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## ON THE MAP

## Status and future strategies for Concentrating Solar Power in China

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### Keywords

13th 5-year plan, China, Concentrating Solar Power, innovation, policy

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### Abstract

China is the world leader in several areas of clean energy, but not in Concentrating Solar Power (CSP). Our analysis provides an interesting viewpoint to China's possible role in helping with the market breakthrough of CSP. We present a short overview of the state-of-the-art of CSP including the status in China. A blueprint for China's CSP development is elaborated based on China's 13th 5-year program, but also on China's previous success factors in PV and wind power. The results of this study suggest that China could play a more prominent global role in CSP, but this would require stronger efforts in several areas ranging from innovation to policies.

## Introduction

During the last years, renewable energy industries have significantly grown, in particular in China, because of favorable domestic and overseas business conditions [1, 2]. Most of the growth in solar energy has originated from photovoltaics which has exceeded a total capacity of 200 GW<sub>p</sub>, most of which has been constructed in <10 years [3]. This rapid market growth can be linked to down spiraling costs of PV. The phenomenological growth of PV has overshadowed the other solar technologies. For instance, Concentrating Solar Power technology (CSP), which was earlier identified as a very promising future clean energy option [4], has slowly progressed both in terms of technology development and cost reduction compared to PV.

Albeit the still higher price of CSP, it has several advantages over PV such as easy coupling to other sources of energy and the capability for dispatched use through thermal energy storage. However, to become a worthy option, major technological and economical progress will be necessary. The possible role of China in such a development, which is the subject of this study, is interesting,

as China is the world leader in several clean energy areas such PV and wind power [5]. China has centrally contributed to the price reduction in these in the past [6]. This success can be traced back to the innovation and manufacturing system of China, but also to successful economies of scale efforts. Based on these past experiences, one may ask if Chinese clean energy strategies could still make a significant impact to the worldwide development of other new energy technologies such as CSP.

In case of CSP, most of the development has taken place outside China, in particular in the United States, Spain, and recently also in North Africa. By the end of 2015, the global installed capacity of CSP was 4940 MW, of which just around one percent was found in China [7]. Bibliometric analysis of CSP research similarly shows only modest contributions from China [6, 8–11]. These findings confirm that China is not yet in the forefront of CSP development. However, considering China's strong foothold in the other fields of clean energy, a logical follow-up question would be to find the reasons for such a situation. For example, are the technology and market prospects of CSP not good enough for Chinese industries, or are there may be other reasons such as national

prioritization of technologies, missing know-how, lack of innovations, lacking conditions for utilization, etc. that may hamper China to enter the CSP field. Concerning the future of CSP as a clean energy source, one could also ask what would be needed that China became a major player in CSP and could China trigger a similar positive cost development as in case of photovoltaics which led to a technology breakthrough. The purpose of this study is to investigate the development and strategies for CSP in China along the above lines.

## State-of-the-Art of CSP

The three main technology options for CSP are listed in Table 1. The most common type of CSP, or over 90% of all installed systems [12], is a parabolic trough (PT) system in which a solar-heated high-temperature steam drives a steam turbine to generate electricity in large scale of hundreds of megawatts [13]. The highest conversion efficiency (>30% [14]) is reached with a parabolic dish-type point receiver using a Stirling engine, but it is limited in scale to some megawatts at present. Solar tower systems employing large heliostat mirror fields concentrating solar irradiation to a receiver on the top of a tower can reach high concentration ratios and can be built from medium to very large scale. The technical performance and viability of all three technologies have been demonstrated, but in terms of commercial deployment, the PT systems have proceeded furthest [12]. Most of the PT plants have been built in the United States and Spain, but recently a major system was also erected in Morocco [15].

Each of the three CSP technologies has its specific development needs. In PT systems, steam and salt are often employed as heat transfer medium; for heat storage steam, salt, and oil, respectively. One important component for the success of PT has been the vacuum tube receiver [20], including Chinese involvement, for example, by the Beijing Day Rising Vacuum Technology Development

Company, which successfully developed a glass-metal transition seal structure of vacuum tubes. In case of Central Towers, the heliostats and the receiver structure are key components subject to development needs, for example, durability, costs, and efficiency [21–24]. For the Parabolic Dish technology, the receiver structure and the heat engine are the main concerns [25, 26].

