The Dragon Awakens: Will China Save or Conquer Concentrating Solar Power?

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Abstract. After three years of low growth and an increase in global costs, the announcement and implementation of the Chinese demonstration programme for concentrating solar power (CSP) has changed the outlook for the technology from gloomy to better than ever. Here, we analyse the Chinese CSP strategy, its drivers, and its effects on CSP industry and costs in China and globally. We find that the Chinese demonstration programme has led to the emergence of new CSP industry actors, and that it helped to the reduce global average costs of new CSP stations to USD 0.12 per kWh. However, the Chinese expansion, which is supplied almost exclusively by Chinese companies, follows a wholly different cost trajectory than the expansion in the rest of the world, which is almost exclusively served by non-Chinese companies: whereas costs in both markets have decreased, the cost of Chinese CSP stations under construction is 40% lower than that of plants built elsewhere. We conclude that the Chinese support programme has thus succeeded in its central aims of leapfrogging and has built up a domestic industry capable of building stations and most components at lower costs than foreign competitors. However, Chinese companies are not yet active outside China, nor do we find many foreign participants in the Chinese market. The effects of the Chinese CSP programme on markets and industries outside China have thus far been limited: the Chinese and non-Chinese markets currently largely exist in parallel, each with their own supply chains. Whether the new Chinese companies seek to and manage to conquer the global market as well remains to be seen but so far, they have not.

1. INTRODUCTION

China the Saviour

Concentrating solar power (CSP) is one of few technologies that can provide dispatchable renewable power on a large scale. As it can both generate bulk renewable power and be built to compensate fluctuating renewables like wind power and solar PV, it could play a key role in the decarbonisation of power systems worldwide [1-6]. Despite these advantages, CSP has led a life in the shadow of other renewables, and its expansion has been slow and confined to just a handful of countries. Especially the years following the cancellation of policy support in Spain (last station completed in 2013) and the US (2015) were weak, as support schemes introduced elsewhere were too few and triggered too little expansion to compensate for the loss of these lead markets. The low construction rates 2015-17 hit the industry hard, and many suppliers were struggling financially or left the CSP market altogether [7, 8]. At the same time, the levelised cost of electricity (LCOE) of new CSP stations increased: the average LCOE of new CSP stations becoming operational in 2015-16 exceeded USD 0.22 per kWh, almost four times the average cost of new onshore wind farms and twice that of PV [9]. The outlook for CSP was bleak and its very survival as a commerical technology seemed to hang in the balance.

In late 2016, the Chinese government announced a CSP demonstration programme of 20 projects, amounting to 1.35 GW of new capacity to come online by the end of 2018. The program is currently being implemented, and although many stations are delayed and a handful have been cancelled, most had started construction by mid-2018 [10]. Consequently, more than half of the 1.6 GW of solar-only CSP capacity under construction globally (May 2018) is Chinese. The Chinese government has announced that a second CSP programme will be implemented in 2019, adding another 4 GW before 2022 [11-13]. If successful, China would in only five years have added as much CSP capacity as all other countries combined since 1984 [14], making the expansion outlook better than in a long time.

Yet there are still many questions surrounding the Chinese CSP strategy and its impacts. Here, we investigate China's CSP strategy since 2016 and its implications for cost and industry development (domestically in China and globally). We then discuss China's long-term strategy and what it could mean for the international CSP sector.

China the Conquerer

Undoubtedly, China's market entry was a step change for CSP. However, following the precipitous decline in deployment between 2015 and 2017, the global CSP supply chains for solar-specific parts (e.g. heliostats, receivers and heat transfer fluids) are thin, with only a handful of experienced companies still active, mainly based in Europe and the United States, where there are no domestic CSP markets. Hence, one would expect that the Chinese strategy will be to build up a domestic CSP industry and to learn from the remaining experienced foreign companies through joint ventures or collaboration on specific projects. Such collaboration could, if successful, be an opportunity for the remaining European and American CSP companies to access a new large market – or it could be threat: historically, Chinese industry has proven very capable of learning, and then outperforming its former partners.

