Global Supply Chain Report

Summary
Electric Vehicle
Solar PV
Apparel
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Where the Sun Shines: The Changing Landscape of the Global Solar Supply Chain

Executive Summary

Solar power, the third largest renewable energy source in global electricity generation, has experienced remarkable growth in recent years. Driven by a significant expansion in solar photovoltaic (PV) installed capacity, the contribution of solar power to global electricity generation increased to 6.9% in 2024. This upward trend is expected to continue due to the improving cost-effectiveness of solar energy, a wider range of applications, and the pressing need for renewable energy sources to combat climate change and ensure energy security in an increasingly complex geopolitical landscape.

Solar PV is the dominant technology used in solar power generation, with most solar panels in use being crystalline silicon panels. These solar panels are produced by a global supply chain that encompasses the entire production cycle, from the mining of raw materials (i.e., quartz) and the refining of polysilicon to the manufacturing of solar cells and the assembly of solar panels. The global aspect of the solar supply chain further reveals a complex network intricately woven into the fabric of global economic and political dynamics, reflecting broader trends in geopolitics, domestic industrial policies, market forces, technology, and sustainability.

In recent years, geopolitical tensions and trade protectionism have escalated, resulting in increased import tariffs and other duties on solar products. Meanwhile, supportive domestic industrial policies, such as financial incentives and support mechanisms, could bolster local solar production. Free trade agreements (FTAs), on the other hand, could help reduce or eliminate tariffs on solar inputs and components among signatory countries, thereby facilitating solar sourcing based on cost considerations and the development of regional solar supply chains.

The supply of raw materials and components, along with production capacity and costs, are crucial determinants of competitiveness within the solar supply chain. Countries that rely on imported raw materials and solar inputs render their solar supply chain vulnerable to various risks. Meanwhile, countries with high production costs may find themselves at a disadvantage in the global or even the domestic market and may need to depend on imports for their domestic solar deployment.

Significant advancements in solar technology have been made over the past decade. The rapid and widespread adoption of new technologies could not only lower costs and enhance competitiveness but also help set global technological trends in the solar industry.

Environmental, Social, and Governance (ESG) factors are increasingly shaping the solar supply chain landscape. Growing awareness of climate change and the shift towards renewable energy are driving investments in solar technologies and manufacturing, while also influencing the formulation of energy policies.

In terms of geography, China has been the undisputed leader in solar manufacturing over the last decade. It has leveraged its production scale, vertically integrated supply chain, technological prowess, and cost efficiency, along with government support, to excel in all facets of the global solar supply chain. While protectionist duties imposed by the US and other countries since the early 2010s have prompted some shifts in solar cell and panel manufacturing from the Chinese mainland to regions like Southeast Asia, China still controls approximately 85% of panel production and over 90% of upstream manufacturing stages.

Looking ahead, the global solar PV supply chain landscape is undeniably undergoing major transformations, with rising trade tensions and government interventions likely to further fragment the global solar supply chain. On one hand, newly imposed and potential US duties on imported solar cells and panels from Southeast Asian countries may hinder their solar manufacturing industry. On the other hand, the US and India, buoyed by trade protectionist measures and substantial government support, are emerging as strong contenders in the solar manufacturing arena, attracting investments from both domestic and international players seeking diversification away from China.

Despite these shifts, we expect China to maintain its absolute leadership in the global solar PV supply chain for the foreseeable future, thanks to its competitive production costs, technological leadership, and complete solar supply chain. China's pivotal role is further exemplified by the globalization of its solar manufacturing, with investments diversifying beyond Southeast Asia to the Middle East, Africa and other countries.

Contents

I. Introduction

1. Solar power

Solar power is the third-largest renewable energy source for global electricity generation behind hydropower and wind power. Two principal solar technologies are used to generate electricity: solar photovoltaic (PV) and concentrated solar power (CSP), which operate in fundamentally different ways (see Table 1). Since CSP accounts for less than 0.5% of solar power capacity worldwide, this report will focus exclusively on solar PV.

Table 1: A comparison between solar PV and CSP

	Solar PV	CSP
Electricity generation	Solar PV technology directly converts sunlight into electricity. When solar PV cells absorb light, electrons will be knocked loose. The movement of free electrons creates a current, which is then captured and transferred through wires, generating direct current (DC) electricity. This DC electricity is then converted into alternating current (AC) electricity for uses.	CSP systems convert sun heat into electricity indirectly. They use mirrors or lenses to reflect and concentrate sunlight onto a receiver. This concentrated energy heats a fluid, which generates steam to drive a turbine and produce AC electricity.
Scalability	Solar PV systems can be deployed in various sizes, ranging from small rooftop installations to large-scale solar farms.	CSP systems require substantial land and are typically deployed for utility-scale power generation.
Energy storage	To provide electricity after sunset, a PV power plant must be paired with a separate energy storage system.	CSP systems can be integrated with thermal energy storage technology, allowing them to continue generating electricity at night.[1]
Electricity cost	It has a lower levelized cost of electricity (LCOE)[2].	Its LOCE is double that of solar PV.

[1] Many CSP power plants use molten salts as the heat transfer fluid, which can be stored in huge, insulated tanks, retaining its thermal energy for months. This allows a CSP plant to continue generating electricity after sunset, providing a stable source of electricity.

[2] The LCOE is a measure of the average cost of generating electricity from an energy system over its entire lifespan, including construction, operation, and maintenance costs.

2. Solar PV supply chain

The solar PV supply chain consists of a network of interconnected industries and processes involved in the production, distribution, and deployment of solar panels (often called modules[3]). It covers the entire production cycle, from the mining of raw materials and the manufacturing of solar cells to the assembly of solar panels and their deployment worldwide.

At the heart of this solar supply chain are companies which design, manufacture, transport and install solar panels around the world. Examining the solar supply chain from a global perspective reveals a complex network that spans countries, continents, regulatory regimes, and even great-power competition. This network extends beyond manufacturing to encompass an intricate web of economic and political relationships among nations, as well as the recent surge in industrial policies aimed at promoting domestic solar manufacturing.

Understanding the dynamics of the ever-changing global solar supply chain is essential for analyzing the opportunities and challenges within the solar sector. This understanding will not only inform strategic decisions but also guide collaborative efforts to enhance the efficiency and resilience of the global solar supply chain in the years to come.

In this article, we will provide a comprehensive breakdown of the solar PV supply chain, investigate the dynamic landscape of the global solar industry, and explore the latest trends and developments shaping its evolution. By examining these emerging trends, we aim to offer insights into how the industry is adapting to recent changes and addressing its challenges. From market forces and regulatory changes to technological advancements and shifts in geopolitics and global trade dynamics, this article will highlight the key factors driving transformations in the global solar supply chain and their implications for the solar industry. We will also present our forecasts regarding shifts in the geographical distribution of the global solar supply chain landscape.

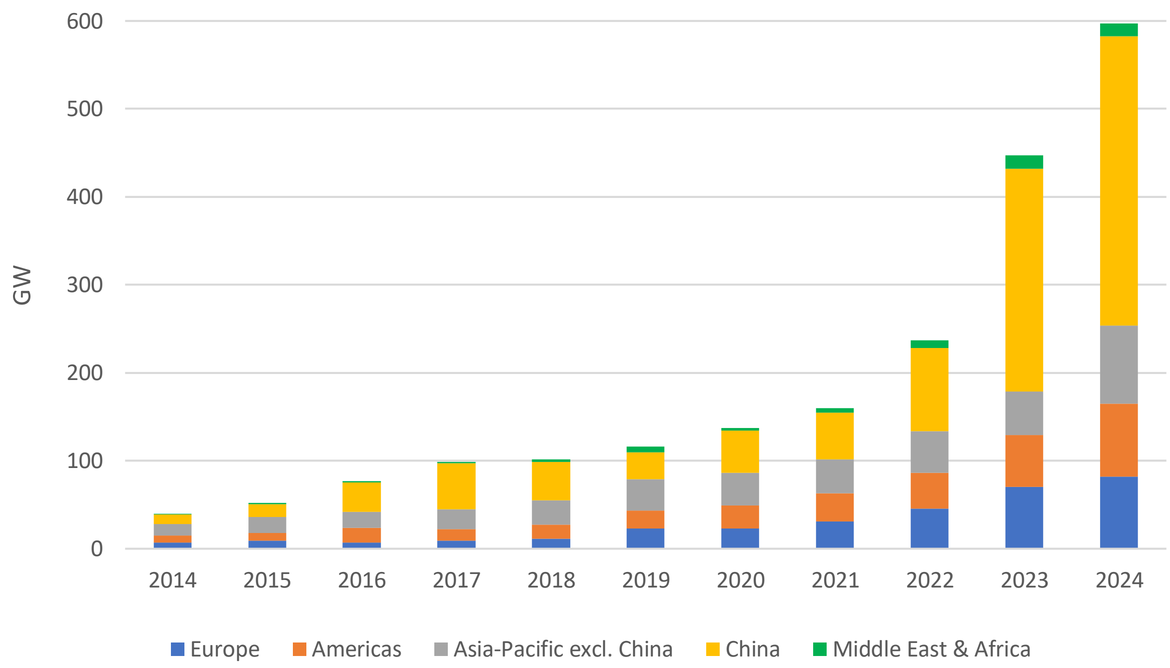
[3] Solar panels and solar modules are often used interchangeably, but they are not exactly the same. A solar module is a single, pre-assembled unit of solar cells wired together. In contrast, a solar panel is a more general term that can refer to either a single module or a collection of modules that are connected together.

II. An Overview of the Solar Market

1. Global solar PV installed capacity continues to surge

The solar energy market has experienced significant growth in recent years. According to SolarPower Europe, a total of 597 gigawatts (GW) of new solar PV capacity was installed in 2024, accounting for an impressive 81% of the 735 GW of newly installed renewable power generation capacity. This 597 GW of new solar PV installed capacity is a record high and marks a remarkable 33% increase compared with the 449 GW added in 2023 (see Figure 1).[4]

Figure 1: Annual solar PV installed capacity, 2014-2024



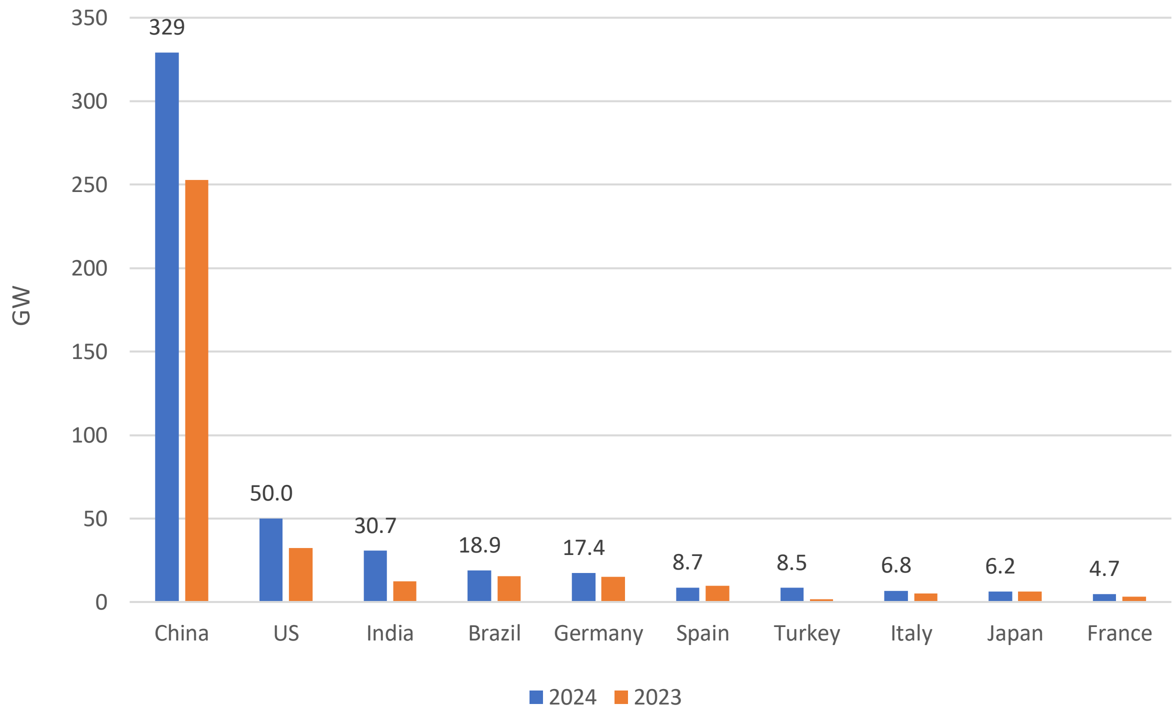
Source: Global Market Outlook for Solar Power 2025-2029, SolarPower Europe

While 2024 saw an unprecedented growth in new solar PV installed capacity, it is important to note that the majority of this expansion was driven by China. As the leading supplier of solar panels and the largest solar market for years, China accounted for more than half of the newly installed solar PV capacity in 2024, adding a record 329 GW of new capacity, which represents a 30% growth year-on-year (yoy). In contrast, the rest of the world managed to install only 267 GW of new solar PV capacity in 2024, achieving a higher growth rate of 36% yoy compared with China.

[4] SolarPower Europe, *Global Market Outlook for Solar Power 2025-2029* (2025), 18, https://www.solarpowereurope.org/insights/outlooks/global-market-outlook-for-solar-power-2025-2029.

Besides China, other significant solar PV markets include the US, India, Brazil, and several European countries such as Germany and Spain (see Figure 2). Meanwhile, notable emerging markets for solar PV installations include Pakistan, Chile, and Saudi Arabia.

Figure 2: Top 10 solar PV markets, 2023-2024



Source: Global Market Outlook for Solar Power 2025-2029, SolarPower Europe

As of the end of 2024, global solar PV installed capacity surpassed 2,200 GW, representing an elevenfold increase from just 178 GW ten years ago. With this surge in installed capacity, solar power is contributing a larger and larger share to global electricity generation. In 2024, it accounted for 6.9% of the world's total electricity generation, up 1.3 percentage points from the previous year and up 3.7 percentage points since the start of the decade in 2020.[5] Currently, solar power ranks as the third-largest renewable energy source for global power generation. However, it is projected to become the largest renewable energy source by 2030, according to the International Energy Agency (IEA).[6]

[5] SolarPower Europe, *Global Market Outlook for Solar Power 2025-2029* (2025), 16, https://www.solarpowereurope.org/insights/outlooks/global-market-outlook-for-solar-power-2025-2029.

[6] International Energy Agency, *Renewables 2025* (2025), 24, https://iea.blob.core.windows.net/assets/76ad6eac-2aa6-4c55-9a55-b8dc0dba9f9e/Renewables2025.pdf.

2. Key trends in the global solar PV market

Apart from surging market demand, the global solar PV market is experiencing the following trends:

2.1 Declining costs

Technological advancements, efficiency improvements, and economies of scale in solar manufacturing are driving down the cost of solar power generation. Between 2010 and 2024, the global average LCOE for utility-scale solar PV projects plummeted by 90%, from US$ 0.417 per kilowatt-hour (kWh) to just US$0.043 per kWh (see Table 2). This makes solar PV energy 41% cheaper than the least-cost fossil fuel-fired alternative (i.e., coal).[7] As solar PV technology becomes more affordable and price-competitive, it is increasingly accessible to a broader range of consumers and businesses.

Table 2: LCOE of renewable energy sources, 2010 and 2024

Energy source	$US/kWh		
	2010	2024	Change
Bioenergy	0.086	0.087	+1%
Geothermal	0.055	0.060	+9%
Hydropower	0.044	0.057	+30%
Solar PV	0.417	0.043	-90%
CSP	0.402	0.092	-77%
Onshore wind	0.113	0.034	-70%
Offshore wind	0.208	0.079	-62%

Source: Renewable Power Generation Costs in 2024, International Renewable Energy Agency

2.2 Wider geographical reach

Solar deployment is no longer concentrated in a few leading markets. While China and the US still lead in solar PV installations, many countries across Asia, Europe, the Americas, and Africa are rapidly increasing their solar installed capacity.

2.3 Greater variety of uses

The solar PV market is expanding beyond large-scale ground-mounted solar farms. There is significant growth in rooftop solar, community solar, and distributed generation projects that serve residential, commercial, and industrial users.