Other R&D areas of interest for CSP include high-capacity thermal storage systems and distributed combined cycle systems [27, 28]. Research on thermal storage comprises storage materials and structures, which also affect the efficiency and investment cost of a CSP. Due to temperature limitations, flammability, and costs, steam or thermal oil is not an attractive option as a high-temperature TES material. Whereas molten salts represent an alternative already utilized in the latest CSP plants [29]. An inevitable drawback of molten salt is solidification at low temperature and decomposition at high temperature, which limits the operating temperature range. Recent research shows that a salt mixture could operate between 80°C and 560°C [30]. At present, a two-tank molten salt storage is the only commercially available concept with a large thermal capacity for CSP plants [30]. Hydrated sodium and nitrite are applicable as storage materials, but their efficiency often drops after repeated cycles. Synthetic oils are used as heat transfer fluid (HTF) in CSP, but they have limitations for high-temperature storage use.

Current CSP systems are mostly limited by the temperature limits of the materials used, which impose limitations on the efficiency of the power plant through the turbine inlet temperature. For example, the storage materials used limit the maximum temperature of the HTF. Corrosion and deterioration of molten salts increase with temperature, which requires using more expensive storage tank materials. All these factors restrain maximum temperature levels and hence also the turbine efficiency.

**Table 1.** Typical characteristics of solar-thermal power technologies.

Property	Parabolic trough (PT)	Parabolic dish (PD)	Central tower (CT)
Typical power range, MW	30–320	3–25	10–200
Concentration ratio	10–100	500–1000	>1000
Conversion efficiency, %	~14 [16]	~30 [19]	>15
Advantages	Commercially available with long-term experience; Modular and suitable for hybrid operation [17]; Can be coupled to heat storage	High conversion efficiency; Modular, suitable for hybrid use	High conversion efficiency; Suitable for hybrid use
Disadvantages	HTF working fluid limits operating temperature to 400°C; Spills/leaks [18]	Commercial viability need to be verified; Cost targets in mass production need to be verified	In experimental phase; Commercial investment and operating costs need to be confirmed
Costs	Potentially low investment costs	Structure of receiver is complex and costly	Still high investment costs

One new development is the use of supercritical carbon dioxide ( $\text{sCO}_2$ ) as heat transfer fluid in a Brayton cycle. While no CSP plant uses  $\text{sCO}_2$  yet, it has gained a lot of attention for next-generation power plants [31]. For example,  $\text{sCO}_2$  in a closed-loop recompression Brayton cycle has been proposed for CSP. A main benefit from  $\text{sCO}_2$  could be a higher cycle efficiency compared to supercritical or superheated steam cycles [32].

Combining solar-thermal power with fossil fuel generation can increase the capacity factor of the solar applications [33]. Rankine, Brayton, and combined cycle power generation schemes have been proposed in this context. The U.S. CSP plants have operated as hybrids employing gas as secondary fuel.

As to future prospects of CSP, the International Energy Agency, European Solar Thermal Energy Association, and Greenpeace forecast that CSP could account for 3–3.6% of the global energy supply in 2030 and 8–11.8% by 2050, which would require two-digit capacity growth in the coming years, which has not yet been demonstrated [34]. Other studies estimate that the price of CSP could decrease to \$0.05/kWh by 2025 [35], which would be highly competitive.

