energies

Review

Concentrating Solar Power Technologies

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Received: 3 February 2019; Accepted: 12 March 2019; Published: 18 March 2019

Abstract: Nowadays, the evolution of solar energy use has turned into a profound issue because of the implications of many points of view, such as technical, social, economic and environmental that impose major constraints for policy-makers in optimizing solar energy alternatives. The topographical constraints regarding the availability of inexhaustible solar energy is driving field development and highlights the need for increasingly more complex solar power systems. The solar energy is an inexhaustible source of CO_2 emission-free energy at a global level. Solar thermal technologies may produce electric power when they are associated with thermal energy storage, and this may be used as a disposable source of limitless energy. Furthermore, it can also be used in industrial processes. Using these high-tech systems in a large area of practice emboldens progress at the performance level. This work compiles the latest literature in order to provide a timely review of the evolution and worldwide implementation of Concentrated Solar Power—CSP—mechanization. The objective of this analysis is to provide thematic documentation as a basis for approaching the concept of a polygeneration solar system and the implementation possibilities. It also aims to highlight the role of the CSP in the current and future world energy system.

Keywords: concentrated solar power (CSP), installed capacity; solar energy resources; solar thermal plants; thermal energy storage (TES)

1. Introduction

Prefacing the improvement of inexhaustible energy supply worldwide and non-polluting power sources [1,2], represents one of the major purposes of power generation at a global level [3–5]. Renewable energies (sunlight, sunscreen, water strength, biomass, wind power) and renewable raw materials are alternatives to fossil resources [3]. Solar activity represents one of the purest types of energy [6]. The huge amount of this type of energy underlies almost all natural processes on Earth [7]. It is, however, quite difficult to capture and store in a usable form (mainly heat or electricity) [8,9] that would facilitate its subsequent use [10].

The potential of solar resources, which far exceeds the potential of fossil fuels, is given by the following characteristics [1]:

- Solar resources are inexhaustible (the Sun provides the Earth with 15,000 times more energy than the annual energy consumption of atomic or fossil energy; the solar source can supply the Earth's energy needs for at least five billion years);

- Solar resources are wholly or partly available everywhere, assuming regional decentralized operation;
- The transformation of solar resources into secondary energy and in secondary materials like heat, fuel, electricity does not emit CO_2 not shielding the global environment;
- There is the possibility of developing a sustainable civilization model [1].

Solar Thermal Energy (STE) is the most important type of solar power activity and represents one of the important technology resources, producing energy useful in various applications such as: building, electromobility and manufacturing. The integration with thermal energy storage (TES) comes with the possibility to make STE unique and dispatchable when mixed with other inexhaustible sources of energy. For a long period, expansion of the thermal solar activity industry has been associated with TES theory. It is important to provide high tech sources which facilitate the distribution of the demanded energy supply [11].

Unlike photovoltaic (PV) panel technologies, Concentrated Solar Power (CSP) has an inherent capacity to store heat energy for limited intervals of time for later conversion into electricity. When combined with thermal storage capacity, CSP plants are able to produce electricity even when clouds block the Sun or after sunset. [12]. Additionally, for instance, one megawatt of installed CSP avoids the emission of 688 tons of CO_2 compared to a combined cycle system, and 1360 tons of CO_2 compared to a coal/steam cycle power plant. One square mirror in the solar field produces 400 kWh of electricity per year, avoids 12 tons of CO_2 emission, and contributes to 2.5 tons savings of fossil fuels during 25-year operation life time [13].

This work aimed to provide a state-of-the-art review of the development of CSP technologies over the last decade. First, the article provided a summary on the status of the EU's main objectives for renewable energy sources (RES) development, which intended to highlight the role of the CSP in the current and future energy system of Europe. The main CSP technologies are presented and the suitability map for installation of solar thermal power plants according to the direct normal irradiance (DNI) was illustrated. There is discussion regarding the worldwide stage of installation of capacities based on CSP technology, as well as CSP plants that are currently operating or under construction. The goal of this review was to provide a thematic documentation that can be a starting point for developing a research project within National Research and Development Institute for Cryogenic and Isotopic Technologies—ICSI Rm. Valcea, ICSI Energy Department. This work has already achieved results in some "smart city" examples in Europe [14]. It aimed to approach the concept of a polygeneration solar system, which involved the possibility of obtaining several forms of useful energy from solar resources: electricity, thermal energy (heat), mechanical work produced by steam, chemical energy in the form of hydrogen (fuel), cooling energy, light flux, etc.

Romania, one of the EU members, through energy policies, adopted strategies and research activities [15], has an intense orientation towards the world solar economy [16], which requires a revolution in energy technology, making the technical development of productive forces replicable internationally [1].

2. Materials and Methods

To compile the review based on a literature research of Concentrated Solar Power (CSP) technologies for sustainable power generation, existing relevant studies that were analyzed based on different types of CSP along with thermal energy storage (TES) technologies, and the worldwide state of implementation of these concepts have been identified.

A systematic literature search was carried out in Science Direct, MDPI, ResearchGate, Google Scholar and specialized technical platforms to identify relevant studies involving review analysis of different types of CSP and TES technologies and installed capacities, during the last 10 years. The concept of CSP technologies is not new, and a significant number of studies have already been conducted by researchers. The identified research works have been characterized according to the technologies reviewed, methodology adopted and the sustainability parameters discussed.

