4 From latecomer to first-mover advantage

Why Chinese solar PV manufacturers acquire stronger competitiveness in the global market

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1 Introduction

China has the world's largest installed base of both wind- and solar-power plants. It is noteworthy that in both cases, most of the equipment is supplied by domestic Chinese companies. In this respect, China has achieved green growth as its domestic companies have also grown during the process of emerging as a renewable energy powerhouse. In both wind and solar power, Chinese domestic companies had no presence in the global market prior to the 1990s, but in 2018, more than 36.6% of wind turbines and 72.7% of photovoltaic (PV) solar panels installed worldwide were produced by Chinese companies.¹ How were Chinese companies able to catch up in a period of less than 20 years?

There is a difference in the wind and solar markets as to what triggered the growth of domestic companies. Chinese wind turbine manufacturers started to grow in the late 2000s, by leveraging the introduction of wind turbines into the Chinese domestic market. The world's second-largest manufacturer of wind turbines, Goldwind, with a 13.8% global market share as of 2018, is no newcomer, having been founded in the 1980s. But up until the mid-2000s, when wind power generation in China saw rapid growth, Goldwind's production was limited to small and midsize wind turbines. Although significantly lagging in technology at the time compared with foreign companies, Goldwind began to grow on the back of government policies, mainly the Renewable Portfolio Standard (RPS) policy, to expand the domestic market, and caught up in technology aided by the government's protectionist industrial policies as well as through subsequent acquisitions of second-place foreign companies. (Horii, 2014). Not only Goldwind but several of the many companies founded in the late 2000s also rode the wave of the rapid expansion of the domestic market and now hold positions in the global ranking.

On the other hand, PV manufacturers, similar to wind power players, began to grow in the late 2000s, but initially most of their sales were to the

export market. Although Chinese wind turbine manufacturers now have a large share of the global market, they mainly serve the domestic market with only limited export, while PV manufacturers have been growing in the rough waters of international competition from the very beginning.

From the latter half of the 2000s, latecomer Chinese PV companies expanded their production rapidly, and massive exports by Chinese companies triggered a sharp price decline that led to a series of bankruptcies of formerly leading manufacturers in Europe and the United States. In response, the EU and US governments imposed anti-dumping measures. The Chinese companies abruptly lost their major markets, being placed on the verge of bankruptcy.

The Chinese government made a complete turnaround from its previous cautious stance, deciding to introduce a feed-in tariff (FiT) for solar power to provide a market for Chinese companies to survive. As a result, China's domestic solar market expanded dramatically, and in just a few years, China became the world's leading country for solar power. The Chinese PV industry plunged into a severe recession from 2011 to 2012, which saw the bankruptcy of Suntech, the world's then-largest PV manufacturer. But from 2013 onward, it returned to a growth cycle again.

In May 2018, the Chinese government replaced the FiT with competitive power purchase from all forms of power generation, including coal-fired power. The Chinese government has emphasized economic efficiency in the diffusion of renewable energies as a principle. In fact, the government let wind power, with its superior economic efficiency, be introduced ahead of solar power. A FiT for solar power was implemented as an emergency measure to help domestic companies from the sudden import restrictions, and its replacement can be understood as a return to that principle. The replacement of the FiT forced Chinese PV manufacturers to redesign their development strategies.

Looking closely at individual companies, leading companies have been rapidly changed. Suntech and Yingli Solar, which used to be in the leading position in the world market, went into bankruptcy, or were defeated by another new, fast-growing company. In other words, China's PV industry has achieved rapid development while repeatedly undergoing an active internal metabolism.

Against this backdrop, this paper poses the following three research questions.

1) China's PV industry has been hit by changes in the external environment: import restrictions by Western countries on the grounds of anti-dumping and unfair subsidies in 2011, and the termination of the FiT system in 2018. Has the growth model of the Chinese PV industry transformed in response to these changes? If it has, how?

2) In the PV industry in China (as well as in the world), the ups and downs in the management of PV companies are severe, as companies that were once the world leaders might go bankrupt or disappear from the rankings in just a couple of years. What are the factors behind this?

3) How can the implications of the rise of the PV industry in China and its impact on the world, especially Asia, be evaluated?

Previous research has shed light on the sources of competitiveness of China's PV industry through the early 2010s. Uno and Sakakibara (2009) showed how the global PV industry underwent a structural change in the second half of the 2000s. Under the traditional vertically integrated model, PV production equipment was produced in-house and the value chain was completed in-house, as in the case of Japanese companies. On the other hand, under the new horizontally divided model, PV production equipment was produced separately from downstream PV production as Western companies started to sell their PV production equipment in their process to withdraw from the depressed PV business. Owing to this structural change in the global PV industry, Chinese companies, which were latecomers and had no accumulated technology, came to be able to enter the PV market (downstream) in the late 2000s. In addition, Marukawa (2014) and Chen (2015) found in their detailed case studies that the source of competitiveness of the early Chinese PV industry was low prices, which was made possible by the generous support provided by Chinese local governments, especially in the form of low-cost or free land grants and the provision of low-interest loans. In a sense, competitiveness of Chinese PV industry before 2010 was boosted by the "cunning" approach under the state capitalism, and in this sense, the import restrictions imposed by Western countries were to an extent justifiable.

