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Trailing—or Governing—the Market? Two Decades of Industrial Policy for China's Solar Sector

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Abstract

There is probably no other advanced industrial sector in which China plays a greater role in global supply chains than in the solar industry. From the production of basic material inputs to the assembly of solar modules, Chinese firms dominate virtually every segment of global solar photovoltaic (PV) supply chains. This paper reviews the role of industrial policy in shaping China's current position in current solar supply chains. The author argues that China's solar industry started as an export-oriented sector driven primarily by subnational government investments in manufacturing capacity. While the Chinese central government enabled the role of subnational actors to some degree, the center responded to subnational government actions more than it guided them. Although the central government has taken a more active role in shaping domestic markets since its first intervention in the solar industry in 2009, it has continued to primarily address unintended consequences caused by misaligned incentives for subnational actors.

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I. Introduction

There probably is no other advanced industrial sector where China plays a greater role in global supply chains than in the solar industry. From the production of basic material inputs to the assembly of solar modules, Chinese firms dominate virtually every segment of global solar photovoltaic (PV) supply chains. China currently accounts for 72 percent of the global production of polysilicon, the basic input into the production of solar cells. The ten largest manufacturers of wafers—the thin silicon plates from which solar cells are manufactured—are headquartered in China and jointly account for 97 percent of global production. Eighty-one percent of solar PV cells and 77 percent of solar PV modules are currently manufactured in China, according to a recent supply chain review conducted by the U.S. Department of Energy.[1]

The rapid development of China's solar industry since joining the World Trade Organization has long prompted accusations of unfair government intervention: China went from producing less than 1 percent of global solar PV modules to dominating global supply chains.[2] Since 2013, Chinese solar panels have been subject to a series of trade remedies in the United States. Tariffs were put in place after a string of anti-dumping and countervailing duty disputes, but thus far they have done little to diminish the central role of Chinese manufacturers in this sector.[3] The Biden administration estimates that the share of electricity generated from solar will have to grow from the current rate of 4 percent to 40 percent to meet U.S. climate goals by 2035. To diminish reliance on Chinese firms, the 2022 Inflation Reduction Act has made some domestic tax incentives conditional on ambitious local content requirements. The U.S. government, it appears, is no longer willing to cede the global solar sector to China and is now enacting just the types of industrial policies it has long accused China of using to distort global markets in its favor.[4]

In this paper, I review the role of industrial policy in shaping China's current position in current solar supply chains. I argue that China's solar industry started as an export-oriented sector driven primarily by subnational government investments in manufacturing capacity. While the Chinese central government enabled this role of subnational actors to some degree—not least by eventually designating solar as a strategic emerging industry, which in turn allowed subnational administrations to arrange preferential bank loans for manufacturing expansion from state-owned

1 U.S. Department of Energy, "Solar Photovoltaics - Supply Chain Deep Dive Assessment."

2 Helveston and Nahm, "China's Key Role in Scaling Low-Carbon Energy Technologies."

3 Lewis, "The Rise of Renewable Energy Protectionism: Emerging Trade Conflicts and Implications for Low Carbon Development."

4 U.S. Department of Energy, "Solar Photovoltaics - Supply Chain Deep Dive Assessment."

development banks—the center responded to subnational government actions more than it guided them. While the central government has taken a more active role in shaping domestic markets since its first intervention in the solar industry in 2009, it has continued to primarily address unintended consequences caused by misaligned incentives for subnational actors.

The remainder of this paper proceeds with a review of the current state of play in the global solar PV industry and shows that Chinese firms are dominant in most segments of solar supply chains despite no structural input cost advantages. I then review three distinct periods of solar PV industrial policy in China, arguing that the industry emerged initially without central government support. The center only began to intervene domestically when global export markets became volatile because of the 2009 financial crisis and trade remedies in the United States (and to some extent Europe) that caused production to shift to other Asian economies. The conclusion compares solar PV industrial policy to other clean tech sectors, most notably EV batteries and wind, both of which were subject to far more targeted central government industrial policy.

2. The State of Play

Crystalline solar PV modules—the dominant solar technology on the market today—are made up of polysilicon, the main material input, which is manufactured by purifying metallurgical-grade silicon from quartz pebble. Such solar-grade high-purity silicon is subsequently further purified, using a few different technologies, though the Siemens process is most common. It is then cast into monocrystalline, or, less commonly, multicrystalline ingots, which are in turn cut into thin wafers. The wafers are turned into cells in several additional steps, which include texturing, cleaning, etching, and printing silver paste metal connections on the wafer. Once produced, the cells are turned into modules by arranging and connecting them on a back sheet, which itself is now often transparent for bifacial solar modules. The cells on the back sheet are laminated with a plastic material and mounted in an aluminum frame with front (and optionally back) glass. Although alternative technologies exist—for instance in the form of thin-film solar technologies in which PV materials are deposited and etched directly on glass avoiding the use of polysilicon as a raw material—rapid cost declines for crystalline technologies have allowed them to retain the vast majority of global market share. In 2021, crystalline (c-Si) modules accounted for 95 percent of global sales, with cadmium-telluride (CdTe) thin-film modules making up the remaining 5 percent of global production.[5]

5 IEA, "Special Report on Solar PV Global Supply Chains," 13.

Although China accounted for less than 1 percent of global solar PV production when it joined the World Trade Organization in 2001, it now dominates every step in the production of crystalline, c-Si, solar PV modules. China has vastly surpassed every other economy in new solar PV manufacturing capacity investment, at least since 2005, and now holds a commanding share not just in cell and module production, but all also in the production of solar-grade silicon which U.S. and European manufacturers once dominated. According to the International Energy Agency (IEA), China currently accounts for less than 40 percent of global solar demand but manufactures more than 70 percent of polysilicon used in solar manufacturing. China also makes 97 percent of wafers, nearly 80 percent of cells, and more than 70 percent of modules, with the remaining market share primarily taken up by other economies in the Asia-Pacific region.[6] Analyses by Bloomberg New Energy Finance differ slightly in the percentages assigned to China's manufacturing share for these supply chain segments but largely confirm the IEA numbers.[7] In 2021, China exported over USD 30 billion in solar modules. Solar trade alone has accounted for roughly 7 percent of China's trade surplus since 2017.[8]