3. Considerations Regarding the CSP Technologies

3.1. Main Policies and Objectives for Renewable Energy Sources (RES) Development

The power of the sun and of the wind, as well as the power provided by biomass and biofuels, along with geothermal and hydro power energy are used as alternatives for fossil fuels to avoid the emissions that can trigger the greenhouse effect, and reducing the dependency volatility for fossil fuels, especially oil and gas [4,17,18].

The future post 2020 timeframe study, as well as the EU legislation on the promotion of renewable sources is under debate. The fundamental process of society's development is based on the availability of an inexhaustible power supply [3,19]. Contributing to most of the proposed energy requires, ensuring the transition to a sustainable energy system, the security of supply, reduction and even elimination of the greenhouse gas emissions, and the industrial development, that would lead to job growth and significantly lower energy costs [20]. The objectives of "20-20-20" strategy to be fulfilled by 2020 have set the following three key targets:

- 20% reduction in EU greenhouse gas emissions compared to 1999 levels;
- 20% increase in the share of energy produced from renewable sources in the EU;
- improving the energy efficiency in the EU by 20% [15].

As the European energy system faces an increasingly pressing need for sustainable, affordable and competitive energy for all citizens, the European Commission adopted on 30 November 2016 the legislative package "Clean Energy for All Europeans", which seeks to implement strategies and measures to achieve the objectives of the Energy Union for the first ten-year period (2021–2030), in particular for the EU's 2030 energy and climate objectives, and refers to: energy security, energy market, energy, de-carbonization, research, innovation and competitiveness [15,19,20].

In a wider perspective, the EU established a set of long-term objectives in roadmaps by 2050. Regarding the building sector, the main three roadmaps are:

- The EU's objective of moving to a low-carbon, competitive economy by 2050, which identified the need to reduce carbon emissions in the residential and service sectors (generically referred to as the real estate sector) by 2050 compared to 1990 levels;
- Energy Perspective 2050, where "increasing the energy efficiency potential of new and existing buildings is essential" for a sustainable future;
- The Energy Efficient Europe Plan, identifying the real estate sector as one of the top three sectors responsible for 70% to 80% of the total negative environmental impact. Achieving better construction and optimizing their use within the EU would reduce by over 50% the amount of raw materials extracted from the underground and could reduce water consumption by 30%.

These roadmaps are a long-term aspiration that is not only desirable from a social and economic point of view, but also ecologically essential [15,19,20]. In many countries, the strong development of the heating sector from renewable sources [21] has been a key factor in achieving and surpassing the intermediate targets in these EU member states. This is true, for example, in Bulgaria, Finland and Sweden, where development was mainly driven by the use of low-cost fuel from biomass. The use of an inexhaustible supply in the field of transport [22] has lagged behind in most countries, except for Sweden, Finland, Austria, France and Germany.

However, most Member States are about to meet and even surpass their targets by 2020, based on the planning and assessment of current policies [3,19,20]. This makes it an entirely possible target not only for the EU members, but also for the entire EU (Figure 1) [15].

Solid biomass fuels were the main factor that produced heat from inexhaustible sources in 2013 [23], while during 2014, a report was published in regards to the production of heat and electricity based on the solid sustainable and gaseous biomass. This report was published by the European Union and contained information on current planned EU actions that were supposed to maximize the benefits of the biomass usage while avoiding negative impacts on the environment [15].

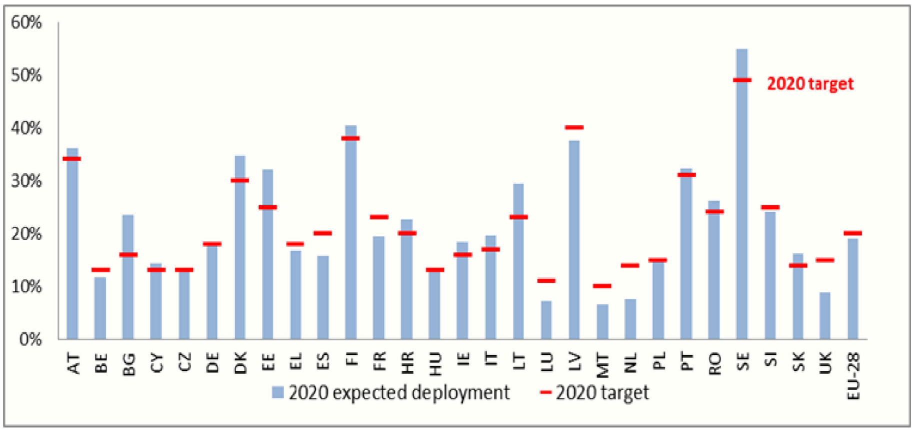


Figure 1. Implementation chart of renewable energy sources (RES) in the EU member states and 2020 targets [15].

The power plants based on concentrated solar radiation (CSP) are considered to be an interesting alternative for generating electricity from renewable energy on a large scale worldwide [24,25]. Although their development has not been so rapid, some relevant projects were still in pending or cancelled in countries like Australia, and expansion of solar heat supply capacity is expected to be taken into consideration in the following years [26].

Electricity power, the fastest growing form of energy [27], is the power sector that contributes more than any other to the reduction of fossil fuels worldwide [28]. By 2040, an increase of around 40% (based on the current fleet) of the electricity requirement is expected. This increase by 7200 gigawatts may substitute the existing energy generators [5,29]. The strongest growth of renewables in many countries raises their share worldwide power generation, to one third by 2040 [15,30].

