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Working Paper

Reconfiguring globalisation: A review of tariffs, industrial policies, and the global solar PV supply chain

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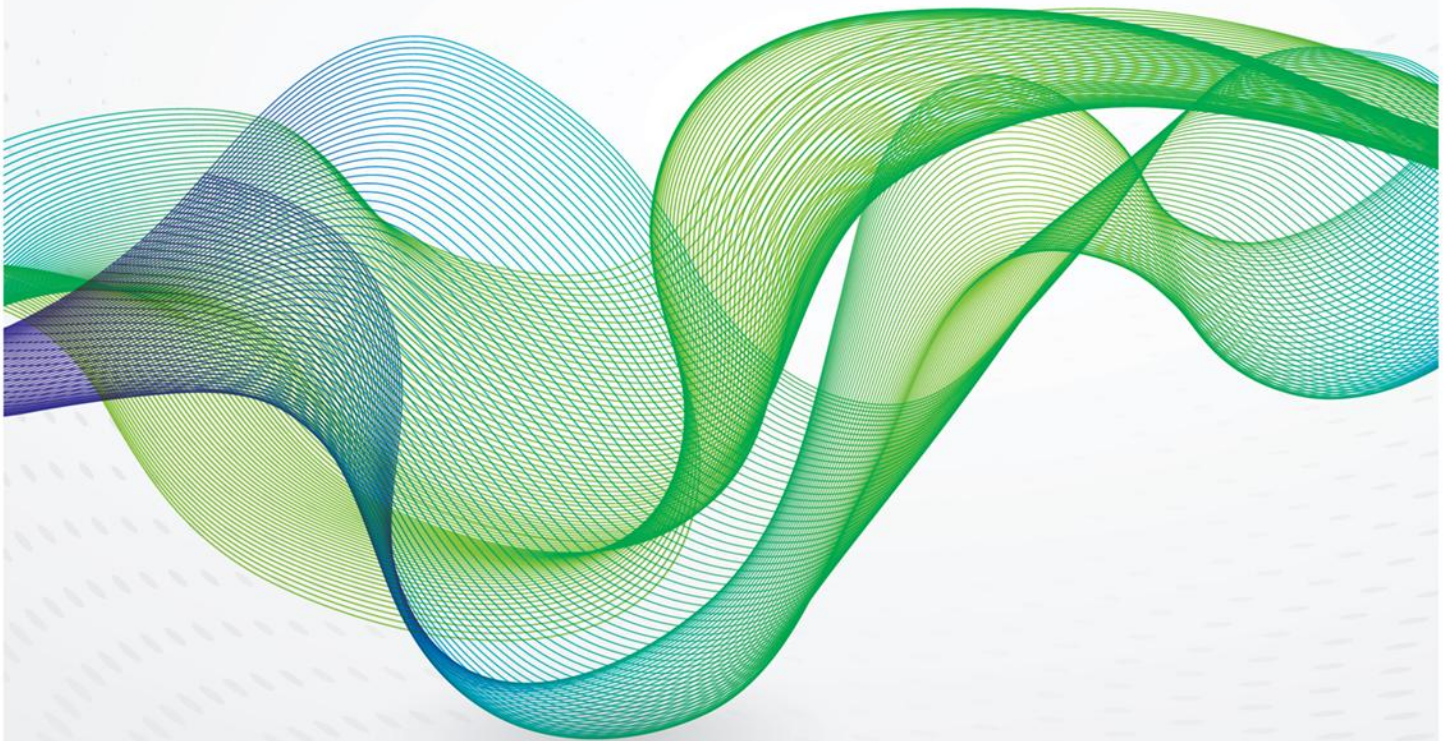
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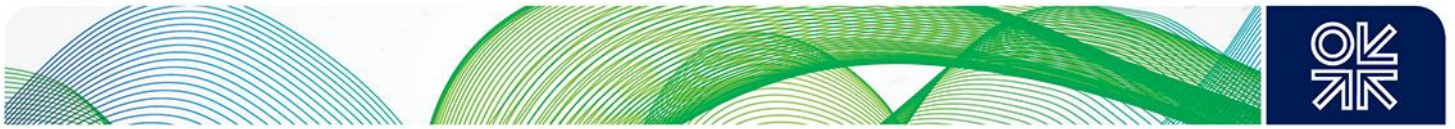
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December 2024

Reconfiguring Globalisation: A Review of Tariffs, Industrial Policies, and the Global Solar PV Supply Chain



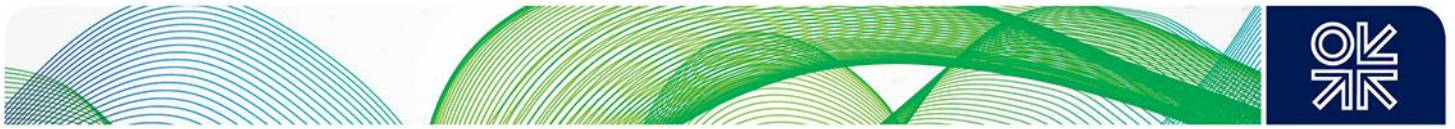


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Executive Summary

- The trade war of the early 2010s on solar PV initiated by the US and European Union (EU) triggered a major wave of bankruptcies in China that proved to be a temporary setback for the industry. China's efforts to stimulate domestic PV deployment sustained the industry's growth and drove rapid cost reductions for Chinese-manufactured modules. To circumvent Western tariffs, Chinese firms relocated a modest proportion of downstream capacity to Southeast Asia. Consequently, growing cost disparities between Chinese and Western products, coupled with frequent tariff circumvention practices, undermined the efficacy of the Western tariff regimes. Ultimately, tariffs failed to deliver any meaningful development in the US and European solar manufacturing sectors.
- Policy interventions and geopolitical alignments recently have significantly redirected investment flows, as evidenced by corporate announcements. Heightened trade tensions and geopolitical rifts have spurred Chinese firms to invest in Southeast Asia and the Middle East. Similarly, the US Inflation Reduction Act (IRA) led to a surge of inbound reshoring investments by Western and domestic manufacturers.
- China's competitive advantages in mass manufacturing make it the most cost-effective location for solar PV equipment manufacturing. Moreover, China already maintains a lead in crystalline silicon (c-Si) technologies. While the US partly shielded its domestic market from Chinese imports with a complex tariff regime, it bears almost triple the global price for solar panels and twice the investment costs of China for its PV manufacturing. An expected tightening of the tariff regime could further exacerbate the cost disparities.
- The surge in China's PV manufacturing overcapacity presents an irreconcilable dilemma for the rest of the world (ROW) in the coming years. A flood of Chinese imports is expected to obliterate the manufacturing sector in countries lacking trade defences, such as the EU, but increase the availability of low-cost solar panels, accelerating their deployment. Countries that opt for robust trade barriers, such as the US, face the necessity of pairing prolonged subsidies to sustain domestic industries, a choice that will inevitably inflate energy transition costs. Even so, US manufacturers may still fail to compete, particularly if IRA incentives are repealed or technology and cost gaps with Chinese producers further widen.



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Introduction

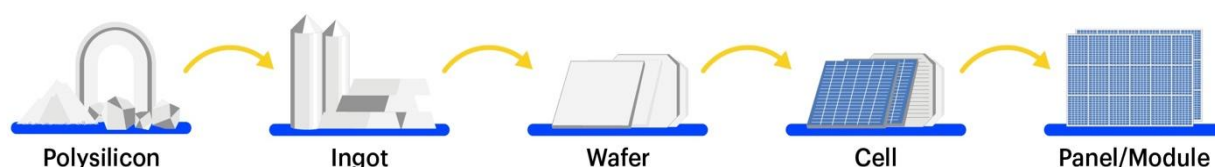
Trade barriers have become an increasingly popular policy design for protecting and nurturing domestic clean-tech manufacturing industries in major economies, including the US, EU, Canada, and India. Confronted with a surge of Chinese solar photovoltaics (PV) imports at drastically reduced prices, a consequence of China's rapid manufacturing expansion, multiple countries are poised to launch or strengthen existing trade barriers. However, despite extensive discussion within policy and industry circles, the effectiveness and broader impact of such policies remain underexplored in the existing literature. This paper attempts to address this gap by exploring the role of trade barriers as major economies grapple with the dilemma between decarbonisation and de-risking from Chinese equipment critical for the energy transition.

This paper begins by analysing the trade conflicts of the early 2010s and their impact on the US, EU, and Chinese industries, as well as on the global supply chain. It then explores how recent and impending trade conflicts — along with the rise of green industrial policies aimed at promoting import substitution — are reshaping the global supply chain by assessing both government policies and corporate responses. Lastly, the paper examines policy solutions for the rest of the world (ROW), considering trade actions and industrial policies in the context of China's overcapacity in 2024.