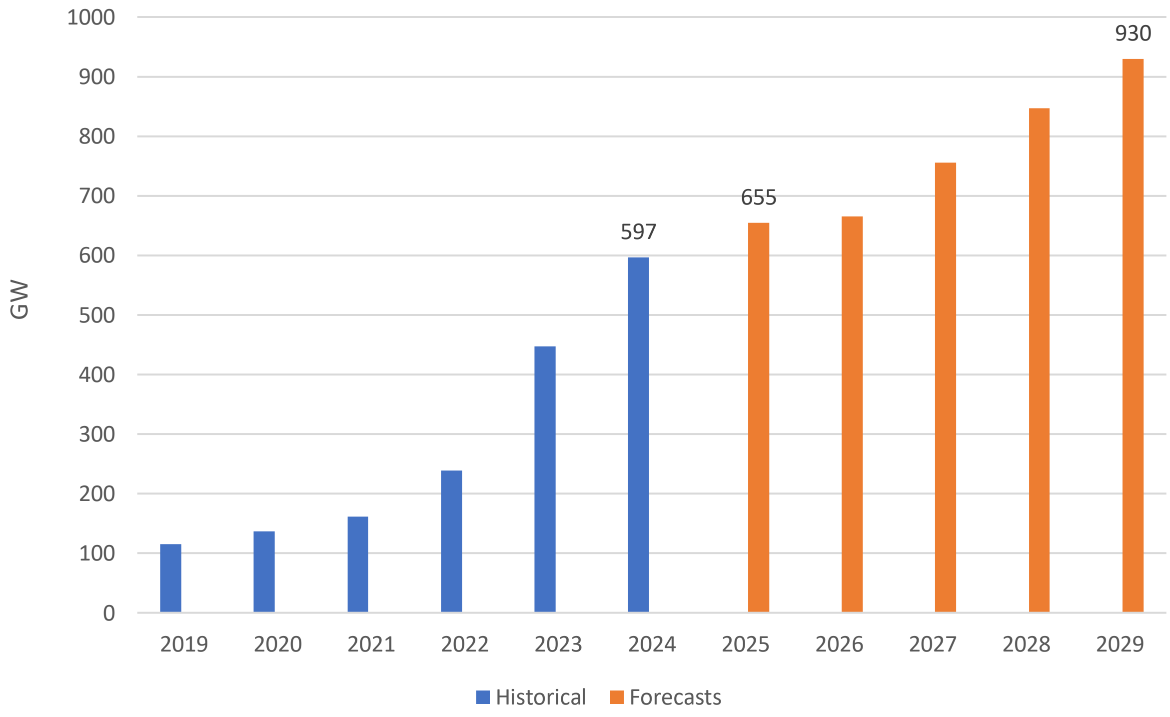
[7] International Renewable Energy Agency, *Renewable Power Generation Costs in 2024* (2025), 17, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Jul/IRENA_TEC_RPGC_in_2024_2025.pdf.

3. Outlook of the global solar PV market

The global solar PV market is set to maintain its impressive growth trajectory in the coming years. This growth is fueled by several key factors, including the increasing cost-competitiveness of solar energy due to ongoing technological advancements, a wider range of product offerings, the growing urgency for renewable energy sources to address climate change challenges, and the need for energy security in an increasingly complex geopolitical landscape.

According to SolarPower Europe, under a medium scenario, the global solar PV market is projected to reach 655 GW in 2025, representing a 10% increase from 597 GW in 2024. The market could further expand to 930 GW by 2029 (see Figure 3).[8] As more countries and businesses recognize the importance of transitioning to sustainable energy solutions, the solar PV sector will likely play a crucial role in shaping a cleaner and more resilient energy future.

Figure 3: Forecasts for the global solar PV market (medium scenario), 2025-2029



Source: Global Market Outlook for Solar Power 2025-2029, SolarPower Europe

[8] SolarPower Europe, *Global Market Outlook for Solar Power 2025-2029* (2025), 45, https://www.solarpowereurope.org/insights/outlooks/global-market-outlook-for-solar-power-2025-2029.

III. Breaking Down the Solar PV Supply Chain

Solar panels are produced through a complex global supply chain. Currently, the majority of solar panels in use are crystalline silicon panels, which account for over 98% of the global market. Thin-film PV technology[9] is the second most prevalent, representing about 2% of the market. Given the limited market share of thin-film technology, this section will focus on the supply chain for crystalline silicon solar PV.

The supply chain for crystalline silicon solar panels begins with the refining of polycrystalline silicon (polysilicon) from quartz. This polysilicon is then melted at high temperatures to grow silicon ingots, which are subsequently sliced into thin sheets known as wafers. These silicon wafers undergo further processing to manufacture solar cells. Finally, the cells are assembled to produce solar panels.

The following sections will explore the solar PV supply chain, tracing the journey from raw materials to the final product, spanning the four main segments of the manufacturing process: the refining of polysilicon, the production of wafers, the fabrication of cells, and the assembly of panels.

Table 3: Principal segments of crystalline silicon solar supply chain and their key features

Key feature	Refining of polysilicon	Production of wafers	Fabrication of cells	Assembly of panels
Capital requirement	High	Moderate	Moderate	Low
Energy intensity	High	High	Moderate	Low
Labour intensity	Low	Low	Low to Moderate	Moderate
Technology requirement	Moderate	Moderate	High	Moderate

[9] Thin-film PV technology utilizes thin-film layers of photovoltaic materials to absorb and convert sunlight into electricity. While several materials can be used for thin-film solar cells, cadmium telluride (CdTe) is the most commonly employed, accounting for about 95% of the thin-film PV market. Thin-film solar panels are significantly lighter and can be made flexible, allowing for installation on a variety of surfaces, including curved or unconventional structures. In addition, thin-film panels tend to perform better in low-light conditions and at high temperatures compared with silicon panels. However, thin-film solar panels generally have lower power conversion efficiency and experience higher degradation rates over time, which can lead to reduced performance and shorter lifespans compared with silicon panels. Thin-film PV technology reached its peak in the late 1980s, when it accounted for 30% of the solar PV market, but its market share has declined since then. Because thin-film technology uses different materials from crystalline silicon-based solar technology, it has an entirely different production process and supply chain.

1. Polysilicon

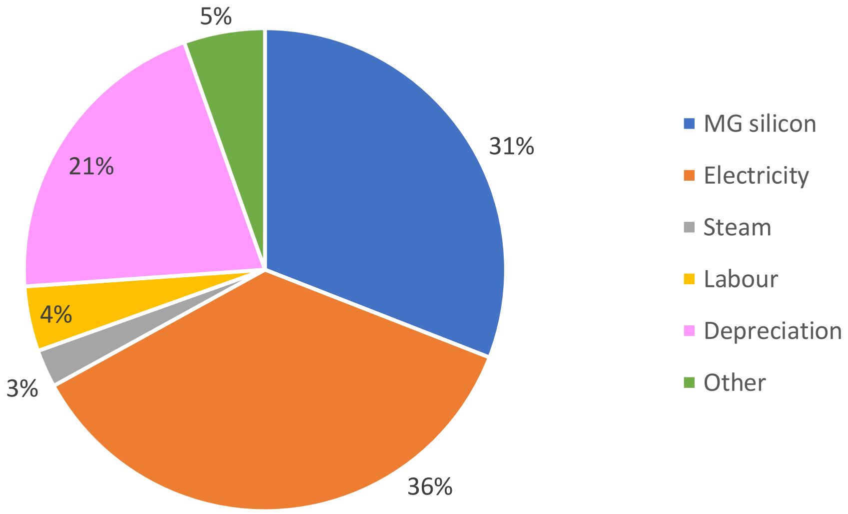
1.1 Refining of polysilicon

Polysilicon, a purified form of silicon used in solar panels, is derived from silicon dioxide (also known as silica). Silicon dioxide is a natural compound made of silicon and oxygen, occurring in nature as quartz or sand.

To produce metallurgical-grade (MG) silicon, quartz or silica sand is processed by removing the oxygen through a reaction with carbon. MG silicon is then refined to eliminate impurities and produce solar-grade polysilicon. The most commonly used technique for producing solar-grade polysilicon is the Siemens method.[10] The end result of the Siemens process is U-shaped silicon rods, which are then broken into small chunks. While MG silicon is 99% pure, solar-grade polysilicon typically has a purity of at least 99.9999%.

The production of polysilicon is highly capital- and energy-intensive, with depreciation and electricity costs making up 21% and 36%, respectively, of the total production costs (see Figure 4).[11]

Figure 4: Cost structure of polysilicon production (at full production capacity), 2025



Source: Solarzoom; China Galaxy Securities

[10] Siemens process is a chemical vapor deposition based process, in which highly purified silane gases such as trichlorosilane (TCS) are heated in the presence of silicon rods. The silicon rods are heated electrically and are mounted into the reactor by graphite electrodes, sometimes called seed-chucks. The TCS then decomposes and ultra-pure silicon deposits on the heated silicon rods.

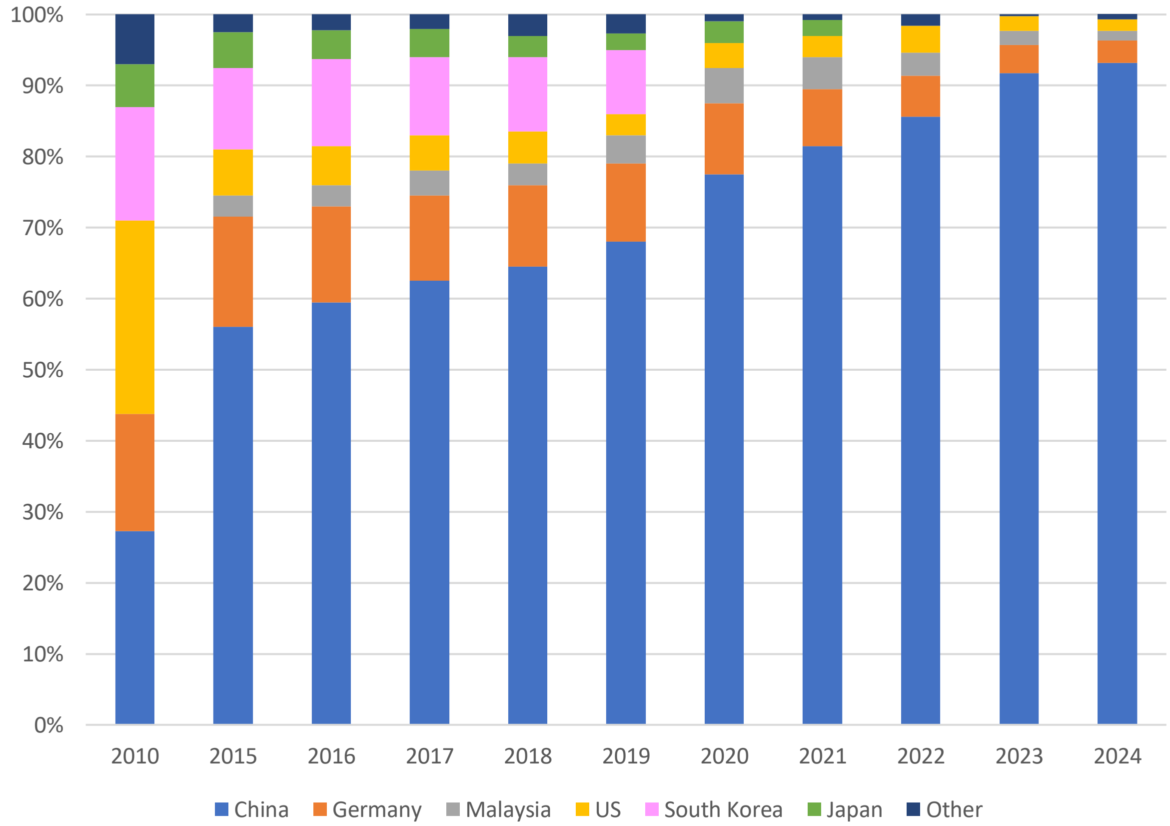
[11] The proportions of various expenses in total production costs change when production facilities operate below full capacity, due to the fixed-cost nature of certain expenses, particularly depreciation costs. For example, at 50% capacity, MG silicon, electricity, and depreciation costs make up 22%, 23%, and 47%, respectively, of total production costs.

1.2 Major producers of polysilicon

Until the mid-2000s, solar polysilicon was produced at just 10 facilities owned by seven companies in the US, Europe and Japan. However, in the late 2000s, Chinese polysilicon producers began ramping up their production capacity, challenging the dominance of developed countries. By 2008, the US still accounted for 43% of the world's polysilicon production, with the small town of Hemlock, Michigan, being the largest producer globally.[12]

By 2010, however, China's polysilicon production had caught up to that of the US, leading to a more geographically diversified production landscape. By this time, both China and the US represented about a quarter of global production, while Germany and South Korea each accounted for around 15%. Since then, polysilicon production has increasingly concentrated in China (see Figure 5).[13]

Figure 5: Market shares of global polysilicon production by country, 2010-2024



Source: International Energy Agency, with South Korea and Japan included in 'Other' from 2022

[12] David Fickling, "How the US Lost the Solar Power Race to China," *Bloomberg*, September 30, 2024, https://www.bloomberg.com/graphics/2024-opinion-how-us-lost-solar-power-race-to-china/.

[13] In early 2020, South Korean polysilicon manufacturers OCI and Hanwha Solutions announced to close their domestic solar-grade polysilicon production facilities because of high electricity prices and operating losses, leading to a complete loss of South Korea's production share. OCI has continued its polysilicon production in Malaysia since then.

Data released by China Photovoltaic Industry Association (CPIA) show that global annual polysilicon production capacity reached 3.394 million metric tons at the end of 2024. Of this, China's annual production capacity was 3.231 million metric tons, accounting for 95.2% of the world's total. In 2024, global polysilicon production totalled 1.957 million metric tons, with China contributing 93.2% of that amount (1.82 million metric tons), ranking first in the world for fourteenth consecutive years.[14] Other polysilicon producers include Germany, Malaysia, and the US.

Despite accounting for over 90% of global polysilicon production, China still imported 40,000 metric tons of polysilicon in 2024, making it the largest importer of polysilicon in the world. This is primarily because nearly all the immediate downstream products—silicon wafers—are produced in China.

In 2024, the top 10 polysilicon producers globally included nine Chinese companies and one German company (Wacker—which has plants in Germany and the US). The top five Chinese polysilicon producers alone accounted for over 60% of the world's production capacity and output (see Table 4).

Table 4: Top 10 polysilicon producers by production capacity, 2010 and 2024

2010			2024		
Rank	**Company**	**Share of capacity**	**Rank**	**Company**	**Share of capacity**
1	Hemlock (US)	12.6%	**1**	Tongwei Solar (China)	22.0%
2	Wacker (Germany)	10.7%	**2**	GCL (China)	12.0%
3	OCI (South Korea)	9.5%	**3**	Daqo (China)	10.8%
4	GCL (China)	7.4%	**4**	Xinte (China)	10.0%
5	REC (US)	5.8%	**5**	East Hope (China)	8.2%
6	Tokuyama (Japan)	2.9%	**6**	Lihao (China)	5.3%
7	MEMC (US)	2.7%	**7**	Hoshine (China)	3.3%
8	LDK (China)	2.3%	**8**	Qiya (China)	3.3%
9	ReneSola (China)	2.1%	**9**	Asia Silicon (China)	3.0%
10	China Silicon (China)	1.8%	**10**	Wacker (Germany)	2.7%
	Sub-total	57.7%		Sub-total	80.7%

Source: Silicon Branch of China Nonferrous Metals Industry Association

In China, most polysilicon manufacturing is located in the western provinces of Xinjiang, Inner Mongolia, Sichuan, and Qinghai, which together account for over 85% of the country's polysilicon production.

[14] China Photovoltaic Industry Association. *2024-2025 nian zhongguo guangfu chanye niandu baogao*. 2024-2025 年中国光伏产业年度报告 [2024-2025 China Photovoltaic Industry Annual Report]. 2025.

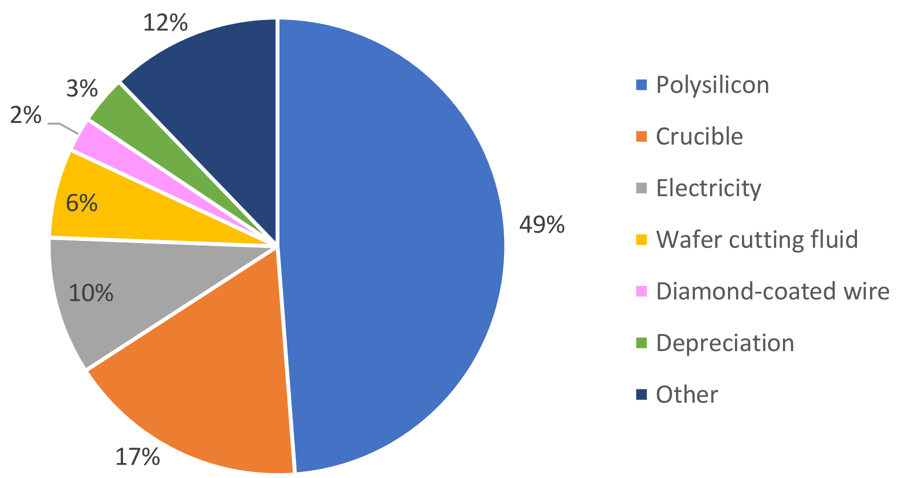
2. Wafers

2.1 Manufacturing of wafers

Silicon wafers serve as the base of a solar cell, functioning as a semiconductor that generates electrical current within the solar cell. The continuous-Czochralski process is commonly used to produce single-crystal silicon wafers (monocrystalline wafers) from polysilicon feedstock.[15]

This method involves melting the polysilicon at over 1,400°C in a crucible and then solidifying the melt to grow a single-crystal cylindrical ingot. The resulting ingot is sliced into thin wafers, typically 130 micrometres thick, using diamond-coated wires.

Figure 6: Cost structure of wafer manufacturing, 2023



Source: PV InfoLink

2.2 Major producers of wafers

Silicon wafers represent the most concentrated segment of the global solar supply chain, with nearly all wafer production capacity and manufacturing located in China. According to data published by CPIA, the global annual wafer production capacity reached 1,394.9 GW at the end of 2024, of which China accounted for 1,348.8 GW, representing 96.7% of the total. Global wafer production was 803.0 GW in the year, with China's production at 775.8 GW, representing 96.6% of the total, maintaining its position as the top producer for 11 consecutive years (see Table 5).[16] Meanwhile, Vietnam and Malaysia ranked second and third respectively in wafer production.