Due to global population industrialization and growth, the energy demand has increased dramatically. We can obtain renewable energy through natural resources such as geothermal, biomass, wind and solar heat power. This is the focus of most countries, especially due to the sustainability benefits by reduction of CO_2 and greenhouse gas emissions.

Among the technologies based on the use of solar sources to produce energy, the technology using parabolic mirrors outstanding by high efficiency, compactness and the advantage of modularisation that allows them to be placed in isolated places, independent of access to conventional energy sources. This technology is part of the radiation focusing category, the mirrors having a role of capturing and concentrating incident solar rays in the focal area where the receiver is located, which is usually coupled to an electric generator. Thus, solar energy is transformed into thermal energy into the receiver, then to mechanical energy in the engine and finally to electricity in the generator [31]. Coupling of technologies through integration of thermal energy storage (TES) to concentrating solar power (CSP) brings uniqueness to this type of power converter among all other renewable energy generating alternatives [30,31].

3.2. Direct Normal Irradiance (DNI)

Direct Normal Irradiance (DNI) is defined as the solar irradiance collected by a normal plane, directly from the Sun, being of high importance, respectively is the basis of the functioning principle of CSP technology [32–34].

Figure 2 presents a map of the global distribution of direct normal irradiation, where four zones can be further distinguished [35–37] based on their suitability for the installation of solar thermal power plants (Figure 3) [37]. Thus, zone I—excellent—has great potential and records maximum DNI values of 3652 kWh/m^2/y. It is followed by zone II—having a good potential for exploitation of DNI, which has average values of 2800 kWh/m^2/y. Zone III allows to install thermodynamic solar power plants with DNI values of 1700 ÷ 2100 kWh/m^2/y. And, finally, area IV—not suitable for these types of energy generation systems that have a DNI of 365 ÷ 1700 kWh/m^2/y [37,38].

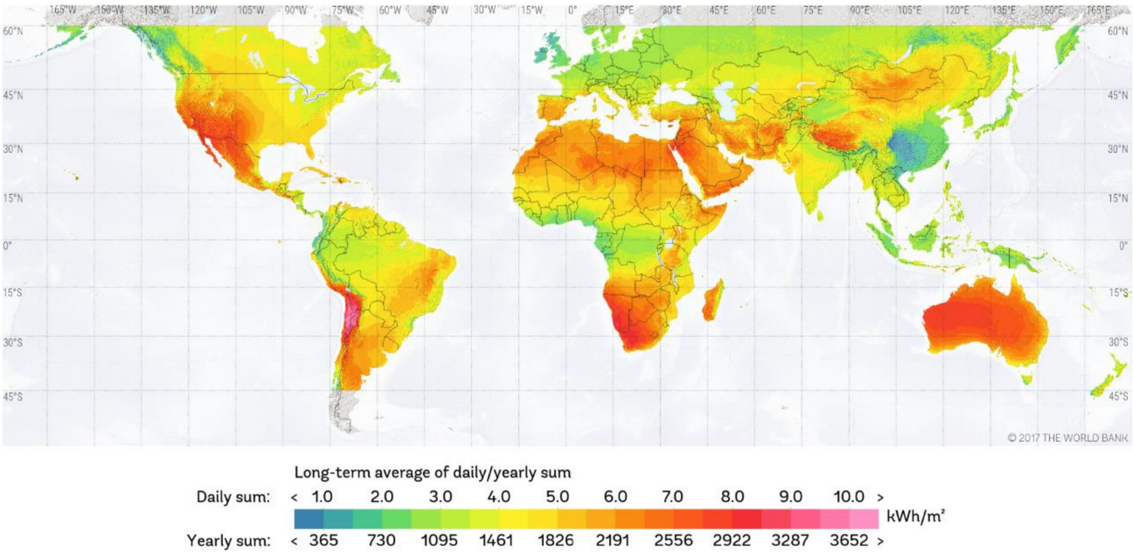


Figure 2. Distribution map of direct normal irradiation [36].