This chapter is organized as follows. In Section 2, how China's PV industry strengthened its own competitiveness by changing the growth model will be analyzed. In the face of anti-dumping measures by the EU and the United States in 2011, China's PV industry shifted to domestic demand and succeeded in lowering PV prices and improving quality. Section 3, by giving an example of new technology (PERC PV) commercialized in recent years, analyzes the factor that makes the leading companies in the PV industry change so frequently. Then, in Section 4, the overseas development of Chinese PV companies in the 2010s and the recent surge in exports will be analyzed, and how the overseas strategies of Chinese companies are changing and the impact that the development of China's PV industry has had on other countries, especially in Asia will be evaluated.

This chapter analyzes both overall situation of the Chinese PV industry and individual PV companies. Such an approach was necessary because some data and qualitative information of the Chinese PV industry are not available, in which cases we attempted to estimate the overall situation of the industry from the data and qualitative information of individual companies. The data and qualitative information used were obtained from the China Photovoltaic Industry Association (CPIA) and other statistical and annual reports published by the Chinese government and various industry organizations, as well as from papers and articles available on the

internet. The sources of the data and qualitative information are clearly indicated.

The contribution of this chapter is to provide novel empirical findings. First, China's PV industry has established a genuine competitive advantage by completing a domestic value chain and driving the development of cutting-edge technologies. Second, anti-dumping measures fostered Chinese PV companies and directed them to locate production plants in Asia. Third, the replacement of the FiT made China's PV exports resurge.

2 Strengthening the competitive advantage of China's PV industry in the 2010s

2.1 Fierce competition among companies in the domestic PV market

In 2011, the EU and US governments began restricting imports of Chinese PV, putting Chinese PV companies at risk of losing the major markets upon which they were relying for nearly 90% of their business. The reason China's PV industry managed to survive and subsequently strengthen its competitiveness was because it succeeded in transforming its previous export-led growth model. In 2011, China's PV production was 19.8 GW, accounting for a 56.6% share of the global market, of which 89.5% was exported. Only approximately 10% went into the domestic market, with China's share of global PV installation standing at only 4.4%. By 2017, however, production had increased to 72 GW, but the export share had fallen to 26.4%, with more than 70% of Chinese PV sold to the domestic market.

Although this shift was made possible by the Chinese government's introduction of the FiT system for solar power, China's PV companies could not have peaceful place by FiT but be thrown into fierce competition. The purchase price set under the FiT was at the lowest level in the world at the time. The FiT purchase price per kWh was RMB 1.15 in 2011, RMB 1.0 in 2012, and RMB 0.9/0.95/1.0 in 2014 (varying by region, considering sunshine conditions and other factors. The same note applies hereafter) and RMB 0.8/0.88/0.98 in 2016. Converted into dollar terms, the purchase price equates to 9.3 cents in 2011, 7.9 cents in 2012, 5.2/5.5/5.8 cents in 2014, and 4.9/5.4/6.0 cents in 2016, respectively, while the global levelized cost of electricity (LCOE) was 28.6, 22.3, 16.4, and 11.4 cents, respectively (IRENA, 2020). The purchase price of FIT in China was 60%–70% lower than that of global solar projects until 2014.²

As FiT purchase prices for solar energy were set at a level far below global price levels, power generation companies in China had to place greater importance on price when selecting PV, which in turn encouraged competition among PV producers. In fact, competition for survival among companies was fierce. For example, the domestic average shipment price (monocrystalline PV 156*156 mm, more than 4.3 W) plummeted more than 30% from

RMB 6.4/W in June 2011 to RMB 4.2/W in January 2012. Furthermore, it fell to RMB 2.2/W in January 2013 and RMB 1.4/W in August 2016 (Wang, 2018).

Looking at the market concentration of the PV industry, as of 2011, there were 115 PV producers in China, out of which 14 companies had a production capacity of 1 GW or more and accounted for 53% of the total production capacity. On the flip side, 47% of the production capacity was in a competitive market structure made up of about 100 companies with less than 1 GW of capacity.³ Meanwhile, as of 2017, the number of companies with more than 1 GW of capacity had grown to 21, with 11 companies having more than 2 GW, and the top three companies with more than 5 GW of capacity (CPIA [2018]). However, if the percentage of production capacity of the top 14 companies against total production capacity is calculated as in 2011, it accounted for 58%, only a slight increase from 2011. There were still many companies with a production capacity of less than 1 GW. While the top firms expanded their production capacity as of 2017, the presence of many midsize firms suggests the continuation of fierce competition.

In addition to a fierce competition among a lot of companies, the purchase price was lowered every few years, leading Chinese PV companies to increase their competitiveness successively. The share of Chinese companies in global PV production increased from 56.6% in 2011 to 69.0% in 2017. In 2005, Japanese companies held a dominant share of the market (Table 4.1a). In 2011, while Chinese companies had increased their presence, there were still powerful companies in both Europe and the United States, as well as three Taiwanese companies (Table 4.1b). Also, Japan's Sharp was barely holding on either. However, by 2017, except for one South Korean company⁴ and one Taiwanese company, most of the top companies in global market share had come to be dominated by Chinese companies.

