A comparative Study on Photovoltaic and Concentrated Solar Thermal Power Plants

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Abstract **- Recently solar energy receives a great attention as an important source of renewable energy. Solar energy is converted to electrical energy directly through photovoltaic (PV) or indirectly through concentrated solar power (CSP) system which converts solar energy to heat energy which in turn can be used by thermal power station to generate electricity.**
This paper present a comparative study between the two types of solar power (PV&CSP). This study includes types, components, initial and running costs, efficiency, advantages, disadvantages and storage systems.

Index Terms - Renewable energy sources; solar photovoltaic; concentrating solar power; thermal engine; storage systems.

I. INTRODUCTION

The sun is the most plentiful energy source for the earth. All form of energy like wind, fossil fuel, hydro and biomass energy have their origins in sunlight. Solar energy falls on the surface of the earth at a rate of 120 petawatts, this means all the solar energy received from the sun in one days can satisfied the whole world's demand for more than 20 years. [1].

The potential of several renewable energy source based on today's technology is shown in Fig1. Future advances in technology will lead to higher potential for each energy source. However, the worldwide demand for energy is expected to keep increasing at 5 percent each year. Solar energy is the only choice that can satisfy such a huge and steadily increasing demand. [2].

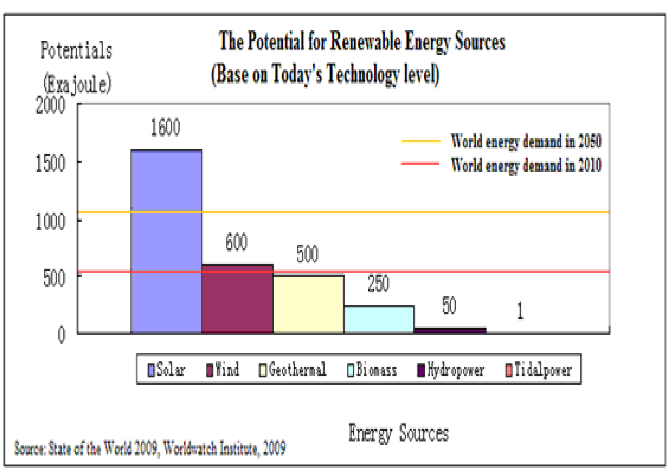

Fig. 1: The Potential for Renewable Energy Source

Renewable energy is the energy which comes from natural resources such as sunlight, wind, rain, tides and geothermal heat. These resources are renewable and can be naturally replenished. Therefore, for all practical purposes, these resources can be considered to be inexhaustible [3].

Among renewable energy source, solar technologies are capturing large interest. Most of the solar power systems in the market today can be divided into two major classes: the direct and the indirect solar power. The direct solar power refers to a system that converts solar radiation directly to electricity using a photovoltaic (PV) cell. The indirect solar power refers to a system that converts the solar energy first to heat and after that to electrical energy, as in the case of concentrated solar power (CSP). In a CSP plant, sunlight is focused on a heat exchanger; this heat is used to drive the turbine. The problems with these technologies are inefficiency and a very high capital cost. The typical efficiency of a CSP is about 15%. the highest efficiency of a silicon cell for example is 20%.On the other hand, Concentrating Solar Power (CSP) technology is now acquiring an increasing interest, especially if built with thermal energy storage, Moreover; economic issues have been treated for CSP in order to verify which the profits, the breakeven are and so on. [4].

The aim of this paper is to compare a PV plant with a CSP plant from technologies of system, types and components of system, efficiency, initial costs comparison, advantages, disadvantages, life cost of electricity (LCOE) and storage systems

II. PV SYSTEMS

Solar photovoltaic, also called solar cells or PV, are electronic devices that convert sunlight directly into electricity. The modern form of the solar cell was invented in 1954 at Bell Telephone Laboratories. Today, PV is one of the fastest-growing renewable energy technologies and is expected to play a major role in the future global electricity generation mix. A PV system consists of a number of PV cells grouped together to form a PV module, along with auxiliary components. [5].