1. The Manufacturing of Solar PV, Explained

The solar PV industry primarily employs two technologies: c-Si cells and modules; and thin-film modules, predominantly made from cadmium-telluride (CdTe). C-Si modules, constituting over 95 per cent of global production, are almost exclusively produced by Chinese manufacturers.¹ This paper focuses on c-Si modules due to their predominance in the market.

Figure 1: Solar PV Manufacturing Process



Source: IEA (2022)

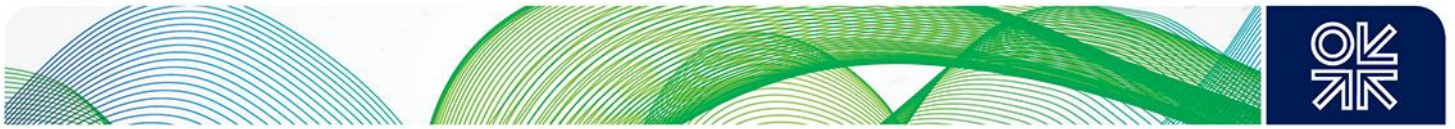
The production of c-Si modules encompasses five critical stages, beginning with polysilicon, derived from the raw material quartz which contains silica. This initial step is a carbothermic reduction process transforming the quartz into metallurgical-grade silicon (MGS). The MGS is then typically refined to produce solar-grade polysilicon. Following purification, the polysilicon is processed into monocrystalline or multicrystalline silicon ingots, which are the precursors to the respective types of c-Si modules. Next, these ingots are sliced into thin wafers using diamond-coated wire saws. Each wafer undergoes intricate processes to enable electricity generation, creating a functional cell. Finally, individual solar cells are interconnected in series and parallel configurations to assemble a complete solar module (Figure 1). Once mounted and connected to a grid, the completed module is capable of converting sunlight into electricity.^{2 3}

The solar industry is rapidly innovating, with newer cell technologies offering higher efficiencies — generating more power under the same sunlight conditions. Most notably, the Chinese industry is currently shifting from Passivated Emitter and Rear Cell (PERC) to Tunnel Oxide Passivated Contact (TOPCon) capacity.

¹ CRS (2022). US Solar Photovoltaic Manufacturing. <https://crsreports.congress.gov/product/pdf/R/R47093>

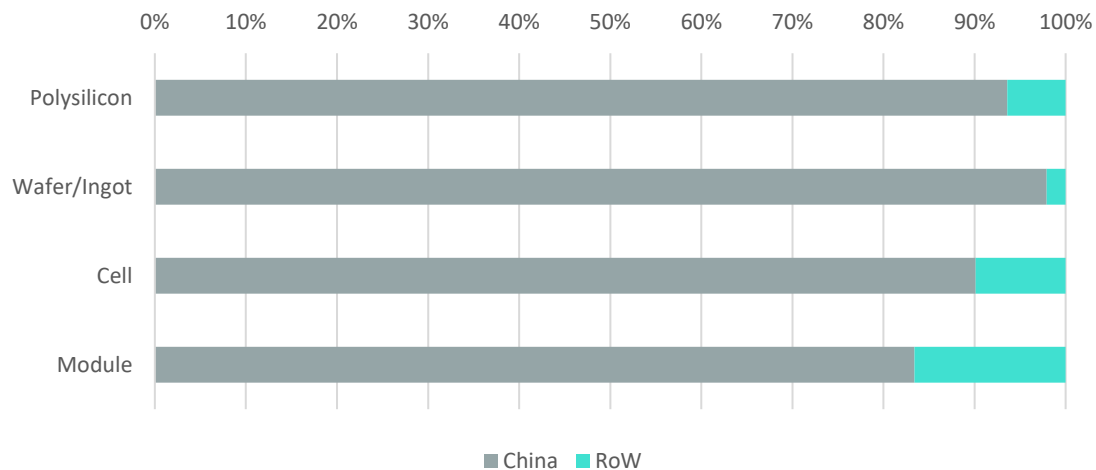
² Department of Energy (2021) Solar Photovoltaic Manufacturing Basics. <https://www.energy.gov/eere/solar/solar-photovoltaic-manufacturing-basics>

³ IEA (2022). Special report on solar PV global supply chains. <https://iea.blob.core.windows.net/assets/d2ee601d-6b1a-4cd2-a0e8-db02dc64332c/SpecialReportonSolarPVGlobalSupplyChains.pdf>



Emerging virtually from scratch in the early 2000s, China rapidly caught up with Western manufacturers who had dominated the solar PV industry for decades. As of 2023, over 80 per cent of global production capacity across all stages is in China.⁴ When including the substantial capacity in Southeast Asia owned by Chinese corporations, Chinese companies effectively control over 90 per cent of global capacity in all segments (Figure 2).⁵

Figure 2: Share of Solar PV Manufacturing Capacity Distribution by Region, 2023



Source: CPIA (2024)

2. Re-examining the Role of the State

A popular Western narrative attributes China's success in solar PV manufacturing to the Chinese government's strategic efforts to build a globally competitive industry through generous subsidies, including cheap loans, land, power, and other financial and policy support. It also contends that China engaged extensively in unfair trade practices, such as selling goods in international markets at prices below domestic prices, a practice known as 'dumping' in trade law.⁶ Dumping is viewed as a tactic to eventually eliminate foreign competition and establish global dominance at the cost of taking short-term losses.⁷ This narrative argued that China's unfair state-led trade practices have cost the Western PV manufacturing sector and jobs. It predominantly shaped Western policymaking, featuring in the trade agendas of the last three US Presidents.^{8 9 10} The narrative also provided the legal basis for Western governments to impose trade defences, most notably anti-dumping and countervailing duties (AD/CVD).^{11 12}

⁴ CPIA (2024). Mixed Results in Solar PV Sector in 2023. https://mp.weixin.qq.com/s/_wNs_KrhJsPpQtEafGPeA

⁵ Author's calculation

⁶ World Trade Organization (1994). Technical Information on anti-dumping.

https://www.wto.org/english/tratop_e/adp_e/adp_info_e.htm

⁷ Deutch & Steinfield (2013). A Duel in the Sun: The Solar Photovoltaics Technology Conflict between China and the United States. <https://energy.mit.edu/wp-content/uploads/2013/05/MITEI-WP-2013-01.pdf>

⁸ On 6 October 2011, then US President Barack Obama blamed the Chinese government as doing 'whatever it takes' to support domestic solar industries when asked about the bankruptcy of Solyndra, a major US solar PV producer. See

<https://obamawhitehouse.archives.gov/the-press-office/2011/10/06/news-conference-president>

⁹ White House (2018). Remarks by President Trump at Signing of Section 201 Actions.

<https://trumpwhitehouse.archives.gov/briefings-statements/remarks-president-trump-signing-section-201-actions/>

¹⁰ White House (2024). Remarks by President Biden on His Actions to Protect American Workers and Businesses from China's Unfair Trade Practices. <https://www.whitehouse.gov/briefing-room/speeches-remarks/2024/05/14/remarks-by-president-biden-remarks-by-president-biden-on-his-actions-to-protect-american-workers-and-businesses-from-chinas-unfair-trade-practices/>

¹¹ USTR (2018). FACT SHEET Section 201 Cases: Imported Large Residential Washing Machines and Imported Solar Cells and Modules. <https://ustr.gov/sites/default/files/files/Press/fs/201%20Cases%20Fact%20Sheet.pdf>

¹² White House (2024). FACT SHEET: Biden-Harris Administration Takes Action to Strengthen American Solar Manufacturing and Protect Manufacturers and Workers from China's Unfair Trade Practices.

<https://www.whitehouse.gov/briefing-room/statements-releases/2024/05/16/fact-sheet-biden-harris-administration-takes-action-to-strengthen-american-solar-manufacturing-and-protect-manufacturers-and-workers-from-chinas-unfair-trade-practices/>



A closer examination of China's solar PV industry development reveals that the state-centric narrative is simplistic. China perfected its practice of industrial policies by playing a central role in early industry planning and funding in many target sectors — such as advanced manufacturing and information and communication technology — to which the state devoted substantial resources.¹³ In some sectors, such as automobiles and high-speed railways, China limited the participation of foreign enterprises by requiring them to establish joint-ventures with Chinese entities with the mandate of fostering technology transfers.¹⁴ ¹⁵ And in sectors such as telecommunications, utilities, and oil and gas, China maintained an effective oligopoly by only allowing the operation of a few state-owned enterprises.¹⁶