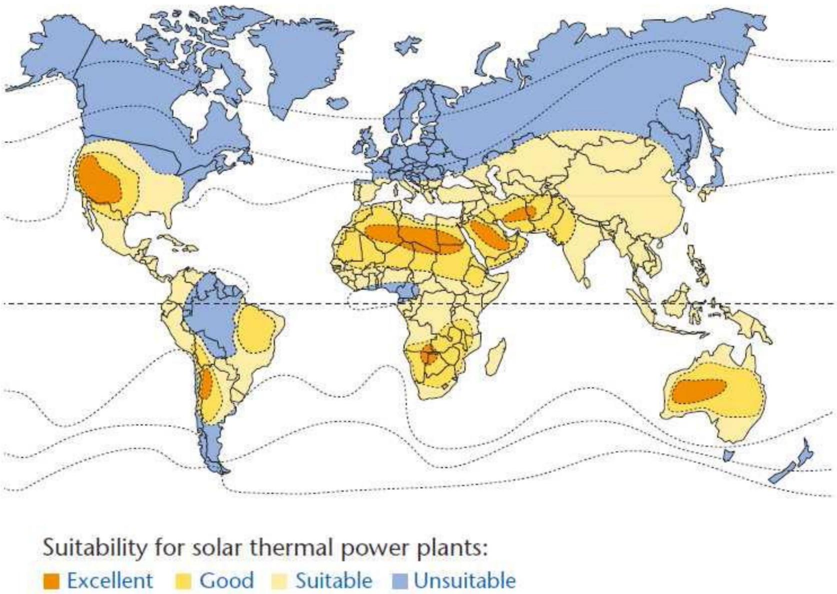


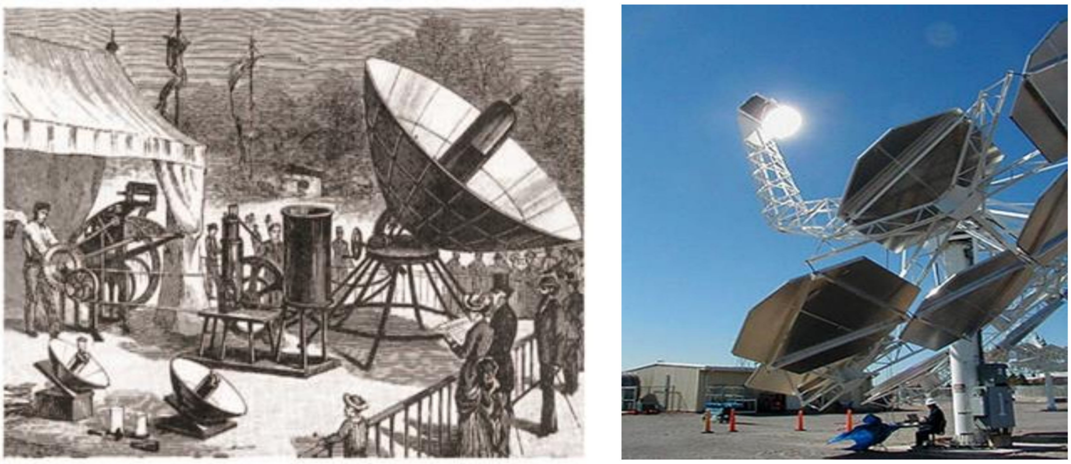
Figure 3. Suitability map for installation of solar thermal power plants [37].

For an efficient operation of thermal solar plants, DNIs need to record values above 1800 kWh/m^2/y [39]. The most favorable CSP resource [37] areas are thus in North Africa, the south-western United States, northern Mexico, north-western India middle East, southern Africa, Chile, Australia, Peru and the western parts of China. Other relevant areas such as southern areas from Europe, Turkey and US, central area of Asia, Brazil and also Argentina and China, are included [40,41].

3.3. The Concept of Concentrated Solar Power (CSP)

One of the first studies on the possible use of sunlight, dating back to 1774, in the late 18th century, belongs to Antoine Lavoisier who created a large optical device containing a glass lens to focus and concentrate the sunlight on the surface of a burning material. Later, in 1878, a parabolic collector was designed and built to test the impact of the Sun's rays on a steam boiler to heat the water from its interior to the boiling point, and to release steam under pressure. This boiler by means of a mechanical device, was ran and powered a printing press. [42,43] Figure 4a presents the first concept of a solar parabolic collector.

Sophisticated solar power (CSP) technologies are currently under development but are still not as accessible as conventional photovoltaic panels in providing confidence and reliability [44,45]. Figure 4b presents a modern solar parabolic concentrator concept [46].



(**a**) (**b**)

Figure 4. Solar parabolic collector [43,46]. (**a**) First concept; (**b**) Modern concept.

Solar energy concentrating systems use parabolic mirrors that reflect the sunlight on a single point over the receiver's surface from where it is collected and transformed into thermal and electrical energy. Parabolic mirrors are designed to focus solar radiation on the receiver, which heats the gas to a relatively high temperature, which is then used to move a turbine or steam to power a Stirling engine running an electric generator, thus producing electricity [31,43].

Thermodynamic solar systems put into operation optical concentrators that exploited direct sunlight. The main specific of CSP technology(illustrated in Figure 5), when compared to other renewable energy conversion equipment is represented by a thermic stock system that generates electrical power during intervals of time with cloudy skies or the sun setting.

As compared to photovoltaic panels (PV), CSP uses DNI in order to provide heat and electricity without CO_2 emissions where the DNI level is higher in comparison with others [43,47,48]. The CSP commercial technologies are the following [39,49–52]:

(a) *Linear concentrating systems* which include parabolic troughs and linear Fresnel reflectors: Parabolic Parabolic Troughs (PTs) usually count on oil as synthetic fuel to facilitate an exchange of power from the collector pipes into heat. During this process, the water is boiled and it evaporates, running the turbine and driving the plant to create electric energy. On a commercial basis, we can say that CSP is proved to be the most established technology. Linear Fresnel reflectors (LFR) make up a series of ground-based flat mirrors placed at angles that help concentrate the sunlight, in order to locate a receiver from several meters above. Compared to PT, the LFR shows a lower performance [39,49–52].

(b) *Solar Power Towers (STs)* increase the number of computer-assisted mirrors to track the Sun in an individual way over two axes. In this way it concentrates the solar irradiation onto a single angle which we can fix on the top on the tower, placed in a central point; there, the heat produced by the sun conducts a thermodynamic cycle and produces electricity, so that the ST plants can approach higher temperatures than the other two above mentioned systems (PT and LFR) [39,49–52].

(c) *A Parabolic Dish (PD)* is made up of a parabolic dish-shaped concentrator that mirrors the Direct Normal Irradiance into a receiver located at the focal point of the dish. The main advantages of PD technologies include high energy efficiency (up to 30%) and modularity (5–50 kW), in addition to being particularly suited to distributed generation systems [39,49–52].