[15] Before 2019, polycrystalline (multicrystalline) wafers dominated the market due to their lower costs. However, with better photoelectric conversion efficiency, monocrystalline wafers have quickly replaced polycrystalline wafers since then. The market share of monocrystalline wafers increased from 45% in 2018 to 65% in 2019, 90.2% in 2020, 94.5% in 2021, and 99% in 2023.

[16] China Photovoltaic Industry Association. *2024-2025 nian zhongguo guangfu chanye niandu baogao*. 2024-2025 年中国光伏产业年度报告 [2024-2025 China Photovoltaic Industry Annual Report]. 2025.

Table 5: Global production capacity and output of silicon wafers, 2020-2024

Year	Production capacity (GW/year)			Production output (GW)		
	Global	China	China's share	Global	China	China's share
2020	247.4	240.0	97.0%	167.7	161.4	96.2%
2021	415.1	407.2	98.1%	232.9	226.6	97.3%
2022	664.0	650.3	97.9%	381.1	371.3	97.4%
2023	974.2	953.6	97.9%	681.5	668.3	98.1%
2024	1,394.9	1,348.8	96.7%	803.0	775.8	96.6%

Source: China Photovoltaic Industry Association

In 2023, all ten of the leading wafer producers were Chinese companies, with the top three manufacturers—TCL Zhonghuan, LONGi, and JinkoSolar—accounting for nearly half of the world's silicon wafer production (see Table 6).[17]

Table 6: Top 5 silicon wafer producers in the world, 2023

Rank	Company	Factory location	Production capacity (GW/year)	Production output (GW)
1	TCL Zhonghuan	China	155	133.7
2	LONGi	China	167.4	124.9
		Malaysia	2.6	2.6
3	JinkoSolar	China	78	69
		Vietnam	7	7
4	GCL Group	China	58.5	51.1
5	JA Solar	China	78.5	45.4
		Vietnam	5	4.7

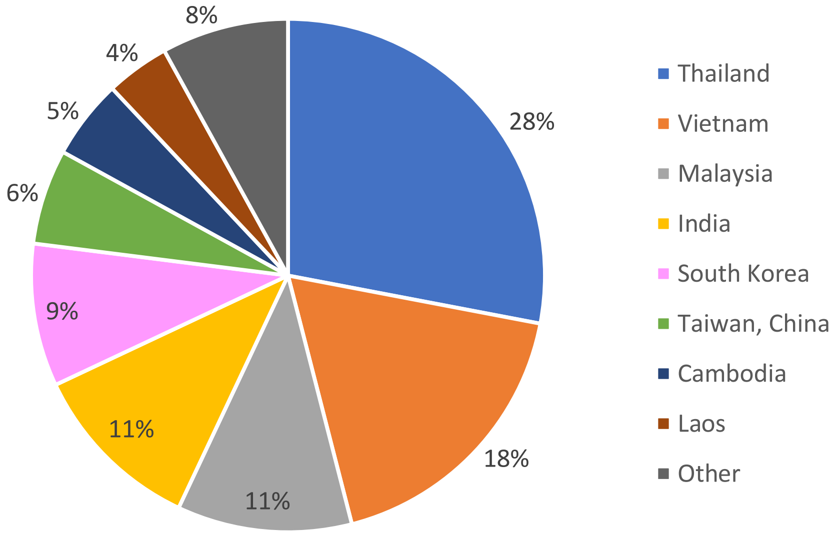
Source: The International Energy Agency Photovoltaic Power Systems Programme

In China, five provinces—Inner Mongolia, Yunnan, Ningxia, Qinghai, and Sichuan—are responsible for around 90% of the country's wafer manufacturing.

In 2024, China exported 60.9 GW of wafers to other solar cell producing countries, particularly Thailand, Vietnam, and Malaysia, where Chinese solar cell manufacturers have substantial operations (see Figure 7).

[17] Gaëtan Masson, Melodie de l'Epine, and Izumi Kaizuka, *Trends in PV Applications 2024* (International Energy Agency, 2024), 52, https://iea-pvps.org/wp-content/uploads/2024/10/IEA-PVPS-Task-1-Trends-Report-2024.pdf.

Figure 7: Major export markets of Chinese mainland silicon wafers by export value, 2024



Source: China Chamber of Commerce for Import and Export of Machinery and Electronic Products

3. Solar cells

3.1 Fabrication of solar cells

During the cell fabrication stage, silicon wafers undergo various treatments, including texturing to reduce reflectance and enhance light absorption, doping (adding other materials to change the electrical properties of the silicon), and creating electrical contacts to allow for the collection of generated electric current, transforming the silicon wafers into functional solar cells.

Solar cell technology evolves rapidly. The passivated emitter and rear contact (PERC) was the most commonly used solar cell technology from 2019 to 2023.[18] However, the tunnel oxide passivated contact (TOPCon) technology[19], boosting a superior power conversion efficiency[20] of 25.4% in 2024 compared with PERC's 23.5%, has quickly overtaken PERC over the last

[18] Compared with conventional aluminum back surface field (Al-BSF) solar cells, PERC cells incorporate an additional passivation layer at the rear of the cells, which enhances light absorption and reduces electron recombination. PERC replaced the Al-BSF as the most popular solar PV technology in 2019. The market share of PERC technology reached its peak at 91% in 2021 but declined to 63% in 2023, rapidly losing market share to the TOPCon technology.

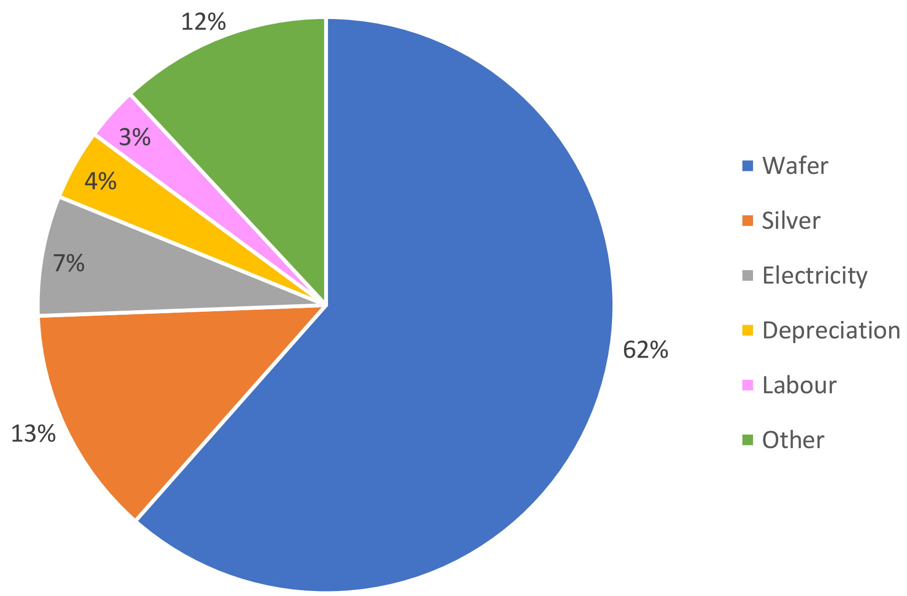
[19] TOPCon technology was first introduced by the German solar research institution Fraunhofer ISE around 2013-2014, but it was not until 2019 that solar cell producers scaled it up for mass production. TOPCon technology is an upgraded and more advanced version of PERC technology. TOPCon cells feature a thin tunnelling oxide layer between the silicon wafer and the passivating contact layer. This structure minimizes electron recombination and enhances the overall efficiency of the cell.

[20] The power conversion efficiency of a solar cell is the percentage of solar energy that is converted to electricity. Improving this power conversion efficiency helps make the solar PV technology cost-competitive with conventional energy sources.

couple of years. In 2024, the market share of TOPCon cells reached 71.1%, followed by PERC cells (20.5%).[21]

The structure of TOPCon cells is only slightly different from that of PERC cells. This similarity allows PERC cell manufacturers to make minor upgrades to their production lines to produce TOPCon cells, facilitating the industry's transition to this technology. TOPCon is expected to remain the dominant solar cell technology for at least the next decade, while PERC cells are anticipated to be phased out rapidly over the next few years.[22]

Figure 8: Cost structure of TOPCon solar cells, 2024



Source: Solarzoom

3.2 Major producers of solar cells

From 2012 to 2024, global production of solar cells surged from 38 GW to 753.2 GW, with China's production rising from 21 GW to 695.1 GW. In 2024, China accounted for 92.3% of global solar cell production (see Figure 9).

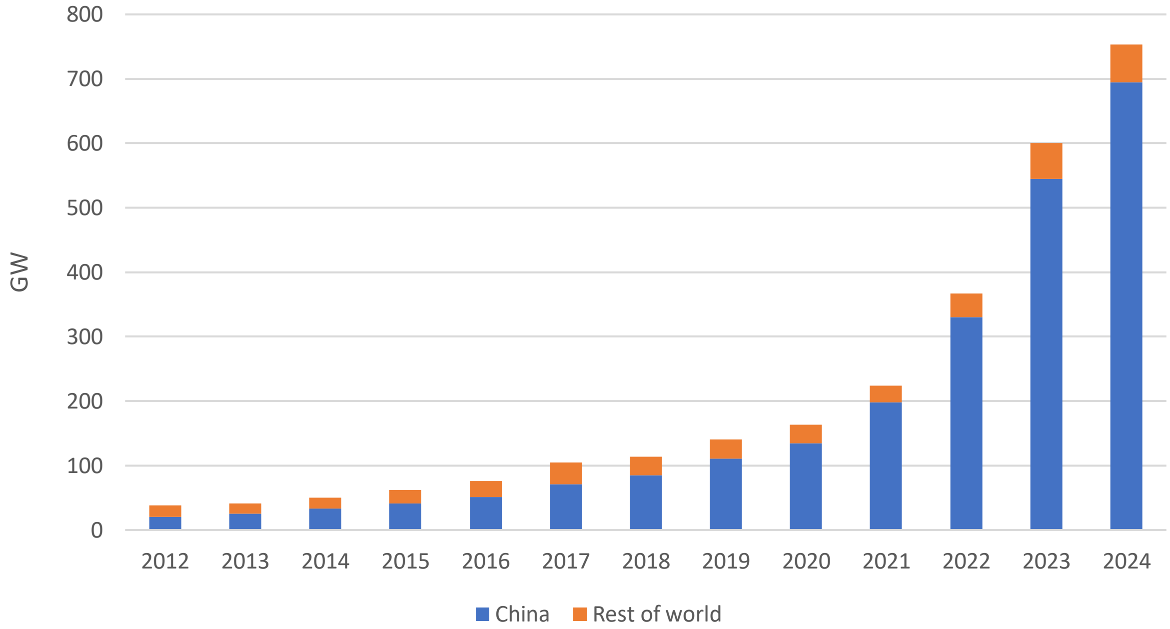
Meanwhile, the global annual cell production capacity reached 1,427 GW at the end of 2024, with China's capacity at 1,303 GW, representing 91.3% of the world's total.[23]

[21] China Photovoltaic Industry Association. *Zhongguo guangfu chanye fazhan luxiantu (2024-2025 nian)*. 中国光伏产业发展路线图（2024-2025 年）[China PV Industry Development Roadmap (2024-2025)]. 2025.

[22] Markus Fischer, Michael Woodhouse, Torsten Brammer, and Puzant Baliozian, *International Technology Roadmap for Photovoltaics, 16th ed*. (VDMA, 2025), 35, https://www.vdma.org/international-technology-roadmap-photovoltaic.

[23] China Photovoltaic Industry Association. *2024-2025 nian zhongguo guangfu chanye niandu baogao*. 2024-2025 年中国光伏产业年度报告 [2024-2025 China Photovoltaic Industry Annual Report]. 2025.

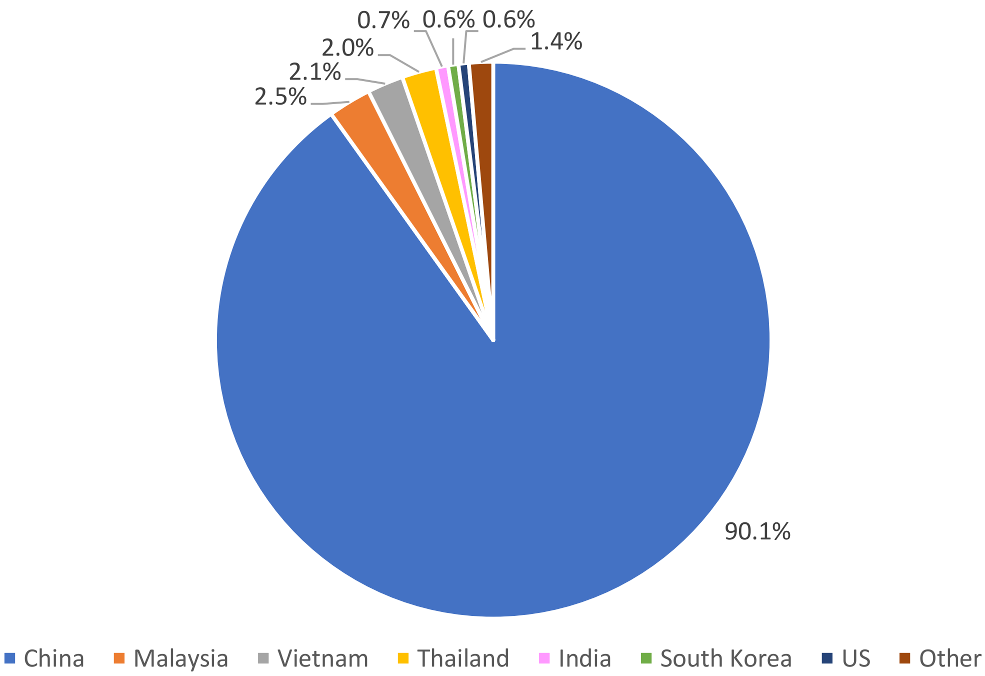
Figure 9: Global production of solar cells, 2012-2024



Source: China Photovoltaic Industry Association

Besides China, Southeast Asian countries like Malaysia, Vietnam, and Thailand, and the US are also producers of solar cells (see Figure 10).

Figure 10: Major solar cell producing countries in the world, 2024



Source: The International Energy Agency Photovoltaic Power Systems Programme

In China, Jiangsu, Anhui, Zhejiang, and Sichuan are the leading provinces for cell production, together accounting for over 70% of the country's output.

In 2024, the top five solar cell producers in the world were all Chinese companies. Tongwei was the largest producer, with a cell production of 89.1 GW, accounting for 12% of the world's total, followed by JinkoSolar and JA Solar in second and third place, respectively (see Table 7).

Table 7: Top 5 solar cell producers by production volume, 2023-2024

2023			2024		
Rank	**Company**	**Production (GW)**	**Rank**	**Company**	**Production (GW)**
1	Tongwei	80.8	**1**	Tongwei	89.1
2	JinkoSolar	63.9	**2**	JinkoSolar	81.3
3	LONGi	62.3	**3**	JA Solar	70.4
4	JA Solar	45.5	**4**	LONGi	60.8
5	Trina Solar	44.3	**5**	Trina Solar	59.4

Source: The International Energy Agency Photovoltaic Power Systems Programme

However, since most major solar companies are integrated manufacturers involved in various segments of the solar PV supply chain, a significant proportion of their cell production is typically used for in-house panel assembly. When measuring only external sales and excluding production for in-house panel assembly, Tongwei remained the largest solar cell supplier, while SolarSpace and Jietai ranked second and third, respectively, in 2024. Nevertheless, from 2019 to 2024, the top five solar cell suppliers globally were all based in China (see Table 8).

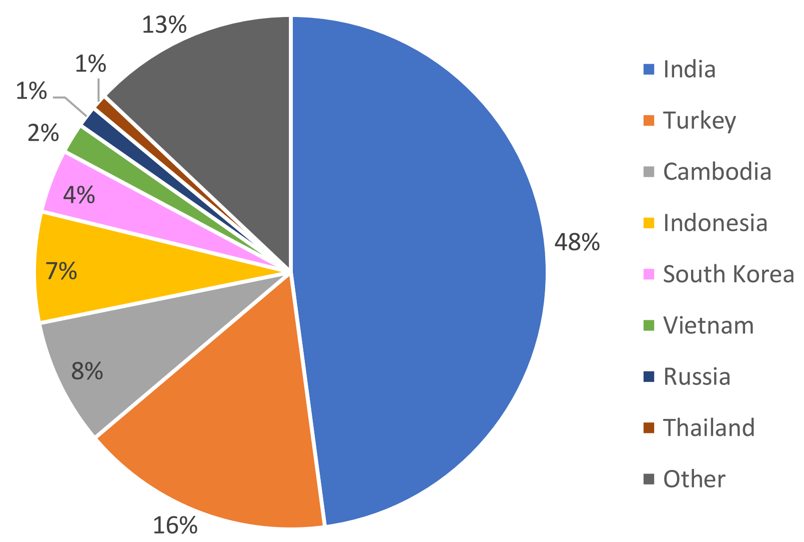
Table 8: Top 5 solar cell suppliers by shipment volume, 2019-2024

Rank	2019	2020	2021	2022	2023	2024
1	Tongwei	Tongwei	Tongwei	Tongwei	Tongwei	Tongwei
2	Aiko	Aiko	Aiko	Aiko	Aiko	SolarSpace
3	SolarSpace	Runergy	Runergy	Runergy	SolarSpace	Jietai
4	Uniex/Jietai	Lu'an	SolarSpace	SolarSpace	Jietai	Yingfa
5	Runergy	SolarSpace	Lu'an	Jietai	Runergy	Aiko

Source: PV InfoLink

In 2024, China exported 58.3 GW of solar cells, an increase of 41.5% yoy. However, the export value decreased by 37.3% yoy to US$2.61 billion due to a plunge in cell prices. The top five export markets were India, Turkey, Cambodia, Indonesia, and South Korea, which together accounted for 83% of China's cell exports (see Figure 11).