2.2 Domestic production of PV production equipment

The turning point for the development of PV companies in China was the transformation of the traditional vertically integrated industry structure into a horizontal structure with divided functions, and the availability of PV production equipment in the external market. Prior to 2010, it was mostly Western companies such as Meyer Burger (Switzerland) and AMTECH (the United States) that supplied production equipment to Chinese PV companies. Since Western companies were generating revenue through the upstream operations of the supply chain, import restriction by the EU and the United States could impact the upstream business of Western companies. Therefore, there were even arguments for co-existence and co-prosperity with Chinese companies in the United States (Deutch and Steinfeld, 2013).

Later, however, Chinese companies began to enter the market for PV production equipment. Assisted by China's policy to encourage domestic

Table 4.1a Major PV companies in the world market in 2005 (Unit: MW)

	2005
Sharp (JN)	428
Q Cells (DE)	166
Kyocera (JP)	142
Sanyo (JP)	125
Mitsubishi Electric (JP)	100
Shot Solar (US/DE)	95
Suntech (CN)	82
Others	644
Total	1,782

Source: Compiled by the author based on the data from Marukawa (2014).

Table 4.1b Major PV companies in the world market in 2011 (Unit: MW)

	2011
Suntech (CN)	2,070
First Solar (US)	1,981
JA Solar (CN)	1,775
Yingli Solar (CN)	1,684
Trina Solar (CN)	1,604
Motech (TW)	1,120
Canadian Solar (CA/CN)	1,058
Sun Power (US)	922
Gintech (TW)	882
Sharp (JP)	857
Neo Solar (TW)	806
Q Cells (DE)	783
Others	644
Total	32,907

Source: Compiled by the author based on the data from Marukawa (2014).

Table 4.1c Major PV companies in the world market in 2017 (Unit: MW)

	2017
Trina Solar (CN)	7,400
JA Solar (CN)	6,500
Hanwha Q-Ceks (KR)	5,400
Canadian Solar (CA/CN)	5,300
Jinko Solar (CN)	5,200
Tongwei (CN)	4,100
Shunfeng PV (incl. Suntech) (CN)	3,900
Aiko Solar (CN)	3,500
Motech (TW)	3,200
Yingh Solar (CN)	3,100
LONGi (CN)	2,000
Rosen Energy (CN)	2,000
Uniex PV (CN)	2,000
Talesun Solar (CN)	2,000
Others	97,400
Total	123,200

Source: Compiled by the author based on the data from CPIA (2018).

Table 4.1d Major PV companies in the world market in 2019 (Unit: MW)

	2019
Tongwei (CN)	13,400
JA Solar (CN)	9,200
LONGi (CN)	8,400
Hanwha Q-Ceks (KR)	7,050
Aiko Solar (CN)	6,950
Trina Solar (CN)	6,850
Canadian Solar (CA/CN)	6,500
Jinko Solar (CN)	6,600
Risen Energy (CN)	4,500
Uniex PV (CN)	3,900
Others	66,750
Total	140,100

Source: Compiled by the author based on the data from CPIA (2020).

production of production equipment, Jingsheng Mechanical & Electrical Co., Ltd (JSG), Shenzhen S.C., and other Chinese companies launched production. They initially started with limited equipment and eventually advancing to complete manufacturing on a turnkey basis. For example, in the directory of the world's major PV cell and module companies published on the website of ENF,⁵ there were 14 silicon crystalline cell and 20 module turnkey systems suppliers in 2007, of which only one was a Chinese company (Uno and Sakakibara, 2009). By 2020, however, the number of cell turnkey systems suppliers had increased slightly to 16 and the number of modules turnkey systems suppliers increased significantly to 56, with Chinese companies accounting for five of the cell and 33 of the module turnkey systems suppliers. Also, in terms of revenue from the global PV production equipment market as of 2017, the Meyer Burger (US\$498 million) was the top runner, followed by Jingsheng Mechanical & Electrical Co., Ltd. (US\$281 million) in the second place. Statistics are available for 18 companies, with total sales of US\$2.025 billion constituting only 42% of the total market, but of which Chinese companies accounted for \$1.12 billion, or a 55% share.

The entry of Chinese companies into the production equipment market is thought to have had a major impact on the cost reduction of production equipment. Figure 4.1 clearly shows a sharp shrink of the PV production equipment market after 2012. Even though PV newly installed capacity has continued to increase after 2012, why the equipment suffered a significant decline in sales? The answer is that Chinese companies started to manufacture production equipment as well, which led to a price destruction causing unit prices to fall significantly. Chinese production equipment manufacturers increased their market competitiveness against Western manufacturers, by lowering prices substantially. Western manufacturers, faced with the low prices offered by Chinese companies, had no choice but to respond to the sharp contraction in sales by also cutting prices.

Figure 4.1 The gap between sales of PV production equipment and PV diffusion.

Source: Compiled by the author based on the data from CPIA (2018) and (2020), and BP (2020).

