Mechanisms of unrelated diversification enabling China's demonstration of nascent renewable energy technologies: the case of concentrated solar power

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Abstract

China's rapid formation of a globally dominant PV industry has recently been explained as being enabled by entrepreneurs accessing resources required for industry formation, being knowledge, markets, finance and legitimacy, and using these to supplement domestically available resources where needed. The importance of access to global knowledge and markets has previously been stressed in similar explanations of catching-up, or upgrading in global value chains, in other renewable energy sectors and other industries in latecomer countries. The current article analyzes the geographic origins of resources for formation of the Chinese Concentrated Solar Power industry, a sector that is still in a formative phase, globally. It is found that a competent domestic sector is forming, with a limited dependence on foreign resources. The domestic market is almost entirely captured by domestic firms already in its earliest formative phases, and Chinese equipment manufacturers and developers are already making strides into global markets. Development of components and design of complete plants, as well as systems integration capabilities, are largely rooted in domestic research institutes and corporate R&D. The findings indicate a greater potential for genuine leapfrogging in sectors with less matured global innovation systems, for countries that have attained a certain minimum level of development of domestic capabilities. This suggests that a greater role should be attributed to the maturity of the global innovation system both in selecting focus sectors in catch-up country stimulus policy as well as in analyses of industry diversification in latecomer contexts.

1. Introduction

China is increasingly regarded as a key locale in the development process of renewable energy technologies and other clean-tech. Its substantial markets for clean energy technologies, strong support policies, abundant capital and its strong generic manufacturing capabilities have helped the country become the largest consumer and manufacturer of wind turbines, PV panels, and electric vehicles. This status is particularly remarkable as Chinese markets and production for these technologies were still near non-existent in the first half of the 2000's. Apart from being the largest global contributor to the deployment of these technologies, China has also been credited as being a country with particular strengths in the scaled-up manufacturing of equipment (Nahm & Steinfeld, 2014), that have generally led to rapid cost reductions. Such reduced costs have enabled rapid market expansion not only domestically, but in foreign markets as well. China has further been credited with translating or adapting technologies developed in advanced economy countries for use in less developed contexts, thus acting as a conduit for North-South and subsequent South-South technology transfer or diffusion (Urban, 2018).

Much empirical work on China's rise in these sectors has highlighted mechanisms of learning, catching-up, or upgrading in global value chains as enabling this rapid rise. Development and demonstration of these technologies had occurred in a global core of advanced economies, whilst a periphery of emerging economies depended on foreign experience and technology to develop domestic manufacturing capabilities, at a moment when these technologies were at or close to mass production stages.

The technology of concentrated solar power generation is currently in demonstration phases, globally. A discernible global regime, lead firms, or global value chains are yet to be formed. Nevertheless, Chinese activity in this technological field is rapidly increasing. A long list of Chinese pilot and demonstration projects is in operation already, and twenty commercial scale solar thermal projects, with a combined capacity of 1,350 MW and a variety of technological pathways, has been under construction since 2016.

CSP plants are made up of building blocks from various different types of industry, in a form of 'neue kombinationen'. Individual building blocks, such as reflectors, receiver tubes or receiver blocks, systems for the use of molten salt as a heat-transfer fluid, heat storage & exchanger systems, dry cooling systems, solar tracking and other control systems, and others, depend on competencies present in various different types of industries, and are furthermore still under development. The Chinese activity in this sector suggests, then, that (regions in) China is (are) diversifying into new-to-the-world niches. The limited development of the sector at a global scale suggests that this diversification process is unlikely to be explained as a process of catching-up or upgrading in global value chains, as the global technology and experience pool is limited. Recent contributions that have stressed how (early) industry formation in clean-tech sectors in China and other emerging economies was influenced by transnational linkages between established global innovation systems and nascent domestic industries (Binz, Truffer, Li, Shi, & Lu, 2012; Gosens, Lu, & Coenen, 2015; Quitzow, 2015), or even largely built up by combining innovation systems resources available at the global level (Binz & Anadon, 2018), are therefore likely to fall short in explaining the Chinese activity in Concentrated Solar Power, or other globally embryonic industries.

The current article aims to clarify the mechanisms that enabled the increased Chinese activity, and rapid global market share growth, in this embryonic technological field. The focus of the analysis is on 1) identification of the (geographic) origins of the knowledge, markets, financing, and other system building resources enabling Chinese activity in this sector, and 2) identification of the (organizational) origins of strategic agency and the roles in system building of individual actors in the technological field. This is done through a review of Chinese government policy, a review of the constellation of actors involved in demonstration projects (developers, knowledge providers, equipment suppliers, etc.), as well as interviews with Chinese researchers in engineering departments of leading universities, policy makers, equipment manufacturers and project developers. This draft will later be supplemented with patent statistics. The findings are that these projects are characterized by a limited dependence on foreign resources. The bulk of the project developers, design institutes, EPC contractors, equipment manufacturers and financiers are domestic. Chinese developers and equipment manufacturers have entered both domestic and foreign markets. A number of the Chinese EPC can be characterised as lead firms that have sought to procure equipment largely from Chinese suppliers, that often required technical assistance from the lead firm, as these suppliers usually had related but no specific experience in the manufacture of CSP components. Only a limited share of components was required to be imported. These findings suggest that geographical constellations likely differ when latecomer countries enter sectors with different maturation at the global level, and that this in turn may have consequences for the potential for truly leapfrogging rather than entering into lengthy periods of following but not quite catching-up with the global frontier in such sectors.

2. Theory & method

Global markets for Concentrated Solar Power are small and limited to a small number of countries, a dominant design is yet to emerge and several different technological generations currently compete for market share, and a clear set of lead firms and/or global value chains are yet to form (more on this in section 3). As such, the technology/sector has clear characteristics of being in its formative phase, globally (Bento, Wilson, & Anadon, 2018).