Figure 11: Major export markets of Chinese solar cells by export value, 2024



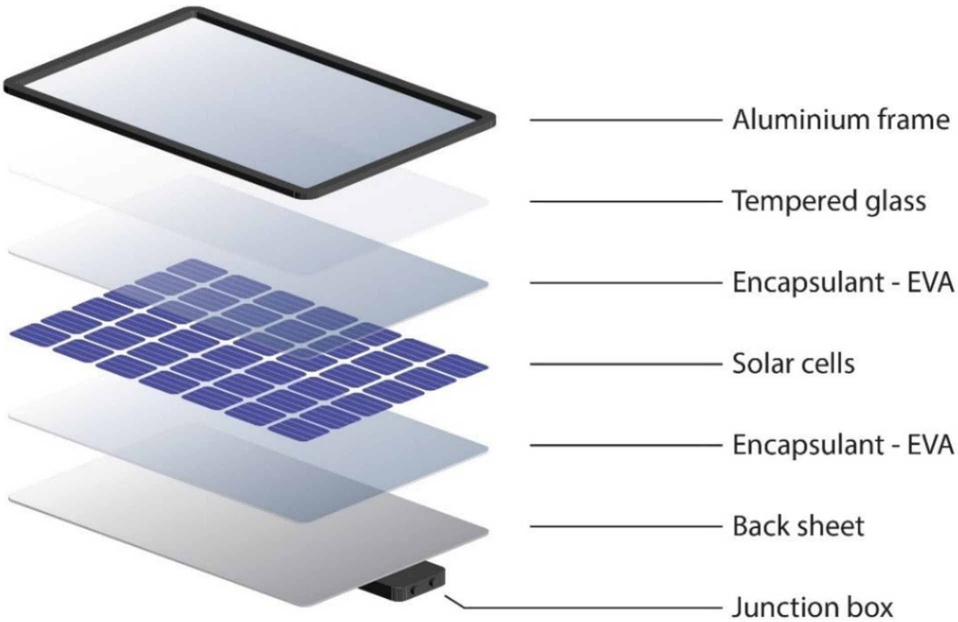
Source: China Chamber of Commerce for Import and Export of Machinery and Electronic Products

4. Solar panels

4.1 Assembly of solar panels

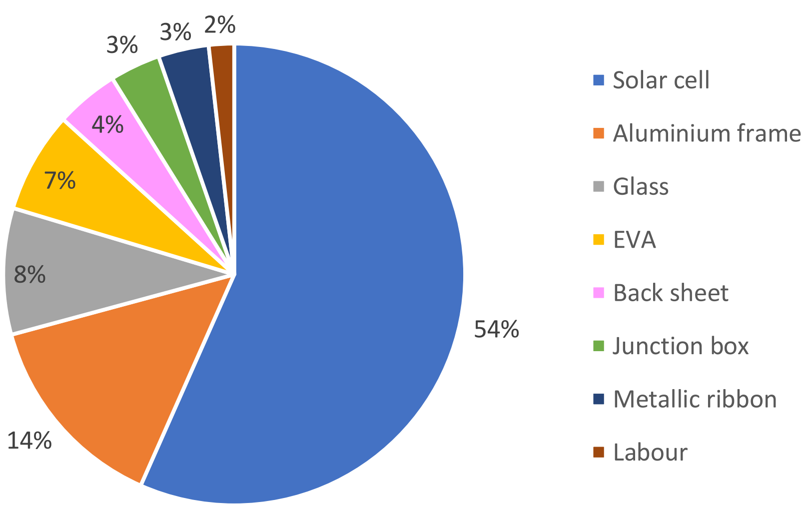
The process of solar panel assembly involves several steps. Individual solar cells are connected in series with metallic ribbons to form a string, which increases the voltage output. Multiple parallel cell strings are then arranged into a larger cell array, boosting the overall current. This array is mounted on a layer of encapsulant situated on top of a back sheet. Another layer of encapsulant is placed over the array, and a front glass sheet is then applied on top of this second encapsulant layer. The entire assembly is then laminated under heat and pressure to bond all the layers together, creating the final integrated solar panel (see Figure 12).

Figure 12: Basic structure of a solar panel



The front glass sheet protects the cells from the weather. The ethylene vinyl acetate (EVA) film is a plastic layer used to encapsulate the cells and hold them in place. The aluminium frame protects the edges of the laminate section housing the cells while providing a solid structure for mounting the solar panel. The back sheet, made of various polymers or plastics, is the rearmost layer of a standard solar panel, providing both mechanical protection and electrical insulation.

Figure 13: Cost structure of solar panel assembly, 2023



Source: PV InfoLink

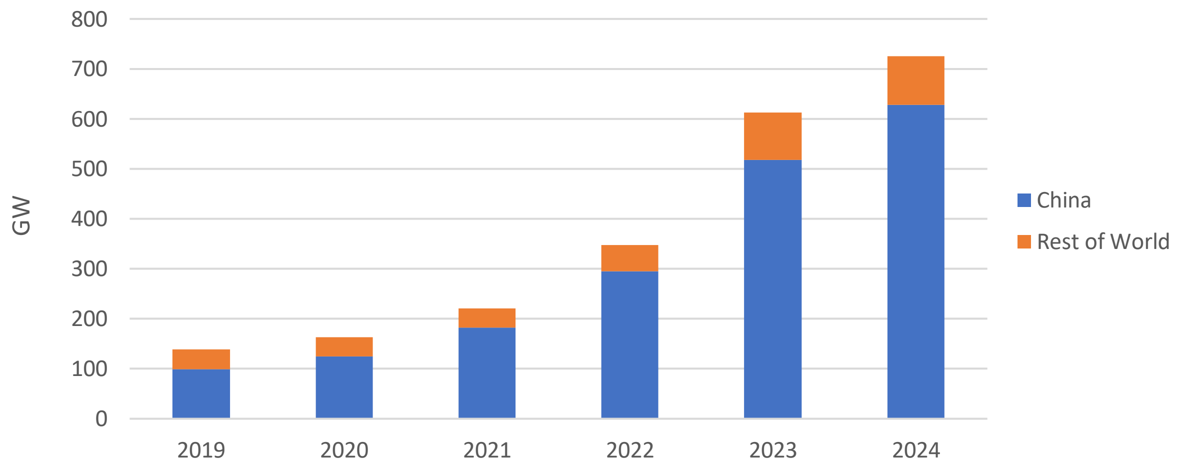
4.2 Major producers of solar panels

Compared with the manufacturing of silicon wafers and solar cells, solar panel assembly is more geographically diversified due to its lower technical complexity and trade restrictions against Chinese-made solar panels. However, China remains the absolute leader in panel production. It is also the primary manufacturer of panel components, including solar glass, EVA, back sheets, and junction boxes.[24]

From 2004 to 2024, the share of global solar panel production manufactured in China surged from 1% to 86%. According to data released by CPIA, global solar panel production was estimated at 725.9 GW in 2024, with China's production totalling 627.5 GW, ranking first in the world for 18 consecutive years (see Figure 14).

Meanwhile, the global annual panel production capacity reached 1,388.9 GW at the end of 2024, with China's annual production capacity at 1,156.5 GW, accounting for 83.3% of the world's total.[25]

Figure 14: Global production of solar panels, 2019-2024



Source: China Photovoltaic Industry Association

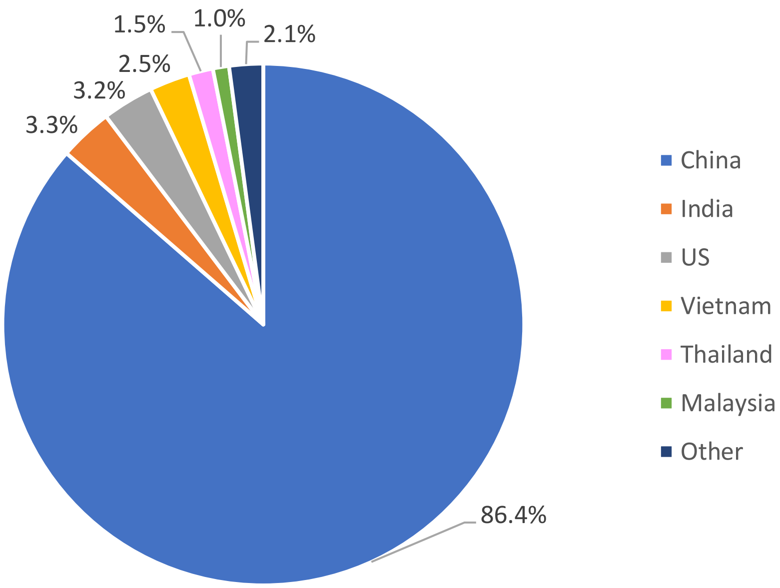
In China, Jiangsu, Zhejiang, and Anhui are the top provinces for panel production, together accounting for two-thirds of the country's output. Jiangsu and Zhejiang, being coastal provinces, have the added advantage of easier international shipping.

[24] In 2024, Chinese companies, including their overseas facilities, accounted for 90% of global production of solar glass, EVA, and back sheets.

[25] China Photovoltaic Industry Association. *2024-2025 nian zhongguo guangfu chanye niandu baogao*. 2024-2025 年中国光伏产业年度报告 [2024-2025 China Photovoltaic Industry Annual Report]. 2025.

Outside of China, only a few Asian countries—India, Vietnam, Thailand, and Malaysia—and the US[26] have meaningful solar panel manufacturing capabilities (see Figure 15).

Figure 15: Major solar panel producing countries in the world, 2024



Source: The International Energy Agency Photovoltaic Power Systems Programme

The solar panel industry exhibits a high level of market concentration, with the top five manufacturers—all Chinese companies—accounting for over 50% of global solar panel production in 2024 (see Table 9). As the world's largest manufacturers of solar panels, all five companies have established fully or partially vertically integrated supply chains (see Figure 16).

Table 9: Top five solar panel manufacturers, 2024

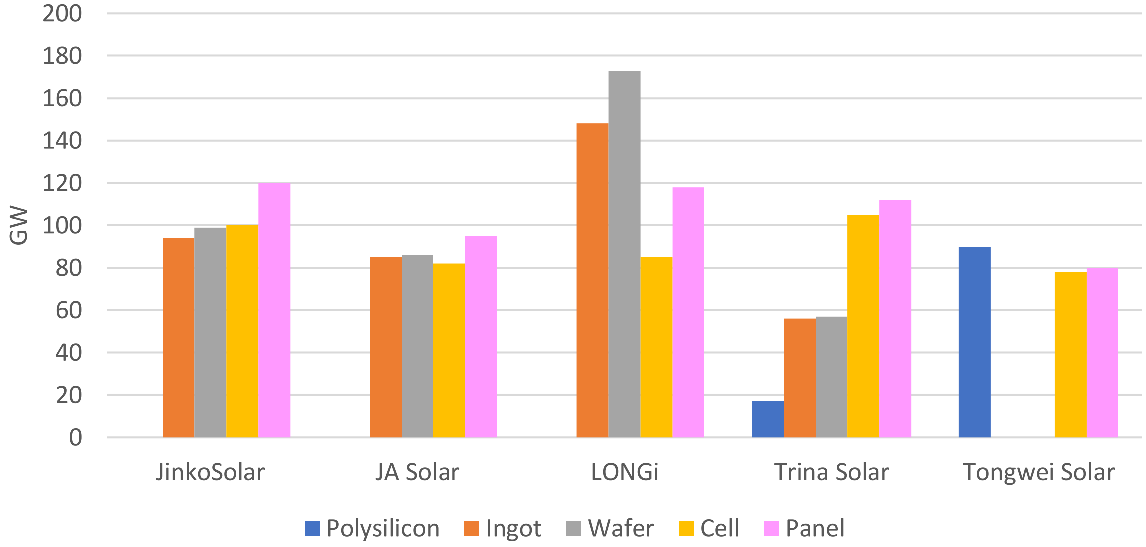
Rank	Company	Production (GW)	Shipment (GW)
1	JinkoSolar	89.8	92.9
2	JA Solar	72.1	74.2
3	LONGi Green Energy	70.2	75.8
4	Trina Solar	66.0	70.5
5	Tongwei Solar	55.0	45.7

Note: Production volumes are manufacturers' own production, whereas shipment volumes include commissioned production (i.e., manufacturers have other companies produce solar panels on their behalf) and OEM procurement (i.e., manufacturers buy solar panels from other companies to sell under their own brand).

Source: The International Energy Agency Photovoltaic Power Systems Programme

[26] The US is the largest producer of thin-film panels in the world. While crystalline silicon panels dominate the global market, about one-third of solar panel production in the US utilized thin-film technology in 2024.

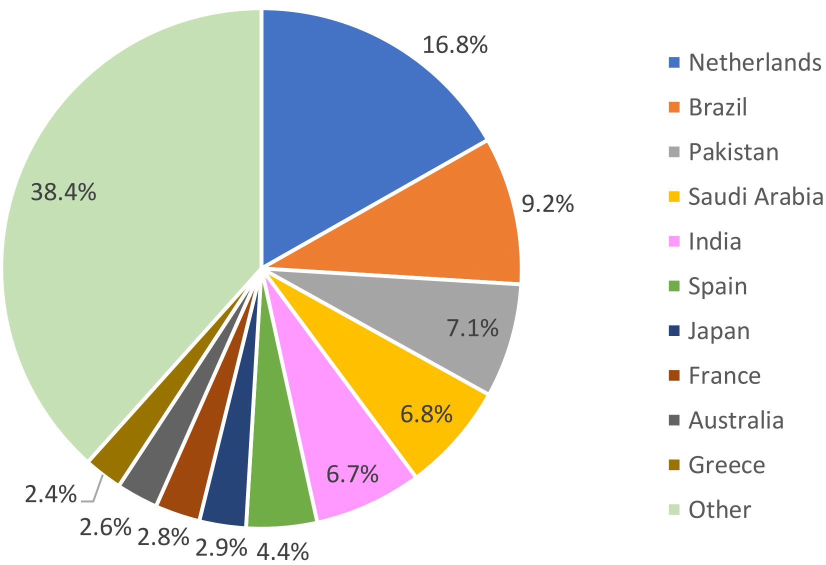
Figure 16: Production capacity of major solar producers, 2024



Source: BloombergNEF, Equipment Manufacturers: PV—updated 24 September 2024, as cited in Progress in Diversifying the Global Solar PV Supply Chain, Renewable Energy Institute

In 2024, China's exports of solar panels reached 236.2 GW, an increase of 9.9% yoy. However, the export value was US$28.0 billion, down by 29.2% yoy due to a decline in panel prices. The Netherlands was the largest importer of China's solar panels, although around 60% of these imports are re-exported, mainly to other EU countries. Brazil, Pakistan, Saudi Arabia, and India were also major markets for Chinese solar panels (see Figure 17).

Figure 17: Major export markets of Chinese solar panels by export value, 2024



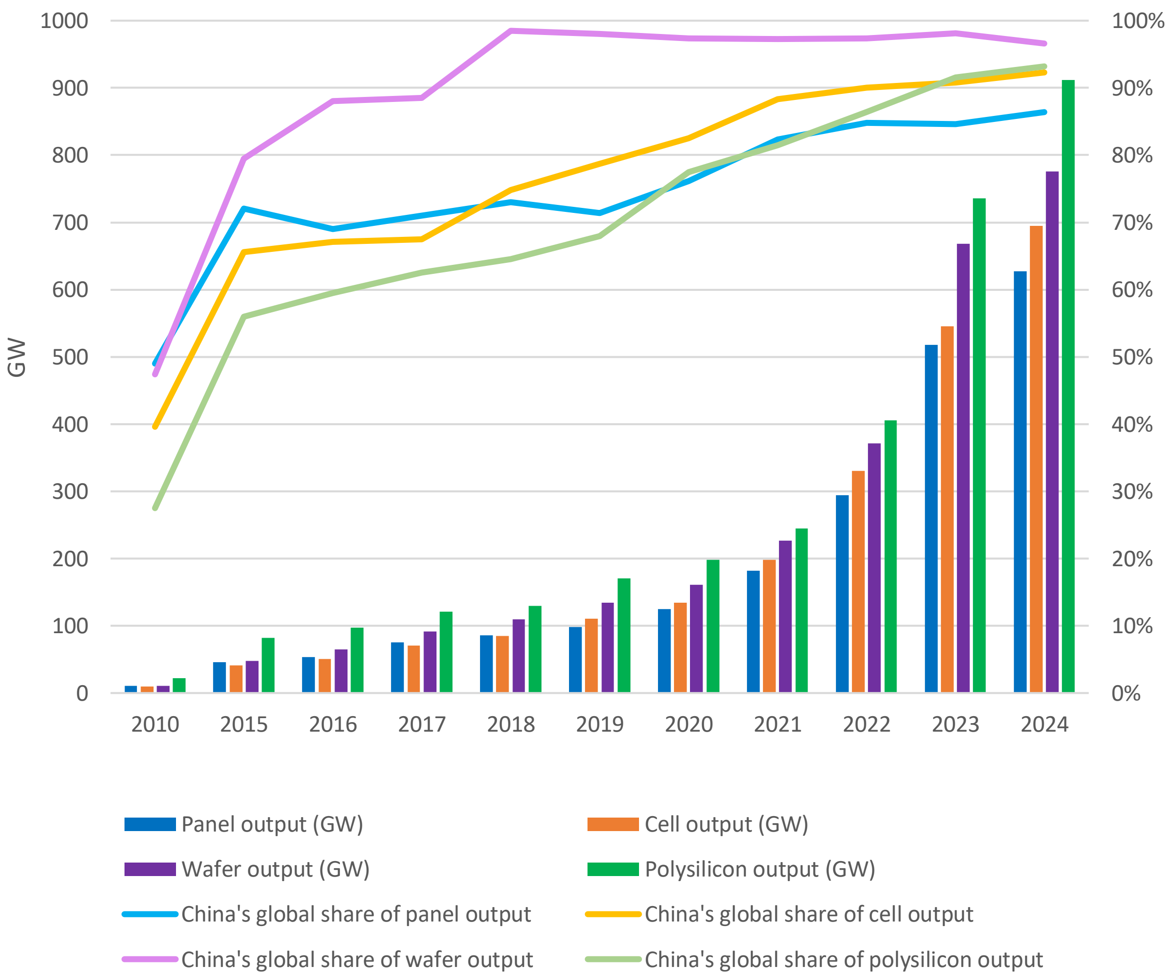
Source: China Chamber of Commerce for Import and Export of Machinery and Electronic Products

5. China’s pivotal role in the global solar PV supply chain

Over the last 15 years, global solar PV manufacturing has increasingly shifted from Europe, the US, and developed Asian countries to China. In 2010, China’s share in the various manufacturing stages in the solar PV supply chain was around 40%; today, this figure has more than doubled to about 90% (see Figure 18).