In addition, the Chinese government implemented the “Top Runner system” that resembled the Japanese ones to pursue high-level performance standards. It certified the products of companies that had achieved top-level conversion efficiency for each technology type as Top Runners, and qualified them for government procurement. In particular, adoption in large-scale mega solar projects led by the central government, called Top Runner (领跑者) projects, was highly lucrative to PV manufacturers in terms of sales volume and profit margin. Thus, each company actively invested in technology to obtain certification. As a result, investment in PV with high conversion efficiency—albeit highly priced—was maintained, which led to practical application of PERC PV.

2.3 Short summary

The Chinese government opted to create a domestic market for solar power as an emergency measure against import restrictions imposed by Western countries but set the FiT purchase price at an extremely low level—even by global standards, leading to severe price competition in the domestic market. Although the scale of production of top-ranking firms expanded greatly, many midsize firms remained. Market concentration did not increase much after the shift to domestic demand, and the competitive structure was maintained within the industry organization. In addition, the top companies in the ranking were also in a state of flux, with Suntech and Yingli Solar, once

the world's largest PV producers, dropping significantly in the rankings and later disappearing from the list, indicating frequent comings and goings as well as fierce competition among companies.

In addition, during this period, Chinese companies caught up with technology, strengthening their competitive advantage. Chinese companies also entered into the production equipment market, and apparently succeeded in reducing the investment cost of production equipment substantially compared with the situation prior to 2010, when they were relying on supply from Western companies. The government also contributed in the background by operating the Top Runner system, successfully guiding Chinese companies to improve their price competitiveness as well as greatly increasing their technological level.

China's domestic solar installations jumped from only 3 GW in 2011 to 175 GW in 2018, but foreign companies could not easily access the Chinese market. The domestic market thus provided an arena for Chinese companies to foster an overwhelming competitive advantage through economies of scale. As a result, in 2017, most of the top global PV producers were Chinese.

China's PV industry since the 2010s, which shifted to a domestic market driven growth model, has evolved into a completely different nature compared with when it made its first advance in 2010 through a "cunning" approach supported by the industrial policies of local governments. The competitive advantage of Chinese companies is now underpinned by solid factors: the economies of scale through bold and large-scale investment; the value chains comprised purely of Chinese companies, including upstream production equipment; and the advanced technology that is approaching the world's most advanced level.

3 First-mover advantage in PERC PV

In 2018, China's PV industries were forced a shift in the growth model once again. The policy was announced for the phasing out of FiT, which would be revised for solar power to compete with coal-fired power generation on an equal footing. When the reforms were announced in May 2018, the transition to a competitive system was set to take place around 2022, but that timeline is likely to be accelerated. In 2020, tendered projects based on prices referencing the wholesale price of coal-fired power in regions with solar power installations would expand to 33.05 GW, and the average wholesale price of subsidized power of RMB 0.65 per kWh in 2019 would decline to RMB 0.33, and the total amount of subsidies would be halved from RMB 3 billion to RMB 1.5 billion. As a result of this reduction in price subsidies, as shown in Figure 4.2, China's domestic solar market slowed in 2018 and new installations began to decline, with domestic new installations falling by 32% year-on-year to 30.1 GW in 2019.

In 2018 and 2019, significant changes occurred within the industry organization. In just two years, many companies expanded their production volume

Figure 4.2 Total and newly installed capacity of PV in China.

Source: Compiled by the author based on the data from BP (2020).

dramatically. But two companies, in particular, Tongwei and LONGi, made remarkable strides, growing three and four times, respectively, when comparing their production volumes in 2017 and 2019. On the other hand, Trina Solar, which was in the top spot as of 2017, has not only sunk to sixth place, but its production volume itself has shrunk (Table 4.1c, 4.1d).

Looking back at the development history of the PV industry, the industry saw not only changes between 2017 and 2019, but frequent changes to the companies in the top group as well as their rankings. In the early years, the center of production shifted from Europe and the United States to Japan, and in a short period of time thereafter, Chinese companies drove out non-Chinese companies with their overwhelming competitive advantage. Looking at individual Chinese companies, the leading company has changed rapidly from Suntech to Yingli Solar, then to Trina, and finally to Tongwei. The words “prosperity and decline” and “rise and fall” come to mind, and the cycle is so short. Why do competitive companies in the PV industry get replaced in such a short period of time?

One of the reasons for Tongwei’s advance and Trina’s decline from 2017 to 2019 can be attributed to the rise of monocrystalline silicon PV with PERC technology. The year 2017 was actually one of significant changes in PV product specification preferences. In China’s domestic market,

polycrystalline silicon PV had traditionally been the mainstay, but in recent years, there has been a rapid increase in the share of monocrystalline silicon PV. As of 2015, 85% of the market was dominated by polycrystalline silicon PV at 85% against monocrystalline silicon PV at only 15%, but from then monocrystalline silicon PV overtook polycrystalline silicon PV taking a 31% share of the market in 2017 and 62% in 2019. It was almost the first time that monocrystalline silicon PV held a larger share than polycrystalline silicon in solar cells, except for a close call in 2000, and in that sense 2019 was a landmark year. Monocrystalline silicon PV are expected to hold 90% of the Chinese market in 2020.