A CSP plant combines a number of building blocks that draw experience from diverse industries and fields of engineering. This includes the reflectors, receiver tubes or receiver blocks, systems for the use of molten salt as a heat-transfer fluid, heat storage & exchanger systems, dry cooling systems, solar tracking and other control systems, and others. A number of these elements, such as curved mirrors, and receiver tubes or blocks, are unique to their application in CSP plants. Molten salt system pumps, storage and heat exchanger have application in a number of different power system industries, whereas solar trackers have previously also been used in PV plants (although sparingly, and only single axis tracking). The steam generation systems are fairly similar to those in other power system projects though they require a high degree of customization for each individual project, whereas the turbine and generators are fairly generic components.

Previous related experience for the manufacture of the reflectors can be found in mirror or glass manufacturing industries, which have no previous experience in power plant applications. Related experience for receiver blocks and heat exchanger systems can be found in boiler manufacturing industries, but these have no experience in the construction of a 'solar field', i.e., the field of reflectors and other systems that collect the sunshine. Even at the level of individual components there are combinations of previously unrelated experience. A receiver block, for example, requires an absorptive coating, for which knowledge is typically not present in boiler manufacturers that manufacture these receiver blocks. A receiver tube is made of a steel inner tube, a glass outer tube, an absorptive coating on the steel tube and protective coating on the glass tube, and a bellow of folded steel that connects the glass and steel tube and preserves the vacuum in between them. Experience for these components or sub-components can thus be found in diverse industries that would not necessarily have previously collaborated.

The apparent diversification of Chinese firms or regions into a sector unrelated to their previous experience, and into a sector that is in a formative phase, globally, presents somewhat of a conundrum.

First, industrial branching out in latecomer countries has historically typically been focused on the replication or transplantation of industries for globally established technologies (Boschma, Coenen, Frenken, & Truffer, 2017)(see also Table 1). Such a notion is also present in the literature on catching-up, which has argued that national governments may stimulate industrial upgrading by orchestrating learning and capability development of domestic infant industries in globally established sectors with well-developed export markets. The literature on global value chains similarly points to the potential for local industry formation by entering into well-established global supply chains.

Second, on the dimension of related versus unrelated diversification, there are indications latecomer environments provide inferior conditions for industries to branch out into unrelated activities. Unrelated diversification was found to be more likely in knowledge intensive regions, and in regions in countries with more liberal market economies (Boschma et al., 2017). Neither of these conditions are reminiscent of the Chinese environment, or of many of the other Asian catch-up countries. In contrast, Pinheiro et al (2018) found that unrelated branching out mostly occurred when countries were "at an intermediate level of economic development, and when they have higher levels of human capital", a description that does more closely resemble China's current status.

Table 1. Typology of regional diverisifation. Reproduced from (Boschma et al., 2017).

		REGION	
		RELATED	**UNRELATED**
SECTOR	REGIME	Replication	Transplantation
	NICHE	Exaptation	Saltation

In terms of geographical constellations that enable unrelated diversification, Boschma et al (2017) indicate that unrelated diversification may occur through combing previously unconnected technological capabilities from within a region, or otherwise by incorporating capacities from outside. They provide examples of foreign-educated entrepreneur returnees or multinationals that establish themselves within the region, but close in saying that the issue of region-external resources remains underdeveloped in current theorizing (Boschma et al., 2017). A recent contribution by Binz and Anadon (2018) developed a framework for the resources required for industries to diversify, highlighting that entrepreneurs in latecomer environments might be able to access resources that go beyond mere capabilities from the global innovation system. They referred to knowledge, markets, finance and legitimacy (Table 2), and stressed the ability of Chinese entrepreneurs in accessing these resources present at global system levels and anchoring these resources in domestic infant industries as crucial in explaining the rapid formation of China's PV industry.

Table 2. Key system resources for industry formation. Reproduced from (Binz & Anadon, 2018).

Resource	Sub-dimensions
Knowledge	Codified knowledge (Know-what) Tacit knowledge (Know-how)
Markets	Commodification
	Niche markets
Financial investment	Venture capital, banks, equity and institutional investors Government subsidies
Technology Legitimacy	Institutional embedding
	Technology certification, standards

In the current article, this framework of resources for industry formation is applied to China's CSP sector. Seen the relatively less matured global innovation system, it is expected that geographical constellations of these resources will be different from cases where a latecomer entered the industry at a moment when global systems were relatively well formed. Specific attention will be paid to the different building blocks of CSP plants, some of which (primarily the reflectors and receiver tubes) can be categorized as standardized mass produced products, whereas others are highly customized design-intensive products. The different types of products have previously been shown to have different potential in rapid catching-up (Binz, Gosens, Hansen, & Hansen, 2017; Schmidt & Huenteler, 2016), something potentially related to the accessibility of these industry formation resources.

2.1.1. Method

Data was collected through 1) a review of a number of (Chinese) news sites that focus on the CSP industry, specifically, CSP Focus, CSP Plaza, and CNSTE (the latter is run by the Chinese National Solar Thermal Alliance). These sites report, amongst others, on updates on policy, as well as project status updates and results of tenders. These sites, as well as a number of annual industry status reports by the Chinese National Solar Thermal Alliance were parsed to create a database of projects, and the role of individual firms or research institutes in these projects, in order to identify key industry players. This was supplemented with information from interviews with 18 experts in developer companies, equipment manufacturers, policy making, industry alliance groups, and engineering departments of key universities (this interview campaign is still ongoing). The interviews with developers and equipment manufacturers focused on the institutional work required to get policy support and attract investment, the work required in identifying and/or training equipment or component suppliers, the geographical origin of knowledge, components, engineers, and investment, and the considerations in selecting either foreign or domestic sources, were available, for these resources.

3. Sector overview

3.1. Description of Concentrated Solar Power technologies

Concentrated Solar Power (CSP) is a set of technologies that utilizes a large surface area of reflectors (mirrors) that reflect sunlight onto a much smaller receiver area, where heat is collected. This heat can be utilized directly in industrial processes or in space heating, or it can be utilized to generate steam for the generation of electrical power. It is also referred to as Solar Thermal, together with solar water heater (SWH) systems, but are different from such SWH systems because of the much larger area of reflectors that concentrate the sunlight before it is collected in a central receiver in CSP systems. It differs from solar PV because it collects heat for use in a semi-conventional turbine & generator system for the production of electricity, rather than using the photovoltaic effect as in PV panels.