China is the only country in the world with a complete domestic solar supply chain. As discussed in previous sections, China now controls over 90% of global production of polysilicon, which is essential to manufacturing ingots and wafers. Silicon wafers, which are processed to make solar cells, are almost entirely produced in China. China also controls over 90% of global solar cell production and over 80% of solar panel production.

Figure 18: China’s production of and global share in manufacturing stages of the solar PV supply chain, 2010, 2015-2024



Note: Polysilicon values have been converted to GW using the US National Renewable Energy Laboratory’s assumption of 2.0 grams per watt.

Source: Compiled from data released by China Photovoltaic Industry Association

IV. Forces Shaping the Future Global Solar Supply Chain Landscape

The future global solar supply chain landscape is being reshaped by a multitude of political, economic, social, environmental and technological forces. Some of the key factors include:

1. Geopolitics and trade protectionism

1.1 Proliferation of trade remedies against solar products

In an era marked by burgeoning geopolitical uncertainties, overdependence on energy products from a limited number of countries poses significant risks to energy security and supply chain resilience. Some countries view China's supremacy in the solar supply chain as a potential threat and have opted to raise trade barriers against Chinese solar products. Since 2011, the number of tariffs and anti-dumping and countervailing duties (AD/CVD) imposed on imported solar products has been rising, particularly against those from China, highlighting heightened trade tensions in the solar industry (see Table 10). Notably, the three largest solar PV markets outside of China—namely the US, India and Brazil—have all placed tariffs on imports of Chinese solar panels.

Table 10: Trade remedies against solar products in force in selected economies, August 2025

Economy	Trade remedy measure	Duty rate
China	AD duty on solar-grade polysilicon from the US and South Korea	• US: 53.3%-57.0% • South Korea: 4.4%-113.8%
US	AD/CVD on solar cells and modules from the Chinese mainland and Taiwan, China	• AD duty: 18.32%-249.96% • CVD: 14.78%-49.79%
	Section 201 tariffs on solar cells and modules from most countries and regions	• 14% from 7 Feb 2025 through 6 Feb 2026
	Section 301 tariffs on solar cells and modules from the Chinese mainland	• 50% since 27 Sep 2024
	Section 301 tariffs on solar wafers and polysilicon from the Chinese mainland	• 50% since 1 Jan 2025
EU	AD/CVD on solar glass from Malaysia, the Chinese mainland, and Taiwan, China	• AD duty: 17.5%-75.4% • CVD: 3.2%-17.1%

Economy	Trade remedy measure (cont.)	Duty rate (cont.)
India	Basic customs duty on solar cells and panels	• Solar cells: 25% • Solar panels: 40%
	AD duty on EVA and the aluminium frames for solar panels from the Chinese mainland	• US$590-897 per metric ton for EVA • US$403-577 per metric ton for solar frames
	AD duty on solar glass from the Chinese mainland and Vietnam	• US$570-664 per metric ton
Brazil	Import tariffs on solar modules	• Tariff rate of 25%

Source: Compiled from public information

In response to these tariffs and AD/CVD, some solar companies are relocating their manufacturing to countries that are not affected. This practice, known as 'tariff-jumping', is leading to the emergence of new solar manufacturing hubs and altering the dynamics of the global solar supply chain.

1.2 Relocation of Chinese solar production

The US has been targeting Chinese solar products over the past decade, prompting some shifts in solar production from the Chinese mainland to Taiwan, China and subsequently to Southeast Asian countries. In 2012, the Obama administration ruled that China had subsidized its solar producers and imposed AD/CVD on Chinese mainland producers of solar cells (whether or not assembled into modules), but Chinese mainland producers responded by shifting cell production to Taiwan, China.

In 2015, these duties were amended and expanded to cover solar cells (whether or not assembled into modules) made in Taiwan, China, as well as Chinese mainland solar modules that were made using solar cells produced elsewhere. In 2018, the Trump administration imposed an additional 25% tariff on solar cells and modules from the Chinese mainland following a Section 301 investigation.

As a result of these protectionist duties, Chinese solar cells and panels have almost been phased out completely of the US market. Meanwhile, major Chinese solar producers have relocated their US-oriented production to Southeast Asia since mid-2010s. Companies like JinkoSolar, Trina Solar, LONGi, and JA Solar have established integrated production capacity for silicon wafers, solar cells, and panels in Southeast Asia. As of the end of March 2024, more than half of the panel production capacity and nearly two-thirds of the cell production capacity in Southeast Asian countries were established by Chinese companies (see Table 11).

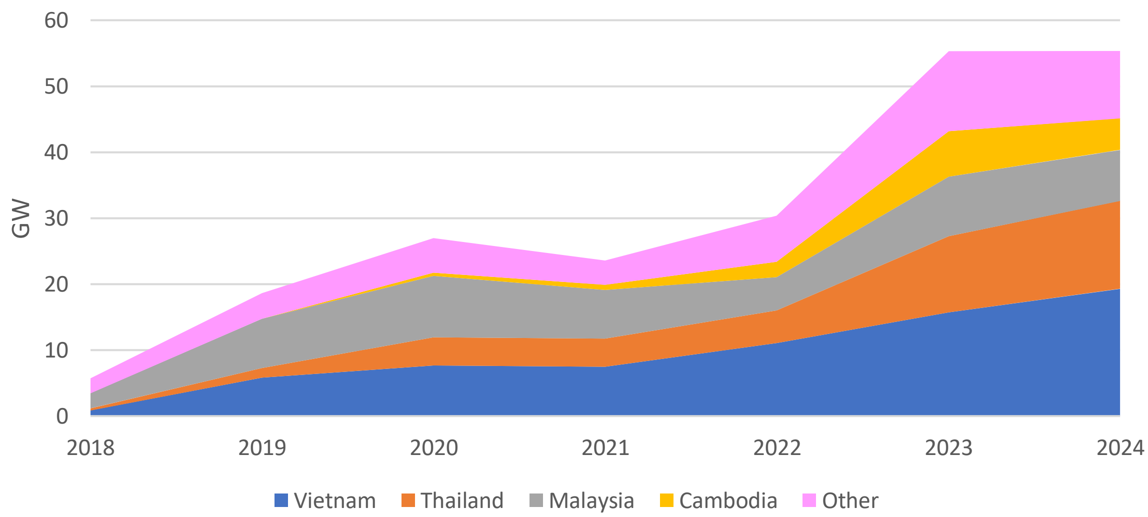
Table 11: Solar manufacturing capacity of Southeast Asian countries, end-March 2024

	Total capacity (GW/year)	Chinese-owned (GW/year)	Example of Chinese operations
Silicon wafer	34.2	27.6	• Vietnam: 7 GW by JinkoSolar, 6.5 GW by Trina Solar • Malaysia: 4.1 GW by LONGi
Solar cell	69.6	45.2	• Vietnam: 8 GW by JinkoSolar, 4.5 GW by Trina Solar, 3.35 GW by LONGi • Malaysia: 7 GW by JinkoSolar, 3 GW by LONGi, 1.5 GW by JA Solar • Thailand: 1.3 GW by Trina Solar
Solar panel	93.2	50.2	• Vietnam: 8 GW by JinkoSolar, 7 GW by LONGi, 5 GW by Trina Solar • Malaysia: 7 GW by JinkoSolar, 3 GW by LONGi • Thailand: 1.25 GW by Trina Solar

Source: Solarbe.com

Solar panel imports from Vietnam, Thailand, Malaysia, and Cambodia, the four countries most benefitting from production shifts from China, began to increase and dominate the US market in 2019 (see Figure 19). These four countries combined to export 45.2 GW of solar panels to the US in 2024, accounting for 82% of all solar panel imports into the country.

Figure 19: US solar panel imports by country, 2018-2024



Note: Data collected from the following US Harmonized Tariff Schedule codes: 8541.40.6015, 8541.40.6020, 8541.40.6035, 8541.43.0010, 8541.43.0080

Source: Compiled from data from USITC DataWeb

In February 2022, a US solar producer alleged that solar cells and modules completed in Cambodia, Malaysia, Thailand, and Vietnam were using components manufactured in China and circumventing US AD/CVD orders. In August 2023, the US Department of Commerce determined that solar producers were indeed operating in these countries to evade US duties. In April 2025, the US announced final orders imposing combined AD/CVD rates as high as 3,521% on solar cells (whether or not assembled into modules) imported from these countries (see Table 12).[27]

Table 12: US AD/CVD on Southeast Asian solar cells

Country	Selected exporter /producer	AD rate	CVD rate	Combined AD/CVD rate
Cambodia	Hounen Solar	117.18%	3,403.96%	3,521.14%
	Solar Long	117.18%	3,403.96%	3,521.14%
	SolarSpace	117.18%	534.67%	651.85%
	Country-wide	*117.18%*	*534.67%*	*651.85%*
Malaysia	Hanwha Q Cells	0%	14.64%	14.64%
	JinkoSolar	1.92%	38.38%	40.30%
	Baojia	81.24%	168.80%	250.04%
	Country-wide	*1.92%*	*32.49%*	*34.41%*
Thailand	Trina Solar	111.45%	263.74%	375.19%
	Sunshine	172.68%	799.55%	972.23%
	Taihua	172.68%	799.55%	972.23%
	Country-wide	*111.45%*	*263.74%*	*375.19%*
Vietnam	JA Solar	52.54%	68.15%	120.69%
	JinkoSolar	120.38%	124.57%	244.95%
	Trina Solar	77.12%	124.57%	201.69%
	Shengtian	271.28%	542.64%	813.92%
	Country-wide	*271.28%*	*124.57%*	*395.75%*

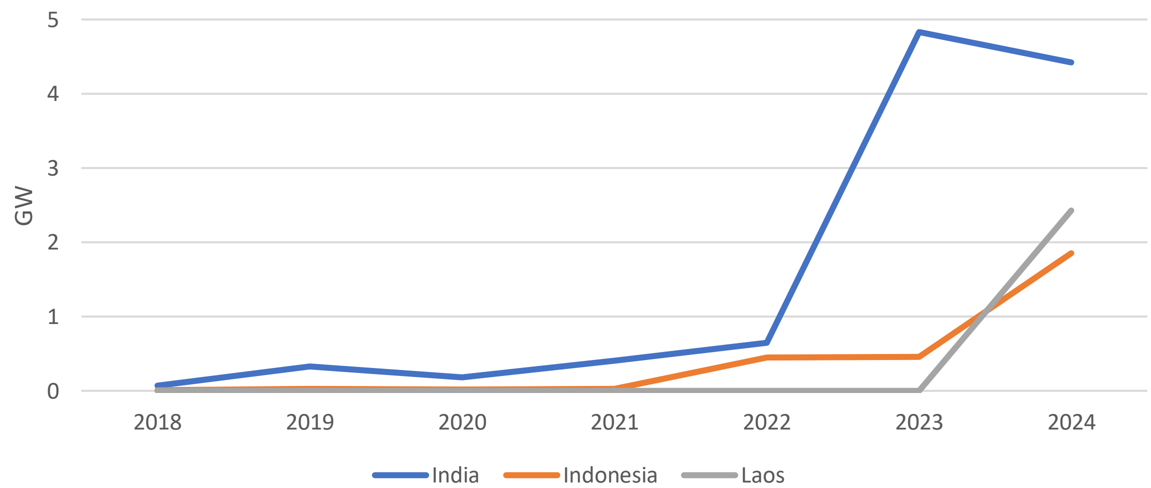
Source: Compiled from announcements by the US Department of Commerce

[27] The AD/CVD rates are specific to individual companies and countries. The overall AD/CVD rates differ significantly between companies and countries, with rates ranging from 14.64% for Hanwha Q Cells in Malaysia to 3,521.14% for Hounen Solar and Solar Long in Cambodia.

Amid these investigations and duties, Chinese solar companies were exploring new production bases outside of these four Southeast Asian countries for US-oriented production. Initially, Southeast Asia remained the top choice for production shifts due to its relatively low costs and proximity to China. For example, SolarSpace launched the first phase of a 5 GW cell factory in Laos in September 2023, and Trina Solar opened a 1 GW solar cell and panel manufacturing plant in Indonesia in November 2024.

However, as Chinese-owned solar facilities in these countries gradually began operations, US panel imports from them have started to rise in recent years (see Figure 20), raising concerns among US solar producers. On 16 July 2025, the American Alliance for Solar Manufacturing Trade Committee filed a new petition with the US Department of Commerce, requesting AD/CVD investigations into solar cells (whether or not assembled into modules) made in India, Indonesia, and Laos. The petition claims that Chinese companies are routing their solar exports through these countries. On 7 August 2025, the Department of Commerce announced the initiation of AD/CVD investigations. It remains to be seen whether this latest round of investigations will trigger another wave of production shifts.

Figure 20: US solar panel imports from three Asian countries, 2018-2024



Source: Compiled from data from USITC DataWeb

2. Domestic industrial policies

To expand domestic solar manufacturing and build more resilient supply chains, many countries are implementing policies that prioritize the establishment of local solar manufacturing capabilities. These policies often include incentives such as tax credits, grants, direct subsidies for solar manufacturing projects, and funding for research and development (R&D) in solar technology.

2.1 China

China's industrial policies have fundamentally transformed the global solar supply chain landscape.

2.1.1 Policy support in the 2000s and 2010s

In the early 2000s, the Chinese government announced plans to expand the adoption of solar energy and introduced various incentives for the solar industry.[28] Throughout the 2000s, an estimated US$50 billion (from both private and public sources) was invested in solar manufacturing in China, leading to a substantial expansion in production capacity. This expansion also enabled economies of scale and contributed to a significant decline in production costs. The resulting plunge in solar product prices led to a raft of bankruptcies among American and European solar companies in the late 2000s and early 2010s[29], which further consolidated the stronghold of China in the industry.

Following the 2008 financial crisis, major European markets reduced solar deployment and cut imports of solar products from China. To support its solar industry, the Chinese government implemented a range of policies to stimulate domestic solar deployment, culminating in the introduction of a nationwide feed-in tariff scheme[30] for solar PV in 2011. These initiatives were designed to stimulate the largely untapped domestic market, but the surge in domestic demand also facilitated further capacity expansion.

2.1.2 Recent policy shifts to curb excessive investment

Even though national subsidies for the solar industry ended in 2022, investment in the sector remained robust. However, with an abundant supply throughout the global solar supply chain, 'involution-style' competition within the industry has intensified, resulting in a sharp decline in solar prices globally and significant losses for Chinese solar companies over the past two years.[31]

[28] At that time, China's central government viewed wind power as a more promising renewable energy source and provided relatively little support for solar power development and manufacturing. Instead, it was the local governments, eager to establish the high-end manufacturing industry, that offered substantial subsidies to solar companies.

[29] Another factor contributing to the collapse of European solar companies was the withdrawal of government subsidies for the solar industry in Europe following the 2008 global financial crisis.

[30] Under this scheme, solar projects received guaranteed payments for the electricity they generated from solar power and fed into the power grid. The scheme began to be phased out in 2018, with central financial subsidies cancelled in 2021.

[31] Data from the CPIA reveal that, as of June 2025, the average prices of polysilicon, silicon wafers, solar cells, and solar panels in China fell by 88.3%, 89.6%, 80.8%, and 66.4%, respectively, compared to their recent peak prices in 2021 and 2022. In addition, over 40 Chinese solar companies announced plans for delisting, bankruptcy, or reorganization in 2024, while the 31 A-share listed solar companies reported a total net loss of 57.47 billion yuan for the year.

