Opportunities of Concentrated Solar Power

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Concentrated solar power (CSP) has been considered an emerging technology that could disrupt the energy production sector. The possibility to store the electricity generated during the sunny operating hours in the form of heat enhances energy dispatchability and gives CSP a unique value proposition that conventional renewable energies cannot provide cost-efficiently since it requires the integration of costly large-scale battery systems.

Keywords: solar energy ; power generation ; solar heating ; solar tower ; dispatchability ; innovative materials ; standardization ; barriers ; drivers

1. Introduction

Renewable energy technologies are gaining importance in the global electricity grid mix, and Concentrated Solar Power (CSP) is one of the most debated [1][2][3][4][5][6]. The Strategic Energy Technology (SET) Plan targets the deployment of low-carbon technologies in a fast and cost-competitive way to boost the transition towards a climate-neutral energy system [7]. In Activity 5 of Research and Innovation (R&I) activities, the SET-Plan urges as a priority the development of “Improved central receiver molten salt technology”. Wind and photovoltaics (PV) have reached an outstanding installed capacity of more than 1000 GW worldwide [8], achieving reliable and cost-competitive green energy. However, both technologies are not dispatchable, which is an increasingly important feature for the electrical grid and therefore limits their penetration [9]. CSP concentrates the sun’s energy into high-temperature heat used to (i) produce electricity via thermodynamic cycles at high efficiency, (ii) hybridize with heat from other sources such as fossil or renewable fuels, and (iii) store it cost-effectively to be delivered when required by the grid. These are the reasons why CSP is a flexible and dispatchable renewable energy technology (RET) that must become a key element for a sustainable energy transition balancing the grid scenarios in a wise way and allowing maximum penetration to other RETs.

2. Economic Considerations of Grid-Connected CSP Towers and the Business Opportunity for Thermal Energy Storage

It should be remembered that CSP has an important competitive advantage over other renewable energies since the increased penetration of non-dispatchable RES reduces the grid flexibility and increases the need for systems that allow decoupling weather-driven generation from demand. By adding thermal-to-electricity storage to CSP plants, new business opportunities arise for CSP with TES to offer such services to the network operators. If the LCOE of PV power plants and onshore wind farms would incorporate an additional storage system with large scale batteries, it would result that the CSP with the LCOE of TES would be lower, because the thermal storage in CSP plants is already considered in the LCOE of CSPs [10]. At the end of 2019, an estimated 21 GWh of TES operated together with CSP plants [11].

Another approach to fairly compare CSP plants with other renewable and conventional power plants is to consider different indicators, such as the levelized avoided cost of electricity (LACE). The LACE represents the potential cost of providing electricity to the grid through a new power plant project, and it is calculated as the weighted average cost of the marginal cost of electricity dispatch [12]. In order to make the right calculations, LACE takes into account different territorial indicators, such as daily and seasonal variation in demand, the existing grid mix generation, the heat produced, the fuel cost and the ability to dispatch on-demand power [13]. In simple terms, since the avoided cost can be seen as the potential revenues of the candidate project and the LCOE as the cost to produce electricity, if the LACE is higher than the LCOE, the related plant is considered economically attractive. Thanks to the fact the LACE considers many different local and dispatchable parameters to calculate its final value, if considered when comparing CSP plants to other options, it can boost the CSP option among the others (especially when the thermal/electrical storage is included in the analysis) [14].

3. High-Temperature Concentrating Solar Heat for Industrial Applications

CSP can be used to provide energy and/or process heat to industries. Many industries require heat for their production processes. Current solar heat generators for industrial processes focus on industries using low to medium temperatures, up to 400 °C. Typical processes suitable for the integration of solar heat are the drying of food or products, cleaning, fermentation, and steam generation.

The very high-temperature solar plant opens the way for using concentrating solar heat (CSH) also for high-temperature industrial processes or for the pre-heating phase of very-high-temperature processes. Examples of high-temperature industrial processes (300 °C to 700 °C) are distillation, nitrate melting or forced air drying. Examples of very-high temperature processes (>700 °C) are chemical processing and material transformation processes as used in the cement, steel, or glass industry. All these industries are confronted with increasing costs for fossil fuels and emission rights and increasing pressure from stakeholders and society to reduce their greenhouse gas (GHG) emissions.

4. Materials, the Technological Challenge for CSP Uptake

4.1. Materials for Focal Point Receivers

One of the main concerns regarding the efficiency of CSP is the performance of the materials used to manufacture all the different components of the power plant (receiver, storage system, heat exchangers, etc.) [15]. Another innovation for improving the performance of the CSP materials is to use specific coatings and surface treatments to improve emissivity and thermomechanical properties, such as the use of plasmonic technology based on nanoparticles and the integration of metal-oxide coating by sol-gel deposition on the solar receiver [16][17].