This difference with PV is also one of the key technical advantages of CSP. Thermal energy can be stored more efficiently and far less costly than electric energy (Zhao, Wu, Hu, Xu, & Rasmussen, 2015). Most modern CSP plants have on-site systems for the storage of thermal energy equivalent to several hours of full output of the plant. The 20 Chinese demonstration projects, for example, all have on-site thermal storage, equivalent to anywhere between 4 and 16 hours (NEA, 2016). This thermal storage makes that electricity can be generated and dispatched on demand, largely resolving issues of grid integration due to the intermittency of generation of PV and wind farms. With up to 16 hours of storage as in some of the Chinese demonstration plants, the CSP plants can even produce electricity throughout all 24 hours of the day.

There are several different overall designs for CSP plants (figure 1). The parabolic through design is by far the most common design in currently operational plants, whilst recent plants, and those under construction, are increasingly frequently using the central tower design (SolarPACES/NREL, 2018). The other designs listed in figure 1 are less common but still used in a number of operational plants.

Plants can be further differentiated by the type of heat-transfer fluid and, related, the maximum operating temperature of the receiver. Higher operating temperatures are desirable as they allow for higher solar-to-power conversion efficiencies. Some systems, mostly earlier and small-scale or low temperature systems use water or steam as the heat transfer fluid. The conventional heat-transfer fluid in parabolic throughs is thermal oil, which allows operating temperature of up to circa 350 °C, after which the synthetic oil will begin to degrade. In central tower designs, molten salt, which allows operating temperatures of up to 600 °C is more common. It is also the conventional medium for thermal energy storage. Recent through design plants, and many under construction, have also used molten salt, allowing similarly high operating temperatures. A downside is that very large maintenance cost can be incurred when the salt coagulates (freezes), and this is more likely to occur in through designs, as a typical 50 MW through plant will have circa 100 km of receiver tubes carrying the molten salt, versus ca. 1 km of pipelines in a central tower design plant. Further developments are being tested, with receiver designs and salt types that would allow for operating temperatures up to 800 °C, and systems using supercritical CO_2 as the heat transfer fluid, which could allow for operating temperatures up to 1000 °C.

Taken together, it is clear that a dominant design has not yet been solidly established. With regards to the different layouts of the power plant, it can be argued that different types of layouts may have different benefits and will therefore co-exist for some more time. Developments for higher temperatures are not incremental improvements but genuinely different generations of receiver technologies, with industry analysts expecting the ever higher temperature variants to occupy increasingly large market shares. Water and thermal oil based systems are likely to be largely pushed out by molten salt and other HFT based systems in the near future.

Figure 1. Designs of Concentrated Solar Power plants. Top left: parabolic trough; top center: central tower receiver; top right: linear Fresnel; bottom left: Enclosed parabolic trough; bottom center: central beam down tower with ground-level receiver; bottom right: Parabolic dish with Sterling engine.

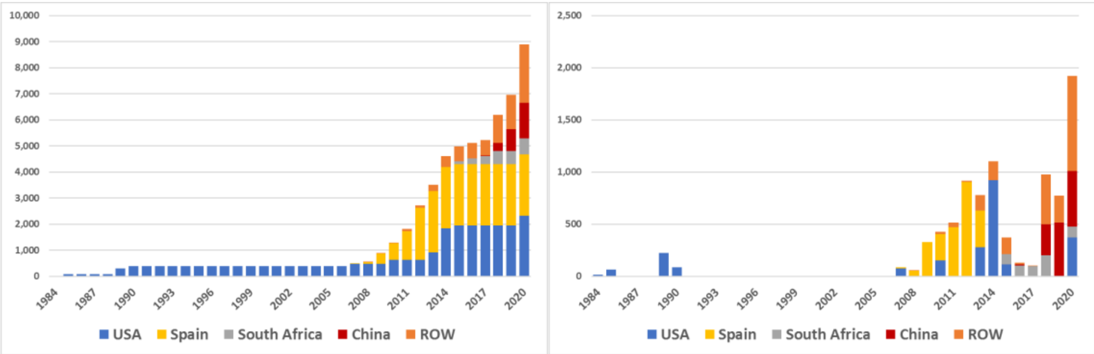
3.2. Global sector developments

Global operational capacity of CSP plants stood at 5,216 MW by year-end 2017, with annual additions of operational capacity at around several hundred MW between 2009 and 2015 (Figure 2). This is equivalent to 1.0% of cumulative global wind power capacity, or 1.3% of global PV capacity in 2017 (GWEC, 2018; PV Magazine, 2018). Stated another way, global CSP installations are currently at a scale that wind power reached more than twenty years ago (in 1996), and PV reached more than a decade ago (in 2005).

The first commercial scale projects for electric power generation with concentrated solar power were built in the mid-eighties in California. A total of 354 MW, in 9 phases, made up the Solar Energy Generating Systems (SEGS) which are still operational today. The SEGS is made up of parabolic troughs with thermal oil as the HTF.

After completion of the SEGS systems, it took a full 27 years before any other CSP project became operational. In the late 2000's and early 2010's, the global market was almost entirely driven by developments in Spain (Figure 2), where generous support policies were put in place. The first plant to come online in this CSP renaissance was the 10 MW Planta Solar 10, or PS10, which became operational in 2007, followed by the 20 MW PS20 in 2009, both developed by the Spanish Abengoa Solar. The PS10 and PS20 were also the world's first commercial scale solar power tower projects. Another Spanish developer, Gemasolar, built another 20 MW solar power tower, which became operational in 2011. This was the first commercial plant, globally, to utilize molten salt as the Heat Transfer Fluid. The large majority of projects since 2007, however, both in Spain and elsewhere, were still of the parabolic trough variant, with thermal oil as the HTF. Since then, the Spanish support policies have been reduced, together with most of its renewable energy tariffs, and Spanish development of CSP has ceased. The current growth markets for CSP are in the MENA region, and China.