In response, the Chinese government has implemented several measures to curb excessive investment in the solar sector and stabilize solar prices, including:

- Reduction in export tax rebates: The rebate for solar products has been lowered from 13% to 9%, compelling solar companies to raise their export prices.
- Stricter capital requirements for new projects: A minimum capital ratio[32] of 30% is now mandated for new solar manufacturing projects, raising the entry and expansion barriers for market participants.
- Enhanced requirements for conversion efficiency and resource consumption: The government has raised the power conversion efficiency standards for solar cells and panels in both existing and new projects. Stricter requirements have also been imposed on energy and water consumption. These changes are aimed at phasing out outdated production capacity.

Consequently, there has been a slowdown in solar investment in China, with some announced projects being cancelled. Certain existing manufacturing capacity has also been taken offline, leading to a reduction in production output. According to data from the CPIA, in the first half of 2025, China's production of polysilicon and silicon wafers reached 596,000 metric tons and 316 GW, respectively, representing declines of 43.8% yoy and 21.4% yoy.

2.2 The US

The US has one of the longest-standing and best-funded R&D programmes for solar energy in the world, through the Solar Energy Technologies Office of the Department of Energy. Supported by government grants and loans, US companies have become major producers of CdTe thin-film technology, accounting for about 90% of global production, including their overseas plants. For example, First Solar, the largest solar manufacturer in the US specializing in CdTe thin-film modules, has received at least US$970 million in grants, tax credits, loans, and loan guarantees from the US federal and state governments between 2009 and September 2025, according to a database compiled by advocacy organization Good Jobs First.[33]

[32] The capital ratio refers to the proportion of total investment that is financed by shareholders' own capital.

[33] "Subsidy Tracker Parent Company Summary (First Solar)," Good Jobs First, accessed October 1, 2025, https://subsidytracker.goodjobsfirst.org/parent/first-solar.

2.2.1 The Biden administration's efforts to boost solar manufacturing

The *Infrastructure Investment and Jobs Act* (IIJA) and the *Inflation Reduction Act* (IRA)[34], two major pieces of legislation enacted during the Biden administration, provided historic grants, subsidies, and tax credits for the renewable energy sector. The IIJA allocated US$73 billion for grant programmes and initiatives to support energy infrastructure, including solar farms. Meanwhile, the IRA included over US$1 trillion in tax incentives over 10 years to produce and deploy clean energy technologies.

For the solar industry, the IRA provides tax credits for solar manufacturing through the Advanced Manufacturing Production Tax Credit (45X credit), which covers solar raw materials, cells, panels, and supporting products (see Table 13). The IRA also provides tax credits of up to 30% of the investment amount for capital investment in solar facilities through the Advanced Energy Project Investment Tax Credit (48C credit).[35] In addition, solar ingot and wafer production facilities and equipment qualify for the 25% investment tax credits under the Advanced Manufacturing Investment Credit (48D credit)[36], part of the *CHIPS and Science Act of 2022*.

Table 13: Tax credits for solar production under the IRA

Eligible components	2022-2029	2030	2031	2032
Solar-grade polysilicon	US$3/kg	US$2.25/kg	US$1.5/kg	US$0.75/kg
Solar wafer	US$12/$m^2$	US$9/$m^2$	US$6/$m^2$	US$3/$m^2$
Solar cell	US$0.044/$W_{dc}$	US$0.033/$W_{dc}$	US$0.022/$W_{dc}$	US$0.011/$W_{dc}$
Polymeric back-sheet	US$0.4/$m^2$	US$0.3/$m^2$	US$0.2/$m^2$	US$0.1/$m^2$
Solar module	US$0.07/$W_{dc}$	US$0.525/$W_{dc}$	US$0.35/$W_{dc}$	US$0.175/$W_{dc}$

Source: US Department of Energy

The IRA was viewed as a game changer for the solar manufacturing industry in the US. The generous tax credits offered under the IRA have strongly incentivized companies to establish or expand solar manufacturing facilities in the country. According to an analysis by Deloitte, from the third quarter of 2021 to the second quarter of 2023, a staggering US$227 billion in public and private investments was announced for utility-scale solar projects.[37]

[34] The IIJA was signed into law in November 2021, while the IRA came to effect in August 2022.

[35] Solar manufacturers may claim only one of the two credits for a single facility. If the facility has claimed a 48C credit for the investment, it cannot claim the 45X credit for the solar products that are made at the facility.

[36] 48D credit can be taken in addition to the 45X or 48C credits.

[37] Deloitte Research Center for Energy & Industrials, *2024 renewable energy industry outlook* (2023), https://www.deloitte.com/content/dam/insights/articles/2024/us176758_e-i_e-i-outlook-renewable-energy/pdf/Full%20PDF%20report%20-%202024%20renewable%20energy%20industry%20outlook.pdf.

Notably, prior to Trump's second term, leading Chinese solar makers were also establishing solar panel manufacturing capacity in the US to circumvent imports duties, and to take advantage of domestic market opportunities[38] and financial incentives for solar investment (see Table 14).

Table 14: Solar panel manufacturing facilities in the US established by Chinese companies

Company	Annual capacity	Location	Production commencement
Hounen Solar	1 GW	Orangeburg, South Carolina	Oct 2023
LONGi[39]	5 GW	Pataskala, Ohio	Feb 2024
JinkoSolar[40]	2 GW	Jacksonville, Florida	2Q 2024
Runergy	2 GW	Huntsville, Alabama	Oct 2024
Trina Solar[41]	5 GW	Wilmer, Texas	Nov 2024
JA Solar	2 GW	Phoenix, Arizona	4Q 2024
Boway[42]	2 GW	Greenville, North Carolina	Apr 2025
TCL Zhonghuan[43]	2 GW	Albuquerque, New Mexico	Early 2026

Source: Compiled from company announcements and public information

2.2.2 Policy shift in Trump's second term

Everything changed when Donald Trump was re-elected as US President in late 2024, who considers renewable energy sources like solar and wind to be 'expensive and unreliable'.[44] On 4 July 2025, Trump signed the *One Big Beautiful Bill* (OBBB), which significantly rolls back

[38] The US market provides higher gross margins for solar panel makers than other markets do. Take Trina Solar for example. Its gross margin in the US market was 34.16% in 2024, which was significantly higher than that in China (6.36%), Europe (5.17%), and other markets (4.03%).

[39] The project is conducted through a newly formed company called Illuminate USA, a joint venture with Invenergy, a US renewable developer.

[40] Established in November 2017, the JinkoSolar factory in Florida had an annual capacity of 0.4 GW. In 2023, JinkoSolar invested US$52 million to expand its annual capacity to 2 GW.

[41] On 6 November 2024, Trina Solar announced that it had entered into an agreement with Freyr Battery (now known as T1 Energy), a US clean energy solutions provider, to sell its solar module manufacturing facility in Texas for US$340 million. The transaction closed on 24 December 2024.

[42] The project is done through Boway's subsidiary Boviet Solar, which is headquartered in Vietnam.

[43] The project is done through TCL Zhonghuan's subsidiary Maxeon, which is headquartered in Singapore.

[44] On his first day in office (20 January 2025), Trump signed executive orders that withdraw the US from the landmark *Paris Agreement*, suspend offshore wind leasing from all areas of the US outer continental shelf, and revoke a Biden executive order aimed at ensuring half of all new vehicles sold in the US would be electric by 2030. He also put a 90-day freeze on the distribution of federal funds allocated through the IIJA and IRA, which impacted many solar programmes.

the tax incentives for solar manufacturing projects provided by the IRA and introduces new restrictions on eligible companies. Key changes implemented by the OBBB include:

- Tax credits from the IRA will be phased out more quickly. To qualify, solar projects must either be completed by the end of 2027 or begin construction on or before 4 July 2026.
- All new solar projects must meet strict foreign ownership and sourcing requirements to be eligible for any tax credits. Complex foreign entity of concern (FEOC) rules render solar projects owned or controlled by a 'prohibited foreign entity', or that source components from such entities, ineligible for tax credits. This includes all companies owned or controlled by the Chinese government or its citizens.[45]

Furthermore, the US Environmental Protection Agency has cancelled the Solar for All programme, which was designed to provide solar energy for low- and middle-income households and help them reduce their electricity costs. This decision is likely to reduce the demand for solar panel installations in the US.

With government support for solar energy significantly diminished under Trump's second term, the expansion of solar manufacturing in the US is expected to slow. Some previously announced plans for new facilities or capacity expansions are now facing cancellation. A report published by the Solar Energy Industries Association estimated that the OBBB could threaten over 330 solar and solar-powered storage factories in the US.[46] For instance, Chinese solar companies, the primary targets of Trump's policies, have scaled back their expansion efforts in the US. A notable example is JA Solar, which sold its module assembly plant in Arizona to materials manufacturer Corning in April 2025.

2.3 India

In March 2020, India introduced the Production Linked Incentive (PLI) Scheme to provide performance-linked incentives for selected manufacturing sectors, in order to enhance domestic manufacturing capabilities and reduce reliance on imports. The PLI Scheme was expanded in November 2020 to include the manufacturing of high-efficiency solar panels.

Through the first three tranches of the PLI Scheme, more than US$3 billion has been allocated to build 130.7 GW of solar manufacturing capacity. As of 30 June 2025, manufacturing capacity of 18.5 GW of solar modules, 9.7 GW of solar cells, and 2.2 GW of ingot-wafer production had been developed under the PLI Scheme.

India has also reinstated the *Approved List of Models and Manufacturers* (ALMM) mandate from 1 April 2024. Only solar products and manufacturers on the ALMM are eligible for

[45] Apart from China, other countries targeted under the FEOC rules include Russia, Iran, and North Korea, none of which are major investors in the US solar industry.

[46] Solar Energy Industries Association, *Impact of House Reconciliation Bill* (2025), https://seia.org/wp-content/uploads/2025/05/House_Reconciliation_Analysis_2025-05-22.pdf.

government-backed projects. By creating a non-tariff barrier for imported products, the ALMM mandate gives domestic solar producers a significant advantage over foreign competitors.

The effectiveness of these policies is evident in the decline of solar panel imports, which fell from US$3.36 billion in the fiscal year 2021-22 to US$2.15 billion in the fiscal year 2024-25, demonstrating some progress in import substitution.

2.4 Turkey

Under the Renewable Energy Support Mechanism (YEKDEM), Turkey provides purchase guarantees and feed-in tariffs for solar power systems and other renewable energy sources installed between July 2021 and December 2030. Additional remuneration is available for projects that utilize domestic components. Turkey also aims to install at least 5 GW of new solar energy capacity annually until 2035 to meet its 2053 carbon neutrality target.

Thanks to these policies and import duties on solar panels, Turkey has emerged as the largest solar panel producer in Europe. It is also the largest importer of Chinese solar cells, which are primarily used for the assembly of solar panels in the country.

To reduce its dependence on imported solar cells from China, Turkey launched the High Technology Incentive Programme in July 2024, allocating US$2.5 billion to promote investment in domestic solar cell production. As of April 2025, five solar manufacturers, including Chinese company Astronergy, had committed to establishing solar cell manufacturing capacity in Turkey, according to the country's Ministry of Industry and Technology.

3. Supply of raw materials and critical components

The supply of raw materials is crucial in shaping the global supply chain for any product, and in the case of solar PV, silicon is the key material. However, as the second most abundant element in the Earth's crust, silicon is not considered a bottleneck material for solar PV products.

The situation is quite different when it comes to the supply of intermediate inputs. China excels in every manufacturing stage of solar panels, from polysilicon to wafers, cells, and finished panels. Furthermore, it is the primary producer of essential panel components such as glass, EVA, back sheets, and junction boxes. Consequently, non-Chinese solar panel manufacturers must rely on Chinese suppliers for wafers, cells, and panel components, which can render their supply chains vulnerable. This dependency has prompted some countries to invest in developing local production capabilities for solar inputs and components.

4. Production capacity and costs

4.1 Production capacity

The majority of solar manufacturing capacity expansion in recent years has taken place in China, positioning the country to maintain a majority of global solar manufacturing capacity by 2030, including 90% for polysilicon, 95% for wafers, 85% for cells, and 75% for panels, according to IEA estimates[47], despite substantial investments in solar manufacturing in other countries.

Over the past few years, the global solar industry has enjoyed ample supply[48], leading to a significant decline in prices throughout the entire solar supply chain. From late 2022 to the end of 2024, the average price of solar modules dropped by 60%. While the decrease in solar panel prices may facilitate broader adoption of solar energy, it has also caused considerable disruption on the supply side, resulting in the cancellation of hundreds of GW of solar manufacturing projects worldwide. If low solar prices persist, new investment in solar manufacturing will likely be discouraged, especially in countries and regions with insufficient policy support. Given China's vast manufacturing capacity, a slowdown in new entrants to the market will only further solidify China's leadership in solar manufacturing.

4.2 Production costs

Production costs play a crucial role in determining the location of solar manufacturing. Thanks to economies of scale and a highly integrated supply chain, China has become the most cost-competitive producer across all segments of the solar PV supply chain. Estimates suggest that a solar panel made in China is 40% cheaper than one produced in India, 50% cheaper than in Europe and 65% cheaper than in the US.[49] Although other countries have increased government support for their local solar manufacturing, achieving cost competitiveness comparable to that of China remains a challenge. China's advantage in production costs is likely to persist for the foreseeable future.

It is noteworthy that there are trade-offs between supply chain security/resilience and production costs. A major reason for the high solar panel prices in the US is the protectionist measures imposed on imported solar products, which aim to support the domestic solar industry and encourage the establishment of a local solar supply chain. Countries should

[47] International Energy Agency, *Renewables 2025* (2025), 90, https://iea.blob.core.windows.net/assets/76ad6eac-2aa6-4c55-9a55-b8dc0dba9f9e/Renewables2025.pdf.

[48] According to data compiled by China Galaxy Securities, global production capacity for polysilicon, silicon wafers, solar cells, and solar panels are estimated to reach 1,337 GW, 1,088 GW, 1,157 GW, and 1,343 GW, respectively, in 2025. These figures are at least 60% higher than the global demand for new solar PV capacity for the year.

[49] Huaiyan Sun, *How will China's expansion affect global solar module supply chains?* (Wood Mackenzie, 2023), https://www.woodmac.com/news/opinion/how-will-chinas-expansion-affect-global-solar-module-supply-chains/.

strike a balance between their domestic manufacturing ambitions and the potential increase in production costs, which ultimately impacts the prices consumers have to pay and other policy goals such as decarbonization.[50]

5. FTAs & trade preferences

Free trade agreements (FTAs) can lead to the reduction or elimination of tariffs on solar inputs and raw materials among signatories. This allows companies to source solar inputs from members within the trade bloc strictly based on cost considerations, facilitating the development of an efficient regional supply chain.

One important FTA for the global solar supply chain is the China ASEAN–Free Trade Area (ACFTA). Established in 2010, ACFTA is a free trade area that includes China and all member states of the Association of Southeast Asian Nations (ASEAN)[51]. The ACFTA has lowered overall costs for Southeast Asian solar manufacturers that rely on imported solar inputs from China. As a result, many major Chinese solar companies have relocated their production facilities from China to Southeast Asia, capitalizing on the cost advantages and favourable trade terms. This trend has not only spurred the expansion of solar manufacturing in the region but also strengthened the regional solar supply chain in the Asia-Pacific region since the mid-2010s.

Meanwhile, the North American Free Trade Agreement (NAFTA), which came into force on 1 January 1994, promoted the nearshoring of solar production to Mexico. The NAFTA established a free trade zone among the US, Canada, and Mexico, which prompted some solar companies to set up factories in Mexico to take advantage of its lower production costs and zero-tariff access to the nearby US market. For example, Singapore-based Maxeon Solar Technologies established two panel manufacturing facilities in Mexico in 2011 and 2016, respectively, to produce solar panels for the US market.[52]

[50] Georgia Edmonstone, *Should Australia make solar panels? Supply chain security through global engagement* (United States Studies Centre at the University of Sydney, 2024), 15, https://www.ussc.edu.au/should-australia-make-solar-panels-supply-chain-security-through-global-engagement.

[51] At that time, ASEAN had ten member countries: Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam. In October 2025, Timor-Leste also joined ASEAN.

[52] In 2018, the Trump administration imposed Section 201 tariffs on all solar cells and modules from almost all countries, and neither Mexico nor Canada was exempt. After the *United States-Mexico-Canada Agreement* (USMCA) came into effect and replaced the NAFTA on 1 July 2020, these tariffs still applied to Mexico and Canada. On 4 February 2022, the Biden administration extended these Section 201 tariffs for an additional four years. On 15 February 2022, a USMCA panel ruled that US tariffs on Canadian solar products were in violation of the USMCA. On 7 July 2022, the US and Canada issued a *Joint Memorandum of Understanding*, under which the US has lifted its tariffs on Canadian solar product imports. However, Mexico's negotiation with the US to pursue tariff exemption has stalled.

6. Technology

6.1 Solar cell technology

The solar cell is widely considered the core of the solar supply chain. Manufacturers need strong R&D capabilities to continually innovate and enhance power conversion efficiency and reliability of their solar cells. In fact, possessing or adopting advanced solar cell technology is essential for any company or country looking to build its own solar supply chain and potentially become a leader in the global solar supply chain, both in production and in setting trends in solar technology.

Bolstered by years of investment in R&D, Chinese manufacturers have become global leaders in solar technology. They have established significant technological barriers, particularly through new patents[53], making it challenging for new entrants to compete in the market.