4.2. Heat Transfer Fluids (HTFs)

An additional important matter is related to the thermal energy storage materials: usually, the heat transfer fluid is molten salts or, more rarely, synthetic oil [18]. To increase the working temperature of the energy storage application, new materials, for example, liquid metals (sodium or lead), currently used in nuclear reactors [19], are being investigated to prove the validity of heat transfer fluids that can work with temperatures up to 900 °C [20].

4.3. Materials for Heat Transfer Fluid and Energy Storage Containers

In parallel with innovative heat transfer fluids, the testing of materials with good corrosion resistance, minor oxidation and better self-healing properties than reference commercial ones are currently ongoing [21]. This is the case for some alloys, such as the FeCrAl steels, materials whose properties can be useful for the lead-cooled fast reactor (LFR) community, creating a knowledge transfer that can speed up the technology's development. In any case, on the energy storage side, the use of lead as an HTF requires innovations in the field of advanced steels.

4.4. Materials Outlook

In order to achieve the desired performance, each cited material should be validated through tests that are usually expensive to make, especially when these materials have to be applied on real-sized pilot sites [22]. The research in the solar thermal field is focused on X-ray tomography to analyze the deformation and damage that innovative materials have after being tested [23][24][25][26].

5. Policy Enablers for CSP

Examples of currently available policy instruments are:

- Feed-in tariffs: premium/tariff/payment for newly installed renewable energy sources.
- Net metering: the sales of excess electricity generated by solar systems from households and commercial establishments to the grid.
- Investment tax credits: a percentage of the investments on solar projects, businesses or individuals are allowed to deduct from their taxes.
- Subsidies: a direct monetary aid supplied by a government to a private industrial actor.
- Financing facilitation: financial services such as a renewable energy financing portfolio, low-interest loans or micro-credits, offered by financial institutes to businesses and/or individuals.
- Renewable energy portfolio: penetration targets for renewable energy in the overall electricity supply mix.
- Public investment: government and/or donor-funded projects to support solar energy.

- Government mandates and regulatory provisions: government laws and regulations supporting transmission companies and electricity utilities to supply or purchase electricity generated from renewable energy plants.

6. Barriers, Obstacles and Framework Conditions

All new technologies, especially renewable energies, can face different barriers in order to be developed in a structured and well-functioning energy system. Although utilities, which appreciate the CSP dispatchability, are really glad to give it access to the grid [3][9][27][28], planning and permitting processes can be slow in many countries since authorities are familiar with PV and other renewables but not with CSP [29]. This issue has delayed grid access as well as permissions or access to water or gas networks for many CSP plants. Furthermore, previous to permit confirmation, the related environmental impacts must be analyzed, taking into account the loss of animal habitat, water use, visual impacts and the effects on endangered species. In fact, the pace of the permitting process has been one of the most frequent problems for CSP installation [30].

6.1. Political

The future achievements of CSP depend on suitable countries, producers and consumers sharing a common vision of a sustainable future. According to ESTELA [19], the problem is political: the LCOE should not be considered as the only important parameter to compare different renewable energies.

6.2. Economic

CSP capacity development does not depend only on its LCOE, but on other renewable energies too. If solar PV and wind energy become even cheaper than today's levels, CSP would probably no longer represent an effective alternative for electricity production, considering the IRENA data [31].

6.3. Social

CSP technology is not generally known to the public. Solar-energy-based power generation is typically perceived as photovoltaic power generation [32]. Thus, the great potential of thermal energy storage, and hence, the dispatchable nature of CSP is not sufficiently present in public opinion [19].

6.4. Technological

Currently, commercial molten-salt tower plants are experiencing many technological challenges (durability issues of the receivers and TES tanks, non-optimal solar flux control, limited heliostat calibration possibilities), which result in lower electricity production, and hence, lower productivity compared to the expected ones [33][20].

6.5. Environmental

Probably the most severe environmental concern is the relatively high water consumption of CSP plants [34][35][36].

6.6. Legal

Legal incentives would be required in order to boost the deployment of CSP until economic competitiveness is reached [29]. Subsidies and incentives such as preferential loans, zero land cost and tax support are useful in decreasing the CSP plant LCOEs by almost 20% [12].

7. Recommendations

Further research should be focused on analyzing the political, environmental and economic constraints for the other types of CSP power plants, namely PT and LF, to understand if the problems met for the development of solar towers are the same, or if instead, it results in it being easier or harder to implement CSP projects if based on alternative technologies. This could give policymakers and investors a wider understanding of CSP technology trends. A further study could focus on describing the drivers and barriers in the most suitable regions for CSP that were not included in this study (especially MENA, China and the USA) to understand if the CSP market could have any advantages if implemented in those areas.

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