Figure 2. Global installations of CSP. Cumulative (left) and annual (right) installations (MW). Commercial scale projects only. Includes operational plants for years up to 2017, and plants under development or planned for 2018 and onwards. Source: (Electric Power Planning & Engineering Institute, 2018; SolarPACES/NREL, 2018).



The relatively weak development of global markets, and the stop-and-go nature of the major markets, has caused difficulties for CSP equipment manufacturers and developers. A number of the Spanish firms that had taken an early lead in market shares, including Abengoa, Acciona, or ACS-Cobra have only been able to continue to operate, because they managed to build activities in foreign growth markets, and/or because the CSP business is not their core activity (Helioscsp, 2012; SolarPACES/NREL, 2018). A number of other firms have been less successful and have filed for bankruptcy or were acquired. Examples include:

- Luz International Limited (US) was the firm that developed the SGES projects in California (SolarPACES, 2018). It went bankrupt in 1992, with its assets and technology acquired by Solel (Isreal) (PVNEWS, 2016).
- The Israeli Solel was acquired by Siemens (Germany) in 2009, whilst Siemens closed down its CSP activities in 2012 (PVNEWS, 2016). Siemens completely wrote off the value of the CSP investment, and sold its CSP assets and technology it at a steep loss to Rioglass Solar in 2013 (Helioscsp, 2013a). Rioglass Solar is co-owned by Rioglass, a laminated glass producer, and Abengoa. Siemens/Solel were at one time the second largest firm in the supply of receiver tubes, with a 37% share of the market (Chaanaoui, Vaudreuil, & Bounahmidi, 2016).
- SCHOTT Solar (Germany) was long the undisputed leader in the supply of receiver tubes for parabolic through plants, with a 61% share of the market (Chaanaoui et al., 2016). SCHOTT closed down its receiver tube production in Germany in 2014 due to falling demand (SCHOTT Solar, 2014). In 2016, Schott Solar sold its remaining CSP activities to Spanish Rioglass, a manufacturer of reflectors for parabolic troughs (SCHOTT Solar, 2016), although it continues to manufacture the glass tubes that are used as outer tubes in CSP receiver tubes.

- Solar Millennium AG (Germany), a designer and developer involved in 2,500 MW of parabolic through plants, filed for insolvency in 2011 (Solar Millenium, 2013; SolarPACES/NREL, 2018)
- SkyFuel, Inc. (US), a designer and manufacturer of parabolic through systems, was acquired by Wuhan Kaidi New Energy (China) in 2015 (SkyFuel, 2017).
- TSK (Spain), a designer and developer of CSP plants, acquired German Flagsol, a company that had been involved in construction of the first US CSP plants and in the early phases of the Spanish CSP plants, in 2013 (Helioscsp, 2013b).
- Acciona (Spain), one of the country's leading CSP power plant developers, sold of five of its six CSP plants in 2018 to reduce debt by 760 million euros. Note that Acciona's primary business activity is the development of wind power plants (New Energy Update, 2018), and that the financial woes cannot be attributed solely to the CSP activities.
- Abengoa (Spain), another of Spain's leading CSP power plant developers, filed for bankruptcy for its US entities in 2016. It narrowly managed to prevent bankruptcy of the company as a whole after a deal was struck with its creditors, in which the creditors received between 90 and 95% of equity in the company in return for outstanding loans (Buck, 2016; Neumann, 2016). Note that CSP is only a fraction of Abengoa's activities and that, as with Acciona, these difficulties cannot be attributed solely to the CSP activities.

Industry shake-outs are not uncommon in industries with cycles of rapid growth and decline, nor necessarily an indication of an entire industry in trouble. The wave of closures and acquisitions in the CSP sector is occurring in a stage much earlier than it did in the wind or PV industry, however. The recent shake-out has seen an already small number of firms active in the CSP sector reduced even further, including some of the firms that were leading in market or technological aspects.

The entry of Chinese firms into the sector (next section), then, comes at a moment when the technological developments are still fluid, and when global markets are too small and too young to have developed or sustained a clearly discernible global regime, lead firms, or global value chains.

3.3. Chinese sector developments

3.3.1. Small scale pilot activities

The earliest CSP pilot plant in China was constructed during the 7th Five-Year Plan period (1986-1990). It was a 24 meter parabolic trough, built entirely for research purposes. The project was funded from the Science & Technology budget, and carried out by a consortium of the institute of Electrical Engineering of the Chinese Academy of Sciences (hereafter IEE-CAS), Qinghua University, and at least one domestic equipment manufacturer called Sanpu (interview WZF/DFL).

It wasn't until halfway through the 2000's before further pilot projects were undertaken. In 2004, Himin Solar , together with IEE-CAS, built a 2*6m parabolic trough in Tongzhou, a suburb of Beijing (Author's CSP project database, 2018). Himin Solar is a firm best known for its solar water heater devices. China's first tower type project, a 70 kW tower in Jiangning, Jiangsu, was completed in 2005, by the Chinese Academy of Engineering, and again IEE-CAS and Himin (Wang, Yang, Jiang, Zhang, & Lund, 2017).

An important test-base was constructed in Yanqing, a suburb in Beijing, from 2010 onwards. In august of that year, IEE-CAS and Himin finished a 24m trough, which was expanded by a further 100m by December of the same year. IEE-CAS received a grant from MOST in the 11th FYP period for the construction of a 1 MW tower, which was finished in 2012, and used heliostats supplied by Himin, and a receiver block from Dongfang boiler. In the 12th FYP period, IEE-CAS developed a 1 MW trough system, with one third of the solar field supplied by three different domestic manufacturers; Rayspower, Royaltech, and ? (interview DFL).