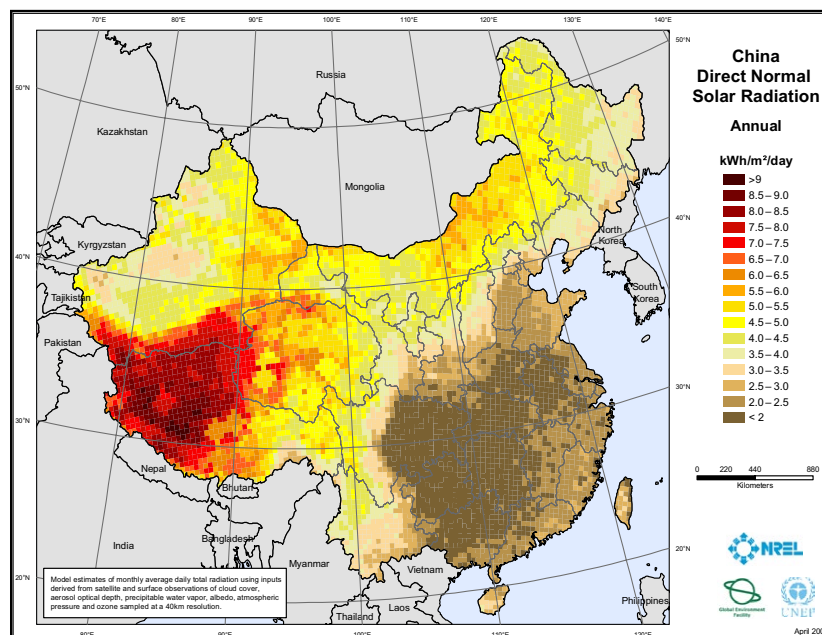
Chinese development and deployment of CSP is modest as stated earlier [36]. It is unlikely that the CSP technology could change the structure of electricity supply in China, but it could have potential for large-scale development in the future to be discussed in the next chapter.

## Status of CSP Technology Development in China

### Resource potential for CSP

China has potential to develop CSP [37] in terms of the solar resource. Figure 1 illustrates the direct normal solar radiation resource available in China [http://swera.unep.net/ (accessed 10 September 2016)]. The best regions are found in the western part of the country with highest daily mean values of direct normal radiation around 9 kWh/m<sup>2</sup> in the Qinghai-Tibet Plateau and Sichuan Basin. A minimum value of 5 kWh/m<sup>2</sup>,day is the limit of CSP for economical reasons [38], which is met in most parts of the northern and western China.

Concerning land-use requirements, a CSP plant typically requires 20,000 m<sup>2</sup> of land area per MW [34]. It is estimated that China has 2.63 million km<sup>2</sup> of land area not conflicting with other uses such as food production, most of which is located in the northern and the western China with high solar insolation values [39]. Although the DNI and gross land area available is high, two important factors limit the gross potential of CSP in China: (1) CSP requires very flat land (<2% grade over the entire array field) which eliminates the use of mountainous and hilly sites; and (2) most of the power demand is in the eastern part of China, whereas the potential is in the west, meaning that upgrading of the transmission grid



**Figure 1.** Direct normal solar radiation in China. (Note: This map was created by the National Renewable Energy Laboratory for the U.S. Department of Energy with data provided by UNEP and the Global Environment Facility.)

or employing storage may be necessary for large-scale CSP schemes.

### Status of R&D

Since the 1970s, China has carried out relevant basic research on the development of solar-thermal power generation under the different Programmes of the Ministry of Science and Technology [40]. Key players in the CSP R&D in addition to enterprises have included several institutes of the Chinese Academy of Sciences (CAS) (Institute of Electrical Engineering, Changchun Institute of Optics, Fine Mechanics and Physics, Institute of Engineering Thermophysics), Himin solar energy group, and Southeast University [41], among others. Key R&D fields include the design and manufacture of condensers, design of collector field and system control, preparation of key materials, heat exchanger and energy storage systems for molten salts, high-precision heliostat technology, high-temperature tower absorber technology, high-temperature thermal storage technology, manufacturing process of trough evacuated tube, etc.

Key R&D facilities and know-how are presented in detail in the next.

### Parabolic trough concentrator and evacuated absorber tubes

The Broad Air Conditioning Company, Institute of Electrical Engineering (CAS), and Hehai University have developed different types of parabolic trough concentrators. In one of the successful designs, honeycomb technology was employed for a 2.5-m-wide and 12-m-long ultra-light reflective structure [42]. China's first high-temperature vacuum receiver, Sanle-3 HCE, was mainly developed by the Southeast University in collaboration with Chinese companies such as Himin, Linuo Paradigma, and IVO (Kunshan) in 2007 [43, 44]. Asia's first parabolic trough power plant (ISCC) was successfully built employing this technology in Ningxia China in October 2011.