Despite increasingly ambitious climate goals across OECD economies in particular, the IEA estimates that global solar production capacity currently exceeds global demand by as much as 100 percent. The exception to this pattern is the production of polysilicon, where global supply is tight. Additionally, a large percentage of China's polysilicon production is located in Xinjiang due to the energy intensity of silicon purification and the low energy prices there. Because of forced labor practices in Xinjiang and global bans on products containing components manufactured in Xinjiang, for instance through the Uyghur Forced Labor Prevention Act in the United States, manufacturers have begun looking for alternative supply chains. Metallurgical-grade silicon has been named by the U.S. government as a beneficiary of state-directed forced labor programs in Xinjiang.[9]

In part because of China's rapid investments in manufacturing capacity and the resulting economies of scale, the cost of c-Si solar PV modules has been falling rapidly over the past two decades. Between 2010 and 2015, China rapidly expanded its production capacity for polysilicon, causing prices to drop by more than 70 percent and reducing market shares for American, German, and Japanese suppliers that had maintained roughly equal market share until then.[10] Technological advances have also helped

6 IEA, 18.

7 Bloomberg New Energy Finance, "Solar PV Trade and Manufacturing: A Deep Dive."

8 IEA, "Special Report on Solar PV Global Supply Chains," 8.

9 U.S. Department of Energy, "Solar Photovoltaics - Supply Chain Deep Dive Assessment," 8.

10 IEA, "Special Report on Solar PV Global Supply Chains," 22.

reduce silicon consumption in the production of wafers, for instance through improvements in ingot-cutting processes and increased wafer sizes. Over the past decade, high-efficiency passive emitter cells have replaced multicrystalline cell technologies, further reducing overall solar generating cost. As a result of technological improvements, scale economies, and competitive pressures because of overcapacity in wafer, cell, and module manufacturing, the cost of solar power has decreased by approximately 90 percent between 2009 and 2021.[11]

In the United States, China's growing dominance in solar PV supply chains as been observed with concern. Industry groups and the government have accused China of unfair industrial policy and trade practices. As a result, the United States has launched several trade investigations and implemented a series of trade remedies as a result. Already in 2010, for instance, a coalition of solar manufacturers successfully petitioned for trade remedies against Chinese solar panels. Although "Coalition for Affordable Solar Energy," made up of installation and maintenance businesses, sought to stop the imposition of remedies, the tariffs took effect in 2021. Chinese manufacturers, in response, shifted some of their production to Malaysia, Thailand, and Taiwan, which led the U.S. Department of Commerce to increase and to expand the geographical scope of the tariffs. Despite vocal opposition from Solar Energy Industries Association, the U.S. solar industry association, remedies were deemed to be appropriate and renewed in 2018 under the Trump administration. They again addressed Chinese subsidies and injury to domestic solar cell manufacturers from artificially cheap imported Chinese solar cells. These measures raised concerns among the domestic solar installation and maintenance firms, which expected rising prices to lead to slumping demand. However, the impact of trade remedies on downstream installation and maintenance industries is not part of the scope of the investigation of the U.S. Department of Commerce and the International Trade Commission.[12]

As mentioned earlier, the U.S. solar market has also been impacted by a Withhold Release Order (WRO) on solar PV products containing silicon materials produced by the Xinjiang-based Hoshine Silicon Industry Co. and other firms. Roughly half of Chinese polysilicon supply is currently produced in Xinjiang. The WRO was issued by U.S. Customs and Border Protection in response to allegations of forced labor practices in Xinjiang and Hoshine in particular. Panels manufactured by Chinese manufacturers have been held up at the border by U.S. Customs and Border Protection, which has disrupted domestic solar PV markets even if many of the panels in question were ultimately cleared of containing Xinjiang-made silicon.[13] The Biden administration has also

11 Lazard, "Lazard's Levelized Cost of Energy Analysis."

12 Nahm, "A Green Economic Recovery: Global Trends and Lessons for the United States."

13 Pickerel, "An Update on WRO Enforcement on Imported Solar Panels."

launched a domestic supply chain review for critical industrial sectors with the goal of examining reliance on Chinese inputs for key technologies from both economic and security perspectives.[14] Existing tariffs placed on Chinese clean energy products as a result of previous trade investigations remain in place, while new tax incentives for solar in the United States are now offering additional credits for domestically made panels and components.

Particularly in light of the Ukraine war, governments in the United States and elsewhere have worried about the overwhelming global dependence on Chinese manufacturers in the solar industry. Along with a broader pushback against globalization and a mercantilist turn in economic policymaking, the United States has passed a new set of tax credits for solar PV installations that are now dependent on meeting local content requirements. Such policies have been justified both from the need to create economic returns on domestic spending on solar PV markets and from security implications of relying on a few Chinese suppliers for entire segments of the solar PV supply chains. Technologically, scholars of China's rise in renewable energy manufacturing and its impact on technological innovation in other parts of the world have warned about the possibility of technological lock-in. Declining prices for solar technologies manufactured in China have made it increasingly difficult for new technologies to break into the market, even if they in principle offer better performance potential in the long run.[15] While traditional, first-generation c-Si cells are estimated to decline to $0.24 per watt in the 2030s according to estimates by the National Renewable Energy Laboratory, next-generation cell technologies could, in principle, bring the costs down to a fraction of that price. These new technologies, possibly costing just a few cents per watt, would use semiconductor materials as well as new perovskite materials. They could entail printing solar PV cells on flexible substrates rather than using the technologies in place today.[16] Yet current competition as a result of overcapacity and rapidly falling prices for c-Si technologies have both made it difficult for existing manufacturers to invest in technological innovation and have made it harder for new technologies (still more expensive and not yet manufactured at scale) to break into the market.[17]

14 U.S. Department of Energy, "Solar Photovoltaics - Supply Chain Deep Dive Assessment."

15 Sivaram, Dabiri, and Hart, "The Need for Continued Innovation in Solar, Wind, and Energy Storage."

16 Sivaram, *Taming the Sun*.

17 Hart, "The Impact of China's Production Surge on Innovation in the Global Solar Photovoltaics Industry."

3. Industrial Policies for China's Solar PV Industries

Despite frequent claims that China's rise in global solar PV industries was the realization of strategic central government industrial policy, the development of China's solar PV sectors initially followed a bottom-up pattern. Its developmental patterns can be understood in three distinct stages. First, until the 2009 financial crisis, China's solar PV industry primarily developed as an export-oriented manufacturing policy with the support of subnational governments. Second, after the financial crisis led many governments in Europe to remove subsidies for solar PV installation, China's central government intervened with the creation of domestic solar markets to save a now sizable solar PV industry. Third, beginning in 2015, and somewhat unsuccessfully, the Chinese central government began removing domestic subsidies and again focused on technological efficiency, production cost, and grid integration in its treatment of the domestic solar PV industry.