A. PV plants

The PV plants can be categorized into two main typologies according to the installation mode: stand alone and grid-connected. The first one refers to PV plants which are not connected to the electrical grid of the local energy utility company. This typology of PV plants is usually used to feed

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small electrical load (e.g. for street lighting) or when the electrical grid is too far (e.g. an isolated rural house). Stand-alone PV plants have a storage battery with stabilizer in order to guarantee that: a) the battery is not over-charged by the PV plant; b) the charge of the battery is not less than a prefixed threshold; c) the electrical loads may be fed directly from the DC side of the inverter for DC loads or from the AC side for AC loads. Anyway, stand-alone PV plants are not used for high power. The second one refers to the PV plants directly connected to the electrical grid of the local energy utility company. In this case, there is no storage battery because the electrical storage is represented just by the electrical grid. In fact, the energy produced by the PV plants and not simultaneously absorbed by the electrical loads is injected in the electrical grid. Then, when the electrical loads require more energy than that produced by the PV plant, the lacking part is taken from the grid. [6]

B. PV Technologies

For describing the use of PV installations is used the maximum power (Wp) that theoretically the PV module can provide. The power of solar PV installations is therefore given in Wp (peak Watts). This power corresponds to the one given by the solar modules at 25ºC at irradiation conditions of 1000W/m2. There are four ranges of power for PV installations depending on the location and the number of housing supplied [7]:

1) *Small-sized installations of 3 kWp, up to 5 kWp*
2) *Medium-sized installations of 30 kWp, with a range between 5 and 100 kWp* t.
3) *Big-sized installation of 300 kWp, with ranges between 100 kWp and 1 MWp..*
4) *3MWp photovoltaic plants, with ranges between 1 and 50 MWp.*

C. PV Concentrators

Concentrating PV (CPV) systems use refractive lenses or reflective dishes to concentrate sunlight onto solar cells in order to make benefit of a higher concentration ratio (CR). There are many types of concentrators, the most known are [8]:

1) *Compound Parabolic Concentrator (CPC)*
2) *Paraboloid Reflector.*
3) *V-Trough Concentrators*
4) *Fresnel's Lenses*

Four important parameters are taken into consideration in order to make the comparison between most important PV concentrators; these parameters are:

- Construction.
- Concentration ratio.
- Reflection.
- Tracking system

The comparison of the studied photovoltaic concentrators is given in Table 1. Based on the obtained results in this table, and depending on any project requirements, the PV concentrator can be selected.

A. Components of the PV Plant

The complete system of typical photovoltaic plant includes different components that should be selected taking into account the individual needs, site location, climate and expectations. The functional and operational requirements will determine which components the system will include major components such as [7]:

1) ***PV Modules***, to convert sunlight instantly into DC electric power

2) ***Inverter***, to convert DC power into standard AC power.

3) ***Battery***, to store energy

4) ***Transformer***, to change the voltage in the installation for being able to connect with the distribution network. It is used a low voltage – medium voltage transformer.

5) ***Utility Meter****:* utility power is automatically provided at night and during the day when the demand exceeds the solar electric power production. The utility meter actually spins backwards when solar power production exceeds house demand, allowing you to credit any excess electricity against future utility bills.

6) ***Charge Controller***, to prevent battery overcharging.

Table1. Comparison between different types of PV concentrators. [9]

Types	Compound Parabolic	Paraboloid Reflector	V-Trough	Fresnel's Lense
Construction	Made by two segments of parabolas	Use an anodized Al or simply a glass mirror which has a high reflectivity	Use arrays of trough shaped mirror	Made of several prisms arranged either linearly or in concentric circles
Concentration Ratio (CR)	$1/\sin\theta a$	$\pi r2/Acell$	$\sin[(2n+1)\psi+\theta]/\sin(\psi+\theta)$	$L.W/Acell$
Reflection of parallel ray into	Point	Point	Line	Point or Line
Tracking system	Not continuous tracking	Two axis	Not exist	Two axis

In addition, there are some component of hardware to complete the system and to make balance of system such as; wiring, over current, surge protection and disconnect devices, and other power processing equipment.

B. Life Cost of Electricity (LCOE)

The LCOE varies by technology, country and project based on the renewable energy resource, capital and operating costs, efficiency and performance of the technology.