Another notable test-base is one by China General Nuclear (CGN, previously China Guangdong Nuclear), a nuclear power group that has long sought to diversify into the development of solar energy projects. In addition to a large number of PV projects, their ambition to diversify into CSP was started with a test-base in Delingha, where they constructed a 1.6 MW parabolic trough as well as a 1.6 MW linear Fresnel project. Planning on the projects was started in 2009, and they were operational in 2013 (Author's CSP project database, 2018).

A further 28 pilot projects (here defined as anything below 10 MW of capacity) was constructed between 2011 and now (Author's CSP project database, 2018).

3.3.2. Two 10 MW tower projects

In 2010, planning started on a 10 MW central tower project by SupCon Solar. This is a full subsidiary of the SupCon Group, which is active in industry automation and control technologies. Site selection was completed in 2010, with the choice for Delingha in Qinghai. A first 5 MW tower was in operation by August of 2012, with a second tower following by December 2012. Both towers initially used water/steam as an HTF, but one tower was retrofitted to use molten salt in 2014, enabling heat storage. The project was the sixth commercially operated tower type project, globally.

In 2013, SunCan was established as a subsidiary of ShouHang IHW, a group active as an EPC in various clean energy and energy conservation projects. The first purpose of the new subsidiary was to construct a 10 MW demonstration project in Dunhuang, in Gansu province. The project was a single tower using molten salt as the HTF. Construction started in August 2014 and the project became operational in December of 2016.

3.3.3. Early phase plans –but little more- for utility scale projects

In 2011, the NDRC held a tender for the development of a utility scale CSP project, which was won by Datang, one of the country's Big 5 power generation groups. The submitted bid was for a 50 MW through project in Ordos, Inner Mongolia. The following year, the NDRC approved four projects, which include the same Datang project in Ordos, a 50 MW trough project in Jinta by Huadian, another one of the Big 5 power generation groups, a 92.5 trough project in Hanas by Hanas Energy, a SOE power generation group, and a 50 MW trough in Delingha by CGN solar, the company that had previously built a test-base in the same city.

Apart from these officially approved projects, at least another 50 utility-scale projects (more than 30 MW) was announced by developer firm between 2012 and 2016. None of these plans, including the ones approved in 2012, were ultimately constructed, primarily due to a lack of financial viability when no Feed-in Tariff was established.

The only project that was followed through on was the CGN Delingha project. This developer successfully sought a soft loan from the Asian Development Bank as well as support from the China Import-Export Bank. Despite attempts to start construction in 2014, tenders for individual EPC tasks and components in the same year, and a strong reliance on foreign equipment suppliers, the project took many years to progress. Only after it was finally included in the list of 20 utility scale demonstration projects (section 3.3.4) and was awarded a FiT, did construction seriously start.

3.3.4. Take off of the domestic sector: 20 'demonstration' projects

On 23 September 2015, the National Energy Administration released a notice asking for applications for CSP demonstration projects. The applications required to have a minimum scale of 50 MW, which would be considered commercial or utility-scale projects in most other countries. The notice asked developers to bid for a FiT, provided a number of minimum technical specifications for different technological routes (i.e., trough, tower, or Fresnel), and required applications to be submitted prior to the end of October of the same year. In September of 2016, notice was given of bid winners, a total of 20 projects and a combined capacity of 1,350 MW (Table 3). The projects were a mix of different routes, with 9 towers, 7 troughs and 4 Fresnel projects, and roughly half private and half SOE developer companies, in an apparent bid to figure out the optimal configuration for project development. All of the projects were awarded a FiT of 1.15 RMB/kWh, with the requirement that the projects would deliver power to the grid before the end of 2018.

Table 3. Description of the 20 projects in China's first batch of CSP demonstration projects

Province	City or county	MW	Type	HTF	Storage length (h)	Storage medium	Conversion efficiency	Developer	Tech source & system integration	Expected
Qinghai	Delingha	50	Tower	Molten salt	6	Molten salt	18.0%	Supcon Solar	Supcon Solar	Dec-18
Gansu	Dunhuang	100	Tower	Molten salt	11	Molten salt	16.0%	Beijing Shouhang IHW	SunCan	Dec-18
Qinghai	Gonghe	50	Tower	Molten salt	6	Molten salt	15.5%	Northwest Engineering	Supcon Solar & Northwest Engineering	Dec-19
Xinjiang	Hami	50	Tower	Molten salt	8	Molten salt	15.5%	NWEPDI	Supcon Solar & NWEPDI	Jun-19
Qinghai	Delingha	135	Tower	Water	3.7	Molten salt	15.0%	SPI Huanghe	Brightsource (US) & NWEPDI	Unclear
Gansu	Jinta	100	Tower	Molten salt	8	Molten salt	15.8%	Three Gorges	SunCan & Northwest Engineering	Dec-20
Hebei	Shangyi	50	Tower	Water	4	Molten salt	17.0%	Dahua & IEE-CAS	IEE-CAS	Dec-19
Gansu	Yumen	50	Tower	Molten salt	6	Molten salt	18.5%	Yumen Xinneng	Shanghai Parasol & Jiangsu XinChen	Dec-18
Gansu	Yumen	100	Tower	Molten salt	10	Molten salt	16.5%	Guohua	SunCan	Abandoned
Gansu	Yumen	50	Through	Thermal oil	7	Molten salt	24.6%	Royaltech	Royaltech	Dec-19
Gansu	Akesai	50	Through	Molten salt	15	Molten salt	21.0%	Shenzhen JinFan	Tianjin Binhai	Dec-18
Gansu	Yumen	50	Through	Thermal oil	7	Molten salt	24.6%	Rayspower	Rayspower	Jun-19
Inner Mongolia	Urad Middle Banner	100	Through	Thermal oil	4	Molten salt	26.8%	CNNC & Royaltech	CNNC & Royaltech	Dec-19
Qinghai	Delingha	50	Through	Thermal oil	9	Molten salt	14.0%	CGN Solar	CGN Solar	Dec-18
Gansu	Gulang	100	Through	Thermal oil	7	Molten salt	14.0%	CECEP	Royaltech & CECEP	Dec-20
Hebei	Chabei	64	Through	Molten salt	16	Molten salt	21.5%	Zhongyang Energy	Skyfuel (US) & Zhongyang Energy	Dec-19
Gansu	Dunhuang	50	Fresnel	Molten salt	13	Molten salt	16.7%	Lanzhou Dacheng	Lanzhou Dacheng	Jun-19
Inner Mongolia	Urad Front Banner	50	Fresnel	Thermal oil	6	Molten salt	18.5%	Huaneng	Huaneng	Unclear
Hebei	Zhangbei	50	Fresnel	Water	14	Concrete	10.5%	CITIC New Energy	Terasolar	Unclear
Hebei	Zhangbei	50	Fresnel	Water	14	Concrete	11.9%	Huaqiang	Terasolar	Dec-19