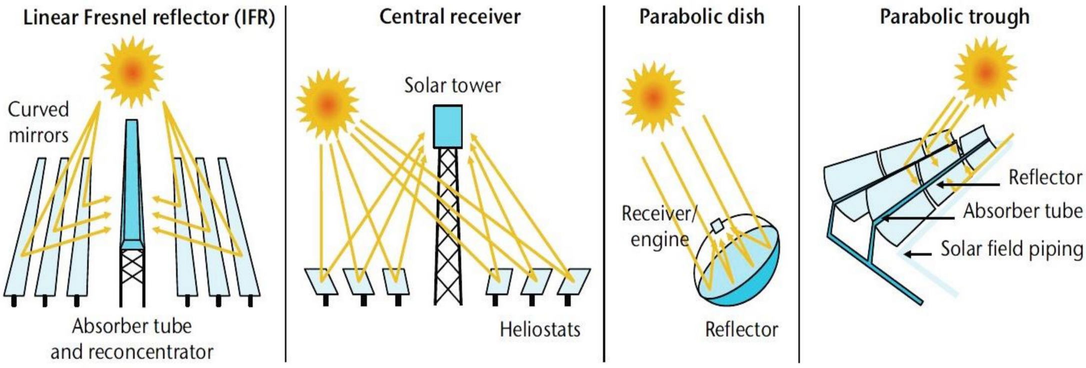


Figure 5. Main CSP technologies [53].

Based on the literature [54–62], the specific features of CSP technologies are presented in a comparative manner in Table 1.

Table 1. Comparison of CSP technologies [54–62].

CSP Type	Operating Temperature (°C)	Ratio of Solar Concentration	Thermal Storage Suitability	Average Annual Efficiency	Land Use Efficiency (Total Area/Power)
Parabolic Trough	20–400	15–45	Suitable	15%	3.9
Linear Fresnel Reflector	50–300	10–40	Suitable	8–11%	0.8–1
Solar Trough	300–1000	150–1500	Highly suitable	17–35%	5.4
Parabolic Dish	120–1500	100–1000	Difficult	25–30%	1.2–1.6

PT systems occupy a large area, having low thermodynamic efficiency due to their low operating temperature. They have a relatively low installation cost and a large experimental feedback. Furthermore, LFR has thermodynamic efficiency due to the low operating temperature, but low installation cost. ST has high thermodynamic efficiency due to a high operating temperature; it occupies a large area, it has high installation cost and records high heat losses. Finally, PD occupies small area, features high thermodynamic efficiency due to high operating temperature, but it requires a high installation cost [54–62].

A percentage of 85% of all CSP research projects is carried out on the parabolic troughs technology; accordingly, the existing data regarding operating experience and cost information generally refers to PT energy systems.

Levelized Cost of Electricity (LCOE) estimated for CSP is still high as compared to the other renewable technologies, as shown in Table 2 [55,63–66].

Power generating technologies based on alternative energies are subject to constant research and development. Costs are expected to decline in the near future due to various pilot projects currently underway in this field being validated and implemented on a large scale (including energy storage solutions).

Table 2. LCOE estimates (€c/kWh) [55,63–68].

Technology	Europe	USA	China
CSP	17.6–43.10	17.6–43.10	16.70–40.50
PV	8.80–22.00	9.70–20.25	6.95–13.15
Wind	6.25–10.30	5.40–11.95	4.30–8.20
Hydro	8.80	7.95	2.65
Coal	10.55–14.95	6.20	3.10–3.45

4. Discussion Regarding the Stage Installation of Capacities based on CSP

4.1. General Considerations on RES

Figure 6 shows a country ranking on total renewable energy production capacity as of the end of 2017 [68].

	1	2	3	4	5
POWER					
Renewable power capacity (including hydropower)	**China**	United States	Brazil	Germany	India
Renewable power capacity (not including hydropower)	**China**	United States	Germany	India	Japan
Renewable power capacity *per capita* (not including hydro)³	**Iceland**	Denmark	Germany/Sweden		Finland
Bio-power generation	**China**	United States	Brazil	Germany	Japan
Bio-power capacity	**United States**	Brazil	China	India	Germany
Geothermal power capacity	**United States**	Philippines	Indonesia	Turkey	New Zealand
Hydropower capacity⁴	**China**	Brazil	Canada	United States	Russian Federation
Hydropower generation⁴	**China**	Brazil	Canada	United States	Russian Federation
Solar PV capacity	**China**	United States	Japan	Germany	Italy
Solar PV capacity *per capita*	**Germany**	Japan	Belgium	Italy	Australia
Concentrating solar thermal power (CSP)	**Spain**	United States	South Africa	India	Morocco
Wind power capacity	**China**	United States	Germany	India	Spain
Wind power capacity *per capita*	**Denmark**	Ireland	Sweden	Germany	Portugal
HEAT					
Solar water heating collector capacity⁵	**China**	United States	Turkey	Germany	Brazil
Solar water heating collector capacity *per capita*	**Barbados**	Austria	Cyprus	Israel	Greece
Geothermal heat capacity⁶	**China**	Turkey	Iceland	Japan	Hungary

Figure 6. Country ranking on total renewable energy production capacity for 2017 [68].