Fig. 2: shows the LCOEs resulting from achieving the installed PV system prices. These LCOEs are calculated using assumptions about O&M expenses, inverter efficiencies, and derate factors (due to losses in wiring, diodes, or shading) [9]

As shown in Fig. 2, assuming the targets are met by 2020, residential PV is projected to be increasingly competitive with residential electricity rates, commercial PV is projected to be increasingly competitive with commercial electricity rates, and utility-scale PV is projected to be increasingly competitive with whole sale electricity rates. Utility-scale PV LCOEs become competitive with California's Market Price Referent (MPR), which is used as a benchmark to assess the value of renewable generation in California (CPUC 2011), by 2015 at higher costs than those targeted in the scenario. This illustrates that, while achieving price targets will allow PV to compete broadly with conventional generation in several U.S. markets

C. Solar PV capital costs

The capital cost of a PV system is composed of the PV module cost and the Balance of System (BoS) cost. The cost of the PV module and the interconnected array of PV cells are determined by raw material costs, cell processing/manufacturing and module assembly costs. The BoS cost includes items such as the cost of the structural system (e.g. structural installation, racks, site preparation and other attachments), the electrical system costs include the inverter, transformer, wiring and other electrical installation costs) and the cost of the battery or other storage system.

Prices for PV modules have fallen by between 30% and 41% in the year to September 2012 and by between 51% and 64% for the two years to September 2012, depending on the technology and source for European buyers. [5]
Prices for PV systems in the United States have dropped by 50 percent or more in recent years, with the sharpest declines for large-scale projects. [10]

D. Electrical Storage Systems (ESS)

The major categories of ESS used in PV plants are [11]**.**:

- Electro-mechanical electrical energy.
- Flywheel Energy Storage Systems (FESS).
- Electro-chemical energy.
- Battery Energy Storage Systems (BESS) there is a wide variety of battery technologies both in production and as topics of research.
- Lead Acid batteries.
- Capacitor and Super-Capacitor Storage Systems
- Electro-magnetic Superconductor Magnetic Energy Storage (SMES).

III. The Concentrating Solar Power Plant

Concentrating solar power (CSP) is a power generation technology that uses mirrors or lenses to concentrate the sun's rays, in most of today's CSP systems to heat a fluid and produce steam. The steam drives a turbine and generates power in the same way as conventional power plants.