The difference between monocrystalline and polycrystalline is that monocrystalline silicon PV are produced by directly processing the raw material polysilicon into ingots, whereas polycrystalline silicon PV are produced by melting scrap generated from the manufacture of computer semiconductors and other products that require higher purity than PV and processing them into ingots. Because of these differences in production processes, the conversion efficiency of polycrystalline silicon PV is less than monocrystalline silicon PV because different nanocrystals of silicon are mixed together; on the other hand, they possess an economic advantage because of the significant savings in raw material costs. Monocrystalline silicon PV with high conversion efficiency are preferred for rooftop systems because of the limited installation space, while polycrystalline silicon PV are preferred for mega solar systems because of the reduction in investment costs. The low conversion efficiency is compensated for by production volume. For a long period, polycrystalline silicon PV were by far the mainstream in the Chinese market, as it was mega solar power that drove the introduction of solar power in China.

However, from around 2012, a new type of monocrystalline silicon PV came into play. It is a “Passivated Emitter and Rear Cell (PERC),” which uses a technology to suppress power generation losses caused by the recombination of carriers (electrons and holes) by forming an inactive layer on the back of the cell. While the average conversion efficiency of conventional BSF PV is 18.6%–19.9%, that of PERC PV is 19.6%–21.3%, more than one percentage point higher. The PERC treatment can be used for both monocrystalline and polycrystalline, but the conversion efficiency improvement by PERC is more pronounced in monocrystalline silicon PV. A monocrystalline silicon PV using PERC technology can produce about 10% more power than a polycrystalline silicon PV of the same size.

This 10% difference has fundamentally changed the competitive conditions between monocrystalline silicon PV and polycrystalline silicon PV. Polycrystalline silicon PV were able to save on raw material costs by using scrap, which was the source of its competitive advantage. However, if the difference in conversion efficiency of 10%, or the resultant increase in income is considered, monocrystalline silicon PV are superior in cost performance. The rapid shift from polycrystalline to monocrystalline in recent

years, as mentioned earlier, is a natural result reflecting economic efficiency. PERC's production capacity jumped from just 0.5 GW in 2010 to 2.5 GW in 2014 and 28.9 GW in 2017.

Tongwei, which became the leader in the 2019 rankings, is a model example of a company that has grown by rapidly expanding production of new monocrystalline PERC PV. The company, originally a livestock feed manufacturer, entered the PV industry in 2013 through a white knight merger with Saiwei LDK, a one-time powerful PV company that had become insolvent at the same time as Suntech Power. Tongwei has since established production bases in four locations in China: 7 GW in Hefei, Anhui Province (Phase 1 completed in November 2013, Phase 2 in January 2019); 13 GW in Chengdu, Sichuan Province (Phase 1 in June 2016, Phase 2 in September 2017, Phase 3 in November 2018, Phase 4 in November 2019); 15 GW in Meishan, Sichuan Province (Phase 1 in April 2020, Phase 2 under construction); and 30 GW in Chengdu (Jintang County), Sichuan (Phase 1 7.5 GW expected to be completed in Q1 2021). A total investment of RMB 20 billion is expected to be spent on the 30-GW project in Jintang.⁶

Tongwei already has a production capacity of 27.5 GW as of August 2020, which will be expanded to 65 GW with the additional projects under construction. Considering that total global solar installations in 2019 were 115 GW, it appears risky for a single company to have a 65 GW production capacity. However, this is also the strategy that supports Tongwei's competitive advantage.

Tongwei is a new PV company, having only entered the market in 2013, so it has ridden the wave of the rapid rise of monocrystalline PERC PV. Except for Hefei Phase 1, which was acquired through the acquisition of Saiwei LDK, all other production lines are PERC PV production lines. As a result, the company is now largely free of the negative burden of past investment in conventional BSF and polycrystalline silicon PV, which have lost their competitiveness in the market. More importantly, Tongwei's investment in PERC PV production lines is concentrated from 2016 onward.

The PERC technology itself was developed in an Australian university laboratory in the 1980s but had since been not paid much attention. It was not until the 2010s that Taiwanese companies and JA Solar first began to commercialize PERC PV. In 2013, JA Solar made other companies realize the potential of PERC PV by surpassing the 20%+ conversion efficiency barrier that conventional BSF PV had been unable to overcome. Since then, companies other than Tongwei have continued their investment aimed at further maturation of PERC PV production technology. It is also important to note that by 2015, domestic companies such as Shenzhen S.C. had become capable of supplying production equipment for PERC, while in 2012, most of the production equipment was procured from Western companies. Taking the example of PECVD (plasma-enhanced chemical vapor deposition) equipment, which is a component of PERC production equipment, Meyer Burger's product price is RMB 17.45 million per unit, while Shenzhen S.C.

priced it at RMB 3.44 million, about one-fifth of the Meyer Burger price (2017, Li, 2020). Tongwei's huge capital investment in the PERC PV production line was made at the time the technology had matured and the economics had improved greatly.