### Heliostats for solar power tower system

China's first CSP demonstration project, a 70 kW solar tower plant (Fig. 2) [45], was constructed by the Chinese Academy of Engineering near Jiangning in Jiangsu in 2006. The heliostats for this project were jointly developed by Nanjing Chunhui Ltd., Institute of Electrical Engineering (CAS), and Himin. Larger heliostats of 100 m<sup>2</sup> were also developed and used in a demonstration project of 1 MW size [46, 47]. A 50 MW photothermal project in Delingha was started in 2011, with Supcon Ltd as the main



Figure 2. Nanjing's 70kW solar power tower system [46].

developer. Its first stage included 10 MW and two solar towers, which were completed in 2014 [48].

### Solar dish

The Institute of Electrical Engineering (CAS) has developed different types of solar dish condensers. In the best design, the focal temperature of the condenser can reach up to 1600°C. The dish tracks the sun's position with a precision of  $\pm 0.2^\circ$ . The reflectivity of the parabolic mirror reaches 94%.

### Molten salt thermal storage

Sun Yat-sen University, Beijing University of Technology, South China University of Technology, and Dongguan University of Technology are key research institutes on multicomponent systems for thermal storage consisting of nitrate, carbonate, and chlorate. In addition, work on thermal storage in nitrates and containers for materials at high temperature (about 550°C) have been carried out at Changzhou Pressure Vessel Inspection Institute for several years.

### Pilot plants

In July 2009, China launched the so-called 'Golden Sun' program to boost the solar sector [49]. The central government will support half of the investment costs of large-scale solar power plants. With a nationwide feed-in tariff plan for solar power development, the government plans to have 10 GW of solar power by 2020. Several pilot-plants to test and demonstrate different CSP technologies have been planned, all listed in Table 2. So far three plants have been finished. Considering the pace of



**Table 2.** Concentrating Solar Power projects in China.

Status	Start	Completion	Location	Size (MW)	Technology
Finished	2004	2005	Nanjing (Jiangsu)	0.07	Solar tower
	2011	2013	Jia yu guan (Gansu)	10	Solar trough
	2010	2013	Yan qing (Beijing)	1	Solar tower
Not finished	2016		Dunhuang (Gansu)	10	Solar tower
	2011		Golmud (Qinghai)	200	Solar tower
	2009		Mon ding (Yunnan)	10	PV& thermal
	2011		Ordos (Inner Mongolia)	50	Solar trough
	2010		De zhou (Shandong)	2.5	Fresnel
	2010		Ruan lin (Hunan)	50	Solar trough
	2009		Golmud (Qinghai)	1000	Solar tower
	2010		Yulin (Shanxi)	2000	Solar tower
	2011		Delingha (Qinghai)	50	Solar trough
			Aba (Sichuan)	100	Tower & trough
Planned			Sanya (Hainan)	100	Solar tower
			Wuwei (Gansu)	100	Solar trough
			Turpan (Xinjiang)	300	Solar trough
			Lhasa (Tibet)	50	Solar tower
			Turpan (Xinjiang)	50	Solar trough
			Jinta (Gansu)	50	Solar trough
			Ningxia	100	Solar trough
			Hangzhou (Zhejiang)	100	Tower & heliostats
			Gansu	100	Multidish

development, it seems unlikely that the goal for year 2020 will be reached.

## Chinese Plans for CSP

### Chinese policy framework

The present top priorities of Chinese development are stated in the 13th 5-year plan for national economic and social development [50]. According to the plan, the Chinese government will set up green development funds to support green and clean production, promote the green transformation of traditional manufacturing and establishment of low-carbon production and recycling in industry, and advocate enterprises to upgrade technology and renovate equipment [51]. All in all, China seems to strive to build a modern energy system, which is cleaner, less carbon emitting, safer, and more efficient than the present one. This sets the basic conditions for promoting the development of solar-thermal power generation in China.