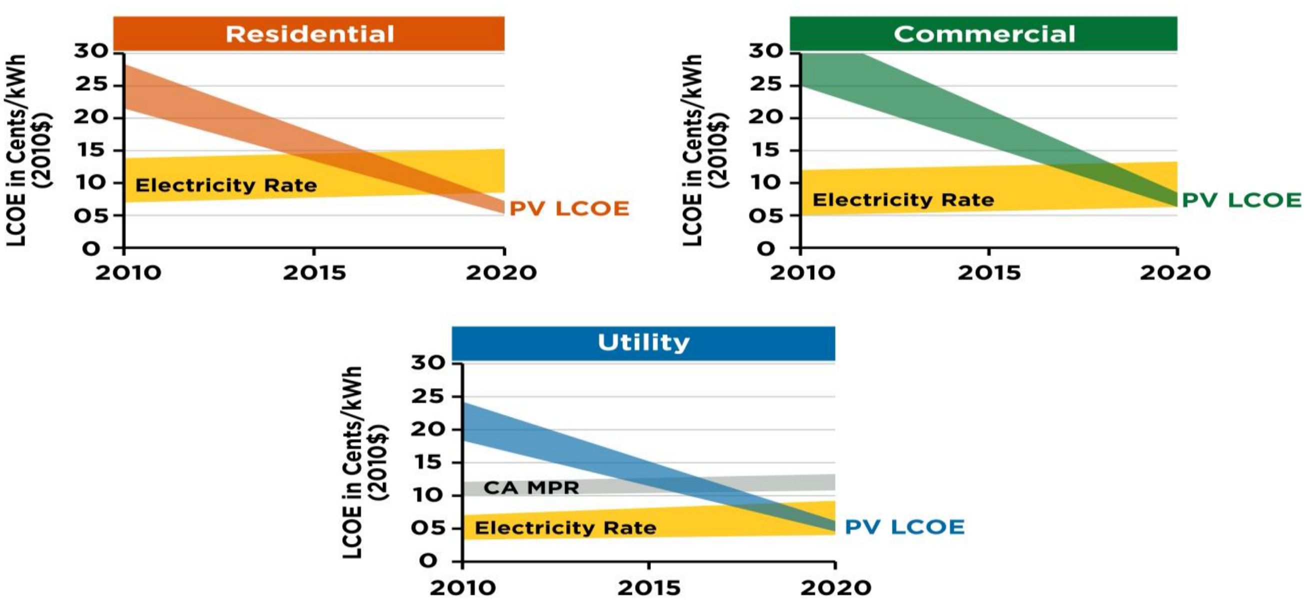

Fig. 2: PV LCOEs by Year and Market Segment

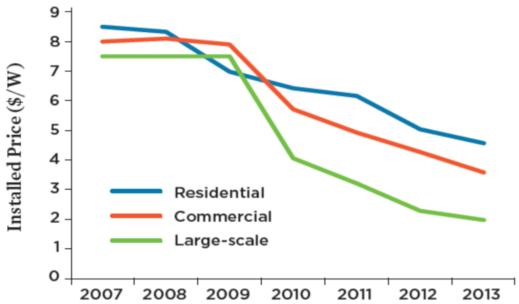

Fig. 3. The Falling Price of Solar PV by U.S. Sector, 2007–2013

A. *CSP TECHNOLOGIES*

CSP plants can be divided into two groups, based on whether the solar collectors concentrate the sun rays along a focal line or on a single focal point. Line-focusing systems include parabolic trough and linear Fresnel plants and have single-axis tracking systems. Point-focusing systems include solar dish systems and solar tower plants and include two-axis tracking systems to concentrate the power of the sun as shown in Fig 4. [12]

B. *CSP Concentrators Assessment*

The aforementioned CSP concentrators' comparison may have eight parameters .These parameters are: application, costs, axis, heat exchange, concentration type, receiver type, advantage and disadvantage.

The concentrators' comparative study is given in Table 2; the best result of the CSP can be deduced.

C. *Cost Analysis of CSP*

The cost of electricity generation from CSP is expected to decrease continuously. According to a study of renewable energy made by the IEA [14], the current CSP technology systems are implemented in the cost range of 0.19$/kWh to 0.25$/kWh. In the conventional power market, CSP competes with mid-load power in the range of 0.037$/kWh to 0.05$/kWh. As different scenarios have predicted, the costs of CSP can be reduced to competitive levels in the next 10 to 15 years. Competitiveness is affected not only by the cost of the technology itself, but also by potential price increases of fossil energy and by the internalization of associated social costs, such as carbon emissions. Therefore, it is assumed that in the medium to long term, competitiveness will be achieved at a level of 0.05$/kWh to 0.075$/kWh for dispatch able mid-load power.

According to another report prepared by Electric Power Research Institute, when the global cumulative capacity of CSP implementation reaches 4GW,the cost of electricity generation from new plants in 2015 could be as low as 0.08$/kWh (nominal 2015dollars) or nearly 0.05$/kWh (real 2005 dollars).

D. *Thermal Energy Storage in CSP Plant*

Thermal energy storage (TES) system is an intermediate and critical subsystem of solar power plant to store and dispatch the concentrated energy into power block (electricity generation).

Thermal energy storage technologies are generally categorized in terms of applied process and loading method meant to direct thermal storage and indirect thermal storage. In direct systems, the heat transfer fluid acts as the storage medium simultaneously, whereas in indirect systems, a storage medium is different from the transferring fluid, the difference between them is determined according to the location of the thermal storage tank related to the medium and transfer material, heat exchanger (HEX) block, pump, valve and number of practical utilities. [15]