The initial focus on export production and the gradual domestic orientation—along with growing exports to Belt and Road Initiative economies in response to tariffs on Chinese solar products in the West—breaks with some traditional industrial development patterns in China. The central government has often used industrial policy to stoke rapid industrial development, only to then intervene to pick winners or to enforce regulations that tamed and shaped the industry as it matured. The case of solar is unusual in that the initiative to grow an entire industrial sector resulted almost entirely from subnational government action, at least initially without guidance or input from central government actors. The center never fully managed to gain control of the sector: Even as it began to intervene in the solar industry in 2009, it continued to primarily address unintended consequences caused by misaligned incentives for subnational governments, which frequently resulted in overcapacity.

3.1 The Export Origins of China's Solar PV Sector, 2000–2009

In contrast to other new energy industries in China, which were often dominated by state-owned enterprises that entered these sectors following central government directions, most of China's early solar firms were established by returning entrepreneurs. Solar firms were frequently founded by Chinese scientists educated in solar PV research laboratories abroad, in particular at the University of New South Wales in Australia.[18] Research funding dispensed through the Chinese central government's 863 and Torch Programs and financial support for high-technology startup

18 Alexander, "Carbon Cutters."

firms in China's High-Technology Development Zones attracted these scientists back to China, where many of them returned to their hometowns to open solar PV firms around the same time that manufacturers sprang up in Europe and the United States. The firms were established in the traditional centers of export production along China's coastal provinces, where most of China's renewable energy firms were located and financial support for the manufacturing economy was available through subnational governments in special economic development zones.

Trina Solar, today one of China's largest producers of solar wafers and modules, was established as a solar PV installer for demonstration projects in 1997. Yingli Solar followed in 1998, setting up its first facility in Baoding's High-Technology Development Zone under the Torch Program in 1993. Tianwei Baobian Electric Co., a state-owned manufacturer of electrical equipment held a 51 percent stake in Yingli's operating subsidiary, Tianwei Yingli, although subsequent restructuring gradually reduced Tianwei Baobian's equity interest.[19] Suntech Power opened its first production plant in Wuxi in 2001, with USD $6 million in funding from the local government in return for a 75 percent equity stake. Canadian Solar was founded in the same year and opened its first manufacturing facilities in Suzhou. In 2004, after global demand for solar panels increased because of improvements to Germany's domestic subsidy regime for renewable energy, a number of additional firms entered the industry. China Synergy, also referred to as CSUN was established in 2004 in Nanjing as a subsidiary of China Electric Equipment Group, a manufacturer of electrical transformers and advanced composite materials. JA Solar began manufacturing wafers in Shanghai in 2005. In 2006, LDK Solar was founded in Xinyu by Peng Xiaofeng, who had previously made a fortune by mass manufacturing protective equipment such as gloves and now saw a market opportunity in producing solar wafers.[20]

China's solar firms were able to build on the experience of Chinese returnees, many of whom had completed graduate degrees and research visits at foreign solar PV laboratories. By far the most important source of basic technology for the Chinese solar sector was the School of Photovoltaic and Renewable Energy at the University of New South Wales in Australia. Rather than relying on licensing and joint development agreements, as was prevalent in other high-technology sectors in China, China's solar firms were able to recruit foreign-trained researchers who indigenously developed solar PV technologies. Additional sources of solar PV technology were American and European manufacturers of solar PV manufacturing equipment. Modern turn-key

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19 Yingli Green Energy Holding Company Limited 2008, 30.

20 Farrel, "In Pictures: Asia's Youngest Billionaires"; Trina Solar, "TSL: Company Milestones"; Yingli Green Energy Holding Company Limited, "Annual Report for Fiscal Year Ending 12/31/2007 - Form 20-F"; Ahrens, "China's Competitiveness: Myth, Reality, and Lessons for the United States and Japan. Case Study: Suntech"; Canadian Solar, "About Us"; JA Solar Holdings, "Annual Report 2006, Form 20-F."

production lines embed critical technologies within the manufacturing equipment, allowing manufacturers to produce solar PV products without having to develop core technologies in-house.

Chinese solar PV firms were relying on foreign producers of manufacturing equipment for access to technology, in particular those from Germany, Italy, and the United States. Already in 2000, Centrotherm, a German manufacturer of cell and module production lines, began selling its products to Chinese customers. Others quickly followed.[21] In this context, many solar PV firms focused on conventional mono- and polycrystalline cell technologies, because mono- and polycrystalline silicone-based PV technologies were subject of research at the University of New South Wales and manufacturing equipment for both technologies was available on global markets. Chinese solar PV firms excelled in bringing these cell technologies to mass production. Even though Chinese laboratories generally lagged in solar PV conversion efficiencies achieved under laboratory conditions, as early as 2007 Chinese solar PV companies were mass producing solar modules with cell efficiencies on par with or better than those of their competitors.[22] However, a lack of central government subsidies for domestic solar PV deployment prevented domestic solar markets in China, requiring Chinese solar PV manufacturers to export more than 90 percent of their production. In contrast to the wind industry, for which China's central government introduced subsidies and other demand-stimulating policies for domestic markets as early as 1997, demand-side subsidies were not announced for the solar sector until 2009 and implemented nationwide until 2011.[23]

3.2 Creating Domestic Demand but Exporting Anyway, 2009–2015

The 2008/2009 financial crisis put an end to generous subsidies that had created demand for Chinese solar panels in several European export markets. Spain, among others, removed some demand-side subsidies to reduce ballooning government deficits. Chinese solar PV manufacturers, which had to date exported most of their products to European markets and had grown into a sizeable industrial sector, were suffering rapidly declining sales (see Tables 1 and 2). At the same time, cost declines because of scale economies and cut-throat competition had made once uncompetitive solar PV technologies more and more affordable.