The emergence and development of China's solar PV industry, however, presents a very different and complex story — the nature and extent of industrial policies underwent dramatic evolutions while the policies of the central and local governments have often diverged. In the early 2000s, a group of pioneering Chinese entrepreneurs established the industry when China possessed minimal technological expertise in the sector and limited domestic installation demand.¹⁷ ¹⁸ China's central government then viewed wind power as a more promising renewable energy solution and provided substantial policy support for the manufacturing of wind turbines.¹⁹ In contrast, solar power development and manufacturing largely grew outside Beijing's favour and received little support from the central government. Still, many solar PV firms benefited from heavy subsidies from local governments that were eager to establish a high-end manufacturing sector. Local governments provided direct cash subsidies, tax rebates, cheap land, and concessional loans to attract businesses, in addition to sustained operational support.²⁰ These policies were driven by the goal of stimulating GDP growth and employment, often complemented by imposing market barriers to non-local solar products. However, this supply-push approach had a heavy impact on driving overcapacity and ran counter to the central government's priority of establishing an efficient and balanced national market.²¹ ²² ²³

In 2011, Beijing adjusted its solar energy policy in response to the trade conflict with the West and domestic overcapacity by launching nationwide feed-in tariffs (FIT) — a demand-pull policy inspired by Europe that fosters domestic installation while easing overcapacity.²⁴ ²⁵ ²⁶ In 2013, the State Council

¹³ The Economist Intelligence unit (2020). Economic Power Play: Assessing China's Trade Policies. https://impact.economist.com/perspectives/sites/default/files/economic_power_play_assessing_chinas_trade_policies_0608.pdf

¹⁴ Lin et al (2016). International Technology Transfer and Domestic Innovation: Evidence from the High-Speed Rail Sector in China. <https://www.railway-technology.com/features/featurethe-importance-of-chinas-high-speed-tech-transfer-policy-5748075/?cf-view>

¹⁵ Prud'homme, D., von Zedtwitz, M., Thraen, J. J., & Bader, M. (2018). 'Forced technology transfer' policies: Workings in China and strategic implications. *Technological Forecasting and Social Change*, 134, 150-168. doi:10.1016/j.techfore.2018.05.022

¹⁶ Duan & Saich (2014). Reforming China's Monopolies Faculty Research Working Paper Series. https://ash.harvard.edu/wp-content/uploads/2024/02/reforming_chinas_monopolies.pdf

¹⁷ Zhang, W., & White, S. (2016). Overcoming the liability of newness: Entrepreneurial action and the emergence of China's private solar photovoltaic firms. *Research Policy*, 45(3), 604-617. doi:10.1016/j.respol.2015.11.005

¹⁸ Deutch & Steinfield (2013)

¹⁹ Zhang, S., Zhao, X., Andrews-Speed, P., & He, Y. (2013). The development trajectories of wind power and solar PV power in China: A comparison and policy recommendations. *Renewable and Sustainable Energy Reviews*, 26, 322-331. doi:10.1016/j.rser.2013.05.051

²⁰ Liu & Xu (2018). The politics of curtailment: multi-level governance and solar photovoltaic power generation in China, *Environmental Politics*, 27:5, 852-871, doi: 10.1080/09644016.2018.1480920

²¹ Corwin, S., & Johnson, T. L. (2019). The role of local governments in the development of China's solar photovoltaic industry. *Energy Policy*, 130, 283-293. doi:10.1016/j.enpol.2019.04.009

²² Yu & Lu (2015). Government improper intervention and overcapacity of strategic emerging industries — a case study of Chinese photovoltaic industries, *China Industrial Economy Journal*, 2015(10): 53-68. doi:10.19581/j.cnki.ciejournal.2015.10.005

²³ Wang & Shi (2014). The Formation of China's Photovoltaic Industry Dilemma: Path, Mechanism and Policy Reflection. *Contemporary Finance & Economics* (01), 87-97. doi:10.13676/j.cnki.cn36-1030/f.2014.01.010

²⁴ National Development and Reform Commission (2011). Notice on Improving the On-grid Price Policy for Solar Photovoltaic Power Generation. https://www.ndrc.gov.cn/xxgk/zcfb/tz/201108/t20110801_964803.html

²⁵ Quitzow, R. (2015). Dynamics of a policy-driven market: The co-evolution of technological innovation systems for solar photovoltaics in China and Germany. *Environmental Innovation and Societal Transitions*, 17, 126-148. doi:10.1016/j.eist.2014.12.002

²⁶ Hu H, Tang P, Zhu Y, Hu D and Wu Y (2020). The Impact of Policy Intensity on Overcapacity in Low-Carbon Energy Industry: Evidence From Photovoltaic Firms. *Front. Energy Res.* 8:577515. doi: 10.3389/fenrg.2020.577515



issued direct guidance to promote industry consolidation and the retirement of inefficient manufacturing capacity.²⁷ The central government also exercised restraint in subsidies and was determined to let market forces guide the FIT scheme. As solar module prices dropped, Beijing promptly refined the scheme and gradually phased it out by 2021.^{28 29} However, local governments continue to fuel supply expansion through subsidies.³⁰

A comparison between China's wind turbine and solar PV manufacturing also reveals that government subsidies alone cannot fully explain the development of renewable manufacturing sectors. China's wind sector notably received much earlier and more consistent support from the central and local governments, both on the supply and demand sides. For example, the central government experimented with demand-side interventions as early as 2003 with a wind concession programme and established a FIT for onshore wind power in 2009, two years earlier than for solar power. In addition, the central government also sustained supply-side subsidies, including tax reductions and R&D support, which were far more substantial than for the solar industry.^{31 32 33} Lastly, there is a high concentration of state-owned enterprises (SOEs) in wind manufacturing while almost none operate in the solar industry. SOEs typically have greater access to preferential loans, land, and government support than private enterprises. Despite having less policy support, China's solar industry achieved a greater global market share and innovation lead than the wind sector.³⁴

Attributing the rise of China's solar PV sector solely to 'state capitalism' also neglects the role of Chinese entrepreneurship and the mobilisation of international resources enabled by relatively unimpeded globalisation. Early Chinese entrepreneurs astutely recognised the growth potentials of solar PV technology, mobilising resources worldwide and leveraging China's manufacturing capabilities. Most leading firms were founded by or employed returned experts with extensive research experience in advanced solar laboratories or companies in Australia, Canada, and Germany.³⁵ Although domestic demand was initially insignificant, the early firms capitalised on China's trade networks to export to Europe in the 2000s, where demand for solar PV panels surged due to various subsidy and incentive programs. Knowledge diffusion was facilitated through international research and development (R&D) collaboration, equipment sales, and supply chain partnerships.^{36 37 38} In the mid-2000s, when seed funding provided by local governments proved insufficient to scale up production, international investors played a crucial role in channelling capital into China's burgeoning solar PV industry – almost all of today's top-tier companies launched Initial Public Offerings (IPOs) on US stock markets.^{39 40}

Favourable economic conditions also shaped China's competitive advantage in solar manufacturing, with unparalleled efficiency in mass production built over decades of experience. The efficiency is

²⁷ State Council (2013). Several opinions of the State Council on promoting the healthy development of the photovoltaic industry. https://www.gov.cn/zwqk/2013-07/15/content_2447814.htm

²⁸ Ye, L., Rodrigues, J. F. D., & Lin, H. X. (2017). Analysis of feed-in tariff policies for solar photovoltaic in China 2011-2016. *Applied Energy*, 203, 496-505. doi:10.1016/j.apenergy.2017.06.037

²⁹ Chinese government (2021). Notice of the National Development and Reform Commission on Matters Related to the New Energy On-grid Electricity Price Policy in 2021. https://www.gov.cn/zhengce/zhengceku/2021-06/11/content_5617297.htm

³⁰ 36Kr (2023). The three major promoters of photovoltaic production capacity expansions. <https://36kr.com/p/2379390816972039>

³¹ New Energy (2019). Changes in wind power prices and policy development in China over the years. http://www.newenergy.org.cn/zcfq/202004/t20200423_553240.html

³² Zhang, S., Zhao, X., Andrews-Speed, P., & He, Y. (2013)

³³ Chinese Government (2006) Ministry of Finance to formulate preferential policies to promote the development of the wind power industry. https://www.gov.cn/jrzq/2006-10/26/content_424152.htm

³⁴ Nahm, J., & Steinfeld, E. S. (2014). Scale-up nation: China's specialisation in innovative manufacturing. *World Development*, 54, 288-300. doi:10.1016/j.worlddev.2013.09.003

³⁵ Zhang, W., & White, S. (2016)

³⁶ Quitzow (2015)

³⁷ de la Tour, A., Glachant, M., & Ménérier, Y. (2011). Innovation and international technology transfer: The case of the Chinese photovoltaic industry. *Energy Policy*, 39(2), 761–770. doi:10.1016/j.enpol.2010.10.050

³⁸ Hove (2024). Clean energy innovation in China: fact and fiction, and implications for the future <https://www.oxfordenergy.org/wpcms/wp-content/uploads/2024/07/CE14-Clean-energy-innovation-in-China-Final.pdf>

³⁹ Binz, C., & Anadon, L. D. (2018). Unrelated diversification in latecomer contexts: Emergence of the Chinese solar photovoltaics industry. *Environmental Innovation and Societal Transitions*, 28, 14–34. doi:10.1016/j.eist.2018.03.005

⁴⁰ Zhang, W., & White, S. (2016)



supported by cost-competitive labour and power, best-in-class infrastructure that facilitates exports, streamlined permitting processes, industrial clusters that foster vertical integration and economies of scale, and a robust capital pool that enables rapid scaling.⁴¹

While this section does not aim to provide a comprehensive overview identifying the drivers that contributed to the growth of China's solar PV sector, it challenges the dominant Western narrative that government subsidies were the main driver behind its development. Due to the opaque nature of Chinese fiscal policies, it is difficult to gauge the magnitude of supply-push subsidies, especially at local levels.⁴² Evidence of subsidies by local governments remains largely anecdotal. However, national policies were mainly targeted at demand creation and have been implemented with restraint. As a result, the extent to which subsidies are at the heart of the industry's development remains a subject of debate. In addition, failure to understand the evolution of China's industrial policy and the contribution of various economic factors leads to a flawed assumption that trade defences alone could help level the playing field for Western industries.