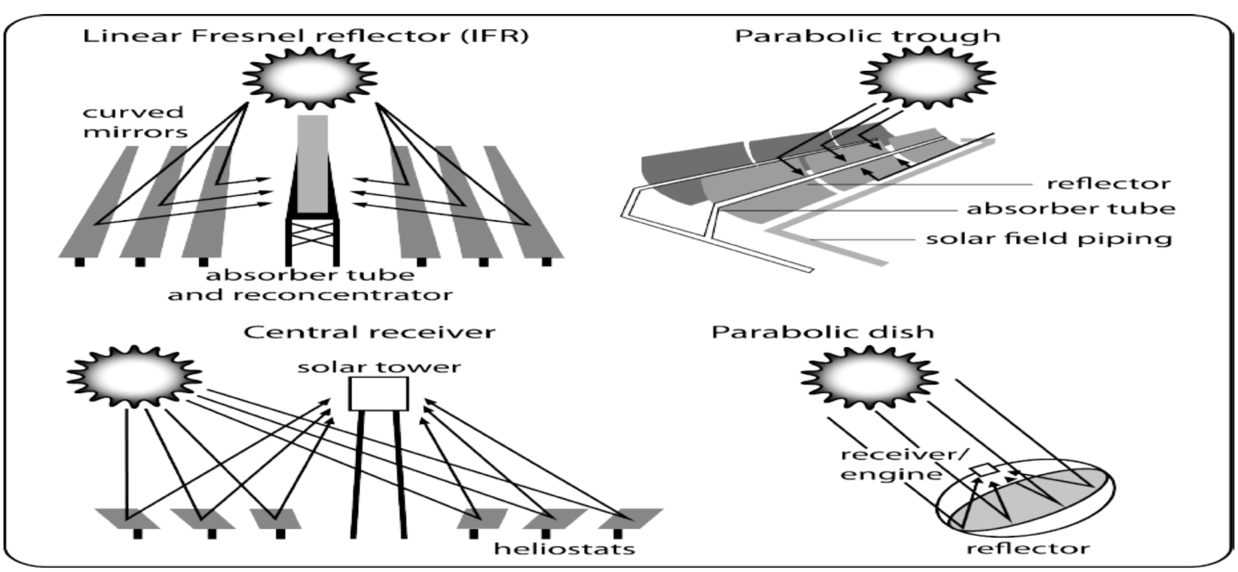

Fig. 4 Schematics of the Four CSP Approaches for Power Generation. [13]

Table2. Comparison between different types of (CSP) [8]

Types	Solar tower	Parabolic trough	Parabolic-Dish	Linear Fresnel
Uses	For large grid-connected power projects in the 30-200 MW size	For large grid-connected power projects in the 30-200 MW size	In single application or grouped in dish farms	Single application
Cost (USD/W)	2.5 - 4.4	2.7 - 4.0	1.3 - 12.6	NA
Axis	Dual	Single or dual	Dual	Dual
Heat exchange	Needed	Needed	Not Need	Not Need
Concentration on (in case of parallel rays)	Focal point	Focal line	Focal point	Focal line
Receiver	Fixed	Mobile	Mobile	Fixed
Advantage	With a lower required salt inventory the operating temperature is high compared to in CSP Trough	Concentrating sunlight to produce ice	Can be placed on a varied terrain using small quantities of water	Doesn't require rotating coupling between the receivers and the field header piping thus providing additional design flexibility
Disadvantage	Each mirror must have its own dual-axis control	A transparent glass tube envelops the receiver tube to reduce heat loss	The conversion from heat to electricity needs the moving of heavy engine, which requires a strong tracking system	Requires a mirror above the tube to refocus the missing rays or a multi-tube receiver that is large enough to capture missing rays without putting a mirror