In the context of broader economic stimulus efforts, the central government for the first time created incentives for domestic solar demand. Notable in the case of solar is that

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21 Nahm, *Collaborative Advantage: Forging Green Industries in the New Global Economy*, chaps. 4–5.

22 Nahm, *Collaborative Advantage: Forging Green Industries in the New Global Economy*, chaps. 4–5.

23 Lew, "Alternatives to Coal and Candles: Wind Power in China"; Ru et al., "Behind the Development of Technology: The Transition of Innovation Modes in China's Wind Turbine Manufacturing Industry."

such central government efforts to shape and support the industry came after nearly a decade of development primarily driven by private sector initiative and subnational government support. Unlike wind, for instance, solar was not included in earlier central government plans to create national champion firms in new energy industries. Starting in 2009, a first nation-wide central government subsidy for solar energy sold to the electric grid subsequently created a small but growing domestic market for solar PV technologies. Additional direct subsidy programs were available to support both the installation of residential and utility-scale solar PV installations.[24] However, these subsidies took a while to take effect—it was not until 2012 that central government support at last led to growing domestic markets. Until then, China's solar PV firms continued to export the vast majority of their production. In 2007, 1.34 GW of solar modules were manufactured in China, but only 20 MW were installed domestically. In other words, domestic installations of solar PV accounted for less than 2 percent of domestic production. This figure increased to 4 percent in 2010 and 15 percent in 2012. Even after the introduction of demand-side policies domestically, in 2013, more than 55 percent of domestic solar PV production was exported (Tables 1 and 2).[25]

Table 1. Trina Solar, Percentage of Net Revenue by Country (in Percent)

Year	Germany	Spain	USA	PRC	Total Abroad
2007	31.4	50.0	/	2.1	97.9
2008	23.9	32.5	/	3.7	96.3
2009	33.9	12.1	/	2.9	97.1
2010	24.1	21.8	14.1	3.8	96.2
2011	37.0	13.2	21.5	7.1	93.9
2012	33.1	1.3	25.5	13.0	87.0
2013	10.4	2.3	17.0	33.1	66.9

Source: SEC Filings (20-F), various years

24 Campbell, "China and the United States - A Comparison of Green Energy Programs and Policies."

25 IEA, "Special Report on Solar PV Global Supply Chains." Earth Policy Institute, "Climate, Energy, and Transportation Data."

Table 2. Yingli Green Energy Holding, Percentage of Net Revenue by Country (in Percent)

Year	Germany	Spain	USA	PRC	Total Abroad
2007	22.0	64.0	0.9	1.5	98.5
2008	41.0	40.0	1.7	2.5	97.5
2009	63.0	6.0	2.0	4.5	95.5
2010	57.0	6.0	10.0	5.0	95.0
2011	45.0	3.5	15.0	22.0	78.0
2012	42.0	3.4	14.0	23.0	77.0
2013	18.0	1.0	22.0	34.0	66.0

Source: SEC Filings (20-F), various years

In 2010, the State Council released a list of seven "Strategic Emerging Industries" to replace the old pillar industries that had long structured central industrial policymaking. The "Decision on Accelerating the Development of Strategic Emerging Industries" included solar PV technologies as well as advanced manufacturing equipment.[26] The emphasis on equipment manufacturing subsequently pervaded the 12th Five Year Plan for the solar PV industry, released in 2012, which called for 80 percent of solar production equipment to be manufactured domestically by 2015. Most of the production equipment had previously been sourced from Europe and the United States.[27] The 2010 Decision called on subnational governments to come up with detailed implementation plans to support strategic emerging industries. Its most immediate effect was to signal that subnational government activities in a wide range of policy areas should support the development of the select seven industries, including in the design of research and development subsidies and tax policies. State development banks were encouraged to lend to solar PV manufacturers (alongside other manufacturing firms), which were able to increase manufacturing capacity despite broad shifts in global demand.

The 12th Five-Year Plan for the solar industry, for the years 2011–2015, called for further growth of China's domestic solar industry, concluding that despite rapid expansion over the 11th Five-Year Plan, the industry had vast room for expansion. The plan set out four basic principles of solar PV support: (1) the support of leading enterprises, (2) focus on technological innovation to reduce the cost of solar PV technologies, (3) the expansion of China's domestic solar PV market, and (4) the improvement of certification and safety

26 US-China Business Council, "China's Strategic Emerging Industries: Policy, Implementation, Challenges, & Recommendations."

27 State Council, "Guowuyuan Guanyu Jiakuai Peiyu He Fazhan Zhanlüexing Xinxing Changye De Jueding [Decision of the State Council on Accelerating the Fostering and Development of Strategic Emerging Industries]."

standards and better enforcement of environmental protection and product safety legislation. The plan set a number of development goals for the Chinese solar PV industry, including the increased domestic production of polysilicon and the development of major solar PV enterprises with 5 GW or more of annual production capacity. It outlined specific technology focus areas, including the development of specialized production equipment to reduce import dependency, energy storage systems, and building-integrated solar PV modules.

The inclusion of solar PV on the list of strategic emerging industries and the goals set in the 12th Five-Year Plan for the solar industry greenlighted subnational government plans to support their local solar firms. As a result, China's solar firms had access to large sums of capital through bank loans, provided by state-owned banks and frequently guaranteed by local government entities or state-owned companies. Media reports estimate that between 2010 and 2012, Chinese wind and solar firms were extended credit lines of USD 47 billion by state-owned banks, although only a fraction of the overall sum had been drawn by the end of 2011. The China Development Bank, one of three state-owned policy banks charged with raising funds for large infrastructure and development projects, reportedly extended USD 29 billion in credit to the 15 largest wind and solar firms, including Yingli Green Energy Holding and Trina Solar.[28] Other reports suggest that until 2012, USD 18 billion in loans were provided to large wind and solar firms by state-owned banks to fund the expansion of manufacturing facilities. These loans were backed by municipal and provincial governments.[29]

There is little publicly available evidence that loans were provided at interest rates far below market rates. Research by Bloomberg New Energy Finance suggests, however, that interest rates ranged between 2.5 percent and 8.5 percent, depending on loan maturities and loan currencies.[30] These interest rates are broadly consistent with annual reports filed with the U.S. Securities and Exchange Commission (SEC) by Chinese solar firms at the time, including Yingli Green Energy Holding and Trina Solar.
Credit lines to expand manufacturing capacity were brokered and backed by local governments and state-owned firms, even in the years after the global financial crisis when the collapse particularly of European markets led to overcapacity in global solar markets. Providing loans was a way to improve local GDP growth rates, employment rates, and other indicators of economic development used to determine cadre

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28 Bakewell, "Chinese Renewable Companies Slow to Tap $47 Billion Credit."

