERSTANDING THE COSTS OF SOLAR THERMAL ELECTRICITY PLANTS

A Joint Paper Presented by

PROTERMO SOLAR
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DCSP
German Association for Concentrated Solar Power

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European Solar Thermal Electricity Association

INTRODUCTION

Cost of electricity from renewable sources are progressively going down in the last years as result of a large deployment of plants. This has been certainly the case of Wind, which has shown a kind of asymptotic approach to its current level after 400 GW installed worldwide or PV, which modules have experienced a reduction in cost of one order of magnitude after 200 GW installed. Further cost reduction expectations are less aggressive as the cost of the other conventional components of a PV plant have already a larger share in the investment than the panels themselves.

For these two most deployed renewable technologies is relatively easy to determine the cost of the generated electricity at a given site – provided that the resource is known –- taking into account the cost of the generating modules as the utility scale plants do not have any kind of thermal storage system.

Solar thermal electricity plants (STE, known also as CSP) have shown significant cost reductions in the recent years, although the deployment level is around 4.6 GW worldwide only. This means that there is huge room for further reduction based in both volume and technologic improvements.

However, cost of STE plants is more difficult to track as there are only relatively a few new large-sized projects awarded, and they have different design conditions in terms of technology, nominal power, size of thermal storage and dispatch profile along with different resources at their sites, support mechanisms and financing conditions.

Apart from the important advantages of the STE plants in macroeconomic terms as compared with other renewables, for instance, local content, job creation, contribution to GDP, taxes, etc., the main value proposition of STE plants is the dispatching capability, thanks to their integrated thermal storage system (and possibly added hybridization) to follow the demand needs. Although in the past there have been many STE plants without thermal storage as the support mechanism allowed for that, it is not foreseeable that this will be the case for standalone STE plants in the future.

Regarding costs and distinctly to what happens in the case of Wind or PV, the simple reference to the nominal power of a STE plant does not provide enough information to figure out neither the investment cost nor the cost of the kWh produced.

In technical terms the data of the nominal power of the plant plus the solar multiple, which reflects how much energy is gathered in the solar field at the design point in comparison with the required thermal power to run the turbine at nominal conditions, will be enough to size the plant. Nevertheless, the common STE literature does not refer to the solar multiple, but to the power of the turbine and the size of the thermal storage in terms of the number of hours which is capable to keep the plant running at nominal power after the sunset. The capacity factor – in terms of percentage of hours operating at nominal power along a year – is another way to point out the storage capability of the plants.

Once the size of the plant is known, its annual energy production can be calculated considering the solar resource at the given site. Then, the data of capital expenditure and the O&M costs along with the specific discount factor for the investment provide the basis to calculate the cost per kWh produced by the plant. But nowadays the requirements on the dispatch profile are adding new variables in designing the plants which make it more difficult to answer the question on the required investment per MW or on the cost per kWh of a STE plant with a given nominal power.

DIFFERENT APPLICATIONS, DIFFERENT INVESTMENT LEVELS

As it will be later explained, besides the solar resource at the selected site and the specific kind of plant, the costs of the kWh will depend on a large variety of factors which differs from one project to another. Investment costs does not vary as much but still –land cost, permits, local content, price of labour force, imports, etc. – could also result in capital expenditure (CAPEX) differences of +/- 10% depending on the country and the particular site.

Some examples to show how large the differences in cost per kW installed could be depending on the type of plant:

Integrated Solar Combined Cycle (ISCC)

This is not a standalone STE plant. A solar field is constructed near a conventional gas fired combined cycle acting a kind of gas saver when the sun is shining. In this case, a few additional equipment, apart from the solar field, will be needed. The marginal cost of the kWh by the energy supplied by the solar field is currently almost competitive as no investment in the power block is required. The only drawback is that the solar share cannot be much higher than 10% on a yearly basis – in order not to harm the efficiency of the combined cycle. Steam from solar fields could be also used to boost coal fired power plants.

Current designs use parabolic trough technology and heat transfer fluid (HTF) as intermediate fluid for these applications. Fresnel linear reflecting mirrors with direct steam generation could provide cost reductions in the future.

Typical current investment costs of this type of installations are around 1300€/kWe equivalent.

Electricity supply at a given time of day

This is going to be an increasing need when significant amounts of distributed PV is deployed in a given country. The requirements to cover the evening peak and to help the electrical system during the morning ramp can be easily done by STE plants. The usual operational mode will be to gather the solar energy during sunny hours and to deliver electricity during a period of 3 – 5 hours per day. Although these plants will have a large thermal storage system, the solar multiple must not necessarily be too high, it could be even lower than 1.

Therefore, the costs of these types of STE plants could be in the range of 2500 - 3500 €/kW.

Typical STE plant with medium–sized thermal storage

Most STE power plants nowadays are being designed to provide power during the day plus an extended period of some 4 – 7 hours, although the payments to the electricity produced might vary with the time of day.

The investment for these type of plants would be in the range of 3500 - 4000 €/kW.