Compared with Tongwei, JA Solar and other companies that had been investing in the commercialization of PERC PV since before 2012 were left with production lines with inferior conversion efficiency, as the investment had been made when the technology was still in its infancy, and at higher investment costs since all the equipment purchases had been made while equipment costs were higher.⁷ Moreover, Tongwei's PERC PV production lines are the world's largest at 7.5 GW each, enabling Tongwei to enjoy maximum economy of scale. As a result, Tongwei has been able to significantly lower its production costs and achieve a higher gross margin ratio than other companies. The gross margin ratio of PV production is 4.4% for JA Solar, 11.2% for Hanwha Q Cells, and 11.3% for Jinko, while Tongwei has a gross margin of 18.5% (Yang, 2018). Those are based on 2017 statistics. It is reasonable to assume that the difference in 2019 was even greater.⁸

These are the reasons behind the rapid rise of Tongwei and LONGi (and the decline of Trina left with its BSF battery production facilities). And perhaps the same mechanism has been at work in the past, when league tables changed dramatically, first in Western countries, followed by Japan, and then on to China, and now even among Chinese companies. The PV industry has been investing heavily in capital equipment for PV production, while rapid technological innovation is still underway. As a result of major advances in technology, conventional products become obsolete in an extremely short period of time, and new, overwhelmingly stronger products emerge. At least until now, the rewards for latecomers have been very impressive.

The biggest factor behind this is the FiT system. Although PV was technically immature and could not be expected to grow into a large market without the FiT system, except for some residential applications. Only under the FiT system, it became possible to sell PV at politically set purchase prices that could cover production costs. Since commercialization of the PV industry began at a stage where potential of technological development was still very large, the industry was kept under an environment of rapid technological innovation. Because of the rapid pace of technological progress, politically set purchase prices often fail to reflect this progress and remain relatively high, resulting in excess profit (rent). So, many PV companies entered the market eyeing the rent generated by this policy.

China's FiT system had a smaller policy rent, compared with other countries, by keeping purchase price very low. However, with the sudden loss of the European market, Chinese PV companies were left with no choice other than to hang on the domestic market with fierce competition. There were also new companies to enter into PV industry in pursuit of rent, although

rent is not very large, but market entry barrier was low owing to the availability of production equipment from external market. The government reduced the purchase price, and as policy rents shrank, Chinese PV companies sought to secure their competitive advantage through economies of scale by expanding production capacity.

On the other hand, since the Chinese government continued to provide large policy rents for national projects under the Top Runner system, companies continued to invest on innovation as well, aiming for the rents. This was what led the commercialization of PERC technology.

Thus, in the 2010s, China's PV industry saw a race to scale up production capacity and pursue vigorous innovation. As a result, existing facilities became stranded assets within a couple of years, and start-up companies without stranded assets gained market competitiveness.

4 Development of the PV industry in China and its impact on the world and Asia

Facing import restriction measures by the EU and the United States, the Chinese government decided to provide huge domestic market by introduction of FiT system to Chinese PV companies, which rushed to new market, resulting in fierce competition. On the other hand, production in third countries and roundabout export were also attempted, with the aim of evading the import restrictions imposed by Western countries. Overseas production capacity of Chinese companies was 12 GW as of 2018 according to Table 4.2, while China's domestic production capacity was 130 GW. This means that overseas production is less than 10% the size of China's domestic production facilities. In terms of production capacity, it is a minor player, accounting for just less than 10%, but if compared to the 41 GW of exports in 2018, the ratio increases to 30%.

The table also shows that most of the investments in overseas production plants were made by leading companies that appeared in the top corporate rankings throughout the 2000s. According to 2017 data, of the top companies with overseas production, Trina had the largest production volume at 1.9 GW, or 26% of the company's production. Jinko was next with 1.6 GW, accounting for 31% of its production, higher than Trina. They are followed by Canadian Solar with 1.3 GW and JA Solar with 1.2 GW (25% and 18% of the production, respectively). Except for Jinko in South Africa and the United States, and Han-energy in Egypt, most of the countries in which the companies have invested are concentrated in the Asian region. Although dwarfed by the rapid growth in China, installation of solar power is steadily progressing in the Asian region. At present, not only roundabout exports to Western countries but shipments to the Asian region are also thought to be increasing. This trend of Chinese companies should be welcomed by the host countries, as it does create a certain amount of employment. There are

Table 4.2 Overseas production capacity of Chinese PV companies in 2018

<i>Country</i>	<i>Company</i>	<i>Capacity</i>	<i>Period to invest</i>	<i>Period to start production</i>
Korea	CNBM	100 MW		2012
South Africa	Jinko	120 MW		2014
Malaysia	JA Solar	400 MW		2015
Thailand	Uniex PV	1.5 GW		2015
Malaysia	Jinko	1.3 GW		2015
Vietnam	Trina Solar	700 MW		2016
Thailand	Chint	300 MW		2016
Vietnam	GCL	600 MW		2017
India	LONGi	2 GW		2018
Vietnam	JA Solar	1.5 GW		2018
India	Trina Solar	1 GW	2018	
Egypt	Han-energy	300 MW	2018	
Malaysia	LONGi	1.25 GW	2019	2020
United States	Jinko	400 MW		2019
Thailand	Trina Solar	500 MW		

Source: Compiled by the author based on the data from Zhu (2019).

also advantages for Chinese companies in terms of labor cost savings and tax exemptions.⁹

On the other hand, China's domestic installation growth started to slow down, following the announcement in 2018 of the policy of phasing out FiT. In response, exports have expanded rapidly since 2018, with exports growing a sharp 61.7% to 66.8 GW in 2019, compared to 41.3 GW in the previous year, and the value of exports regaining the \$20 billion mark for the first time since 2012, rising 29% to \$20.8 billion. It appears that Chinese PV companies are once again increasing their share of exports to overseas markets.