29 Bradsher, "Glut of Solar Panels Poses a New Threat to China."

30 Bakewell and White 2011.

performance and promotions. Solar PV's status, first as a designated high-technology sector, and, starting in 2010, as a strategic emerging industry in central government plans further encouraged local government officials and state-owned banks to continue lending to China's solar PV sector.

Table 3. Short-Term Bank Borrowings of Yingli Green Energy Holding and Trina Solar, including Current Portion of Long-Term Debt, in USD

Year	Yingli	Trina
2007	163,563,089	172,905,295
2008	248,557,724	299,626,000
2009	267,427,776	512,903,000
2010	158,652,178	887,557,000
2011	389,472,291	1,306,833,000
2012	875,820,790	1,208,009,000
2013	935,589,882	1,109,384,000

Source: Annual reports (20-F) filed with the SEC, various years

Between 2009 and 2011, the production utilization rate for China's solar PV industry—the capacity utilization of existing solar PV manufacturing plants—fell from just over 60 percent in 2009 to just under 50 percent in 2011, despite the aggressive expansion of domestic solar PV markets.[31] Even though, in the aggregate, only half of China's solar PV plants were running at capacity, solar PV firms continued to receive credit. Yingli Green Energy Holding and Trina Solar were able to rapidly increase short-term bank borrowings in the years between 2009 and 2011 (see Table 3), despite the complex market environment in global solar PV industries at the time. For instance, in 2009, Trina China secured a five-year credit line of USD 303 million from a syndicate of domestic banks, of which USD 269 million was designated for the expansion of manufacturing capacity.[32]

With few exceptions, loans were provided by state-owned banks and policy banks in China, including the China Development Bank, the China Export-Import Bank, the Agricultural Bank of China, the Bank of China, the Bank of Communications, and the Industrial and Commercial Bank of China. Loan contracts were generally negotiated with the municipal or provincial branch of these national, state-owned banks. Loans were frequently, though not always, guaranteed by municipal government entities or by

Bakewell, "Chinese Renewable Companies Slow to Tap $47 Billion Credit."

31 Zhao, Wan, and Yang, "The Turning Point of Solar Photovoltaic Industry in China: Will It Come?"

32 Trina Solar, "Annual Report 2009 - Form 20-F."

state-owned firms that partnered with the defendants. SEC filings indicate that state-owned banks in several instances waived violations of loan covenants in the aftermath of the 2009 financial crisis and renewed or provided additional loans in subsequent years. For instance, in 2011, Trina China violated the net profit ratio as well as the income to interest ratio included in the loan covenants. Trina China was able to obtain a waiver from the lead bank in the syndicate, the Agricultural Bank of China. The covenants were waived for the entire loan period. In the same year, Trina China entered a three-year credit facility with the China Development Bank over USD 180 million. In 2012, Trina China again violated the debts to asset ratio, current assets turnover, and accounts receivable turnover stipulations in the loan. Again, Trina China was able to obtain a waiver of the covenants and China Development Bank subsequently revised the covenants included in the loan.[33] Due to their status as high-technology enterprises, solar PV firms were sought after by local government administrations, which were able to offer additional preferential treatments, including access to preferential tax rates, land deals, and a range of additional services in China's High-Technology Development Zones.

As noted previously, the production utilization rate for China's solar PV industry, that is, the capacity utilization of existing solar PV manufacturing plants, fell from just over 60 percent in 2009 to just under 50 percent in 2011.[34] During the 11th Five-Year Plan, production capacity for solar PV technologies grew at an annual rate of more than 100 percent and continued to increase at a rapid pace even as the global financial crises affected market demand, particularly in Europe. The incentives for government officials to support the expansion of manufacturing capacity of local firms and the ability of firms to draw on financial support and bank loans to fund such expansions permitted solar PV firms to increase their manufacturing capacity, even during periods of overcapacity in global solar PV markets.

33 Trina Solar, "Annual Report 2012 - Form 20-F."

34 Zhao, Wan, and Yang, "The Turning Point of Solar Photovoltaic Industry in China: Will It Come?"

Table 4. Trina Solar, Annual Production Capacity/Production Output, in MW

	2009 Capacity/Output	2010 Capacity/Output	2011 Capacity/Output	2012 Capacity/Output
Silicon Ingots	500/398	750/705	1200/978	1200/1140
Silicon Wafers	500/358	750/718	1200/971	1200/1080
Solar Cells	600/375	1200/973	1900/1557	2400/1550
PV Modules	600/425	1200/1048	1900/1702	2400/1720

Source: SEC Filings (20-F), various years

Between 2009 and 2012, Trina Solar more than doubled its manufacturing capacity for solar wafers and ingots. The company more than quadrupled its manufacturing capacity for solar cells and modules over the same period. The rapid expansion of manufacturing capacity continued even as plants operated below capacity every year (see Table 4). Although capacity utilization information is not publicly available for Yingli Green Energy Holdings, SEC filings show that manufacturing capacity has grown at a similar pace.

Although the central government's Five-Year Plan for the Solar Industry called for increased in domestic demand, provincial-level five-year plans prioritized the expansion of production capacity for solar PV technologies over support for market demand. For instance, both the Jiangsu 12th Five-Year Plan for Energy Development and the Hebei 12th Five-Year Plan for Electricity Sector Development anticipated only modest increases in the share of electricity generated from renewable sources, while outlining rapid increases in production capacity of local solar PV manufacturers. The mismatch between production capacity and market demand both suggests that subnational governments envisioned solar PV sectors primarily as export-oriented industries over the course of the 12th Five-Year Plan period (2011–2015). Revenue data of both Trina Solar and Yingli Green Energy Holding reflect the divergence between market demand and production capacity in China. The share of revenue generated from domestic sales increased significantly between 2007 and 2013, as central government policies enacted new policies to subsidize the domestic use of solar PV technologies. However, the vast majority of revenue for both firms continued to be generated in Europe, and, increasingly, the United States.