3. Trade War, Round I

Chinese solar manufacturers made rapid capacity expansions since their formation in the early 2000s. China increased its share of global module production from 1 per cent in 2001 to 60 per cent in 2011, after becoming the world's largest module producer in 2007.^{43 44} The industry's growth then was primarily concentrated in the downstream module-assembly sector, while heavily relying upon imports of high-grade polysilicon and ingots. In 2012, China's share of polysilicon production was 30.3 per cent, notably much lower than its dominance in modules.⁴⁵ China also lagged behind Western competitors in core technologies and relied on imports of manufacturing equipment and advanced components.^{46 47} At the same time, the sector was heavily export-driven as limited domestic demand failed to absorb the production output. Until 2012, 90 per cent of the solar products manufactured were exported.⁴⁸

In 2009, the global solar industry faced its first major upheaval, grappling with the repercussions of the global financial crisis. Western companies, increasingly outcompeted by the influx of low-cost Chinese module imports and further strained by a phaseout of government subsidies, began calling for government interventions. Between 2009 and 2012, at least 66 solar companies, primarily American and European, filed for bankruptcy, underwent restructuring or were acquired or shut down.⁴⁹

In response to petitions from domestic corporations, the US and EU initiated anti-dumping/anti-subsidy investigations in 2011, and subsequently imposed AD/CVD on China's solar cell and module imports (Table 1).^{50 51} AD/CVD are tariffs imposed when dumping or subsidies cause 'material injuries' to

⁴¹ European Commission (2023). Photovoltaics in the European Union. https://setis.ec.europa.eu/photovoltaics-european-union_en

⁴² Research on China's subsidies to the clean-tech sector made varying estimates and research on the specific amount of subsidies to the solar industries is lacking

⁴³ U.S. Department of Energy (2008). 2008 solar technologies market report. <https://www.nrel.gov/docs/fy10osti/46025.pdf>

⁴⁴ CPIA (2014). 2011-2012 China Photovoltaic Industry Development Report.

http://www.chinapv.org.cn/association_news/282.html

⁴⁵ CPIA (2023). 2012-2013 China Solar PV Annual Report. http://www.chinapv.org.cn/association_news/284.html

⁴⁶ Deutch & Steinfield (2013)

⁴⁷ Yicai (2022). How did China's photovoltaic industry, which was once suppressed to the bottom, return to the world's first?

<https://m.yicai.com/news/101563201.html>

⁴⁸ Yicai (2022)

⁴⁹ Greentech Media (2015). The mercifully short list of fallen solar companies: 2015 edition.

<https://www.greentechmedia.com/articles/read/the-mercifully-short-list-of-fallen-solar-companies-2015-edition>

⁵⁰ Federal Register (2012). Crystalline Silicon Photovoltaic Cells, Whether or Not Assembled Into Modules, From the People's Republic of China: Amended Final Determination of Sales at Less Than Fair Value, and Anti-dumping Duty Order. <https://www.federalregister.gov/documents/2012/12/07/2012-29668/crystalline-silicon-photovoltaic-cells-whether-or-not-assembled-into-modules-from-the-peoples>

⁵¹ European Union (2013). Council Implementing Regulation (EU) No 1238/2013 of 2 December 2013. <https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:325:0001:0065:EN:PDF>



domestic industries.^{52 53} An ensuing decline in overseas demand soon triggered a major wave of bankruptcies in China, including the failure of the then-market leader Suntech. The wave also severely impacted China's polysilicon sector and led to over 80 per cent of the polysilicon manufacturers halting production in 2012.⁵⁴

In retaliation and as an effort to protect the domestic polysilicon sector from the allegedly dumped Western polysilicon imports, Beijing imposed AD/CVD on polysilicon imports from the US, EU, and South Korea (Table 1).^{55 56 57} The decision, following intense industry lobbying, appeared to be a concession to the upstream sector, although it negatively affected China's downstream sector which heavily relied upon polysilicon imports from the West.^{58 59}

The loss of overseas demand prompted the Chinese central government to introduce several domestic demand-pull policies, including the 'Large-scale PV Power Station Concession Bidding' and 'Golden-sun Demonstration Projects', followed by the most significant nationwide FIT scheme for PV in 2011.

Table 1: US/EU Trade Restrictions on Chinese Solar PV Products, 2011 – 2015

Country	Trade Restrictions	Timeline	Tariff Rate
US	AD/CVD on Chinese-manufactured cells and modules assembled using Chinese-manufactured cells	Investigation Start: November 2011 Final Determination: December 2012	AD: 18.3296-249.96% CVD: 14.78-15.97%
EU	AD/CVD on Chinese-manufactured cells and modules	Investigation Start: September 2012 Final Determination: September 2013 Sunset: September 2018	AD: 27.3-64.9% CVD: 0-11.5% unless agreed on price undertakings
US	AD/CVD on Chinese-manufactured solar PV cells and modules	Investigation Start: January 2014 Final Determination: December 2014	AD: 26.71-165.04% CVD: 11.45-49.79%
China	AD on EU-manufactured solar-grade polysilicon	Investigation Start: November 2012 Final Determination: April 2014	AD: 14.3-42%
China	AD on US and Korean-manufactured solar-grade polysilicon	Investigation Start: July 2012 Final Determination: January 2014 Extended through 2025	AD on US suppliers: 53.6-57% AD on Korean suppliers: 4.4-113.8%

Source: US Trade Representative, Department of Commerce, European Commission, Chinese Ministry of Commerce

⁵² World Trade Organization (1994). Agreement on Implementation of Article VI of the General Agreement on Tariffs and Trade 1994. https://www.wto.org/english/docs_e/legal_e/19-adp_01_e.htm

⁵³ World Trade Organization (1994). Agreement on Subsidies and Countervailing Measures. https://www.wto.org/english/docs_e/legal_e/24-scm_01_e.htm

⁵⁴ CPIA (2013) 2012-2013 China Photovoltaic Industry Annual Report. http://www.chinapv.org.cn/association_news/284.html

⁵⁵ Ministry of Commerce (2014) Announcement No. 5 of 2014 Announcement on the Final Ruling of the Anti-dumping Investigation on Imports of Solar-grade Polysilicon from the United States and South Korea. <http://m.mofcom.gov.cn/article/b/e/201401/20140100466573.shtml>

⁵⁶ Ministry of Commerce (2014) No. 25 of 2014 Announcement on the Final Ruling of the Anti-dumping Investigation on Imported Solar Grade Polysilicon from the European Union. <http://m.mofcom.gov.cn/article/zcfb/gpm/y/201404/20140400568724.shtml>

⁵⁷ Ministry of Commerce (2014) The Ministry of Commerce announced the final ruling on the anti-subsidy investigation of solar-grade polysilicon. <http://m.mofcom.gov.cn/article/ae/ai/201401/20140100466730.shtml>