From Figure 6, it can be seen, that the countries with the largest renewable energy production are China, the US and Brazil, followed by Germany and India. In terms of power generated by CSP capacity, Spain ranks first in the world ranking, being followed by United States that ranks second, and then South Africa, India, Morocco and China. In terms of solar water heating collector capacity, China ranks first in the world ranking, being followed by United States, Turkey, Germany and Brazil.

4.2. Worldwide Capacity of CSP Technologies

Figure 7 shows the concentrating solar thermal power global capacity by country and region over the period 2007–2017. From the statistical data presented in Figure 7, there can be observed a significant increase in renewable energy capacity from 0.4 gigawatts produced in 2007 to 4.9 gigawatts in 2017. Despite the fact that the global capacity increased by only over 2% in 2017 compared to 2016, the CSP industry was active, with a pipeline of about 2 GW of projects under construction around the world, especially in the Middle East and North Africa (MENA) region and in China [37].

Concentrated solar power technologies (CSP) have helped boost developing countries with a high level of direct normal irradiation (DNI) [35] and a specific strategic and/or economic alignment, benefitting from the advantages of these technologies [40]. CSP technologies benefit from better support for energy policies, low oil and gas reserves with limited access to electricity grids, or stringent energy storage needs, thus achieving a strong industrialization and creating new jobs [33].

Ongoing research conducted mainly in Australia, Europe, and the United States, has kept concentrating on the development and improvement of Energy Storage Technology (TES) [69].

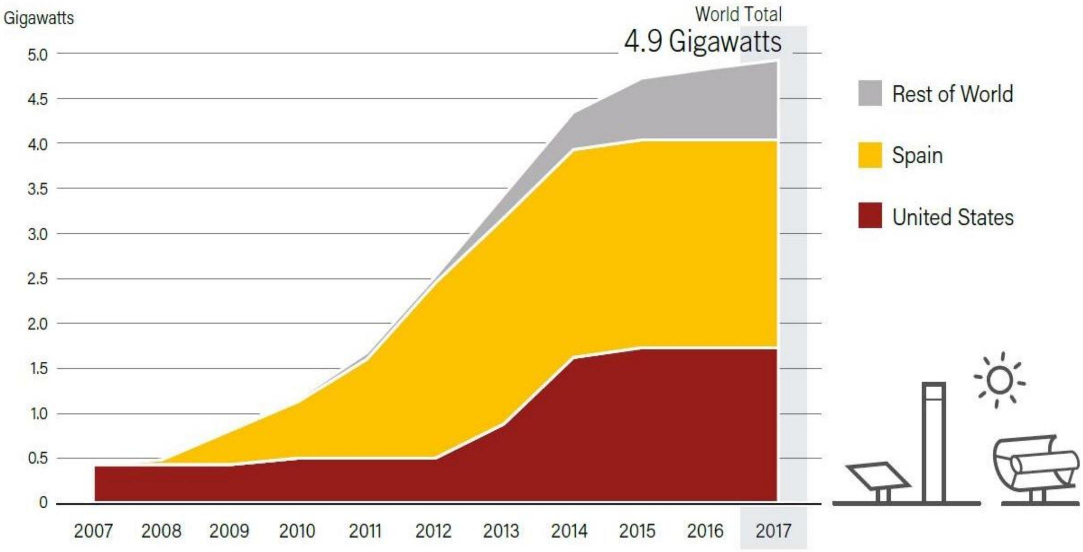


Figure 7. Concentrating solar thermal power global capacity by country and region over the period 2007–2017 [68].

Figure 8 shows the global storage capacity of solar thermal energy during the period 2007–2017. According to the statistical data presented in Figure 8, there is significant increase in the global storage capacity of thermal energy produced from concentrated solar radiation, from the supply of about 0.04 megawatts-hours in 2007 to 12.8 gigawatts-hours, in 2017.

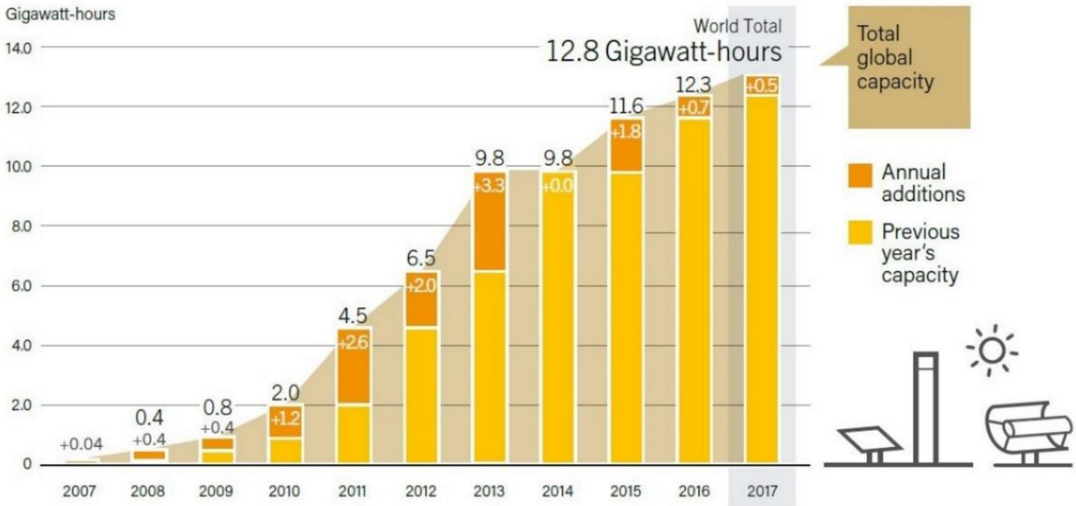


Figure 8. CSP thermal energy storage global capacity and annual additions, 2007–2017 [70].