3.3 Reducing Dependence on Public Support, 2015–Present

Beginning in 2013, the central government began to intervene more aggressively to manage the overcapacity that had begun to build in China's domestic solar industry, both because of continued investment in additional manufacturing capacity and insufficient demand in both domestic and international markets. Central government interventions during this period primarily focused on shaping domestic solar PV markets to both encourage scale and continued investments in technological innovation among domestic solar firms. However, the center did not remove some of the financial incentives for subnational governments, which continued to incentivize ongoing investments in additional manufacturing capacity across the supply chains. The interventions of the central governments therefore primarily addressed the unintended consequences caused by misaligned incentives for subnational governments. Rather than setting up a clear policy strategy to resolve, for instance, some of the overcapacity issues that had plagued China's solar industry for quite some time, policies continued to be ad hoc responses to ever new problems growing out of the activities of subnational governments.

By 2013, trade disputes with the United States and the European Union over unfair trade practices led to the implementation of a range of trade remedies, some of which remain in place today. The tariffs diminished the profitability of the Chinese solar industry, which was already struggling as a result of overcapacity and volatile export markets in the wake of the 2009 recession. Suntech, one of the largest players in the Chinese solar industry, declared bankruptcy in 2013 after several challenging quarters and a massive debt default in 2012.[35] U.S. tariffs caused major Chinese solar firms to establish cell and module assembly plants in other Asian economies, particularly in Thailand and Vietnam, but these plants continued to source wafers from China, which were made using domestically produced polysilicon, primarily from Xinjiang. Chinese firms also began targeting developing economies, at least in part through Belt and Road Initiative programs, for export production to alleviate chronic overcapacity.[36]

The immediate focus of central government policies was to further increase the role of domestic markets. In 2013, the State Council issued guidance calling for domestic installations to increase to 35 GW by 2015, roughly equal to 35 nuclear power reactors in generation capacity. Such goals substantially exceeded the target of 21 GW set in the 12th Five-Year Plan for Renewable Energy Development released by the National Energy Administration. A number of incentive policies were released between 2012

35 Zhang et al., "Evolution of Solar Photovoltaic Policies and Industry in China."

36 Gu and Zhou, "Emission Reduction Effects of the Green Energy Investment Projects of China in Belt and Road Initiative Countries."

and 2018, aiming both to increase domestic PV installations by improving profitability and solving problems with grid interconnection and power market regulation that led to high rates of solar PV curtailment. The central incentive mechanism for solar PV deployment was a resource-based feed-in tariff enacted in 2013, which offered staggered subsidies for solar energy based on the solar resources available in each province. The tariffs were funded by China's Renewable Energy Development Fund. The fund, administered by the Ministry of Finance, collects a surcharge from electricity consumers and allocates subsidies to renewable power installations eligible for subsidies under the feed-in-tariff. When there were insufficient funds available, the fund could draw on the fiscal budget to meet the subsidy obligations but was in principle obliged to refund the fiscal budget when surcharges exceeded demand for subsidies. In practice, the fund has been chronically underfunded and often late to pay out subsidies to renewable power installations.[37]

To manage the growing cost of subsidies paid to solar energy generators through a bonus payment on top of regular electric prices, the National Development and Reform Commission in 2015 announced that it would begin lowering subsidy rates, starting in December of the same year. Subsidies created windfall profits for renewable energy developers as the cost of solar PV technologies continued to decline, and the central government sought to align subsidies with falling technology costs in a series of steps. Solar subsidies were lowered year over year, gradually decreasing from RMB/kwh .90 in 2015 to .50 after June 2018 in the provinces assigned to the lowest solar subsidy zones. Despite such reductions, China reached its 2020 solar installation targets three years ahead of schedule, prompting the decision in the central government to wean the industry off demand-side subsidies altogether and move to a bidding system for new installations.[38]

The reduction in subsidies alone was unable to solve the three central problems facing the Chinese solar market: first, runaway solar installations that were challenging to integrate in local electricity grids; second, a chronically underfunded renewable energy fund, whose primary source of revenue, surcharges placed on ratepayer bills, was unable to keep up with growing demand as a result of rapidly increasing installations; and third, lagging conversion efficiency and poor manufacturing capacity utilization. To address these problems, the central government in 2015 launched a so-called *Top Runner* program.[39] Beginning in 2015, the central government mandated that a certain

37 Zhang et al., "Evolution of Solar Photovoltaic Policies and Industry in China"; Zhao, Wan, and Yang, "The Turning Point of Solar Photovoltaic Industry in China: Will It Come?"

38 Zhang et al., "Evolution of Solar Photovoltaic Policies and Industry in China."

39 Shaw, "Insight."

amount of solar capacity installed each year must use panels that meet set efficiency standards. In 2015, 1 GW of installed capacity was reserved for Top Runner projects, increasing to 5.5 GW in 2016 and 10 GW in 2017. To participate in the Top Runner program and be allocated a share of that capacity set aside for high-efficiency solar installations, panels initially had to exceed conversion efficiencies of 16.5 percent for polycrystalline cells and 17 percent for monocrystalline cells. Specific conversion efficiency standards also existed for other technologies, including CIGS, cadmium telluride, and other thin film technologies.[40] From the beginning, the Top Runner program used an auction system to encourage falling technology costs—the bid that would meet Top Runner efficiency standards at the lowest cost received the rights to build the solar installation.[41] Auctions were implemented nationally in 2018.

Initially, the threat of lower subsidies, the continuing windfall profits due to the slow adjustment of subsidies, and the growing number of projects for high-efficiency panels led to a surge in solar PV installations. Cumulative solar installations exceeded 43 GW in 2015, substantially surpassing the 35 GW goal set of the same year. The introduction of auctions in 2018 took developers by surprise and, at least initially, slowed installations. Solar PV installations in 2018 were 17 percent below 2017 levels but recovered in 2020 when overall solar PV capacity reached 255 GW.[42] Fueled by support of subnational governments, however, capacity expansions continued despite overcapacity in the sector, causing downward cost pressure that cut into the already thin profitability of existing solar firms. A key focus for central government planners was to improve the grid integration of the rapidly growing domestic solar fleet. Gansu and Xinjiang in 2015 and 2016 wasted more than a quarter of the solar power they generated—a process called curtailment—because there was not sufficient demand for power on the grid. Absent a successful national power sector reform and in the context of ongoing administratively determined power trading across provincial lines, NDRC and the National Energy Administration began setting time periods during which renewable energy plants in each region could sell power to the grid, required provincial governments to compensate the developers who had suffered from curtailment, and, in 2018, set the goal of achieving a national curtailment rate of less than 5 percent.[43]

40 Zhang et al., “Evolution of Solar Photovoltaic Policies and Industry in China.”

41 Zhang et al.

42 Auffhammer et al., “Renewable Electricity Development in China”; Zhang et al., “Evolution of Solar Photovoltaic Policies and Industry in China.”