In the current five-year plan of China, CSP is one of the "key energy technologies", to be supported through a demonstration programme [15]. The plan also defines 12 "mega-projects of science research", of which the CSP programme is part. With this programme, the Government aims to "nurture new industries and realize leapfrog progress through project implementation" and hence overtake the international competition by achieving "significant technical breaktroughs […] within 3 to 5 years" [16]. The term "leapfrog" suggests that the Government aim is to build on the knowledge and experience of companies around the world and outcompete them through radical innovation around these existing technologies, or by playing the traditional Chinese trump card of low-cost mass manufacturing [17]. Consequentially, the key instrument of this research programme is not laboratory research (or *learning by searching*), as the programme's name would suggest, but developing industrial commercial-scale projects on the ground (or *learning by doing*). Hence, the Government seeks to "pool strengths from different sectors and vigorously promote collaboration [and] integrate government guidance with market-driven innovation […] with industries as the principal entities" [16]. In the case of CSP, the Government has announced a two-step support scheme. The first, currently ongoing demonstration phase, is set to produce CSP stations of different technical designs, which receive a fixed feed-in tariff so as to allow the new industry to develop, learn and improve processes and procedures [18, 19]. In a second phase, presumably starting in 2019, the emphasis will be on large-scale deployment in the four main solar energy regions of China (Gansu, Qinghai, Inner Mongolia, Xinjiang) [18].

In the past, the Chinese government has pursued similar leapfrogging aims, for example for capturing the global markets for wind power and PV. At least for PV, it was immensely successful. However, the strategies for "leapfrogging" each of these two technologies were quite different, suggesting that there are at least two ways to capture an existing technology and build up a national industry – with a very different impacts on the global energy industry.

With PV, the aim was to capture the manufacturing market for modules. The first 10 MW_p module factories were built in 2002, and already in 2005, Chinese companies held 30% of the global PV module manufacturing capacity. By 2015, they had outcompeted most incumbents in Japan and Europe and held 70% of the market. Three factors were decisive for this: the abundance of cheap labour and energy in China, "learning" by purchasing manufacturing equipment (including entire assembly lines) from abroad, and the return of Chinese executives from PV factories in other countries [20-22]. Interestingly, this strategy did not initially include a support scheme for domestic PV expansion, but was instead focused entirely on export. However, weakening markets in the early 2010s, especially in Europe, caused overcapacity in the domestic module industry, leading China to introduce a support scheme to maintain its newly built up industry [21, 23].

With wind power, the manufacturing capacity development was similarly impressive: while in 2005, Chinese companies held only 1% of the global manufacturing capacity, today almost 50% is Chinese. As the key to cheap wind power lies not only in mass manufacturing, China's traditional strength, but also in the engineering know-how of building and assembling components into a functioning wind power station, the entry barriers to wind power industry markets are higher than for PV. Correspondingly, the Chinese strategy was based on a domestic feed-in tariff with strong local content requirements that not only forced component manufacturing to happen in China, but required foreign companies to enter into joint ventures and joint projects with Chinese companies. The feed-in tariff was thus explicitly created as a technology transfer programme as well as a renewables expansions scheme. Over time, Chinese companies began to buy European licences and patents, and later also entire companies, until pupil became master and Chinese companies could outcompete their foreign competitors in the domestic market, with some 40% lower costs compared to European and American projects [9, 21, 23, 24]. Despite their domestic success, Chinese companies have so far not managed to capture the global market, in part because they are not yet able to build the very large wind power plants that dominate markets outside China. Hence almost all wind farms in China are built with Chinese technology, but almost nothing is exported [21, 25-27].

2. DATA AND METHODS

We have expanded the *csp.guru* dataset with data valid as of May 2018 [10], holding technical, industrial and economic data for all projects operational or under construction around the world, including the ongoing Chinese projects. We complement the May 2018 data for component suppliers for Chinese projects with data from CSP Focus updated in late July 2018 [28]. Our data describe technological (e.g. trough/tower/Fresnel; storage size; capacity), economic (e.g. expected generation, investment costs), and industry parameters (e.g. owner, EPC, component manufacturer). The data coverage exceeds 90% for all economic parameters (e.g. investment cost, expected generation) and 80% for all industry parameters (except for receiver manufacturers, which has 68% coverage). For detailed descriptions of the data, its sources and specific assumptions and uncertainties, please consult [14] (for the August 2016 version) and [29] (for the May 2018 update).