Sources: (Electric Power Planning & Engineering Institute, 2018; NEA, 2016). Notes: IEE-CAS: Institute for Electrical Engineering, Chinese Academy of Sciences; NWEPDI: Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group; Northwest Engineering: Power China Northwest Engineering Co., Ltd; CGN Solar: China General Nuclear (formerly China Guangdong Nuclear) Solar Energy Development Co., Ltd.; CECEP: China Energy Conservation and Environmental Protection Group; CNNC: China Nuclear Energy Technology (Nanjing) Energy Development Co., Ltd; SPI Huanghe: State Power Investment Huanghe Hydropower;

4. Origin of resources and strategic agency for industry formation

4.1. Knowledge

In the pilot project phase, there was an obvious important role for the IEE-CAS and HImin collaboration (section 3.3.1). In these pilot projects, IEE-CAS functioned as the project developer, and was responsible for procurement of equipment and system integration. The collaboration further co-developed a number of key technologies. The development of the heat-resistant coating for receiver tubes that could use molten salt, for example, was researched simultaneously in a post-doc project at IEE-CAS and in the R&D department of Himin solar, with results combined into a final product. A similar arrangement was in place for the development of the glass-to-metal bridge (the component connecting the inner steel and outer glass tube of a receiver tube) (interview WZF/DFL). The Southeast University also worked on a high-temperature receiver tube, developed in collaboration with (again) Himin, Linuo Paradigma, and IVO (Wang et al., 2017).

Apart from the firms already mentioned in section 3.3.1, companies that engaged in equipment development and tested these in pilot project include TRX Solar Tech, Parasol Energy, Terasolar, Lanzhou DCTC, and SunCan, all firms that were later involved in the 20 utility scale projects currently under development (see section 3.3.4).

Foreign involvement in the pilot projects was relatively limited. Cleanergy from Sweden supplied a sterling engine for a 100 kW dish project in 2012. Helio Focus from Israel transferred technology for a dish and sterling engine design for a 1 MW project finished in 2013. Rioglass (Spain) and SCHOTT Solar (Germany) supplied the reflectors and receiver tubes for a 1.5 MW project in 2013. ENEA and CENER supplied consulting services for a 1 MW trough project in 2013. Solastor Australia constructed a 500kW tower in Jiangyin, Jiangsu, together with a local partner, in 2014.

The creation of the firms that built China's first two 10 MW projects had strong foundations in domestic research institutes and companies.

SunCan was founded by a prior post-doc from IEE-CAS, who had experience both theoretically form his PhD and post-doc work there, as well as from project management experience in developing the 1 MW pilot plant by his research group. The key competence brought into this firm was that for system integration, and a strong understanding of design specifications of individual components. Procurement of components occurred largely domestically, which required active cooperation by SunCan and suppliers, where SunCan supplied designs or technical specifications and performed quality control checks. Only a limited number of components, specifically the turbine, the molten salt pump, and high pressure sensors, were sourced from leading foreign manufacturers. The team of engineers employed by SunCan has grown to about 20 by now, all recruited from domestic institutes.

The firm involved in the other 10 MW tower project, SupCon Solar, had most expertise in control systems for the plant. This includes the solar tracking and heliostat control systems, salt temperature monitoring and preheater control system, cloud forecasting systems, and systems for the operational control between receiver output, heat exchangers and storage system, and power generation systems. Overall design and systems integration expertise is secured through consultancy by the Northwest Electric Power Design Institute (NWEPDI), a subsidiary of the Power Construction Corporation of China. Further design expertise for the receiver block, heat exchanger and steam generation system comes from Hangzhou Boiler, a partner of SupCon in SupCon Solar, as well as consultancy by Zhejiang University. SupCon manufacturers only the control system components, and procures the rest. Like with SunCan, it required SupCon to engage in co-development with its suppliers for some of the components. The steel and coating used in the receiver block is imported from US companies, but design and manufacturing is done by Hangzhou Boiler. The tea of engineers at SupCon comes from universities all over China, with a strong representation from the local Zhejiang University.

TRX Solar Tech, a manufacturer of receiver tubes, is a spin-off of the China Academy of Space Technology (CAST). Some of its core capabilities are derived from CAST, specifically its material science background on the effects of solar radiation and vacuum conditions, which are derived from satellite research and manufacturing programs in CAST. TRX developed the absorbent coating for the steel inner tube and the protecting coatings for the glass outer tube, and designed the manufacturing lines for the assembly of components. The glass tubes are sourced form a local manufacturer, whilst the steel-to-glass bridge, a particularly complex component, is sourced from the German Witzenmann. Although it thus relies on foreign supplier for one of its most critical components, it is TRX that performs development, assembly and reliability testing of the final product, as well as design and quality control of domestically sourced components.

Himin Solar, another manufacturer of receiver tubes, derived most of its competences from its experience in production of solar water heater systems. Engineers of Himin stressed, however, that although the overall concept of a SWH and CSP receiver tube were similar, key differences existed in the absorbent coating, because of the very big temperature differences, and in the glass-to-metal bridge (an SWH receiver is composed entirely of glass, with two glass tubes inside each other). Both the coating and the glass-to-metal bridge were developed by Himin itself, with assistance from IEE-CAS.