43 Tan, “China Focus | Solar Energy in China.”

The rapid reduction of solar PV subsidies came as a surprise to domestic solar developers and injected considerable uncertainty, which was compounded by long delays in dispensing owed subsidy amounts from the chronically underfunded renewable energy fund. In 2022, for instance, the fund was so underfunded that the Ministry of Finance needed to inject an additional USD 63 billion to pay arrears owed to solar and wind developers. Subsidy payments owed to individual renewables developers had reached up to 70 percent of their overall market capitalization.[44] Nonetheless, the invectives for Top Runner projects injected incentives to deploy advanced solar PV technologies and retire the production of dated technologies. Module cost continued to fall because of these incentives, while module efficiency continued to increase. Particularly installations of high-efficiency panels in Western China were able to achieve grid parity because of those incentive changes, yet broader issues, including the perpetual underfunding of the renewable energy fund, the low profitability of domestic manufacturers, overcapacity, and broader trade tensions remained unresolved.

4. Discussion and Conclusion

In contrast to industries such as wind power, and to some extent electric vehicles, where central government policy used domestic markets strategically to build technological know-how and weed out nonperforming firms, subnational governments have taken the initiative at critical moments in the development of the solar PV industry. Rather than starting with domestic markets and clear technological benchmarking, such as those in wind and batteries, the Chinese solar industry started as an export-oriented sector driven by subnational government investments in manufacturing capacity.

While the center enabled this role of subnational actors to some degree—not least by designating solar as a strategic emerging industrial sector, which allowed subnational administrations to turn on the spigot of policy lending for manufacturing expansion—the center responded to subnational actions more than it guided them. Subnational investments in a sizeable export-oriented solar industry created a dilemma for the center in 2009, when export markets collapsed in the wake of the global financial crisis and even China's highest performing solar firms were hanging on by a thread. The creation and implementation of domestic demand-side subsidies was a response to the actions of subnational players and a looming wave of bankruptcies, rather than a strategic response to falling solar PV prices and increasing technological efficiency of modules produced in China, even if those two things were also true.

44 Bloomberg News, "China Sets $63 Billion to Pay Subsidies Owed to Renewables Firms."

While the central government has taken a more active role in shaping domestic markets since its first intervention in the domestic solar industry in 2009, it has continued to primarily address unintended consequences caused by misaligned incentives for subnational actors. As I have outlined in this paper using the examples of two Chinese solar manufacturers, Yingli and Trina, access to loans from China's development banks brokered and backed by subnational governments allowed for the expansion of manufacturing capacity, even as declining global demand contributed to overcapacity. Feed-in tariffs and other policy measures to support domestic markets were able to offset declining exports to some degree. Yet investments in production capacity expansion continued to trail growing domestic demand, even as generous feed-in tariffs were slow to adjust to falling prices and created rapidly accelerating domestic installations.

The central government's introduction of auctions as the primary way to allocate domestic subsidies for solar PV installations was another corrective measure, this time intended to address the chronic shortfall in China's renewable energy fund. The fund was funded by ratepayer surcharges and tasked with paying the difference between electricity market prices and the subsidized rates for renewable energy. Surcharges were unable to keep up with rapidly growing installations and slow-to-decline feed-in tariff rates. The auctions were primarily an attempt to reduce the delays in subsidy payments to developers by cutting overall subsidy amounts, but the 2022 injection of USD 63 billion in the renewable energy fund suggests that reforms are not proceeding quickly enough. That is not surprising, given that the behavior of both central and subnational governments, solar manufacturers, and developers, is itself dependent on broader incentive structures that have been slow to change, including a slow-to-reform national power market, and inefficient industrial policy competition (and outright protectionism) between subnational governments.

The interplay between central and subnational interventions in China's solar industry notwithstanding, China has collectively established an overwhelming dominance in an industry that is taking on a central role in global efforts to decarbonize. However, as other countries are increasingly seeking to re-shore manufacturing activities, including solar PV, China's story may not be a lesson for others. Rather than strategically guiding industrial development and benchmarking both cost and technological targets, China succeeded primarily by unleashing unprecedented capital investments for manufacturing expansion using practices grounded in the local developmental state of the 1990s. Technological benchmarks were only introduced much later by the central government to reign in the excesses caused by earlier investment sprees, but even then, the center continued to respond primarily to ever-new problems created by misaligned incentives at the subnational level. Much of the production capacity created as a result of subnational investment sprees sat idle or was designed to produce outdated technologies, cutting into the profit margins of China's most promising solar PV manufacturers by driving down overall prices in the industry. Rather than be an example of strategic industrial policy intervention, China's solar PV industry is a study in addressing unintended consequences without fixing their underlying causes.

References

Ahrens, Nathaniel. "China's Competitiveness: Myth, Reality, and Lessons for the United States and Japan. Case Study: Suntech." Washington, D.C.: Center for Strategic and International Studies, 2013.

Alexander, Cathy. "Carbon Cutters." Crikey, 2013. http://www.crikey.com.au/thepowerindex/carbon-cutters/.

Auffhammer, Maximilian, Min Wang, Lunyu Xie, and Jintao Xu. "Renewable Electricity Development in China: Policies, Performance, and Challenges." *Review of Environmental Economics and Policy* 15, no. 2 (June 1, 2021): 323–39. https://doi.org/10.1086/715624.

Bakewell, Sally and Todd White. "Chinese Renewable Companies Slow to Tap $47 Billion Credit." *Bloomberg*, November 16, 2011.

Bloomberg New Energy Finance. "Solar PV Trade and Manufacturing: A Deep Dive," 2021.

Bloomberg News. "China Sets $63 Billion to Pay Subsidies Owed to Renewables Firms." *Bloomberg.Com*, 2022. https://www.bloomberg.com/news/articles/2022-03-14/china-sets-63-billion-to-pay-subsidies-owed-to-renewables-firms.