Base load plants

There are some current projects which will provide non-stop production during most sunny days of the year. They are normally known as 24/7. These plants are provided with a large solar field and a large thermal storage system which are designed for day cycles. The size of both subsystems are optimized on an economical basis trying to avoid too much dumping of the solar field at summer time when the days are longer. In winter time or in cloudy days the output of the turbine can be slightly reduced to allow for uninterrupted supply.

The investment for these type of plants would be in the range of 5000 - 7000 €/kW.

ELECTRICITY COST FROM STE PLANTS. CURRENT SITUATION AND EXPECTED TRENDS

As it has been already explained earlier, the capital expenditure will depend on the type of service that the STE is requested to provide along with some country specific factors. The selected kind of technology – either parabolic trough or central receiver –might also have different costs, although they are currently showing very close figures. There are not yet commercial Fresnel plants with thermal storage, but in the future they might be further considered for potential choices.

Apart from the obvious influence of the Direct Normal Irradiation (DNI) level, it is nevertheless hard to understand why there are large different in prices which ranged from Power Purchase Agreements (PPA) of c$ 12 / kWh in the USA to Feed in Tariff (FiT) of c€ 29 / kWh in Spain until the recent regulatory change. Prices per kWh in other countries, such as Morocco, South Africa, India, are in between the above mentioned figures, but such big differences converge rapidly to similar figures when the differences in DNI, size of the plant, PPA or FiT duration, escalation, grants, financing conditions, requested return on investments (RoI), etc., are correspondently discounted.

ESTELA has developed an easy tool to take all these differences into account and to interpret the current contracts of commercial projects into the corresponding price of a standard plant of 150 MW, 5 hours of thermal storage, 25 years PPA without escalation, no public support (no grants no subsidized loans) and typical financing and RoI conditions. The plant is kept in the same site and therefore the harmonized costs can be shown within a band with lower costs in places with high DNI levels (i.e. good USA places) and higher costs in moderate DNI sites (i.e. Southern Europe).

Here are some remarks on the discount factors for consideration:

- Size of the plant. It is quite clear that the cost of electricity from a 50 MW plant will be higher than the cost of a 150 MW one. This is not only because the relative differences in investment per MW, but also due to the impact of the O&M costs as well. The differences in equivalent sizes depending on the size of the thermal storage must be also considered.

- PPA duration. If the PPA (or FiT) of a given project last 20 years, the harmonized cost for a 25-year period has to be correspondently lower. Should the PPA be established for a 30-year period the effect on the harmonized costs will be opposite. The discounted cash flows at usual Weighted Average Cost of Capital (WACC) will provide the answer.

- PPA escalation. Some PPAs include escalation clauses with the time either for the whole price or for the embedded O&M cost. As the standard project does not consider escalation at all, the harmonized cost will result somewhat higher when considering this case.

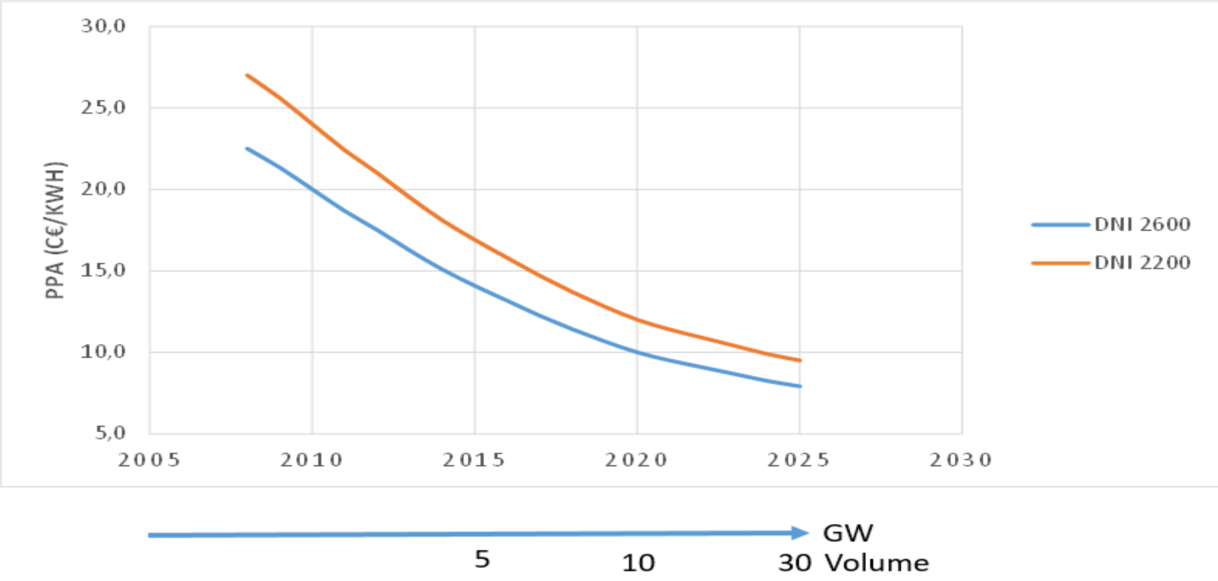
- Grants. The effect of any kind of grants of subsidies can be easily figure out from the discounted cash flow calculations. Removing them will provide increases in the harmonized cost.