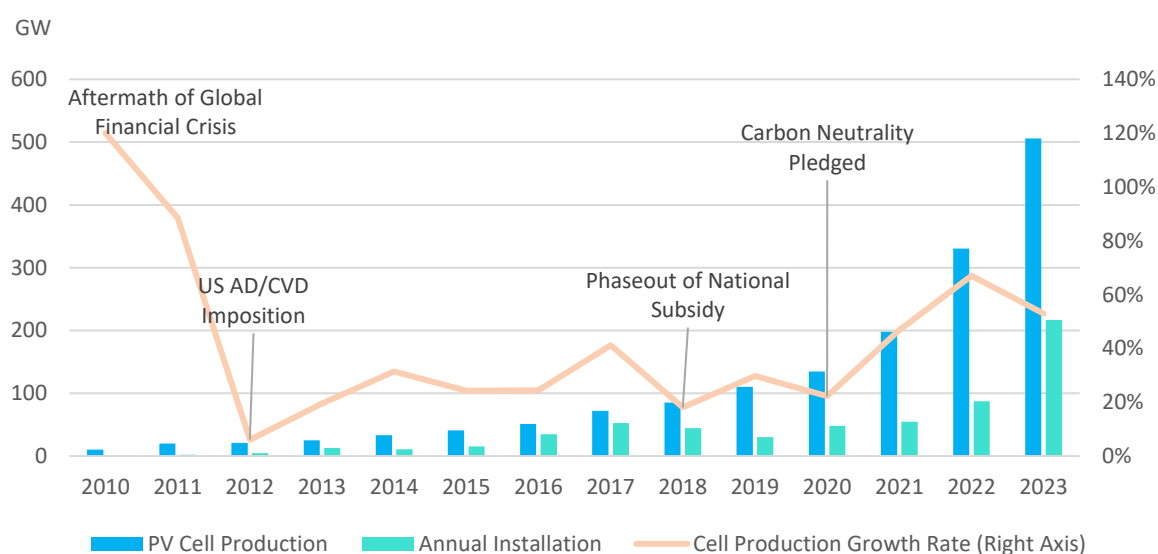
⁵⁸ Caijing (2015) The politics and economics of Polysilicon's AD/CVD. <https://m.caijing.com.cn/api/show?contentid=3958700>

⁵⁹ BJX (2015) Polysilicon Industry Association proposes anti-dumping tariffs on U.S. and South Korean products. <https://mguangfu.bjx.com.cn/mnews/20111213/329354.shtml>



The early 2010s solar PV trade war had a profound impact on the global solar industry. First, although the decline in overseas demand initially triggered a major wave of bankruptcies in China, the demand destruction was soon offset by domestic market expansion. The central government responded by introducing demand-pull policies to stimulate the largely untapped domestic market. Domestic installations gradually outpaced the ROW, making China the world's top market for solar installations (Figure 3). The domestic demand explosion enabled continued supply-side expansion, inviting even more aggressive private investments and fuelling more supply-side subsidy races among the local governments. As a result, Chinese-manufactured module prices continued to decline much faster than in markets shielded by tariffs.

Figure 3: China's Solar PV Cell Production, Growth Rate, and Annual Installation



Source: Caijing, Wind

Second, Chinese companies adapted swiftly to trade restrictions by adjusting and relocating downstream supply chains. Less than two years after the US imposed the first round of AD/CVD on Chinese-manufactured cells, Chinese companies managed to circumvent tariffs by incorporating Taiwanese-manufactured cells into modules exported to the US. This resulted in the second round of AD/CVD imposition and an expansion of the original tariff scope.⁶⁰ In response, Chinese manufacturers gradually established a cell manufacturing and module assembly hub in Southeast Asia, almost exclusively for the purposes of circumventing AD/CVD, a practice known as 'tariff-jumping'.⁶¹ The increase in cell and module exports to the US from Southeast Asia (mainly Malaysia, Thailand, and Vietnam) coincided with a surge in Chinese wafer exports to these latter three countries, as multiple Chinese solar companies had been expanding downstream manufacturing facilities since the mid-2010s.⁶² Although a similar trend was observed in the EU's trade data, tariff-jumping was less pronounced for the European market (Figure 4). This was due to a significant slowdown in solar PV installations in Europe between 2014 and 2017, caused by the lingering European debt crisis and the scaling back of supportive domestic solar policies in major markets like Germany, Spain, and Italy.

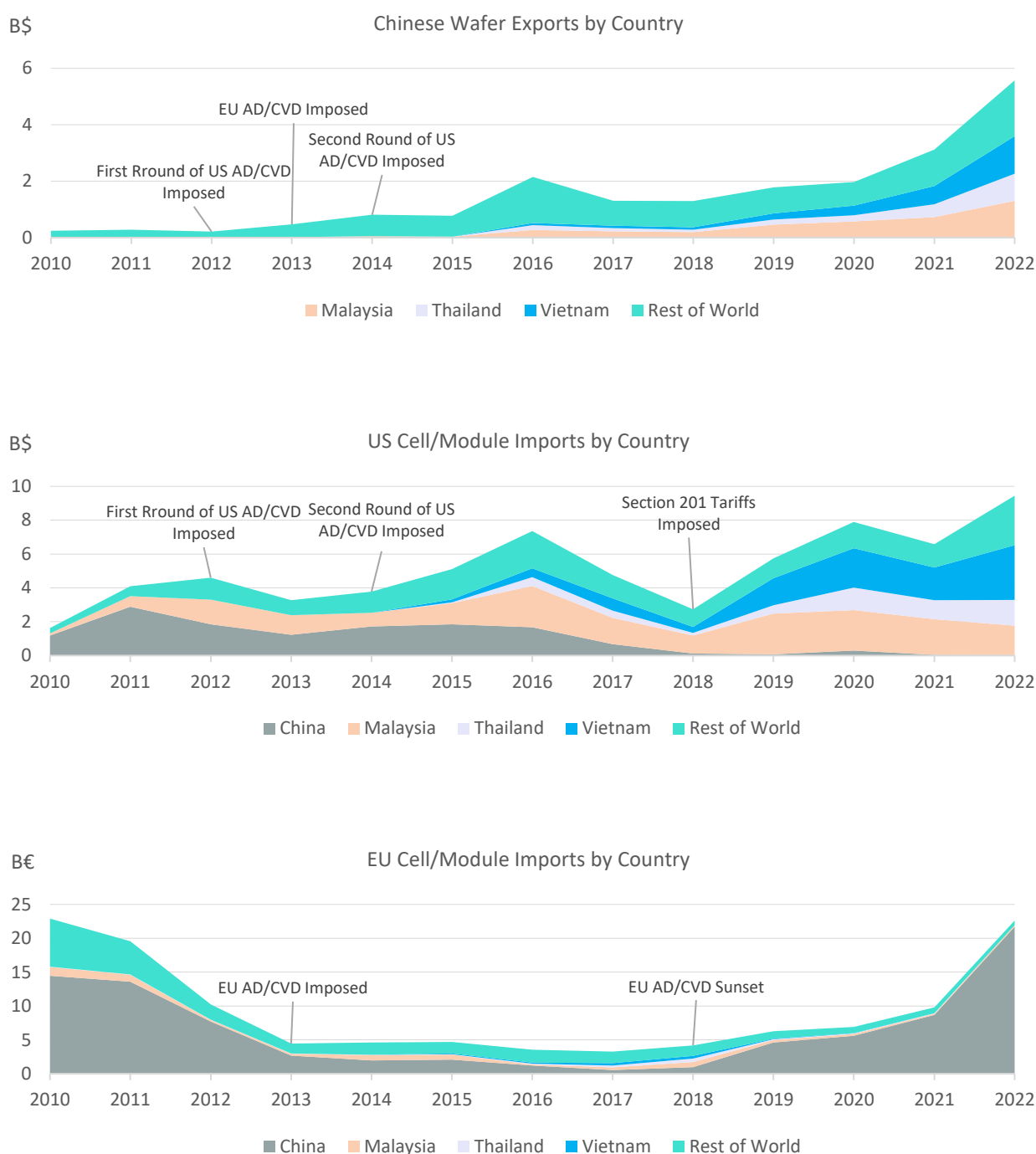
⁶⁰ Federal Register (2015) Certain Crystalline Silicon Photovoltaic Products from the People's Republic of China: Antidumping Duty Order; and Amended Final Affirmative Countervailing Duty Determination and Countervailing Duty Order. <https://www.federalregister.gov/documents/2015/02/18/2015-03183/certain-crystalline-silicon-photovoltaic-products-from-the-peoples-republic-of-china-antidumping>

⁶¹ McCarthy, K. J. (2016). On the influence of the European trade barrier on the Chinese PV industry: Is the solution to the solar-dispute "successful"? *Energy Policy*, 99, 154–157. doi:10.1016/j.enpol.2016.09.055

⁶² *Energy Magazine* (2018). Competing for the New World: Chinese photovoltaic enterprises go overseas. <https://www.inengyuan.com/yuanchuang/383.html>