We calculate the LCOE using investment costs and expected generation as presented by developers or other entities involved in each single project and reported on csp.guru. For all projects, we use a 5% discount rate and 25 years economic lifetime. All assumptions are identical to [14], where the impact of these assumptions are discussed in detail. All average LCOE statements are generation-weighted averages.

3. RESULTS

Industry Structure

The past few years saw a shift in the global CSP supply chain, away from European and US companies to Chinese and other Asian companies (Fig. 1). This development is particularly strong on the project level: whereas practically all projects before 2015 had European or US engineering, procurement and construction (EPC) companies and developers, Chinese and Asian (Indian and Saudi) companies are dominant among recently (2016-today) completed projects and those under construction. To some extent, this follows the geographic shift as companies, especially developers, are often most active in their domestic market. The Chinese CSP companies are extreme in this respect: for all Chinese projects except one (Royal Tech Yumen), development and EPC services are handled by Chinese companies, whereas only one non-Chinese project has been led by a Chinese company (Noor III, Morocco), and that project includes the experienced European EPC partner SENER. In contrast, European, Saudi and US companies are currently only active outside their home countries, as they have no domestic CSP markets.

As shown in Fig. 1, Chinese companies play a smaller role on the CSP-specific component level, with European companies remaining strong in the solar collector (SCA) market (data for receivers, i.e. HCE, are too incomplete to allow robust conclusions). In the detailed supplier list of [28], it is clear that practically all non-CSP specific and low-tech components in Chinese stations are domestically manufactured, showing that the existing industry can supply materials and components adapted for use in CSP projects [30]. Only in a few cases, and only with CSP-specific and highly specialised parts, are components imported; for example, in addition to SCAs, all projects that disclose the heat transfer fluid circuit manufacturers use components from Flowserve (US) or Sulzer (Switzerland) [28].