- Subsidized loans. Same comment as above.

- Return on Investments. In some projects, especially when public investors are part of the ownership, the expected RoI is normally known and therefore, its effect can be taken into consideration when interpreting the price of the project into the price of the standard one.

Currency exchange rate is another variable which can introduce some noise when trying to compare past figures with current rates.

Taken into account the facts and figures from the past years and the expected trends for cost reduction, which will be commented later on, ESTELA is in a position to provide the cost reduction expectations as shown in the graph. These curves corresponds to the best estimates of the industrial companies within the association and they are fully consistent with the harmonized costs of all the STE plants built in the past in the USA, Spain, India Morocco and South Africa at their respective construction time.



Required value for a 25-year PPA without escalation for a 150 MW 5-hour thermal storage STE plant without any kind of financial public support.

These cost reduction curves refer to the year in which the plant starts its construction. This cost reduction trend requires necessarily a minimum volume of projects which has been estimated in 30 GW accumulated by 2025.

Forecast of the American SunShot project are much more aggressive. Their goal is to bring the cost of STE electricity down to c$ 6 / kWh by 2020 not only based on the impact of technologic development on the cost of components, but also consider other important reductions other than costs into account, for example, permits, engineering, EPC, financing, etc.

ROOM AND REASONS FOR COST REDUCTION

When comparing the 4.6 GW of STE plants installed with the 400 GW of Wind or 200 MW of PV, it is obvious to realize that there is a large room for important cost reductions when additional tenths or hundreds GW will be installed. Scale factors, new materials, more efficient manufacturing processes and assembly activities on site will certainly contribute to cost reduction. In addition to this, more performant solar field designs, higher temperatures of the working fluid and the use of new power blocks with larger conversion efficiencies will further contribute for making the cost of the electricity cheaper.

Here are the current and expected costs of the main systems of a STE Plant:

Drivers for Cost reduction in STE

	Today	2025
A) Solar field incl. HTF [€/m²]	160 - 250	100 - 160
B) Thermal Storage [€/kWhth]	26 - 30	18 - 21
C) PowerBlock [€/kWe]	720 - 765	700 – 790
D) System Efficiency	15-17%	18-20%

A) Solar Field

1. Collector with larger Aperture (trough)
2. Improved optics through higher accuracy heliostats, improved field layout (Tower)
3. Advanced assembly procedure, industrialized assembly, industrial automatization in manufacturing; (Sub-) supplier standards; Standardized Design
4. Higher Reflectivity, higher cleanliness
5. Improved durability
6. Improved absorber coating
7. Wireless power supply and control (heliostat
8. Improved optics through higher accuracy heliostats, improved field layout (Tower)
9. Improved O&M procedures

B) Thermal Storage

1. Direct Storage concept (HTF = Storage Medium)
2. Higher temperature difference
3. Adapted thermal storage materials
4. Standardized Design; Sub-Supplier design standards
5. Advanced charging and discharging, improved operation strategies in general

C) Power Block

1. Higher Cycle efficiency
2. Improved hybridization concept
3. Larger Power Block
4. Standardized Design

D) System Efficiency

1. Higher process temperature
2. Lower Parasitic consumption (higher temperature; through: larger aperture and other HTF; Tower: gravitational pressure loss recovery)
3. Adapted Turbine Design (for daily start-up)
4. Improved control and O&M strategies / procedures

In addition what can be identified as soft costs, including project and site development, permits, engineering, EPC risks and corresponding margins, construction and performance insurance, etc. amounts nowadays to around 25 % of the CAPEX. These costs must be accordingly reduced as the total cost does and even the percentage could be further reduced as well.

The costs of structured financing for STE plants have still room for reduction particularly when the track record will provide full confidence on the performance of the CSP plants. This is starting to be the case particularly after the 2.3 GW installed in Spain with an average of 5 years of continuous operation.

Regarding performance, the current conversion ratios from solar to electricity are in the range 15 – 17%. The performance range of STE plants is expected to increase to 18 – 20% and it could be further increased if breakthroughs apply.

BEYOND DISPATCHABILITY: FIRMNESS

Adding firmness to STE plants can be done by hybridizing with biomass, biogas or natural gas.

In the past all hybrid systems – no matter whether they were based on biomass or gas – were designed putting the auxiliary heater in parallel to the solar field, heating the HTF to the same temperature as if the solar field was in operation, in order to cope with cloud passing or absence of solar irradiation. The main drawback of these systems is that the gas is burned at a very inefficient conversion rate. Today more efficient systems have been conceived. For instance, installing an inexpensive open cycle gas turbine where the exhaust energy is recovered in the thermal storage system, as if the energy were coming from the solar field, will provide similar conversion efficiency to a combined cycle and a much more flexible operation of the complete installation.

This concept is under development in the Hysol T&I project, funded by the EC through the FP7 programme. This R&D project is focused in demonstrate that a Solar Hybrid Plant is the best way to get firmness, using at least 80% of renewable resources.

Firmness will be certainly rewarded appropriately by the electrical system – capacity payments are today a hot issue of the new regulations – and thus STE plants can become more competitive.

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