Interestingly, one of the local research groups that was involved in the development of next generation receiver block technologies indicated that they had relatively more interest from foreign parties than from domestic parties for contract research. A key reason, the interviewee argued, was that the technologies developed by his lab were tested at large scale, relatively close to market application, compared with foreign research groups. The group's own testing facility for these next generation receiver blocks was a 1 MW tower.

4.2. Markets

Domestic market formation has, until the official announcement of the 20 demonstration projects in 2016, essentially been non-existent in China. The pilot project activities, the two 10 MW tower projects and the CGN Delingha project were all well under way prior to this domestic market creation. Component manufacturers interviewed for this article all indicated that they entered the industry with a two-pronged strategy, of focusing on foreign markets, and expecting domestic formation to occur relatively shortly afterwards.

The two manufacturers of receiver tubes and one for steam generation systems that were interviewed had managed to sell to commercial scale projects in foreign markets prior to domestic market formation having occurred, but indicated that in the current market outlook, the relevance of foreign and domestic markets was of roughly equal weight. The projects included supply of receiver tubes to Germany, France, India and Spain, and steam generator systems to India and Spain.

The two developers, SunCan and SupCon, were both actively looking, and optimistic about their prospects, to perform either developer or solar field EPC tasks in foreign projects. Already, it was recently announced that the winning bid for EPC services for the DEWA 700 MW CSP plant in Dubai, currently the largest project globally, would go to Shanghai Electric (PR Newswire, 2018). Although construction of the solar field has been subcontracted to the Spanish Abengoa, it may be expected that Shanghai Electric, a manufacturer of power generation and electrical equipment, will be using some of its own products for the remainder of the plant.

4.3. Finance

The pilot projects listed in section 3.3.1 were largely financed with research funding from MOST, but co-sponsored by equipment manufacturers, that were expected to deliver the components at below cost prices.

Investment in the registered capital for SupCon Solar, including for the 10 MW demonstration plant, came from SupCon Group, Hangzhou Boiler, Hangzhou Turbine, and Zhejiang University. Interestingly, the decision to invest in the 10 MW project, and start of construction, occurred prior to the awarding of a Feed-in Tariff. This was only awarded in 2014, in an ad hoc decision by the NDRC, aimed solely at the SupCon project. The decision to invest was one largely based on the desire of the consortium to expand capabilities in large-scale applications of the technology, and the expectation that a domestic market would soon be formed for commercial sized projects. The same partners invested in the 50 MW phase 2 project, but with additional finance from a local investment fund. Local banks were not easily convinced of investing in the project, due to the novel nature of the technology, and the relatively limited development of an industry supply chain.

Similarly, Investment in the registered capital for SunCan, and its 10 MW demonstration plant, came from its parent company, ShouHang IHW (65%), with the remainder invested by a team of private entrepreneurs led by its founder. Again, the decision to invest and construction occurred prior to the awarding of a Feed-in Tariff. For the SunCan project, finished in 2015, the decision was made that the first 10 MW phase would be covered by the same FiT as the 100 MW second stage, although only after the project as a whole is delivering power to the grid.

The project in Delingha, developed by CGN Solar, is the odd one out. This project was a lighthouse project for the Chinese market, and required institutional investors and soft interest rates in order to be financially viable. CGN successfully applied for a $150 million loan from the ADB, good for 47% of investment. Remaining 33% was invested by the China Import-Export Bank, and 20% by CGN itself. The rate for the ADB load was the LIBOR rate plus 0.4%, or roughly anywhere between 1 and 3% for the period since it was awarded in 2014. This compares to a 6% interest rate typically charged by non-institutional investors for the Chinese CSP projects.

Financing has become a hot issue in the development of projects. In early 2018, it became apparent that most projects would not be able to their year-end 2018 deadline (see the expected dates in Table 3). Best prepared for the challenging time-schedule were the developers with previous experience, i.e., SunCan and SupCon, as well as CGN, who had been planning its project for many years. The most critical issue for the other projects appears to have been financing, with private companies not easily managing to find sufficient investors for projects costing several hundred million US dollars, and SOE being hesitant and slow in making the final decision on a relatively novel and risky technology.

Equipment manufacturers spoken to did not having much difficulty with securing investment for production capacity. Production lines were typically scaled up in small steps at a time, and usually with investment for expansions made only when solid orders for supply contracts were received. Scaling up of production capacities was a process in the order of months, rather than years. None of the manufacturers talked to was considering an IPO to raise capital for such expansion, nor were any news items for such plans found for any of the other manufacturers. It should be noted that currently, the pace at which manufacturing capacity is growing might not necessitate extraordinarily large sums of capital.

One project developer, Shenzhen Jinfan, has indicated it has the ambition to create a manufacturing base that would make it essentially self-reliant for manufacturing of reflectors, receivers, and solar tracking equipment. For this purpose, technology is introduced from Reflex (reflectors), Archimedes (receiver tubes, and Sarea (tracking equipment). It is not clear on what contractual arrangement this technology is 'introduced'. The manufacturing base, scaled at 200 MW of annual production capacity, required 600 million RMB of investment, and was co-invested in by Shenzhen Nuclear, which does EPC for nuclear power plants, and Binhai High-Tech Zone, a local government agency.

4.4. Legitimacy

The primary Chinese policy driver for promoting the development of CSP is the possibility of integrated energy storage. This makes the plants capable of dispatching on demand, providing a great benefit over intermittent PV and wind power plants, which are faced with high levels of curtailment, or wastage, in particular in China's Northern and Western regions. The current preferred design by policy makers and grid operators is that the on-site storage for these CSP plants would be at least about 10 hours, which enables these plants to charge their storage during the day time, when PV output also peaks, and discharge the storage only during the night time. The plants further usually require some external source of energy for molten salt preheaters (for preventing coagulation) which could also be supplied by intermittent renewables, thus increasing levels of consumption of these. Although there is also a more generic Chinese policy push to develop next-generation renewables and energy storage technologies, few of the interviewees recognized this sort of industrial policy as a key ingredient driving the policy stimulus.