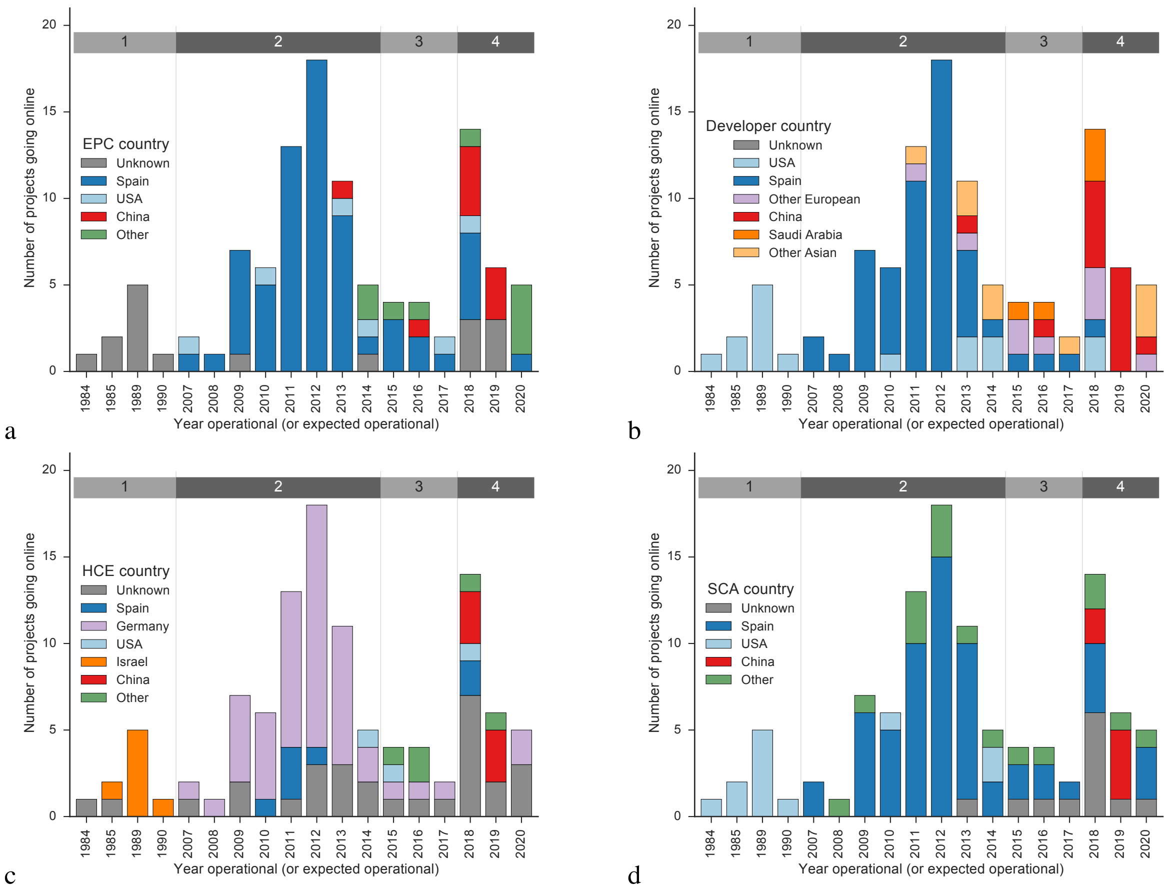

FIGURE 1. Country of origin of the leading company for engineering, procurement and contracting (EPC) (a), project development (b), heat conducting element (HCE) (c), and solar collector assemblies (SCA) (d).

TABLE 1. Developer, EPC, HCE and SCA manufacturer for all CSP projects completed in 2018 or under construction (as of May 2018), as well as the home country of each company. n.k.=not known. Sources: [10, 28]

Project name (country)	**Technology, capacity**	**Developer**	**EPC (country)**	**HCE (country)**	**SCA (country)**
Ashalim plot A (Israel)	Trough, 110 MW	Abengoa (Spain) Shikun&Binui (Israel)	n.k.	Rioglass (Spain)	n.k.
Ashalim Plot B (Israel)	Tower, 121 MW	Megalim Solar Power (US)	General Electric (US)	General Electric (US)	n.k.
Ilanga 1 (South Africa)	Trough, 100 MW	Emvelo, Cobra (Spain)	Sener (Spain)	n.k.	Sener (Spain)
Noor III (Morocco)	Tower 150 MW	ACWA (Saudi Arabia)	Sener (Spain) SEPCO III (China)	n.k.	Sener (Spain)
Delingha (China)	Trough, 50 MW	Delingha Solar Energy (China)	Beijing Shouang (China)	Rioglass (Spain)	Schlaich Bergermann (Germany)
Golmud (China)	Tower, 200 MW	Qinghai CSP Electric Power (China)	China Shipbuilding (China)	n.k.	n.k.
Yumen Xinneng (China)	Tower, 50 MW	Sinogy (China)	Sinogy (China)	Jiangsu XinChen (China)	Jiangsu XinChen (China)
Supcon Solar (China)	Tower, 50 MW	SUPCON Solar (China)	SUPCON (China)	Hangzhou (China)	n.k.
Dunhuang (China)	Tower, 100 MW	Shouhang (China)	n.k.	Shouhang (China)	Shouhang (China)

Project name (country)	Technology, capacity	Developer	EPC (country)	HCE (country)	SCA (country)
Urad Middle Banner (China)	Trough, 100 MW	Royal Tech Changzhou (China)	China Shipbuilding (China)	Royal Tech Changzhou (China)	Schlaich Bergermann (Germany)
Hami (China)	Tower, 50 MW	N.W. Electric Power Design Inst. (China)	N.W. Electric Power Design Inst. (China)	Dongfang (China)	Wuham (China)
Qinhai Gonghe (China)	Tower, 50 MW	Power Construction Corporation of China	Supcon (China)	Supcon (China)	Supcon (China)
Gansu Akesai (China)	Trough, 50 MW	Gansu CSP (China)	n.k.	Archimede (Italy)	Tianjin Binhai (China)
Dacheng (China)	Fresnel, 50 MW	Lanzhou Dacheng (China)	n.k.	n.k.	n.k.
Rayspower Yumen (China)	Trough, 50 MW	Yumen Zhongshangmingde (China)	n.k.	n.k.	Sundhy (China)
Royal Tech Yumen (China)	Trough, 50 MW	Royal Tech Changzhou (China)	Abener (Spain)	n.k.	Abengoa (Spain)