Figure 9 shows the STE worldwide capacity organized by main CSP technologies [71]. A significant percentage of installations in operation or under construction have linear gradient concentrating systems such as parabolic troughs, which operate both with and without storage. The trend was to increase the use of solar-tower technology. Forty one (41) percent of thermal energy storage systems and 41% of all STE plants under construction are in development under Fresnel reflectors, which operate without storage.

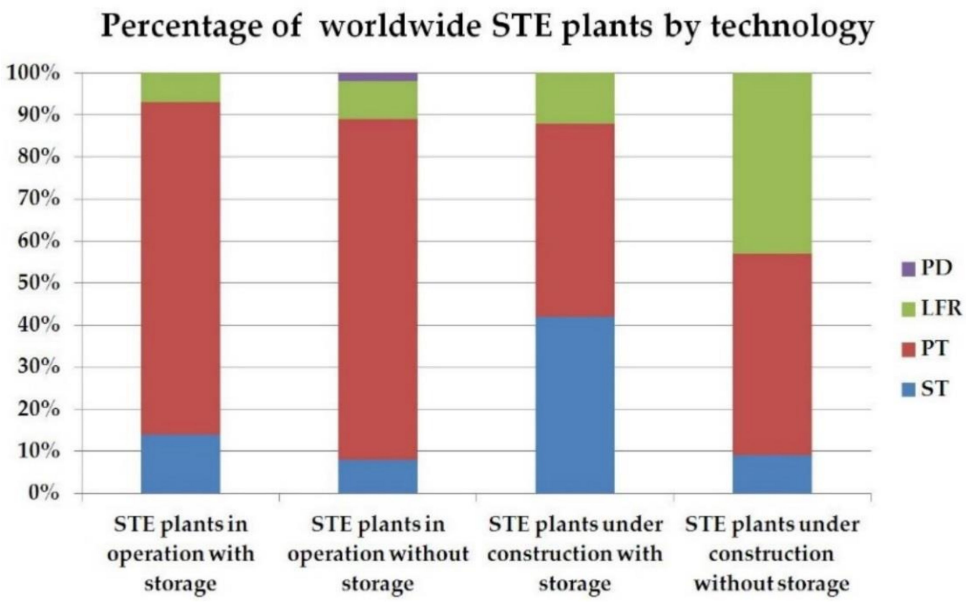


Figure 9. STE worldwide capacity categorized by technology and with/without storage [72,73].

Parabolic dishes are present in a low percentage of approximately 2% of the total STE plants in operation without storage, this type of technology being in the stage of research and implementation at the level of practical applications [72,73].

5. CSP Sunflower 35 Experimental Equipment

Under the research project "ROM-EST: Research Laboratories for Energy Storage", following the research study, a Sunflower 35 solar concentrator was purchased together with a Stirling energy unit to produce energy and heat from concentrated solar energy.

The performance of the Sunflower 35 module according to the manufacturer's specifications is as follows:

- Stirling engine type α, maximum power of 10 kWe at 1500 rpm, useful volume 183 cm^3, maximum yield 25%.
- Maximum power 10 kWe + 25 kWt (for average direct radiation of 1000 W/m^2), ~400 V AC/ 50 Hz/3 phases, IP55, min.
- Max. 600–700 °C.
- Average working pressure is 15 MPa, helium working gas, engine volume 2 L.
- PCU weight: 500 kg.
- Thermal agent control system with 50 °C inlet cooler water temperature and 60 °C hot water outlet temperature from the cooler.
- electrical power in operation: 2–10 kWel;
- maximum thermal flow (in cogeneration) to direct normal radiation> 1000 W/m^2: about 25 kWt;
- thermal flow in operation (in cogeneration system): 9–25 kWterm;
- simultaneous supply of heat and electricity up to 35 kW;
- total annual output of up to 85 MW;
- high efficiency: 25% for power generation, 70% for cogeneration;
- up to 3600 operating hours per year;
- about 26 MW of electric power supplied annually;
- about 59 MW of heat supplied annually;
- completely dispatchable generation;
- control of the level of power generated;

- precision of the Sun tracking system.

The Stirling engine did not require water consumption for power generation or for cooling cycles (closed circuit operation). The Stirling Technology Conversion Unit (PCU 35) of 35 kW was equipped with a 25% efficiency SBT V-183 thermal engine.

This equipment is sturdy and durable, adapts to and resists extreme operating conditions such as temperatures from −20 °C to +50 °C, 100% humidity, snow, sand, wind and dust.

The installation of the solar concentrator together with the power unit and the necessary accessories were initially underwent a preliminary study, which consisted in positioning simulation procedure, which was a preconception of the actual placement and installation mode in the location established. Taking into account these aspects, the installation and assembly positions of the main equipment will be anticipated in a preliminary manner.

The surface requirement for the solar concentrator is about 10×20 m^2, with a favorable position, so as to ensure maximum solar radiation at the lowest shading factor. During the first stage of the installation and commissioning phase, the solar concentrator was installed together with the technical annex for the control and control of the processes.

At a later stage, the power unit with all necessary accessories will be mounted on the support arm of the concentrator, after prior testing of the equipment.