The economy of China is expected to grow by 6.6% a year on average till year 2020, which also implies increasing demand for electricity. To meet the growing power demand, China would have to install as much as 635–860 GW of new-generation capacity between 2005 and 2020, an amount comparable to EU's total installed capacity in 2003 [52]. China's energy policy target is to reach a 15.4% renewable energy share by the year of 2020, and 27.5% in 2050,

respectively [53]. The Ministry of Science and Technology has listed CSP as an important research issue in its document 'Summary of the national mid & long-term science and technology development plan (2006–2020)' [54]. The official targets for solar energy utilization in China as stated in the 13th 5-year plan by 2020 are shown in Table 3. The CSP target is 10,000 MW [55]. We notice that the capacity of CSP needs to grow by a factor of 700 from 2014 to reach the 2020 goals, which is very unlikely given the other constraints mentioned in this article.

The geographical split down of the national CSP targets is shown in Table 4 indicating that most of the planned CSP will be in the northern and western parts of the country. However, some capacity is perceived in other parts of the country as well.

According to the 5-year plan, the total installed capacity of CSP should be 10 GW [55] by the end of 2020. To reach this goal, investments into CSP will annually be supported by ca 100 Billion yuan (1 Chinese yuan = 0.15 US \$). The target is to drive the investment costs below 20 yuan per W and the generating cost close to 1 yuan/kWh by the end of 2020. By 2030, solar power generation as a whole is envisioned to reach a total installed capacity of 400 GW, which would put Chinese industry into international lead [57]. The first batch of CSP demonstration projects was issued by National Energy Administration in September 2016 consisting of 20 plants (9 tower, 7 trough, and 4 Fresnel projects).

**Table 3.** Solar energy targets in China by 2020 [56].

Indicator	Solar	2014	2020
Installed capacity (MW)	Centralized PV	23,380	80,000
	Distributed PV	4672	70,000
	CSP	14	10,000
Electricity (TWh)	Gross generation (PV + CSP)	250	2000
Heat utilization indicator (billion m <sup>2</sup> )	Solar collector area	–	8

In addition, to facilitate the solar-thermal industry needed to accomplish the targets, efforts on technology progress and demonstration promotion are planned as follows [58]: improving the quality of planning of CSP, establishment of a technical standards system, monitor experiences from demonstration projects, improve the economy and management of CSP projects, and finally, to develop a relevant electricity pricing policy to support CSP. The FiT level for CSP is still under debate and the National Development and Reform Commission's Price Department has not yet settled the level of support [59].

During the demonstration stage of CSP in 2016–2017, China will focus its CSP efforts to the western region mainly with the best solar conditions. This will also include coordination of the access conditions to land, water, and power grid. A number of solar-thermal power-generation demonstration projects with a total installed capacity of at least 50 MW will be constructed, either as standalone or part of hybrid plants. Based on the experiences from the demonstration projects, a gradual move to large-scale CSP is planned during 2018–2020. For this purpose, China plans to construct four MW-class solar-thermal power generation demonstration bases in Qinghai, Gansu, Inner Mongolia, and Xinjiang with a total capacity of hundreds of megawatts.

In order to promote the vigorous development of solar energy utilization, the 13th 5-year plan also proposes that

domestic solar product standards should be made compatible to international standards. Meanwhile, stronger international cooperation is also needed to develop advanced energy technology and equipment manufacturing, to improve the industrial technology research and development abilities, and increase the core competitiveness progress [59].

### Core technology readiness for CSP in China

Technology and costs are the two major barriers to CSP development in China. Until now, although there are not yet any commercial CSP plants in operation, several research and demonstration projects have been accomplished (see Table 2).

The technical development of CSP in China is foreseen to comprise four stages or four generations of CSP technologies [60, 61] between 2006 and 2025. Through this technology evolution, CSP should become more effective over time reaching higher temperatures, up to 800–1100°C by 2025. The first-generation CSP employing steam and oil as heat transfer medium is already in industrial scale and the second-generation, which also includes molten salt technology, is entering large-scale demonstration, but the third and fourth stages of CSP are still under research. The current first-generation CSP technology could reach an electricity generation cost of \$100–120 per MWh, which still is higher than that of traditional thermal power plants [38]. To resolve the critical technological problems blocking cost reductions, the Ministry of Science and Technology is funding more research to improve CSP's market position [<http://www.most.gov.cn/tztg/index.htm> (accessed 10 September 2016)].