Levelised Cost of Electricity and the Rise of the Chinese Market

The emergence of a Chinese market and industry has had a profound effect on the cost of new CSP stations: the global average LCOE of all stations that have come online in 2018 or are currently under construction is USD 0.12 per kWh, or some 40% lower than the cost peak of 2015-16 (Fig. 2). In the global perspective, this suggests that CSP costs are rapidly declining, compensating for the recent price bump and bringing costs down towards cost competitiveness with other renewables – even on pure LCOE terms, disregarding the additional system value of CSP (see [12, 31]). This is good news for CSP, as decreasing costs and an outlook of cost competitiveness have been identified as key parameters for its commercial survival [7]. With a positive cost outlook, chances should increase that countries maintain their existing support schemes, and that CSP catches the attention of policy-makers in further countries.

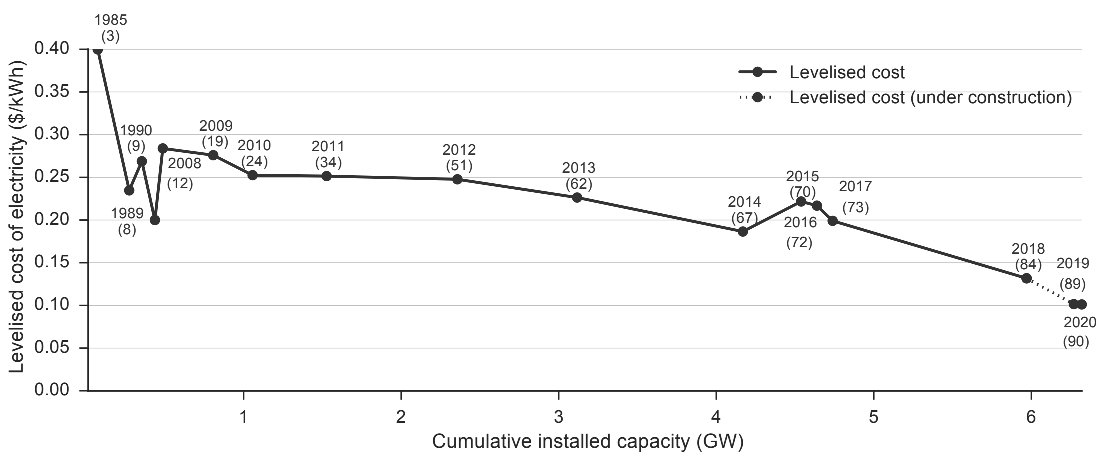

FIGURE 2: Average LCOE for all CSP stations, by year. Numbers in brackets indicate the number of stations in the dataset.

However, as we have already shown that the Chinese market is served almost exclusively by Chinese companies that are hardly active on foreign markets, it makes sense to separate Chinese and non-Chinese LCOE trends. This reveals that the LCOE for Chinese and non-Chinese projects follow entirely different trajectories (Fig. 3): whereas the LCOE of non-Chinese stations have decreased more or less monotonously from USD 0.28 per kWh in 2008 to USD 0.17 per kWh in 2018, Chinese stations deviate strongly, with an average LCOE below USD 0.10 per kWh. Hence, whereas the Chinese stations are approaching cost competitiveness, the non-Chinese stations are not: outside China, CSP still has a long way to go before it reaches cost competitiveness with other renewables on an LCOE basis.