Bradsher, Keith. "Glut of Solar Panels Poses a New Threat to China." New York Times, 2012. http://www.nytimes.com/2012/10/05/business/global/glut-of-solar-panels-is-a-new-test-for-china.html?_r=0.

Campbell, Richard J. "China and the United States - A Comparison of Green Energy Programs and Policies." Washington, D.C.: Congressional Research Service, 2010.

Canadian Solar. "About Us," 2013. http://www.canadiansolar.com/about_us.aspx?id=1.

Earth Policy Institute. “Climate, Energy, and Transportation Data.” Washington, D.C., 2015. http://www.earth-policy.org/data_center/C23.

Farrel, Andrew. “In Pictures: Asia’s Youngest Billionaires.” Forbes, 2008. http://www.forbes.com/2008/09/03/asia-billionaires-wealth-biz-billies_cx_af_0903youngasiabillies_slide_4.html.

Gu, Alun, and Xiaoyu Zhou. “Emission Reduction Effects of the Green Energy Investment Projects of China in Belt and Road Initiative Countries.” *Ecosystem Health and Sustainability* 6, no. 1 (December 16, 2020): 1747947. https://doi.org/10.1080/20964129.2020.1747947.

Hart, David. “The Impact of China’s Production Surge on Innovation in the Global Solar Photovoltaics Industry.” Washington, DC: Information Technology & Innovation Foundation, 2020.

Helveston, John, and Jonas Nahm. “China’s Key Role in Scaling Low-Carbon Energy Technologies.” *Science* 366, no. 6467 (2019): 794. https://doi.org/10.1126/science.aaz1014.

IEA. “Special Report on Solar PV Global Supply Chains.” Paris: International Energy Agency, 2022.

JA Solar Holdings. “Annual Report 2006, Form 20-F,” 2007.

Kanellos, Michael. “Applied Materials Kills Its SunFab Solar Business.” Greentech Media, 2010.

Lazard. “Lazard’s Levelized Cost of Energy Analysis.” New York, NY: Lazard, 2022. https://www.lazard.com/perspective/levelized-cost-of-energy-levelized-cost-of-storage-and-levelized-cost-of-hydrogen/.

Lew, Debra J. “Alternatives to Coal and Candles: Wind Power in China.” *Energy Policy* 28, no. 4 (2000): 271–86. https://doi.org/10.1016/S0301-4215(99)00077-4.

Lewis, Joanna I. “The Rise of Renewable Energy Protectionism: Emerging Trade Conflicts and Implications for Low Carbon Development.” *Global Environmental Politics* 14, no. 4 (2014): 10–35.

Nahm, Jonas. “A Green Economic Recovery: Global Trends and Lessons for the United States.” *Statement before the House Foreign Affairs Committee Subcommittee on Europe, Eurasia, Energy, and the Environment*, 2020. https://docs.house.gov/meetings/FA/FA14/20200923/111050/HHRG-116-FA14-Wstate-NahmJ-20200923.pdf.

———. *Collaborative Advantage: Forging Green Industries in the New Global Economy*. New York, N.Y.: Oxford University Press, 2021.

Pickerel, Kelly. “An Update on WRO Enforcement on Imported Solar Panels.” *Solar Power World Online*, 2021. https://www.solarpowerworldonline.com/2021/11/an-update-on-wro-enforcement-on-imported-solar-panels.

Ru, Peng, Qiang Zhi, Fang Zhang, Xiaotian Zhong, Jianqiang Li, and Jun Su. “Behind the Development of Technology: The Transition of Innovation Modes in China’s Wind Turbine Manufacturing Industry.” *Energy Policy* 43 (2012): 58–69. https://doi.org/10.1016/j.enpol.2011.12.025.

Shaw, Vincent. “Insight: China’s Top Runner PV Program.” *pv magazine International*, 2016. https://www.pv-magazine.com/magazine-archive/insight-chinas-top-runner-pv-program_100023185/.

Sivaram, Varun. *Taming the Sun: Innovations to Harness Solar Energy and Power the Planet*. Cambridge, M.A.: The MIT Press, 2018.

Sivaram, Varun, John O Dabiri, and David M Hart. “The Need for Continued Innovation in Solar, Wind, and Energy Storage.” *Joule* 2, no. 9 (2018): 1639–42.

State Council. “Guowuyuan Guanyu Jiakuai Peiyu He Fazhan Zhanlüexing Xinxing Changye De Jueding [Decision of the State Council on Accelerating the Fostering and Development of Strategic Emerging Industries]” State Council Document 2010/32 (2010).

Tan, Huizhong. “China Focus | Solar Energy in China: The Past, Present, and Future.” *China Focus* (blog), February 16, 2021. https://chinafocus.ucsd.edu/2021/02/16/solar-energy-in-china-the-past-present-and-future/.

Trina Solar. “Annual Report 2009 - Form 20-F,” 2010.

———. “Annual Report 2012 - Form 20-F,” 2013.

———. "TSL: Company Milestones," 2013. http://media.corporate-ir.net/media_files/irol/20/206405/milestones.pdf.

U.S. Department of Energy. "Solar Photovoltaics - Supply Chain Deep Dive Assessment." Accessed August 30, 2022. https://www.energy.gov/sites/default/files/2022-02/Solar%20Energy%20Supply%20Chain%20Report%20-%20Final.pdf.

US-China Business Council. "China's Strategic Emerging Industries: Policy, Implementation, Challenges, & Recommendations." Washington, D.C., 2013.

Yingli Green Energy Holding Company Limited. "Annual Report for Fiscal Year Ending 12/31/2007 - Form 20-F," 2008.

Zhang, Yueqi, Pengcheng Xie, Ying Huang, Cuiping Liao, and Daiqing Zhao. "Evolution of Solar Photovoltaic Policies and Industry in China." *IOP Conference Series: Earth and Environmental Science* 651, no. 2 (February 1, 2021): 022050. https://doi.org/10.1088/1755-1315/651/2/022050.

Zhao, Xin-gang, Guan Wan, and Yahui Yang. "The Turning Point of Solar Photovoltaic Industry in China: Will It Come?" *Renewable and Sustainable Energy Reviews* 41, no. 0 (2015): 178–88. https://doi.org/10.1016/j.rser.2014.08.045.