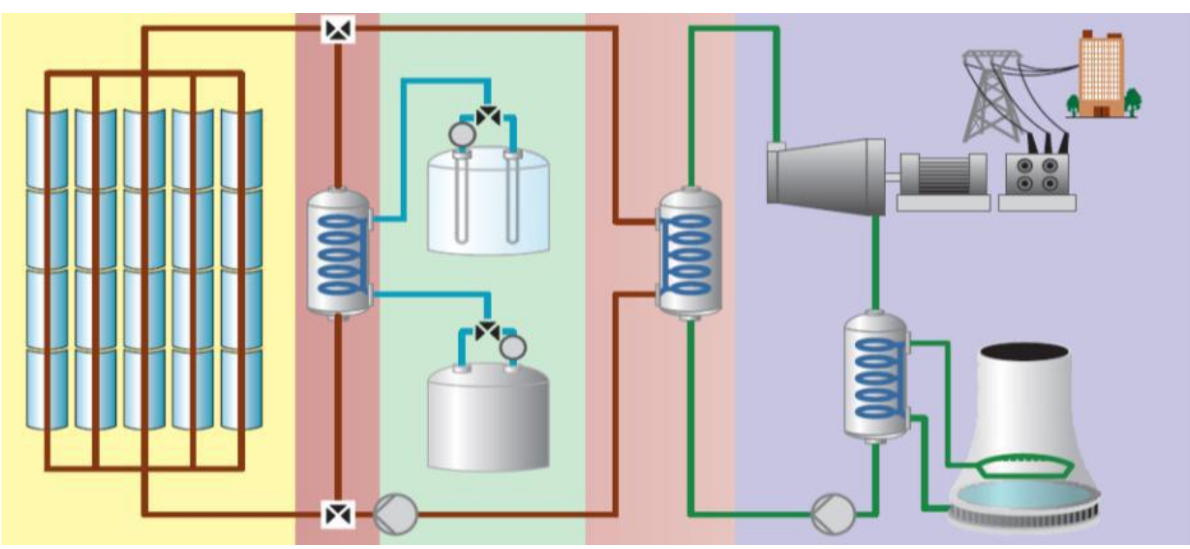

Fig.5: Conventional CSP Plant with thermal storage and oil as working fluid

Source: IEA (2011), "Solar Energy Perspectives"

E. CSP Plant Components

Generally, the CSP plants are consisting of three major components:

- Solar field
- Thermal conversion
- Power generation

Fig. 5 shows the CSP plant components, the concentrating system and solar receiver, heat transfer and thermal storage, heat conversion and power generation.

IV. Comparison between (PV) and CSP.

The (PV) and CSP are different in terms of technical aspects, but both techniques are essential clean energy alternatives to utilize solar power [14].

- PV converts sunlight directly into electricity (DC power) while CSP converts the light energy into thermal energy first, then use traditional turbine to convert heat into electricity (AC power).
- PV can use the solar diffuse radiation while CSP can only convert sun's direct radiation into power.
- Unlike PV's technique relies mostly on developing individual cell and module, the CSP technology relies heavily on the on-site constructing and final assembling and system integration.
- Energy storage of CSP is considerably lower than that of PV. With storage, power production can be shifted according to demand therefore is less dependent on the time period and daily weather conditions.
- The CSP technology is a still undeveloped industry, which is forced to face the competition and cost challenge come from the PV system.
- The Advantage of CSP over PV and many other renewable energy technologies is its ability to store the sun's energy as heat in molten salts, and to use it to generate electricity when the sun is no longer shining and at times when it may be most valuable to the grid. The molten salt heated by concentrating the sun's energy can be stored and kept hot for several hours. When electricity is needed, the heat stored in the salts can make the necessary steam. This storage lets CSP systems extend the "rush hours" of their generation patterns and generate electricity a few hours before the sun rises and a few hours after it sets, making it easier to integrate electricity from such plants into the grid [10].
- Cost comparison between PV versus CSP is presented in Table 3.

Table 3: Cost Comparison – PV vs. CSP [9]

	Utility PV		Residential Rooftop PV		Commercial Rooftop PV		CSP					
	SunShot	Ref.	SunShot	Ref.	SunShot	Ref.	SunShot			Ref.		
	$/W_{DC}$	$/W_{DC}$	$/W_{DC}$	$/W_{DC}$	$/W_{DC}$	$/W_{DC}$	$/W_{AC}$	hours storage[b]	CF (%)	$/W_{AC}$	hours storage[b]	CF (%)
2010	4.00	4.00	6.00	6.00	5.00	5.00	7.20	6	43	7.20	6	43
2020	1.00	2.51	1.50	3.78	1.25	3.36	3.60	14	67	6.64	6	43
2030	1.00	2.31	1.50	3.32	1.25	2.98	3.60	14	67	5.40	6	43
2040	1.00	2.16	1.50	3.13	1.25	2.79	3.60	14	67	4.78	6	43
2050	1.00	2.03	1.50	2.96	1.25	2.64	3.60	14	67	4.78	6	43

V. Conclusion

Photovoltaic solar panels (PV) and concentrated solar power (CSP) are the most two commonly deployed technologies and are expected to have a rapid growth in both the short- and long-terms. Installations of CSP and PV electricity generation devices are growing rapidly. The PV share of electricity generation is greatly reduced as CSP is introduced into the model.

This paper provided a brief summary for those who are interested in solar energy technologies and as a reference for those who want to invest or work in this field. PV and CSP technologies were discussed and reviewed their structure, performance, advantages and drawbacks. In addition, they have been evaluated and compared their mechanism, structure, and efficiency, along with other technical details.

This study shows that PV systems present a noticeable cost reduction as compared with CSP systems. However, the effective energy storage offered by CSP systems make than relevant competitors to PV systems.

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