The largest exporter was Jinko at US\$15.3 billion, followed by Risen Energy at US\$9 billion, JA Solar at US\$8.2 billion, Trina at US\$6.3 billion, LONGi at US\$6.2 billion, and Canadian Solar at US\$5.5 billion. The export ratio of Jinko, Risen Energy, JA Solar, Trina, LONGi, and Canadian Solar ranges from 82%, 80%, 70%, 74%, 63%, and 92%, respectively. It is interesting to note that Suntech, which has almost lost presence in China, is trailing the above major companies with US\$5.1 billion in exports. This must be because exports depend not only on price but also brands and sales channels, for which legacy assets still maintain a certain value. It also may explain why Tongwei, a start-up company, supplies most of its products to the domestic market. Jinko and other major companies may have been forced to resort to export, given Tongwei's overwhelming competitiveness.

In addition, exports in 2019 were driven by exports to Europe, where anti-dumping measures against Chinese-made PV have expired, which reportedly accounted for a third of total exports (CPIA [2020]). For developing countries, India accounts for 8.8%, Vietnam 7.3%, and Brazil 7.0%, and even if other countries are included, the proportions remain between 20% and 30%.

The future growth prospects of the expansion by Chinese PV companies into the Asian region are not promising. A value chain is being completed in China¹⁰ and companies have succeeded in significantly lowering production costs in China by enlarging production lines. On the other hand, for example, according to an executive of Chint, which has invested in Thailand, production costs at Thai plants are beginning to rise due to bottlenecks in export logistics, in addition to a shortage of raw material supplies in Thailand. In other words, it can be said that the benefits of consolidating production in China outweigh the benefits of overseas production. As for the anti-dumping and subsidy import restriction measures by Western countries, which triggered the overseas expansion of Chinese companies, EU decided not to renew the measures upon expiry. This may well be because, under the current situation where Chinese PV companies have established overwhelming price competitiveness by building huge PERC factories, restricting imports of Chinese PV will only result in increasing the cost of solar installation. EU had to abandon its FiT because of the cost burden, but on the other hand, it has no choice but to expand the installation of solar power in order to achieve carbon neutrality. It is assumed that Europe can no longer afford to exclude Chinese-made solar cells and give priority to its own expensive solar cells, and therefore Chinese companies no longer need to make roundabout exports.

5 Conclusion

Since 2011, China's PV industry has undergone a major shift in its growth model from an export-driven model to a domestic demand-driven model. During the process, Chinese PV companies further improved their price competitiveness, established a complete value chain encompassing from upstream to downstream, and have taken the lead in developing new technologies. They have evolved from a competitive but "cunning" advantage propelled by state capitalism to a competitive advantage in the true sense of the word.

On the other hand, after the policy to phase out FiT was announced in 2018, the domestic market growth slowed down and exports started to expand. With the slowdown in the growth rate of the domestic market, the future development of Chinese PV companies will be based on both the domestic market and exports. The domestic market is under more severe downward pressure on prices than overseas markets; however, in light of the past history of Chinese companies, even if individual companies repeatedly

rise and fall, the industry as a whole is thought to further improve its competitiveness through severe competition. Since overseas markets are more attractive in terms of price,¹¹ companies will, on the other hand, focus more on branding and sales channels for export. Tongwei, which suddenly jumped to the top spot in 2019, sells almost all of its products to the domestic market; thus, leading companies could avoid competing with Tongwei by increasing export to overseas markets.

With the phasing out of the domestic FiT system, Chinese PV companies are once again looking to export, which has the desired effect of supplying low-cost PV to other countries. The rapid cost reductions realized since the latter half of the 2000s in the global PV market are largely due to the rise of Chinese companies. The development of China's PV industry throughout the 2010s has been an important factor in the constant improvement of the PV quality/price balance and cost performance, which has supported the rapid expansion of global PV adoption. Although PV companies in other countries were hit hard, the decline of the overseas rivals did not result in the reduction of the pressure on Chinese PV companies. Rather, the pressure became more intense by competition in domestic market, which led to innovation and a continuous decline in average production costs.

Another notable change is that Chinese companies are now leading the way in global PV technology innovation. Attempts to commercialize PERC PV were initially started by Taiwanese companies, but Chinese companies eventually overtook them and achieved commercialization in a very short time. An important factor to develop the innovation capability of Chinese PV companies is the incentive system provided by the Chinese government such as the "Top Runner system," that leads PV companies to reinforce their competitive advantage, including not only in price but also in technology.