6.1.1 Emerging solar cell technologies

Amid advancement in solar cell technology, a group of new cell technologies has emerged as viable alternatives to the two commonly used technologies today: silicon cells and CdTe cells. Currently, Chinese solar companies are at the forefront of R&D in these cutting-edge cell technologies. For example:

- On 19 November 2022, Chinese solar giant LONGi announced that its heterojunction (HJT) solar cells[54] achieved a conversion efficiency at 26.81%, breaking the previous record of 26.7% set by a Japanese company.
- On 28 March 2025, Trina Solar announced that it had developed the world's first industrial-standard solar module using crystalline silicon-perovskite tandem solar cells[55].

Moreover, Chinese companies are often among the first ones to adopt new solar technologies. While some other countries are still expanding their production of PERC cells[56], China is rapidly increasing its production capacity for more advanced technologies such as TOPCon and HJT.

[53] According to data released by China's National Intellectual Property Administration in late 2023, China had filed 126,400 global patent applications for solar cells, ranking first in the world.

[54] HJT is a hybrid cell technology, combining aspects of conventional crystalline silicon solar cells with thin-film solar cells—an HJT cell is formed by adding thin layers of amorphous silicon to monocrystalline silicon.

[55] Perovskites are a class of materials with a specific crystal structure, named after the mineral perovskite. Perovskites have demonstrated great potential for high performance and low production costs in solar cells. However, perovskite solar cells also face challenges such as lower chemical stability and limited lifespan. Crystalline silicon-perovskite tandem cells can combine the high efficiency of perovskite with the long lifespan of silicon, making them a promising option for solar cell materials.

[56] For example, Indian solar manufacturer Waaree Energies commenced commercial production at its 1.4-GW PERC cell production line in February 2025. In the same month, US-based ES Foundry also launched a 3-GW PERC cell factory, which is the largest silicon solar cell plant in the US.

The rapid technology upgrade in China's solar industry is likely to make Chinese solar cells and panels even more competitive than those produced overseas, ensuring that China's leadership in the solar supply chain extends into the future.

6.2 AI technology in solar supply chain

China is leading the way in integrating artificial intelligence (AI) into solar manufacturing. Chinese solar manufacturers are increasingly adopting automation and robotics in their production lines. AI technologies are used to enhance precision and efficiency in processes such as wafer slicing, cell assembly, and module packaging, which helps reduce labour costs and improve output quality. AI-driven systems are also employed for real-time quality control during the production process. For example, TCL Zhonghuan has implemented an Industry 4.0 smart manufacturing system using AI learning models to enhance the flexibility and efficiency of its manufacturing process, resulting in a 23% reduction in energy intensity.[57]

The application of AI in solar R&D holds significant potential as well. Many areas of solar innovation involve challenges that AI is well-suited to address. For example, discovering a stable and easy-to-manufacture perovskite could accelerate the development of cheaper and less space-intensive solar PV systems. However, among the more than 10 million possible perovskite structures, less than 0.01% have been experimentally produced. AI could potentially expedite this process.[58]

7. Environmental, social and governance considerations

Environmental, social, and governance (ESG) factors play a critical role in shaping the global solar supply chain landscape.

7.1 Interplay between climate policies and trade remedy measures

Awareness of greenhouse gas emissions and climate change has grown in recent years. Many countries and regions have set ambitious targets for renewable energy, with solar energy at the forefront. However, the interplay between climate policies and trade remedy measures often leads to conflict. Climate policies typically aim to boost the adoption of renewable energy, which drives up imports of related products like solar panels. This can put domestic industries at risk from a flood of low-cost imports, prompting the use of trade remedies to protect local businesses. Yet, such trade remedies can raise costs and hinder the

[57] World Economic Forum, *Greening the Renewable Value Chain: China Experience* (2024), 8, https://www3.weforum.org/docs/WEF_Greening_the_Renewable_Value_Chain_2024.pdf.

[58] International Energy Agency, *Energy and AI* (2025), 165, https://iea.blob.core.windows.net/assets/601eaec9-ba91-4623-819b-4ded331ec9e8/EnergyandAI.pdf.

deployment of renewable energy technologies, undermining efforts to tackle climate change. As a result, countries must find a balance amid this tension.

Take the EU for example. In June 2013, the EU imposed AD/CVD and restrictions on imports of solar panels, cells and wafers from China.[59] However, in September 2018, the EU decided not to extend these measures in order to boost renewable energy supply. As part of its plan to accelerate the green transition and enhance energy independence, the EU aims to scale up its solar PV installed capacity from 260 GW in 2023 to nearly 600 GW by 2030, as set out in its *Solar Energy Strategy* released in 2022. Given that the EU has limited manufacturing capacity for solar panels, this expansion will likely rely on solar panels imported from China, which supplies around 90% of solar panels used in the EU. Since the current policy priority of the EU is to facilitate a cost-effective growth in solar power generation and meet climate targets, it has ruled out trade measures on solar imports, despite pressure from European solar producers to impose AD/CVD on Chinese solar panels.[60]

7.2 Greening the solar supply chain

While solar power is seen as a key driver and catalyst for the global green transition and decarbonization efforts, the production of solar panels itself can have a significant carbon footprint[61]. Therefore, it is essential for solar panels to be produced through a green manufacturing process.

<u>7.2.1 Carbon Border Adjustment Mechanism of the EU</u>

The EU formally adopted the Carbon Border Adjustment Mechanism (CBAM) on 17 May 2023 to address the issue of carbon leakage[62]. The CBAM will take effect on 1 January 2026, requiring companies to buy CBAM certificates corresponding to the carbon tax that would have been incurred.[63]

[59] On 4 June 2013, the EU announced to impose AD/CVD on Chinese solar products in two stages, starting with a flat rate of 11.8% for the first two months until 6 August, and followed by an average rate of 47.6% from 6 August onwards. On 27 July 2013, a price undertaking agreement was reached between the EU and Chinese solar panel exporters, which consisted of a minimum import price and import quotas for Chinese solar panels. This agreement covered about 75% of Chinese solar panel exports to the EU. Those Chinese exporters that participated in the undertaking were exempt from the AD/CVD. However, the AD/CVD still applied to exporters that did not participate in the undertaking.

[60] The EU's attitude towards solar imports can be summed up by this statement from Mario Draghi, former President of the European Central Bank, made on 17 September 2024: 'Even if those [foreign] countries are using subsidies, we should let foreign taxpayers finance cheaper installation of clean energy in Europe.'

[61] Carbon footprint refers to the amount of carbon dioxide emissions associated with the activities of a person or an entity, or products throughout their entire lifecycles.

[62] Carbon leakage occurs when companies move their high-emission production to countries with looser emission regulations or increase imports of carbon-intensive products. This could undermine the emissions reductions achieved in stricter regions, such as the EU, and may even result in an overall increase in total emissions.

[63] The period from 1 October 2023 to 31 December 2025 serves as a transitional phase during which companies are only required to report carbon emissions data and calculate the number of certificates needed, without incurring any actual carbon tax yet.

In its initial phase, the CBAM covers only a few highly carbon-intensive industries, including cement, iron and steel, aluminium, fertilizer, electricity, and hydrogen.[64] While solar products are not currently included in the CBAM, the EU has indicated that more sectors and products could be added as the mechanism evolves. Consequently, the long-term development of the solar industry will inevitably be affected.

7.2.2 Digital Product Passport of the EU

The Digital Product Passport (DPP) is a mandatory electronic record established under the *European Green Deal* legislation. It provides comprehensive information about a product throughout its lifecycle, including details on materials, components, usage, and environmental impact. This facilitates better tracking and management of products from production to disposal.

The DPP regulation, adopted in April 2024, will gradually become mandatory for nearly all physical products, including solar products, with full implementation expected by 2030.

With the upcoming implementation of the CBAM and DPP, it is expected that EU importers will prioritize solar producers with low carbon footprints and high levels of transparency and traceability throughout their supply chains. As a result, solar producers must begin to understand compliance requirements, explore sustainable practices, reduce their carbon footprints, and prepare for potential cost increases, in order to better position themselves for the changes these regulations may bring.

Some Chinese solar producers have already taken steps to make their supply chains greener. For instance, JinkoSolar operates a 12MW pilot PV recycling line which has achieved an overall recycling rate of 92% for solar panels and a 95% recovery rate for embedded metals such as silicon, silver and copper.[65]

[64] At this point, the exact impact of the CBAM on the solar industry is still uncertain. European Aluminium, an industry association, has argued that imposing a carbon tax on aluminium—a key metal used in solar panel frames—could raise production costs for European solar producers, giving an advantage to Chinese companies.

[65] Anu Bhambhani, "JinkoSolar PV Module Recycling Pilot Plant In Operation," *TaiyangNews*, April 10, 2023, https://taiyangnews.info/technology/jinkosolar-pv-module-recycling-pilot-plant-in-operation.

7.3 Labour rights in the solar supply chain

As the global solar supply chain spans various countries with different labour laws, solar companies face scrutiny over their labour practices, including working conditions, wages, and issues related to forced labour and child labour in mining and manufacturing. This scrutiny could shift the geographical distribution of the solar supply chain from certain countries and regions to others.

For instance, the US government has accused China's Xinjiang autonomous region of using 'forced labour'. The so-called *Uyghur Forced Labor Prevention Act*, which took effect in June 2022, bans the import of goods that are mined, produced, or manufactured in whole or in part in Xinjiang, which at that time accounted for over half of global polysilicon production. Together with the duties on Chinese solar wafers and cells, this law has significantly reduced US reliance on solar inputs and components from China. Only solar modules made with non-Chinese wafers and cells and produced with polysilicon not sourced from Xinjiang can enter the US market without facing substantial tariffs. As a result, Chinese polysilicon producers started investing in other provinces, such as Inner Mongolia and Ningxia, leading to a decline in the share of Chinese polysilicon produced in Xinjiang from 57% in 2021 to 27% in 2023.[66]

In April 2024, the EU also enacted a ban on products made with forced labour, requiring member states to implement the law within three years. This legislation is widely viewed as a move against China and may affect the supply of solar inputs made in Xinjiang to the EU market.

All of these underscore the importance of ESG adherence for solar producers, who must now pay greater attention to ESG concerns and integrate ESG practices into their operations.

[66] Sylvia Leyva Martinez and Elissa Pierce, *Turn of the tide? What the entry of Chinese polysilicon to the US means for the American solar supply chain* (Wood Mackenzie, 2023), https://www.woodmac.com/news/opinion/turn-of-the-tide-what-the-entry-of-chinese-polysilicon-to-the-us-means-for-the-american-solar-supply-chain/.

V. Forecasts for the Global Solar Supply Chain Landscape

Considering the dynamics in geopolitics, government policies, technology, and the market, we predict that the industrial policies and trade remedy measures adopted by various countries will promote a gradual diversification of solar manufacturing outside of China. However, China's leadership in the global solar supply chain will continue.

1. China's leadership will continue

Chinese solar companies are not just competing on cost; they are also at the forefront of solar technology—China now leads in the technologies of almost all solar components and manufacturing equipment. As a result, China has solidified its status as the global leader in solar production over the past 15 years. Currently, no other country outside of China possesses a complete domestic solar supply chain. We believe that these strengths will not diminish anytime soon, enabling China to maintain its leadership in the global solar supply chain.

Although some countries such as the US and India have ambitious expansion plans for solar panel manufacturing, they will struggle to reduce their reliance on essential solar inputs and components from China in the near term, given that China controls over 90% of global polysilicon refinement, wafer production, and cell production. Consequently, the core of the solar PV supply chain—from the refining of polysilicon to the manufacturing of solar cells—will continue to take place mostly in China.

Moreover, the recent plunge in solar product prices may defer new investments in solar manufacturing, thereby slowing the expansion of production capacity in other countries. This will further reinforce China's stronghold in solar manufacturing. According to IEA estimates, China is projected to maintain at least 75% of global manufacturing capacity across all segments of solar PV manufacturing by 2030.[67]

[67] International Energy Agency, *Renewables 2025* (2025), 90, https://iea.blob.core.windows.net/assets/76ad6eac-2aa6-4c55-9a55-b8dc0dba9f9e/Renewables2025.pdf.

2. ODI promotes globalization of Chinese solar manufacturing

China's stronghold in the solar PV supply chain is also evident in the significant overseas direct investment (ODI) made by Chinese solar companies on a global scale. As trade barriers continue to rise, it is anticipated that Chinese solar companies will accelerate their expansion of overseas capacity, and their investment destinations will also diversify beyond Southeast Asia. This trend promotes the globalization of Chinese solar manufacturing and may ultimately enhance China's influence in the sector.

2.1 New destinations for Chinese solar investment

Since 2014, Chinese solar manufacturers have established production bases in Southeast Asian countries to circumvent US duties imposed on Chinese solar cells and modules. However, with increased scrutiny from the US on solar production in Southeast Asia, Chinese solar companies are now compelled to seek alternative investment destinations.

The Middle East and North Africa (MENA) region, a vital hub for China's Belt and Road Initiative, boasts abundant sunlight and a rapidly growing domestic solar market, making it an attractive destination for Chinese solar investments. For example, in July 2024, JinkoSolar announced plans to establish a joint venture in Saudi Arabia to build a solar PV manufacturing facility. With an annual production capacity of 10 GW for both high-efficiency solar cells and panels, the project will be the largest overseas cell and panel factory established by a Chinese solar company. In addition, other solar companies are setting up production facilities in the United Arab Emirates (UAE), Oman, and Egypt. Within the next five to ten years, Chinese companies are poised to control the majority of solar manufacturing capacity in the MENA region, mirroring their current position in Southeast Asia.

Other markets, such as Bangladesh, Pakistan, and Latin America have also emerged as potential destinations for Chinese solar investments. For instance, SJEF Solar is building a 5GW solar cell factory in Puebla of Mexico, expected to commence operations by the end of 2025.

2.2 An emerging trend in Chinese solar investment: Relocating the entire supply chain

In recent years, Chinese solar companies focused on establishing manufacturing facilities for solar cells and panels in Southeast Asia to bypass US tariffs and AD/CVD. However, the US has effectively blocked this route by extending its AD/CVD investigations and duties to solar companies in Southeast Asia that utilize Chinese inputs. In addition, the US government has prohibited Chinese companies from receiving tax credits for their solar facilities, undermining their efforts to set up manufacturing operations in the US. Despite these challenges, the US remains the largest importer of solar panels, presenting irreplaceable market opportunities for solar producers.

For Chinese solar companies seeking to enter the US market, shifting production to other countries is essential. However, this strategy is only feasible if they can source inputs locally. As a result, relocating the entire supply chain to countries with lower geopolitical risks has become a viable solution.

For instance, Sunrev Solar began construction on a US$200 million vertically integrated solar manufacturing facility in Egypt in June 2025. The initial phase of this project includes a 2 GW solar cell and module production facility, expected to be completed in the first half of 2026. The second phase will expand to localized production of silicon ingots and wafers.

Similarly, Trina Solar plans to invest in an integrated solar manufacturing facility in the UAE, with annual production capacity of 50,000 tons of high-purity polysilicon, 30 GW of silicon wafers, and 5 GW of solar cells and panels.

By localizing their supply chain in these countries, Chinese solar companies can mitigate the risks associated with AD/CVD measures and maintain access to the US market, as it becomes harder to justify AD/CVD investigations if solar products are fully produced outside of China. Furthermore, this approach promotes technology transfer to these host countries, contributing to their industrialization. This enables Chinese companies to establish themselves as trusted partners in local markets, thereby gaining support from both local consumers and governments.

3. Industrial policies and trade remedies lead to diversification outside of China

Industrial policies and trade remedy measures play a crucial role in facilitating the diversification of the solar supply chain beyond China.

3.1 Onshoring/reshoring to the US continues despite uncertainty

Although the intersection of energy, industrial and trade policies under the Trump administration creates great uncertainty for the solar sector, the trend of localization of solar manufacturing in the US is expected to continue.

Since the IRA passed, more than 50 companies—including major Chinese solar manufacturers, which were also eligible for the same tax credits before the passage of OBBB—have announced plans for new factories or capacity expansions in the US (see Tables 14 & 15).[68] For example, in late September 2024, First Solar inaugurated a new fully vertically integrated thin-film solar manufacturing facility in Alabama, which has a capacity of 3.5 GW and covers the production process from sheets of glass to modules. It is also building a 3.5 GW solar facility in Louisiana, with commercial shipments anticipated by the first half of 2026.

