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Electricity generation costs of concentrated solar power technologies in China based on operational plants

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ABSTRACT

Recent years witnessed a sharp increase of CSP (concentrated solar power) plants around the world. CSP is currently at its early stage in China, with several demonstration and utility-scale plants underway. China's rising electricity demand, the severe environmental pollution from coal-fired power plants, and favorable renewable energy policies are expected to result in a large-scale CSP deployment in the next years. Detailed CSP studies for China are however hardly available. To fill this knowledge gap, this study collects plant-specific data in a national CSP database in collaboration with local CSP experts. On this basis, this study analyzes and benchmarks the costs of parabolic trough CSP, tower CSP, and dish CSP technologies in China by applying an LCOE (levelized cost of electricity) model. The current LCOE for the different CSP plants falls in a range of 1.2–2.7 RMB/kWh (0.19–0.43 US$/kWh). Among the three CSP technology variants discussed, our sensitivity analysis indicates that the tower CSP variant might have the greatest potential in China. We expect a future cost reduction potential of more than 50% in 2020 and a high share of local content manufacturing for tower CSP.

1. Introduction

China's government is increasingly promoting the deployment of renewable energy technologies in order to cope with the country's rising electricity demand and the increasing air pollution and greenhouse gas emissions from fossil-fueled power plants. CSP (Concentrated solar power) plants are considered as one promising renewable-based electricity generation alternative. China's current Twelfth Five-Year Plan for Solar Energy, which was published by the NEA (National Energy Administration) in 2012, includes a 1 GW capacity target for national CSP installations by the end of 2015 [1]. Demonstration projects for all major CSP technologies have been set up in China's provinces and the commercialization of utility-scale CSP plants is starting.

Many studies have evaluated the technical and economic feasibility of different CSP technology variants in various countries worldwide. Electricity generation cost projections for CSP tower and parabolic trough plants in the United States were carried out by NREL (National Renewable Energy Laboratory), Sargent and Lundy Consulting and Sandia National Laboratories during 2003–2010 [12–14]. The IEA (International Energy Agency) released a CSP technology roadmap in 2010 [15]. The DLR (German Aerospace Center) issued a research report on the potential European technical innovations and research activities for CSP cost reduction in 2005 as part of the EU (European Union)-funded ECOSTAR (European Concentrated Solar Thermal Road-Mapping) project [16]. The electricity prices and potentials for CSP deployment in Australia [17] and Thailand [18] were also recently discussed in the scientific literature. The IRENA (International Renewable Energy Agency) published a global CSP analysis in 2012 [19], accounting for the most recent CSP research reports and consulting studies published since 2010 [20–24].

To the best of our knowledge, a country-wide technical, economic and financial assessment of different CSP technology variants in China is currently not available. A few plant-specific CSP studies for China were recently published. Li et al. [25] assessed the cost of CSP in China based on a hypothetical CSP parabolic trough plant in 2014. A more realistic study for a 50 MW utility-scale CSP parabolic trough plant in Inner Mongolia, China, was published by

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Abbreviations

ADB	Asian Development Bank
BIPV	building integrated photovoltaics
BNEF	Bloomberg New Energy Finance
CAS IEE	Chinese Academy of Sciences, Institute of Electrical Engineering
CDB	China Development Bank
CGNPG	China Guangdong Nuclear Power Group
CF	capacity factor
CSP	concentrated solar power
CSPPLAZA	a website of the solar thermal power industry, China
DLR	Deutsches Luft-und Raumfahrtzentrum, German Aerospace Center
DNI	direct normal insolation
ECOSTAR	European Concentrated Solar Thermal Roadmap
EIT	enterprise income tax
FIT	feed in tariff
ESTELA	European Solar Thermal Electricity Association
Gemasolar	a CSP tower plant in Spain
Golden Sun	a national solar photovoltaic program in China
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
IRR	internal rate of return
ISEGS	Ivanpah Solar Electric Generating System, a CSP plant in the United States
LCOE	levelized cost of electricity
NDRC	National Development and Reform Commission, China
NEA	National Energy Administration, China
NREL	National Renewable Energy Laboratory, USA
NPV	net present value
O&M	operation and maintenance
PS10	planta solar 10, a CSP tower plant in Spain
RMB	renminbi, Chinese currency, equivalent to Chinese Yuan
US$	US dollar, 2013 average exchange rate for RMB currency conversions
VAT	value added tax

the Clinton Foundation in 2013 [26]. A general CSP cost assessment for China is also available in the global IEA report on the projected costs of generating electricity of 2010 [27].