Figure 4: Timeline of Trade Restrictions and Flows



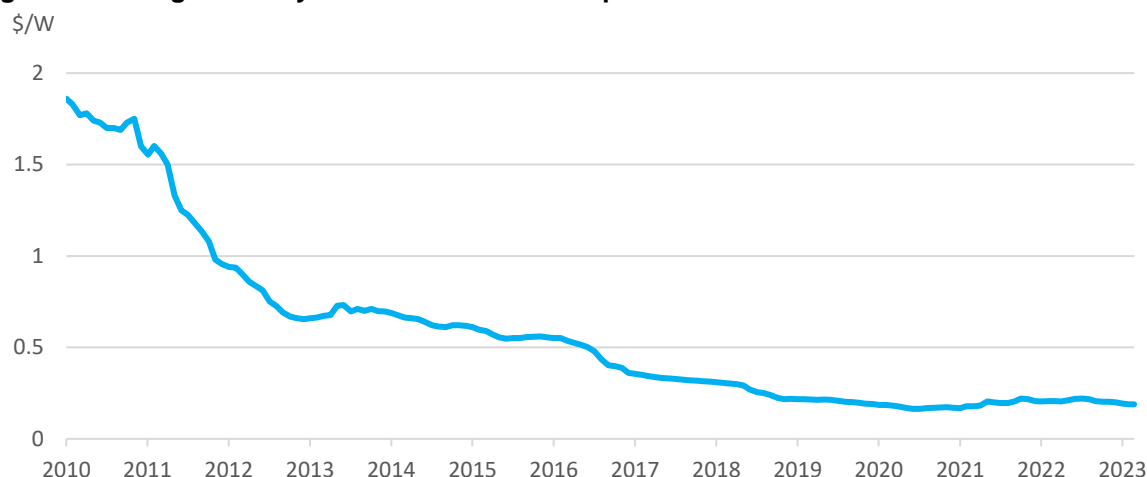
Source: Chinese Customs, Eurostat, Wind, US Census Bureau

As a result, the trade barriers imposed by the US and EU did not lead to the hoped expansion of their solar manufacturing industries. The growing disparities in cost and scale between Chinese and Western manufacturers further diminished the competitiveness of Western companies. The US tariffs regime was undermined by tariff-jumping, and the US solar industry ‘almost disappeared’ as 25 US producers closed



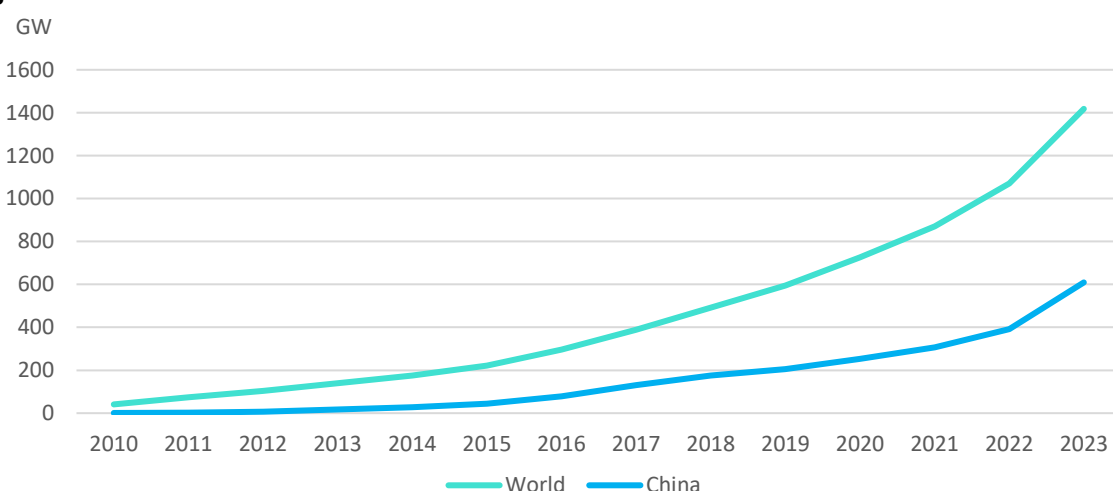
between 2012 and 2017.⁶³ In Europe, tariffs contributed to the slowdown in domestic installations, and the European Commission finally decided to phase out the tariffs in 2018 due to a greater priority to promote renewable installations.⁶⁴ ⁶⁵ This led to a further decline in European domestic production, with Chinese imports quickly rebounding and dominating the market since. However, the world benefited tremendously from the cost reductions and increased production scale delivered by Chinese solar PV, with solar becoming the fastest-growing renewable energy source (Figure 5-6).

Figure 5: Average Multicrystalline Solar Module Spot Price



Source: Bloomberg

Figure 6: Cumulative Solar PV Installation



Source: IRENA

Third, China's AD on polysilicon, coupled with the exponential growth in downstream demand, catalysed a rapid expansion and innovation in its upstream polysilicon industry. Energy-intensive polysilicon manufacturing subsequently expanded in Western China, particularly in Yunnan, Inner Mongolia, and Xinjiang, where industrial power prices consistently undercut those in the power-deficient Eastern regions. Local governments seized this opportunity to foster upstream solar industry clusters, particularly by subsidising electricity, which accounts for 30-40 per cent of total production costs for

⁶³ USTR (2018)

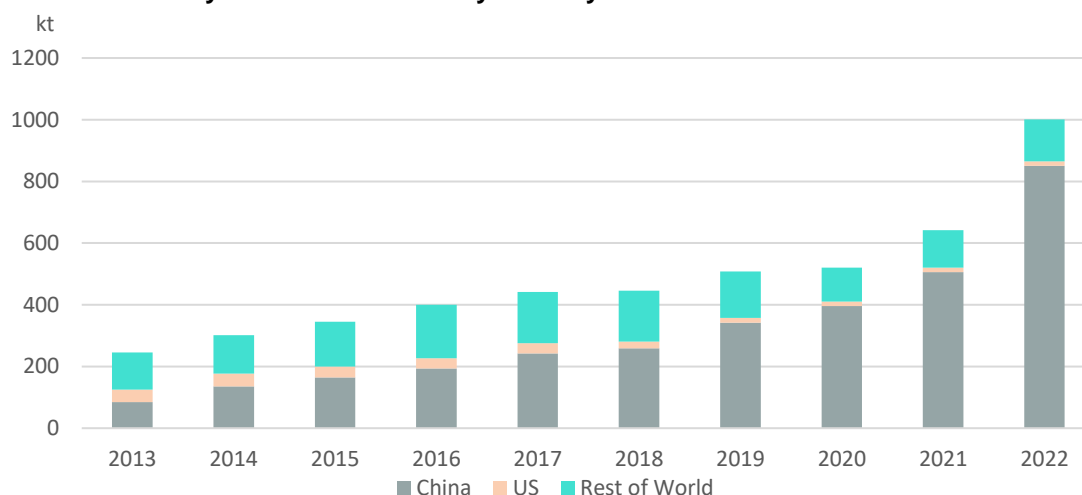
⁶⁴ Euractiv (2018) Commission scraps tariffs on Chinese solar panels. <https://www.euractiv.com/section/economy-jobs/news/commission-scraps-tariffs-on-chinese-solar-panels/>

⁶⁵ European Commission (2023)



polysilicon.^{66 67 68 69 70 71} Combined with the AD on imports from the West, Chinese-made polysilicon made significant capacity expansions, soon displacing most Western competitors from the market (Figure 7).^{72 73} China's share of global polysilicon production increased from 30.3 per cent in 2012 to 91.6 per cent in 2023.⁷⁴

Figure 7: Annual Polysilicon Production by Country



Source: Caijing, NREL

4. Trade War, Round II

The exponential growth of China's solar industry has fuelled further economic frictions. Since 2018, trade restrictions on solar PV products have proliferated, aligning with three key political trends: (1) A recurring call to defend Western manufacturing interests and develop domestic solar industries led to stricter tariff regimes against Chinese exports; (2) Western governments have increasingly adopted industrial policies that prioritised the procurement of domestically manufactured goods; (3) Alarmed by the Russia-Ukraine war in 2022 and its consequential impact on energy markets, the G7 countries are now pursuing a new strategy of 'de-risking' from the China-dominated clean-tech supply chains.^{75 76}

⁶⁶ People's Government of Inner Mongolia Autonomous Region (2014). Implementation Opinions of the People's Government of Inner Mongolia Autonomous Region on Promoting the Development of Photovoltaic Industry.

<http://www.wuhai.gov.cn/wuhai/mlwh/zsyx/xqzc86/1268322/index.html>

⁶⁷ People's Government of Xinjiang Uygur Autonomous Region (2012). Development plan of solar photovoltaic industry in Xinjiang Uygur Autonomous Region (2011-2015) <https://shaanxi.zkzpx.net/xj/zcfg/dfxfq/101626942023317.html>

⁶⁸ The Paper (2019). The most direct reason why polysilicon goes to Xinjiang is the low price of electricity.

https://m.thepaper.cn/newsDetail_forward_4033693

⁶⁹ BJX News (2019). The concentration has further increased. Polysilicon production capacity has been gradually transferred to northwest China. <https://guangfu.bjx.com.cn/news/20190415/974786.shtml>

⁷⁰ R. Fu, T. L. James, & M. Woodhouse (2015). Economic measurements of polysilicon for the photovoltaic industry: Market competition and manufacturing competitiveness. *IEEE Journal of Photovoltaics*, 5(2), 515-524. doi:10.1109/JPHOTOV.2014.2388076

⁷¹ Huatai Futures (2024). Polysilicon production methods and costs analysis.

https://www.htfc.com/wz_upload/png_upload/20240418/1713419450079d23029.pdf

⁷² CRS (2022)

⁷³ Huatai Futures (2024). Polysilicon supply chains.

https://www.htfc.com/wz_upload/png_upload/20240321/1710999111641eed0ac.pdf

⁷⁴ CPIA (2024)

⁷⁵ European Commission (2023). Speech by President von der Leyen on EU-China relations to the Mercator Institute for China Studies and the European Policy Centre. https://ec.europa.eu/commission/presscorner/detail/en/speech_23_2063

⁷⁶ White House (2023). G7 Hiroshima Leaders' Communiqué. <https://www.whitehouse.gov/briefing-room/statements-releases/2023/05/20/g7-hiroshima-leaders-communicue/>



Table 2 provides an overview of the major trade restrictions and import substitution subsidies launched or proposed by the US and EU.