And newly emerging companies such as Tongwei and LONGi invested heavily in state-of-the-art PERC PV and built massive production capacity. The total production capacity of the top 10 companies in 2019 reached 102.43 GW, and with the transition to PERC PV, the PV industry has become an oligopoly. Almost all of the top companies are dominated by Chinese companies, and the Chinese PV industry is establishing its dominance in the global market.

The concern is that China's domestic production capacity will become excessive. While the total production capacity of the top ten companies in 2019 reached 102.43 GW, there is a considerable gap with the actual production of 73.35 GW. This is not surprising as the total global installed capacity in 2019 was 115 GW. Looking at Tongwei's bullish investment plans, it is highly likely that this gap will become larger in the coming years. If demand does not keep up with the huge investment, concern remains that some companies may suddenly fail. The global economic downturn caused by the Covid-19 pandemic may cool down the enthusiasm for green investment, which is not an unfounded fear.

However, as in the past when Chinese companies responded to anti-dumping and subsidy measures taken by Western countries while using the domestic market as a port of refuge and insurance (the Chinese government is also expected to actively provide support if necessary), as in the semiconductor industry, the huge amount of money invested will itself act as a barrier to entry. Therefore, Chinese companies are expected to maintain their overwhelming international competitiveness. As the Covid-19 pandemic worsens the financial situation in many countries, and difficulties in funding for green investment increase, Chinese companies should contribute to the world by leading the global PV industry and continuing to improve the cost performance of PV.

Overseas investment growth of Chinese PV companies is expected to be sluggish in the future. The PV value chain is complete in China, and its efficiency is high. In addition, backed by the economies of scale brought about by its huge production capacity, Chinese PV companies' price competitiveness is outstanding, thereby offsetting any production cost reduction effects at its overseas plants. In the face of the overwhelming price competitiveness of Chinese PV, shutting out Chinese-made PV would be disadvantageous in advancing climate change measures, and it is also unlikely that the import restrictions imposed by Western countries, which originally triggered overseas investment by Chinese PV companies, will be tightened again in the future. In this respect, Asian countries would benefit a little less afterward from China's green growth than the 2010s.

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Notes

- 1 Wind turbine market share calculated from the list of the world's top 15 companies in a Global Wind Energy Council (GWEC) press release (<https://gwec.net/gwec-1-in-5-wind-turbines-are-installed-by-vestas-according-to-new-market-intelligence-report/>). The term "36.6%" (the market share of Chinese companies within the top 15) or higher is applied, since it is possible that part of the 6.8% market share of companies other than the top 15 companies might be held by other smaller Chinese manufacturers. The share of Chinese companies in the PV (module) market is an estimate by RTS Corporation (<https://solarjournal.jp/solarpower/31599/>).
- 2 However, it appears that local government subsidies were provided separately from FIT, especially in provinces in the eastern coastal areas with higher project costs (land costs and other factors). It is difficult to generalize because the situation differs from province to province, but it may be possible to say at the very least that, even taking these local government subsidies into account, the overall

- revenue for developers of PV projects in China was considerably lower than the average revenue of PV projects in other countries.
- 3 However, as shown in Table 8.1, even at the global level, only the top seven companies have a production volume exceeding 1 GW. Companies with a production capacity of 1 GW were not small as of 2011. It should also be noted that, although there were 14 Chinese companies with a production capacity of 1 GW or more, only five Chinese companies are included in the 2011 ranking in Table 8.1 (whereas companies with a production capacity of less than 1 GW from other countries are included). It is assumed that there were many Chinese companies that had just increased their production capacity in 2011, which were still catching up production levels.
 - 4 Hanwha Q CELLS (acquired by a Korean company after the bankruptcy of Germany's Q-Cells, which used to be the world's largest) is headquartered in South Korea, but most of its main plants are located in China, as is Canadian Solar, which is headquartered in Canada.
 - 5 <https://www.enfsolar.com/>
 - 6 Obtained from Tongwei's company website, <http://www.tw-solar.com/qiye/jianjie.html> [accessed on 29 January 2021].
 - 7 For instance, the price of Shenzhen S.C.'s PECVD equipment used by Tongwei decreased by 46% in 2019 compared to 2015. At a time of rapid technology innovation, a difference of just a few years in the timing of introduction can make a huge difference in equipment costs and, ultimately, production costs.
 - 8 For example, Tongwei's capex costs of RMB 420 million per GW in 2018 have fallen to RMB 300 million in 2019. Tongwei commenced operation of a significant amount of additional capacity in 2019, and the fact that costs have fallen so much in just one year suggests that the new, larger facilities are considerably less expensive than older facilities.
 - 9 In Vietnam, for example, labor costs are half of what they are in China, with a four-year tax holiday and tax reduction by 50% for the following nine years.
 - 10 In addition to production facilities, 67% of the world's silicon ingots and 98% of silicon wafers, which are the raw materials for processing, are produced in China in 2019. Although silicon ingots are still a major import item, its degree of dependence on import has fallen from nearly 45% as of 2014 to only 30%.
 - 11 Nevertheless, PV export prices in 2019 were 23.5% lower than in 2017, as major companies competed to increase exports due to slower growth in China's domestic market since 2018.

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