For the safety and proper functioning of the equipment, they must be mounted and installed in a safe location, where they must operate at a constant temperature and protected from bad weather.

For this purpose, a technical annex for the installation of technical equipment for process control and control is placed near the installation, being protected against dust and impurities, with a controlled thermal regime throughout the seasons.

The annex will be divided into two rooms with the following use:

- installation and mounting of the equipment for thermal energy storage;
- installing and mounting of the electricity storing equipment.

Figure 10 shows the installation of the solar concentrator working position together with the technical annex for command and control.

Figure 10. Installed solar concentrator in its working position.

The parabolic metal frame of the solar concentrator was designed to be assembled to the ground by means of a special mounting system that allows quick and easy installation of the building.

The support pillar was positioned vertically in the reinforced concrete foundation on which the solar concentrate drive system was mounted, which is shown in Figure 11.

Figure 11. Solar concentrator support pylon.

After mounting the support pillar, the parabolic metal frame assembly was positioned by the arm and secured to the propulsion system.

Install the control system with all the quick connect connections that are installed on the control board interface of the propulsion system. The Stirling motor assembly of the test equipment is presented in Figure 12.

Figure 12. The Stirling motor assembly.

6. Conclusions

There is no doubt regarding the great global potential of solar energy which is a clean renewable energy form. It has the disadvantage of only supplying intermittent power for electricity generation. This inconvenience can be removed through CSP technology, which together with a suitable heat storage system can generate electricity even with cloudy skies or after sunset. Thermal Energy Storage allows the mitigation of short fluctuations and extension of electricity supply to more desirable periods, making Concentrated Solar Power dispatchable [74].

This work outlines an analysis of the latest scientific literature in order to achieve the state-of-the-art review of the development and worldwide implementation of CSP and TES technologies. In this respect, the following aspects were presented: CSP's position in worldwide policies and targets for Renewable Energy Sources (RES) development, global distribution DNI map alongside to the global map of suitability for installation of solar thermal plants, the concept and the main CSP technologies together with the main TES methods, and, in the end, there have been discussions about the worldwide stage installation of capacities based on CSP. The conclusions can be summarized as follows:

- CSP technology along with TES maximizes the potential of solar energy through polygeneration, providing the opportunity to obtain more energy forms used by a unique resource.
- The main specific characteristic of CSP technologies compared to other renewable energy conversion equipment is the use of a heat storage system to generate electricity even when cloudy or after the sunset due to DNI, in contrast to the photovoltaic panels (PV).
- A percentage of 85% of all CSP research projects is carried out on the parabolic troughs (PT) technology, according to the data available on operating experience.
- Sensible heat storage technology is the most used in CSP plants in operation.
- LCOE estimates for CSP are still relatively high, but these technologies are in constant research and development, and as a number of pilot projects currently underway in this field will be validated and implemented on a large scale, including energy storage solutions, and they are expected to result in declining costs in the near future.
- In terms of power generated by CSP capacity, Spain ranks first in the world ranking, being followed by United States, which ranks second, and then South Africa, India, Morocco, China.
- From the statistical data presented by U.S. National Renewable Energy Laboratory (NREL), a significant increase in CSP capacity from 0.4 gigawatts produced in 2007, to 4.9 gigawatts in 2017, can be noticed.
- Several countries, in addition to the different policies for solar power generation, with which they face the appropriate system planning and operations for power supply systems to provide reliable quality and electrical power, make use of new eco-sustainable plants systems to reduce pollutant emissions and energy consumption [75–77].

One R&D project allowed ICSI Râmnicu Vâlcea to purchase an integrated CSP Dish Stirling SUNFLOWER 35 type system for polygeneration of energy by concentrating solar irradiation, which has been installed in the current location, together with all the accessories necessary for good operation in optimal conditions. The Stirling engine power unit was installed within the CSP Dish Stirling SUNFLOWER 35 integrated system, but only after this equipment had been pre-tested and put into operation.

Author Contributions: Conceptualization, G.B. and C.F.; Methodology, R.-A.F., M.S.R.; Software, A.L.; Validation, G.B., R.-A.F. and M.S.R.; Formal Analysis, M.R.; Investigation, G.R. and A.E.; Resources, C.F.; Data Curation, C.F.; Writing—Original Draft Preparation, R.-A.F., G.R.; Writing—Review & Editing, M.S.R.; Visualization, A.L.; Supervision, G.B., C.F.; Project Administration, C.F.; Funding Acquisition, M.S.R.

Funding: This research received no external funding.

Acknowledgments: This work was supported by a grant of the Romanian Ministery of Research and Innovation, CCCDI-UEFISCDI, project number PN-III-P1-1.2-PCCDI-2017-0776/No. 36 PCCDI/15.03.2018, within PNCDI III.

Conflicts of Interest: "The authors declare no conflict of interest."

Nomenclature

Abbreviation	Definition
CO_2	Carbon dioxide
CSP	Concentrated Solar Power

DNI	Direct Normal Irradiance
EC	European Commission
EU	European Union
ISO	International Organization for Standardization
LCOE	Levelized Cost of Electricity
LFR	Linear Fresnel Reflector
MENA	Middle East and North Africa
PD	Parabolic Dish
PT	Parabolic Trough
PV	Photovoltaic Panel
RES	Renewable Energy Source
STE	Solar Thermal Energy
TES	Thermal Energy Storage
USA	United State of America
WMO	World Meteorological Organization

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