Table 2: Major Trade Barriers and Domestic Manufacturing Subsidies

Country	Trade Restrictions	Timeline	Effect
US	Section 201 Tariffs	Implemented in January 2018; Extended through 2026	Safeguard tariffs with annually decreasing rates on all foreign-made c-Si solar cells
	Section 301 Tariffs (List 2)	Implemented in August 2018	25% tariffs on Chinese-made solar cells
	Section 301 Tariffs	Modified in October 2024	50% tariffs on Chinese-made solar cells and modules
	Circumvention Tariffs	Implemented in June 2024	AD/CVD on most Vietnamese, Malaysian, and Thai cell/module exports using Chinese wafer and polysilicon
	Withhold Release Order	Issued in June 2021	Detains products containing silicon produced by Hoshine Silicon Industry Co. Ltd
	Uyghur Forced Labor Prevention Act	Signed into Law in December 2022	Regional import ban on Xinjiang, China, under rebuttal presumption, requiring proof that imported goods are free from forced labour
	Inflation Reduction Act	Signed into Law in August 2022	Section 45X Advanced Manufacturing Production Tax Credit provides subsidy by unit manufacturing output across different supply chain segments through 2032; Section 48C Advanced Manufacturing Production Credit provides up to 30% of capital expenditure of eligible manufacturing facilities
	AD/CVD on cells and modules from Malaysia, Thailand, Cambodia, and Vietnam	Potential, under investigation	Imposes tariffs on most US cell/module imports from the four countries
EU	Net Zero Industry Act	Proposed in March 2022	Sets a 40% annual manufacturing output/demand target for the EU's solar industry and prioritises domestic products in public procurement
	Carbon Border Adjustment Mechanism	Entered transitional phase in October 2023; Full scope to enter into force in January 2026	Imposes tariffs on aluminium products
	Corporate Sustainability Reporting Directive (CSRD)	Entered into force in January 2023	Requires large foreign companies with substantial operations/turnover in the EU to report ESG (Environmental, Social and Governance) records
	Ban on Imports Made with Forced Labor	Approved in November 2024	Bans imports made with forced labour to be investigated and determined by the European Commission

Source: US Trade Representative, Department of Commerce, Department of Homeland Security, European Commission



The list could be broadly categorised into four main types, each addressing different strategic concerns:

1. **Intensified Tariff Efforts:** The US has significantly escalated tariffs to obstruct direct imports of Chinese modules and counter tariff-jumping practices via Southeast Asia. The cumulative effect of AD/CVD, Section 201 tariffs, and Section 301 tariffs has resulted in a near embargo on direct Chinese imports. In 2022, Chinese modules accounted for less than 0.31 per cent of total US module imports by value, whereas imports from Malaysia, Thailand, and Vietnam represented 68.73 per cent. In June 2024, the US ended a two-year moratorium on circumvention tariffs on most solar cells and modules produced in Malaysia, Thailand, Cambodia, and Vietnam using China-produced wafers.⁷⁷ It is also considering imposing new AD/CVD on all cells and modules from the four countries.⁷⁸
2. **Sanctioning Forced Labour Practices:** A new Western focus on sanctioning imports from Xinjiang has profound implications for the solar sector due to Xinjiang's pronounced role in polysilicon production. The Uyghur Forced Labor Prevention Act (UFLPA) establishes an import 'rebuttable presumption' where all imports 'mined, produced, or manufactured wholly or in part' in Xinjiang or 'produced by an entity on a list' will be prohibited unless importers prove evidence that it is free from forced labour.⁷⁹ In other words, UFLPA imposes a stringent import ban on any goods with a connection to Xinjiang and places a high burden of proof on importers. Top producers such as Hoshine Silicon Industry, Xinjiang Daqo New Energy, and Xinjiang GCL New Energy Material Technology are all designated under the UFLPA entity list.⁸⁰ In 2021, Xinjiang produced 294 kt of polysilicon, making up 58.2 per cent of China's total production or 46.6 per cent of global production.⁸¹ ⁸² The ban initially resulted in a surge of shipments denied, although the shipments denied decreased in 2024 likely due to supply chain adaptations.⁸³ ⁸⁴ Even though the EU passed less stringent measures, multiple Western industry associations and international organisations have already established self-enforced protocols to ensure only sourcing equipment produced free from forced labour.⁸⁵ ⁸⁶ ⁸⁷
3. **Domestic Manufacturing Incentives for Import Substitution:** To boost domestic employment and industry, both the landmark US IRA and the EU's proposed Net Zero Industry Act (NZIA) introduced production/procurement subsidies for domestically produced PV equipment. On the supply side, the IRA provides a subsidy to domestic solar manufacturers covering as much as 30 per cent of capital expenditure.⁸⁸ Additionally, the IRA offers demand-side subsidies for solar

⁷⁷ White House (2024)

⁷⁸ USITC (2024) USITC votes to continue investigations on crystalline silicon photovoltaic cells, whether or not assembled into modules, from Cambodia, Malaysia, Thailand, and Vietnam. https://www.usitc.gov/press_room/news_release/2024/er0607_65269.htm

⁷⁹ Govinfo (2021). An Act To ensure that goods made with forced labor in the Xinjiang Uyghur Autonomous Region of the People's Republic of China do not enter the United States market, and for other purposes.

<https://www.govinfo.gov/content/pkg/BILLS-117hr6256enr/pdf/BILLS-117hr6256enr.pdf>

⁸⁰ Department of Homeland Security (2023). UFLPA Entity List. <https://www.dhs.gov/uflpa-entity-list>

⁸¹ Daqo Energy (2022). Daqo Energy 2021 Annual Report.

<http://www.xjdqsolar.com/uploads/images/%E4%B8%9A%E7%BB%A9%E5%85%AC%E5%91%8A%E5%A4%A7%E5%85%A8%E8%83%BD%E6%BA%902021%E5%B9%B4%E5%B9%B4%E5%BA%A6%E6%8A%A5%E5%91%8A.pdf>

⁸² Xin et al (2024)

⁸³ Reuters (2022). Exclusive: U.S. blocks more than 1,000 solar shipments over Chinese slave labor concerns.

<https://www.reuters.com/world/china/exclusive-us-blocks-more-than-1000-solar-shipments-over-chinese-slave-labor-2022-11-11/>

⁸⁴ CBP (2024). <https://www.cbp.gov/newsroom/stats/trade/uyghur-forced-labor-prevention-act-statistics>

⁸⁵ G7 leaders' 20 May, 2023 communiqué committed to 'continuing to promote decent work and protect rights-holders in global supply chains through a smart mix of mandatory and voluntary measures, including through legislation, regulations, incentives and guidance ...' The language may indicate the political difficulties in building a uniform import ban alliance. See <https://www.whitehouse.gov/briefing-room/statements-releases/2023/05/20/g7-hiroshima-leaders-communique/>

⁸⁶ Solar Energy Industries Association (2021). Solar Supply Chain Traceability Protocol 1.0.

<https://www.seia.org/sites/default/files/2021-04/SEIA-Supply-Chain-Traceability-Protocol-v1.0-April2021.pdf>

⁸⁷ World Bank (2021). Procurement Framework for IPF Projects. <https://projects.worldbank.org/en/projects-operations/products-and-services/brief/procurement-new-framework>

⁸⁸ Solar Energy Industry Association (2022). Inflation Reduction Act: Solar Energy and Energy Storage Provisions Summary. <https://www.seia.org/sites/default/files/2022-10/Inflation%20Reduction%20Act%20Summary%20PDF%2010.13.22.pdf>



installation and power generation that further benefit domestically manufactured equipment. The NZIA sets a target for the EU's solar manufacturing capacity to meet 40 per cent of its annual deployment needs, prioritising domestic products in procurement processes. However, the NZIA lacks the substantial subsidies offered by the IRA.