Most of the CSP components originate from traditional industries, for example, employing steel, glass, and cement, among others. For example, a 50 MW CSP with 4–8 h of heat storage needs 100,000–150,000 t of steel, 6000 t of glass, and 10,000 t of cement [62]. China has for the

**Table 4.** The national layout of solar energy utilization during the 13th 5-Year Plan period [56]. Numbers shown are shares of the total solar electricity target in 2020 (1 = 344 TWh).

Region	Solar PV			Solar CSP	Total
	Centralized	Distributed	Sum		
North China	0.055	0.050	0.105	0.002	0.107
Northwest	0.141	0.012	0.153	0.022	0.174
Northeast	0.010	0.010	0.021	0.001	0.021
East China	0.020	0.071	0.091	0.000	0.091
Central China	0.018	0.032	0.051	0.000	0.051
South	0.014	0.033	0.047	0.000	0.047
Other (Tibet)	0.004	0.001	0.005	0.002	0.008
West	0.146	0.012	0.158	0.024	0.182
Central & East	0.117	0.197	0.314	0.006	0.319

time being a clear oversupply situation of these materials, meaning that CSP will not just offer a clean energy supply scheme [63], but it could also stimulate economic growth in the traditional industry.

A key component of CSP is the concentrator or heliostat, which is composed of an ultra-thin super-white glass silver mirror. Ultra-thin glass technique in China is mature and technologies for self-cleaning glass and long-life silver mirrors already exist. With the advantage of low cost and high performance, heliostats made in China could push domestic CSP development forward. But in spite of such know-how, in practice the mirror products in China lack superior quality, for example, have poor reflectivity and self-cleaning properties [64]. This calls for further technology improvements in the near future.

### Lessons learned from wind power and PV sectors

China has made huge progress in successfully scaling up PV and wind power during the last decade. The experiences from this process could be useful for CSP as well.

One important Chinese lesson was that the government needs to introduce a suitable policy framework to open up the market, but also to scale it up at a correct speed based on the market feedback and industrial progress. For CSP, a so-called benchmark price policy could be introduced in the same way as for wind power and PV. The price can be settled, for example, after one or two rounds of bids. In addition, a clear signal of guaranteed financial support and preferential policies to solar-thermal power generation investment enterprises and manufacturing industries is important [62]. In recent years, the Chinese PV industries have encountered major challenges due to the global economic situation, antidumping, and countervailing investigations, but also because the industries outsourced much of the production to overseas markets, which lead to losing core technologies and intellectual property rights. Therefore, from a Chinese perspective, the development of CSP could be accomplished in a more innovative way, so that core technology and the market power would remain in local possession [65]. In addition, building strong industry chains should be enhanced to establish an independent CSP industry [62]. Another problem appearing in both wind power and PV was the difficulty of grid connections, which resulted in forced partial outage, even >30% in some areas. Therefore, thermal energy storage (TES) could be more strongly used in CSP systems to improve solar and load matching. In this way CSP could be used as a flexible peak-shaving option [62].

### Roadmap for CSP in China

China's CSP industry faces both great opportunities and challenges. In the long run, three stages are suggested for the development of CSP in China:

1. More small- and medium-size commercial CSP projects should be constructed before up-scaling to gain necessary experience. This requires a supported electricity price (FiT) for CSP to share the risks with the new technologies involved;
2. Distributed solar energy systems could provide an important niche market for CSP, for example, remote power and heat supply, desalination on islands, and industrial and agricultural applications with less financial support;
3. For large-scale CSP, combining with TES and hybrid power plants is recommended. Traditional power plants under 200 MW could in this way be hybridized with CSP leading to major CO<sub>2</sub> reductions [62].

In addition to above general lines, we propose below more specific measures for innovation, costs, and policy measures for CSP in China.