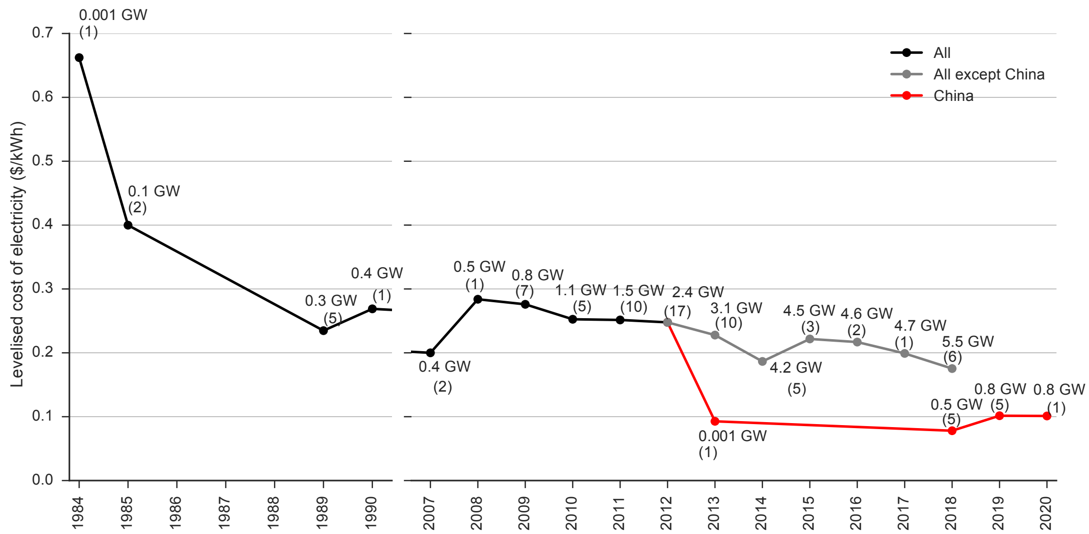

FIGURE 3: LCOE for all CSP stations (operational and under construction), split for Chinese (red) and other (grey) from 2013. Numbers indicate the capacity and number of stations coming online each year (only stations with full cost data).

To us, it is surprising that these two cost curves diverge so strongly. The two sets of stations differ in three variables: technology type, storage size, and developer country of origin. Whereas recent and ongoing (2016-2020) Chinese projects are mainly towers with large storage, built by Chinese companies[1], the non-Chinese stations under construction are typically troughs, with small storage systems, and built by European or US companies[2]. According to conventional wisdom and theory, the cost of the more mature trough technology should be lower and experienced companies should have accumulated know-how and be able to offer lower costs than inexperienced ones building the less mature tower technology. Yet, here conventional wisdom has been turned on its head, and towers built by comparatively inexperienced companies are cheaper. The difference is all the more remarkable given the weak solar resource in China: Chinese stations receive on average 25% less sun than the stations outside China. With the same technology cost, the LCOE of Chinese stations should therefore have been 25% *more expensive* than that of non-Chinese stations, yet, it is 40% *cheaper*. This suggests that the Chinese strategy has been successful, and has already achieved its *leapfrogging moment*: at least in its domestic market, the new Chinese CSP industry seems to have outcompeted all non-Chinese companies in just a few years and is able to build CSP stations at significantly lower cost.

4. CONCLUSION AND DISCUSSION

The start of the Chinese CSP support programme has been a game changer for CSP, with positive effects for both global cost and industry: global average costs of new CSP have decreased strongly, and a large number of new CSP supply chain actors have emerged. Considering both costs and the industry structure globally, things look positive for CSP – possibly better than ever before. In this view, China is strengthening the sector and its outlook – and is indeed *saving* CSP. Within this global trend, however, we observe two very different trajectories.

On the one hand, there is the Chinese trajectory, seeing average costs of currently USD 0.10 per kWh. This brings Chinese CSP close to cost competitiveness, first with PV and, should costs continue decreasing, with conventional power sources. All these projects are Chinese-led, and are built with mainly Chinese components, except for a few specialised ones. It thus seems that the Government's leapfrogging aim has been successfully achieved.

On the other hand, CSP outside China does not follow the same trajectory: the average cost of new non-Chinese stations is USD 0.17 per kWh, which is indeed lower than 3 years ago, but far from competitive with other

[1] The Chinese stations are 60% towers with on average 10.2 h thermal storage, built by Chinese developers (100%) and with Chinese EPCs (90% of projects for which we have data; data is missing for 4 of 13 projects).