Table 15: Major planned new solar capacity / capacity expansions in the US by non-Chinese companies (2024-2027)

Company	Company HQ	Solar panel (GW/year)	Solar cell (GW/year)	Silicon wafer (GW/year)	Polysilicon (metric ton/year)
First Solar	US	7			
DYCM Power	US	6	6		
Warree	India	6	3		
Canadian Solar[69]	Canada	5	5		
SEG Solar	US	3.5	2		
Qcells	South Korea	3.3	3.3	3.3	
Enel/3Sun	Italy	3	3		
Convalt Energy	US	2.3	10	10	
NorSun	Norway		5	5	
Caelux	US		4	4	
Vikram Solar	India		4	4	
Wacker	Germany				80,000
Hemlock	US				35,000

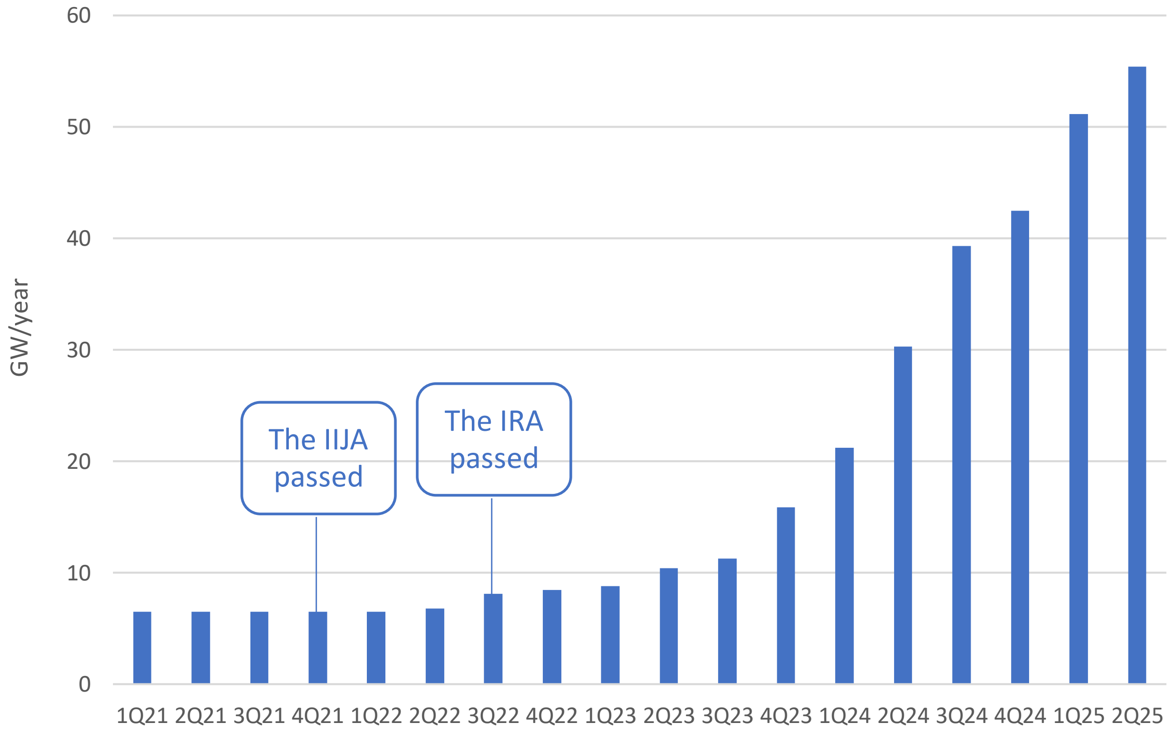
Source: North America Solar Supply Chain Map Edition 1 – 2025

[68] Sinovoltaics, *North America Solar Supply Chain Map Edition 1 – 2025* (2025), https://sinovoltaics.com/sinovoltaics-us-solar-market-supply-chain-map-north-america/.

[69] Canadian Solar is incorporated in Canada by a Canadian citizen with Chinese ancestry. Most of its production capacity is located in China.

As of May 2025, around 400 GW of new production capacity had been announced across the solar PV supply chain in the US, including 140 GW for solar modules, 80 GW for solar cells, 25 GW for silicon wafers, and 10 GW for polysilicon.[70] While many of these plans are unlikely to come to fruition following the passage of the OBBB, it is worth noting that as of June 2025, the solar panel manufacturing capacity in the US already reached 55.4 GW per year (see Figure 21).[71] If all these facilities operate at full capacity, the US will achieve self-sufficiency in solar panel production to meet domestic demand, even if none of the planned manufacturing projects move forward.

Figure 21: Solar panel production capacity in the US, 1Q21-2Q25



Source: US Solar Market Insight (various issues), Wood Mackenzie and Solar Energy Industries Association

While most of the new solar manufacturing capacity established over the last few years is concentrated in module assembly, the US is also slowly expanding its upstream solar manufacturing. In October 2024, US solar company Suniva reopened a 1 GW cell manufacturing facility, marking the return of silicon cell production to the US for the first time since 2019. The US will also begin producing silicon wafers in early 2026, after a 3.3 GW

[70] David Feldman, Jarett Zuboy, Krysta Dummit, Matthew Heine, Shayna Grossman, and Meenakshi Narayanaswami, *Spring 2025 Solar Industry Update* (National Renewable Energy Laboratory, 2025), 73, https://docs.nrel.gov/docs/fy25osti/95135.pdf.

[71] Solar Energy Industries Association and Wood Mackenzie, *US Solar Market Insight Q3 2025* (2025), 6, https://seia.org/research-resources/solar-market-insight-report-q3-2025/.

ingot and wafer production facility built by South Korea's Hanwha Qcells in Cartersville, Georgia becomes operational.[72]

However, building a complete local supply chain goes beyond subsidies and tariff barriers. We expect that the US will remain heavily reliant on imported wafers and cells for the foreseeable future, as there are few announced plans for new polysilicon, wafer and cell facilities, and most of these plans are unlikely to materialize due to the huge investment costs, lengthy construction timelines, technical complexities, and intense price competition, especially in light of the OBBB's passage.[73] Furthermore, US solar panel manufacturers will continue to depend on imports for essential panel components such as solar glass and back sheets. In fact, a significant portion of the current or planned expansion in US solar manufacturing capacity involves only the assembly of solar panels from cells and components produced elsewhere, often by the overseas subsidiaries of Chinese solar companies. All in all, building a complete solar supply chain within the US will take considerable time and effort.

3.2 India is set to become a significant player in panel production but challenges remain

India has adopted a two-pronged strategy that combines supportive industrial policies with duties on imported solar cells and panels to boost its domestic solar industry. This has led to a substantial increase in the country's solar manufacturing capacity and production output. In 2024, India produced 24 GW of solar panels, surpassing Vietnam to become the second-largest solar panel producer in the world. According to India's Ministry of New and Renewable Energy, India's nameplate production capacity for solar panels nearly doubled from 38 GW in March 2024 to 74 GW in March 2025, and further reached 100 GW by August 2025.

Looking ahead, India is well-positioned to become an increasingly important player in panel production. However, it faces challenges similar to those encountered by the US, and these challenges are even more pronounced for India. First, India's production of solar inputs and components lags behind its panel production, which makes the country more of a 'panel assembly factory' rather than a comprehensive solar producer. As of March 2025, India's nameplate manufacturing capacity for solar cells was only 25 GW, just one-third of its capacity for solar panels.

[72] Hanwha aimed to be the first company to establish a complete solar PV supply chain in the US, encompassing polysilicon, ingot, wafer, cell, and module production. However, due to quality issues with the polysilicon produced by REC Silicon, in which Hanwha is the largest shareholder, the company has opted to source polysilicon from OCIM, a Malaysian subsidiary of South Korean OCI Holdings.
[73] For example, in February 2024, CubicPV, a wafer manufacturer backed by Bill Gates' Breakthrough Energy Ventures, cancelled plans to build a 10 GW wafer factory in the US, citing a collapse in wafer prices and a rise in construction costs.

More critically, India is even more reliant on China for its solar development than the US is. With domestic panel manufacturing capacity outpacing cell capacity, India heavily relies on cell imports from China to supply its panel factories. In the fiscal year 2024-25 (April 2024 – March 2025), India's imports of solar cells from China surged 141% yoy to 4.55 billion units. China's share in India's cell imports also increased from 70% to 90%. Furthermore, many of the machinery and equipment used in module manufacturing are sourced from China. In 2024, two Chinese companies made up over half of all manufacturing machinery purchases by India's 10 largest solar importers.[74] Indian module manufacturers often require assistance from Chinese technicians for machine installation, maintenance and repair, as well as training. This dependence on China impedes India's solar capacity development under the PLI Scheme (see Table 16).[75] Overall, India still has considerable progress to make before achieving true self-reliance in solar manufacturing.

Table 16: Capacity awarded and developed under the PLI Scheme, June 2025

Manufacturing stage	Capacity awarded (GW/year)	Capacity developed (GW/year)
Module	48.3	18.5
Cell	44.9	9.7
Ingot-Wafer	37.5	2.2
Total	*130.7*	*30.4*

Source: Ministry of New and Renewable Energy of India

[74] Andy Lin, Rajesh Kumar Singh, and Shruti Srivastava, "US and China are thwarting India's shot at $7 trillion solar prize," *Bloomberg*, August 22, 2025, https://www.bloomberg.com/news/features/2025-08-22/what-india-needs-to-beat-us-china-and-dominate-multi-trillion-solar-industry.

[75] Under the PLI Scheme, selected companies had to commission their solar manufacturing capacity by April 2026. However, progress on the ground stood at less than 25% as of 30 June 2025, with only 30.4 GW commissioned out of the 130.7 GW awarded, data from the Ministry of New and Renewable Energy of India showed.

VI. Concluding Remarks

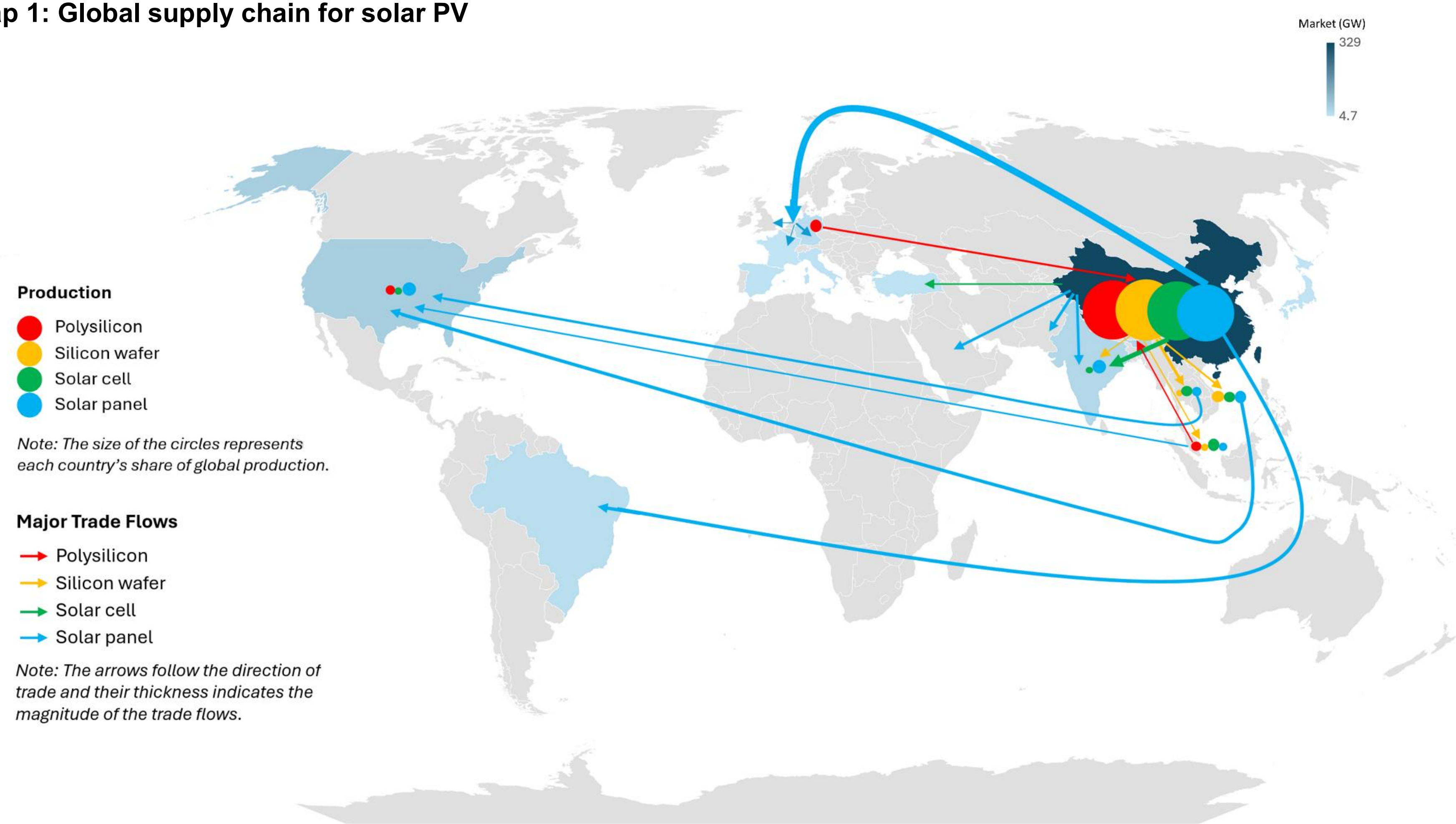
China's leadership in solar manufacturing has been a defining feature of the global solar supply chain over the past decade. However, rising geopolitical tensions, heightened trade protectionism aimed at promoting import substitution, and greater government support for domestic manufacturing are set to fragment the global solar supply chain and reshape its geographical landscape. Countries such as the US and India are beginning to assert themselves as viable alternatives in solar manufacturing.

Despite these developments, China's leadership in the global solar supply chain is expected to continue in the near future, bolstered by its low production costs, technological advancements, and complete supply chain. Rather than diminishing China's influence, the trade barriers and industrial policies implemented by other countries are accelerating the globalization of Chinese solar manufacturing, as Chinese producers rapidly expand their production capacity overseas.

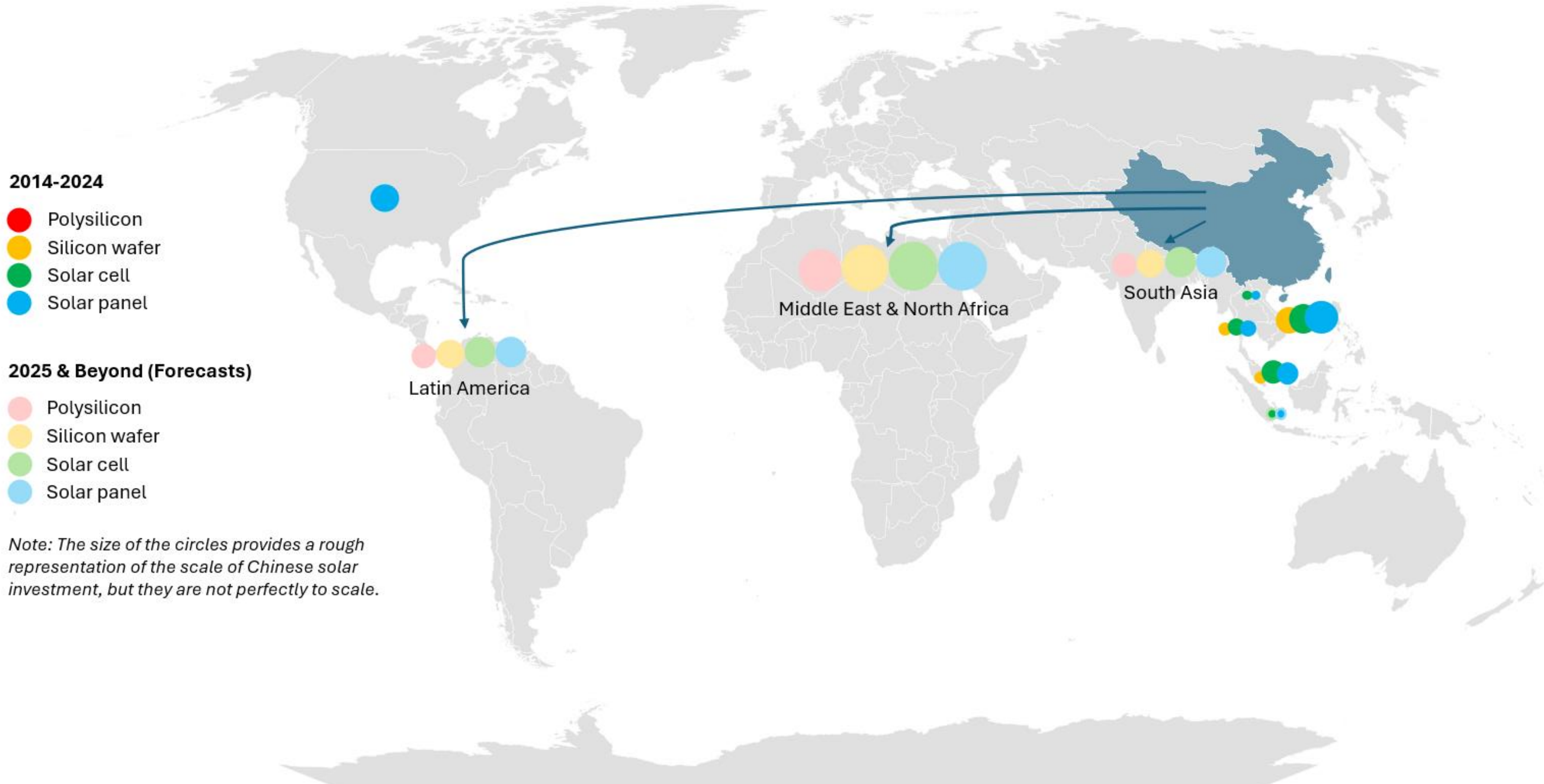
The implications of these trends extend beyond economics and business; they also impact bilateral relations among countries, technological innovation, and sustainability. As we move towards a future focused on sustainable energy and resilient supply chains, it is essential for all stakeholders in the solar industry to grasp the complex dynamics at play, along with the challenges and opportunities that lie ahead. This understanding will not only shape strategic decisions but also steer collaborative efforts to enhance the efficiency and resilience of the global solar supply chain in the years ahead.

Appendix

Map 1: Global supply chain for solar PV



Map 2: Globalization of Chinese solar manufacturing



Our Global Supply Chain Analysis by Industry

Electric Vehicle

Expansion and Diversification: Securing EV Supply Chains Amid Global Fragmentation

Solar PV

Where the Sun Shines: The Changing Landscape of the Global Solar Supply Chain

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