A more comprehensive assessment of CSP technology variants in China is critical for policy makers, energy researchers, and renewable energy industry experts. Therefore this study aims to analyze and benchmark for the first time three different CSP technologies under operation in China. As an expansion of previous studies, this study develops a new national database of seven operational CSP plants in China as of December 2014. First-hand plant-specific data were obtained amongst others through on-site investigations and interviews with local CSP plant operators and domestic energy sector experts. On this basis, this study aims to provide more targeted and detailed insights for future national CSP policies in China, such as a potential CSP-specific feed-in-tariff.

The remaining parts of this study are structured as follows: Section 2 gives an overview of the current deployment of CSP technologies globally and in China. Section 3 describes the methodology and underlying assumptions for the LCOE (levelized cost of electricity) calculations for CSP in China. Section 4 presents the results, including a national database for trough CSP, tower CSP, and dish CSP plants under operation and an LCOE range for CSP in China. Furthermore a sensitivity analysis is carried out to evaluate the future cost reduction potential for CSP. Section 5 concludes the paper and provides targeted CSP policy recommendations for China. Appendix A provides the equations of our LCOE model, and Appendix B lists detailed plant-specific economic and financial data.

2. Current status of CSP technology deployment

2.1. Global status of CSP technology deployment

By 2013 the global cumulative installed CSP capacity reached 3483 MW according to the NREL (US National Renewable Energy Laboratory) [2]. Fig. 1 shows the annual global thermal CSP capacity from 1985 to 2013. While the global CSP capacity remained below 450 MW until 2007, a rapid increase in CSP deployment has been taking place in recent years. From 2007 to 2013 the global average annual growth rate of CSP increased to about 139%. Fig. 2 shows the cumulative installed capacity of global CSP projects under construction in different countries in 2013, as compiled by the authors from NREL [2] and BNEF (Bloomberg New Energy Finance) [3]. BNEF (Bloomberg New Energy Finance) expects a significant deployment of CSP in the short-term future. Based on the current CSP plants under construction globally, the cumulative commissioned global CSP capacity will reach 6146 MW by the end of 2015. This would be equivalent to an almost doubling of the global CSP capacity in 2013 [3].

The cumulative installed CSP capacity in Spain reached 2368 MW in 2013, accounting for 68% of the global CSP capacity. Due to policy changes, no new CSP plants were under construction in Spain by the end of 2013. The parabolic trough CSP technology is the dominant CSP technology in Spain and accounted for about 93% of the country's cumulative installed capacity. Spain is also leading in the CSP tower technology. The first commercial CSP tower plant in Spain started power production in 2007 in Andalucía; it is called PS10 (planta solar 10). The Spanish Gemasolar plant followed in 2011, this CSP tower plant includes a molten salt heat storage system. It is currently the first CSP plant globally that combines a central power receiver with a molten salt heat storage.

Among the CSP plants under operation globally are different CSP technology variants and different project sizes, reaching from small-scale demonstration projects to large-scale utility projects. As shown in Fig. 2 above, the United States is currently leading with 1682 MW of CSP under construction, followed by India with 453 MW under construction. The United States started setting up commercial, utility scale CSP plants since the 1980s. The ISEGS (US Ivanpah Solar Electric Generating System) is currently the world's largest CSP plant. ISEGS has an installed capacity of 392 MW and was put into operation in early 2014 in the Mojave Desert in California [2].

Other countries that have operational utility scale CSP plants include India (104 MW), the United Arab Emirates (101 MW), Algeria (25 MW), Morocco (20 MW), Egypt (20 MW) and Iran (17 MW); all those are parabolic trough CSP plants [2,3].

2.2. Status of CSP technology deployment in China

By the end of 2013 the installed capacity of commercial CSP in China was about 50 MW, equivalent to one utility-scale CSP plant [2,3]. The Twelfth Five-Year Plan for Solar Energy includes a