[2] The non-Chinese stations are 80% trough stations, including 4 hybrid projects, with on average 4.7 h thermal storage, and they are built by European or US developers (60%) and EPCs (100%).

technologies. Almost all these projects are led by non-Chinese companies and all components are manufactured by Western comanpanies, which appear to be falling behind their Chinese competitors, at least on a cost basis.

These findings hinge on our data being correct. Whereas we see no reason why our industry data would be inaccurate, it is striking that the Chinese costs are so much lower than costs anywhere else, despite the weak Chinese solar resource. That the feed-in tariff is 30% higher than the LCOE of the most expensive project is startling, but the situation in Spain in 2007-2011 was similar [14], so it is not entirely unfeasible. Yet, the cost data is uncertain and we assembled it from numerous different sources (see [29] for a discussion of data certainty). Further, the costs of all Chinese stations are reported by developers or other involved companies themselves – and all statements were made during early phases of development, often before the project construction had started. Possibly, some cost statements are thus exaggeratedly low; we will update the data in winter 2018/19 when more projects have been completed and final, actual project costs become available.

The emergence of the Chinese CSP industry has brought rapid cost improvements for CSP, but they are limited to the Chinese market: as the Chinese market is largely separated from other markets, the Chinese CSP strategy has so far had little direct effect outside China. It is not yet clear whether Chinese industry will profoundly change the global CSP landscape, or even conquer the global market: it certainly seems possible, but it has not yet happened. However, an early indication that Chinese companies seek to conquer the global market would be the emergence of joint ventures between Chinese companies and foreign ones with experience in other markets. Indeed, there are a few such projects, including the joint ventures between Brightsource and Shanghai Electric [32] or Rioglass and Zhonghuan [33]. Further, Shanghai Electric is the EPC of ACWA's 700 MW DEWA IV project in Dubai – a project strongly backed by Chinese financing institutions [34, 35].

At the moment, it seems that European and American companies do not face immediate competition from their Chinese counterparts in markets outside China – but they also do not profit much from the growing Chinese market. Although many Western companies announced participation in the Chinese demonstration programme [36], practically all were unsuccessful (see Tab. 1). Whether China will conquer the global CSP industry, as it did with PV, or simply support a domestic expansion with domestic technology, as it did with wind power, will largely depend on the Government strategy in phase two of the support programme. There are first indications on the direction this strategy is may take – and hence what the CSP industry outside China can expect. The first phase of the CSP programme created incentives for a technologically diverse expansion of CSP, allowing domestic companies to test and implement new technologies and encouraged entrepreneurship in critical parts of the supply chain (see also [19]). The high feed-in tariff – 40% above the average stated cost of ongoing projects – suggests that *testing* and *experience building* are main objectives of the first phase, not low cost or rapid expansion. Just like the wind programme, the CSP programme has created a domestic market supplied by domestic companies, but other than the wind programme, it does not appear to aim at technology transfer, and it is not specifically incentivising joint ventures. Many projects rely exclusively on Chinese partners and components, and all projects are primarily supplied by Chinese companies. These companies are evidently capable of producing and supplying most components needed and to assemble these components into a fully functioning CSP station. Further research is needed to identify how this new CSP industry achieved such leapfrogging seemingly without much input from foreign companies – a remarkable feat, given that Chinese companies needed years of joint ventures to master the wind technology, and targeted input of outside experience to conquer the PV module industry.

In sum, we conclude that the the Chinese CSP support programme has improved the global outlook for CSP, with numerous new actors and low costs. In this sense, China is saving CSP as a global technology. Our results show that the Chinese strategy has successfully achieved its aim of leapfrogging, but so far only in China. Direct effects on markets outside China have so far been small, and it remains to be seen whether Chinese CSP companies seek and manage to emulate China's successful industrial strategy in PV module manufacturing to conquer the global market, or whether they rather seek to repeat the Chinese wind power and dominate only their domestic market.

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