Interviewees did point to a legitimacy issue for the technology, largely connected to the usual concerns over novel technologies with limited track record. In particular the cost of CSP was considered a barrier for wide-ranging Chinese policy support. The current FiT, at 1.15 RMB/kWh, was selected to be equal with China's first nationally applicable FiT for solar

PV, launched in 2011 and adjusted in 2013 (current PV FiT are between 0.55 and 0.75 RMB/kWh). Interviewees argued the FiT was too low for the CSP industry at this stage, and pointed out that FiT in PV demonstration projects prior to 2011 had been as high as 4 RMB/kWh. Others pointed out that 1.15 was quite high for renewable electricity, but more acceptable for RE plus storage. Although a power market reform is underway, there are currently no power price premiums for peak regulating units, an ancillary service that CSP plus storage could provide.

Government concerns over cost are further reflected in proposed penalties for projects in the first batch of demonstration projects, where those that fail to meet the December 2018 deadline will see their FiT reduced to 1.12 RMB for projects completed by year-end 2019, and 1.07 RMB for those completed by year-end 2020. Similarly reduced FiT are expected for a second batch of demonstration projects, reflecting a government attitude reluctant to spend generously on another renewable power source, whilst industry argues that this such support is exactly what is needed for an industry at this phase of development.

Some additional legitimacy may be provided by local governments, in particular those in the areas where the CSP plants are being constructed. These Western provinces are among the poorer in China and are happy with the additional economic activity. A number of cities has clarified that development permits would be awarded on the premise that equipment manufacturing would occur within the same cities, introducing high-tech and well-paid labour demand to these cities. Although there are obvious issues with skilled personnel in these areas, a number of manufacturers or developers indicated that some manufacturing tasks were not too demanding on educational levels, and that the local manufacture of some components, in particular the reflectors and frames, could make sense financially as this would prevent substantial transport costs.

Verification of equipment efficiency and durability were a key element in access to foreign markets for Chinese equipment manufacturers. A first foreign project for one of the receiver tubes manufacturers included a multiple year long testing process by the customer, before a contract for a commercial scale project was signed. In other instances, manufacturers sought third party certification to provide reassurances on product quality. China does not currently have domestic product standards for CSP equipment, but rather relies on standards developed by the International Electrotechnical Commission, specifically the IEC Technical Committee TC 117 “Solar thermal electric plants”. Interestingly, a number of Chinese equipment manufacturers and research institutes are represented in this committee. The Chinese industry is thus not merely responding to international quality criteria, but actively helping in developing these global standards.

5. Discussion & conclusion

The formation of the CSP sector in China, although a recent and ongoing phenomenon, appears to present a case where catching-up, or leadership attainment, has been both fast, and largely rooted in domestic resources for industry formation.

The domestic market appears to be almost entirely captured by domestic firms already in its earliest formative phases, and Chinese equipment manufacturers and developers are already making strides into global markets. Development of components and design of complete plants, as well as systems integration capabilities, are largely rooted in domestic research institutes and corporate R&D. Although many projects are experiencing difficulties in attracting investment for project development, the difficulties are not that the finance is not, or to a lesser degree, available in the domestic context, but rather have to do with investor skepticism not uncommon to emergent technologies. Rather than taking cues from established global quality standards, Chinese entities are actively involved in co-developing these.

The Chinese CSP case, then, strongly contrasts with the PV case that was used to highlight the potential for entrepreneurs in latecomer contexts to access resources for industry formation available at a global level, and piece these together with generic domestic capabilities (Binz & Anadon, 2018). CSP plants as a whole do belong to a different category of technology than PV panels, i.e., they are complex engineered product versus mass produced standardized products. Individual CSP components like reflectors and receiver tubes, are closer to the latter typology, and here, too, it is evident that Chinese firms are developing manufacturing capabilities with relatively limited utilization of industry formation resources at a global level.

Other existing perspectives on industry formation in latecomer environments provide equally limited usefulness in explaining the formation of the Chinese CSP sector. There are, for example, elements of a more traditional catch-up strategy in one consortium, the Shenzhen Jinfan project, where a local government has partnered with industry, providing finance, and where efforts are being made to kick-start domestic manufacturing based on importing foreign technology. Similarly, the CGN Delingha project has sought institutional finance and utilized mostly foreign technology, although largely because of ADB requirements in procurement processes on track records for equipment suppliers.

Overall, however, the history of the Chinese CSP sector does not read like a typical catching-up strategy story. Government agencies at either national or local levels have not been intimately involved with sector development; government stimulus has largely trailed industry initiatives lie the two tower projects and the CGN Delingha project. Further, the 20 demonstration projects were selected from a total of 109 projects, and plenty of developers had projects in planning phase prior to the announcement of this policy, revealing an industry ready to move at a moment's notice, rather than one that required strong state guidance. There have further been no policies demanding local content, import tariffs on foreign equipment, or market-for-technology types of policies that were enacted in order to improve the competitiveness of domestic industry versus foreign competition.

Another influential framework for explaining industry formation in latecomer contexts, the global value chain framework, does not appear very applicable either. If anything, the Chinese developer companies in particular jumped straight into the role of lead firms, although their role in instructing and upgrading capabilities in suppliers was limited to the domestic suppliers, whereas foreign suppliers were ready to supply components embodying capabilities exceeding those of the procuring firm.

To a large extent, these phenomena may be explained by a domestic environment with relatively well-developed generic industry formation capabilities, and a global innovation system that has not matured to the extent that resources for formation are easily accessible and/or instrumental in any strategy for industry formation in follower countries. The very short time span over which the Chinese CSP sector has developed these competencies vis-à-vis the global sector appear to indicate a greater potential for genuine leapfrogging, when compared with the lengthy periods as a follower country in e.g., the wind power sector, for countries that have attained a certain minimum level of development of domestic capabilities. This suggests that a greater role should be attributed to the maturity of the global innovation system both in selecting focus sectors in catch-up country stimulus policy as well as in analyses of industry diversification in latecomer contexts.

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