### Innovation and collaboration

Chinese CSP industry needs stronger innovation efforts to speed up the technology upgrading. The Ministry of Science and Technology (MOST) has supported technology research and demonstration power plants in the past [46, 62, 64, 66], which lead to mastering some of the CSP core technologies [<http://www.most.gov.cn/tztg/index.htm> (accessed 10 September 2016)]. Much of this development work has been pursued domestically only, without a clear international context [67], which would need to be reversed now through international collaboration to strengthen own technology base [46, 68]. Several international companies already actively follow the CSP development in China [63, 69], which could offer an opportunity for stronger cooperation and communication with companies or organizations from abroad. We also notice the need of work in thermal storage for CSP considering the previously mentioned challenges in China.

### Cost reduction

An important prerequisite for the success with CSP will be reducing the investment costs. For example, the success of parabolic trough systems in the United States can be attributed to cutting down the investments from \$4500 to less than \$3000 per kW in late 1980s and early 1990s. The CSP electricity cost dropped from \$440/MWh for the



first systems built to \$170/MWh with the ninth system and the system efficiency increased from 9.3% to 13.6% [46]. The same effects need now be reached in the Chinese case by making better use of the scale effects. The industry estimates that in the 1000 MW scale, a power generation cost of 0.7–0.8 yuan per kWh should be possible. However, the required 20 billion yuan investment per 1000 MW is too high for many enterprises to finance [70] as the CSP industry in China is still in a start-up stage. If a continuous flow of smaller projects was realized, the investment cost of CSP could be possibly halved from the present level to <10,000 yuan/kW. The corresponding electricity price would then be close to that of wind power [67].

## Policy support

To help achieving its energy and environmental goals and promote green investment, China has promulgated laws and regulations and put forward a series of policies facilitating green development and attracting and steering investments toward clean development [71]. Due to the fact that CSP is not yet a mature technology, policy support would be essential. The Government is expected to provide a reasonable support scheme and related measures soon. If the government can create favorable conditions for CSP, industry development will be greatly stimulated [67]. In addition, there are two fields of concerns, namely, patents and standards, which need to be addressed. To strengthen the creativity dimension, the government needs to improve incentives and mechanisms for intellectual property rights in near future. For example, a leading enterprise in CSP TES technology, Jiangsu Sunhome New Energy Co. Ltd., has independently developed and mastered the design and manufacture of TES systems for CSP applying for more than 30 patents [65]. In 2014, the China National Solar Thermal Energy Alliance convened an examination meeting of standards passing two standards on CSP technologies, which is a good start, but still inadequate for CSP as a whole. Recently, the National Energy Administration issued the first relevant standards for CSP power generation (5 national and 6 international). A framework for China's CSP standard system remains to be built.

## Conclusions

In this study we have discussed the status and prospect of China's CSP development. Although the potential for CSP in China is good and there exists experience and know-how on CSP, scaling up CSP to a major energy vector would require large efforts both in terms of technology and cost development, but also stronger policy support. The key limitations for CSP in China need also

more attention. Internationally viewed, China lags behind the international development in this field.

The Chinese government has recognized the promising outlook for CSP, which is demonstrated by the positive plans expressed in the 13th 5-year plan. China has now clear targets for CSP development till year 2020, although these may be difficult to reach considering the short time span. To approach these targets, main development work is needed on a broad front, described and elaborated in this study. Notably, China needs to pay more attention to domestic innovations and cost reductions in CSP, which in turn would require a clear financial support system for CSP investments. Also, the geographical mismatch between the high solar resource in the west and the high power demand in the east will need more attention when moving to large-scale CSP deployment.

In terms of international development, China has several positive factors which could speak in favor of global leadership: China has large areas with excellent solar conditions for CSP (although limited by the geographical mismatch), strong basic capabilities in traditional manufacturing important to CSP, and also to some extent special know-how in CSP technologies. China would also profit from stronger international collaboration in the field, standardization, and IPR legislation and management. We propose here a three-step plan for scaling up CSP, with emphasis on smaller-scale CSP plants in short term to gain more experience and then scaling up to 100 MW scale leaning more to thermal storage and hybridization which give clear system benefits.

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## Conflict of Interest

None declared.

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