4. Carbon Tariffs and Footprint Standards: Emerging carbon tariffs and carbon footprint standards may pose longer-term challenges to Chinese solar exports. Currently, the EU's Carbon Border Adjustment Mechanism (CBAM) does not directly target solar equipment, although it taxes aluminium, a key metal input used in mounting rail production. The precise impact of CBAM on the solar PV industry remains to be seen.⁸⁹ ⁹⁰ France also introduced carbon footprint requirements that in effect disqualified most Chinese suppliers from public tenders without government-approved lifecycle emissions assessment certificates.⁹¹ Trade and procurement restrictions based on embedded emissions are expected to widen, as the EU and the US may also introduce similar policies targeting high-carbon solar equipment imports.⁹² ⁹³

5. Reconfiguring Global Supply Chains

5.1 Reglobalisation by the Cents

China's efficiency in mass production — built over decades of manufacturing expertise — has positioned it as the most cost-competitive hub for the solar supply chain. Its efficiency is supported by cheap labour and power, well-equipped infrastructure that efficiently facilitates exports, streamlined permitting processes, generous subsidies from local governments for both capital and operational expenditure, and a robust capital pool that enables rapid scaling. A 2022 study by the National Renewable Energy Laboratory (NREL) found that US-manufactured modules were over 27 per cent more expensive than those from China, on a factory gate minimum sustainable price basis (Figure 8).⁹⁴ However, an analysis of spot prices for monofacial monocrystalline modules from 2020 to the end of 2023 reveals that the US market pays approximately double the global average price.⁹⁵ As of July 2024, US module prices stood at \$0.3/W, roughly three times the price of Chinese modules available in the ROW.⁹⁶ Beyond equipment cost premiums, US manufacturers bear nearly twice the capital expenditure compared to China, highlighting the significant financial burden of domestic manufacturing initiatives (Figure 9). Similarly, the European industry estimated that production costs for integrated cells and module manufacturing in the EU tend to be 70 per cent-105 per cent higher than in China.⁹⁷

⁸⁹ European Aluminium, an industry association, argued that taxing aluminium raw materials instead of solar panels could further inflate production costs for European manufacturers and put Chinese competitors at an advantage. See: https://european-aluminium.eu/wp-content/uploads/2022/10/european-aluminium_aluminium-in-solar_position-paper.pdf

⁹⁰ It also remains to be seen whether CBAM will apply to Scope 2 emissions for aluminium inputs. Scope 2 emissions (largely purchased power emissions) far outweigh the direct Scope 1 emissions in aluminium production due to the power-intensive smelting process. Because of China's world-leading energy efficiency achieved in aluminium production, its Scope 1 emissions intensity is actually lower than Europe's although the Scope 2 intensity is greater due to its predominant use of coal-fired power for heavy industries

⁹¹ Yicai (2024). Strong Chinese photovoltaics lose competitiveness in France: how to break through the carbon barrier. <https://m.yicai.com/news/102081148.html>

⁹² Infolink (2022). How to shore up solar supply chain resilience for a new energy world. <https://www.infolink-group.com/energy-article/insight-solar-topic-how-pv-supply-chain-prepares-in-advance-in-face-of-net-zero>

⁹³ Xinhua (2023). The world's first carbon tariff is implemented, photovoltaic enterprises prepare for carbon footprint certification. http://www.news.cn/fortune/2023-02/17/c_1211729857.htm

⁹⁴ NREL (2022) The Global Solar Photovoltaic Supply Chain and Bottom-UP Cost Model Results. <https://www.nrel.gov/docs/fy23osti/84036.pdf>

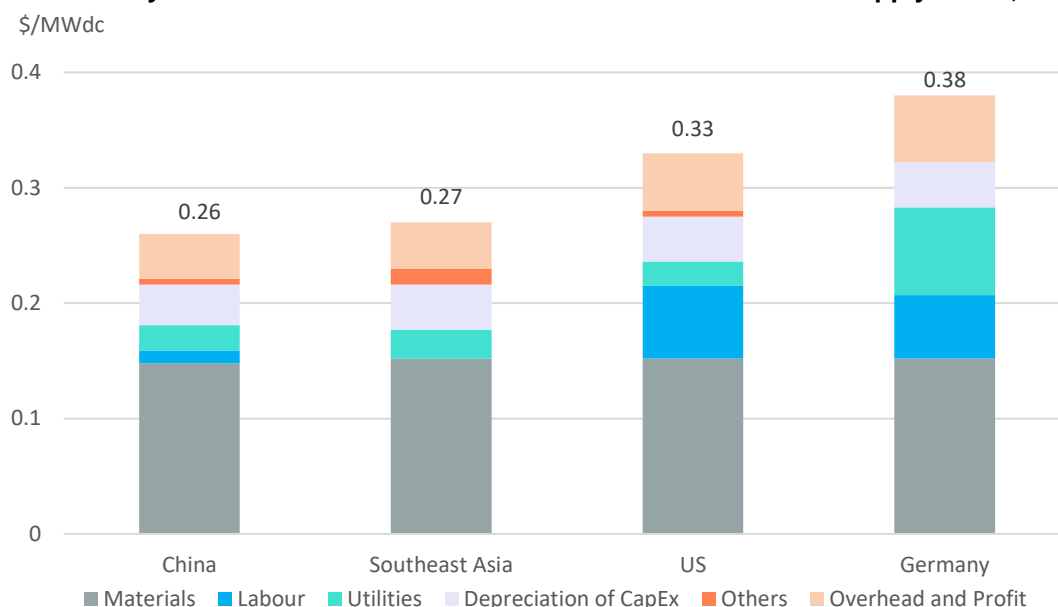
⁹⁵ NREL (2023). Fall 2023 Solar Industry Update. <https://www.nrel.gov/docs/fy24osti/88026.pdf>

⁹⁶ IEA (2024). Renewables 2024. <https://iea.blob.core.windows.net/assets/45704c88-a7b0-4001-b319-c5fc45298e07/Renewables2024.pdf>

⁹⁷ European Commission (2024). The future of European Competitiveness. https://commission.europa.eu/document/download/ec1409c1-d4b4-4882-8bdd-3519f86bbb92_en?filename=The%20future%20of%20European%20competitiveness_%20In-depth%20analysis%20and%20recommendations_0.pdf

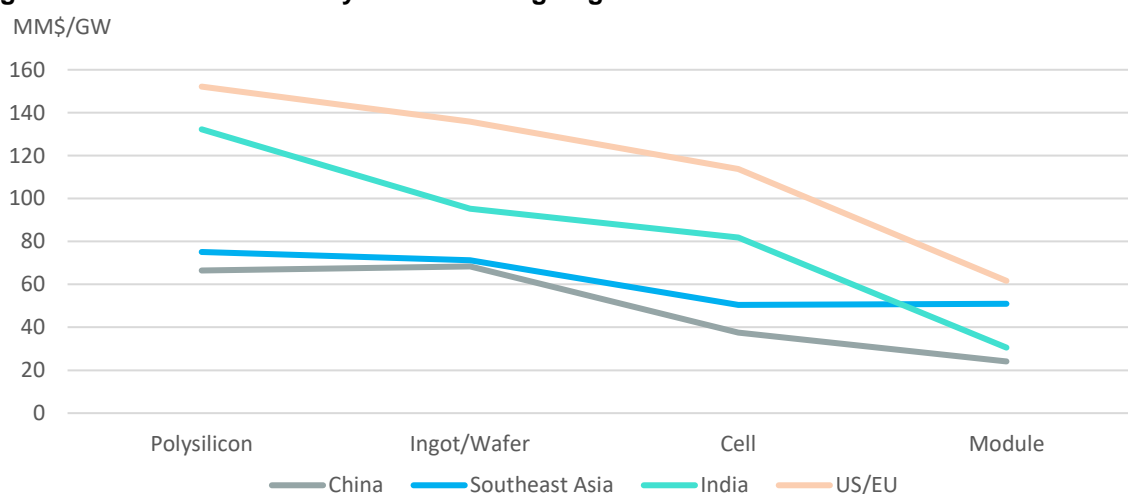


Figure 8: Factory Gate Minimum Sustainable Price for Global Solar PV Supply Chain, 2022



Source: NREL (2022)

Figure 9: Investment Costs by Manufacturing Segment



Source: IEA (2022)

The upstream sector is capital-intensive and requires a much longer lead time for development. In contrast, the downstream sector, especially the module assembly, demands much lower upfront costs and a shorter lead time. As a result, Chinese producers opted to invest in limited downstream capacity overseas primarily for tariff-jumping purposes. Chinese producers established approximately 15 per cent of their module production capacity in Southeast Asia to supply the US market, while the majority of the supply chain is based in China.⁹⁸ Even though Southeast Asia is a secondary investment choice after China by dint of cost and efficiency, Chinese industry stakeholders frequently expressed frustrations about the administrative complexities of doing business, frequent power cuts, and a lack of upstream supplies in the region.⁹⁹

⁹⁸ Author's calculation based upon data of 2022

⁹⁹ 36 Kr (2023). Photovoltaic going to Vietnam: a blessed place for large factories, Waterloo for small factories? <https://36kr.com/p/2558964134354820>

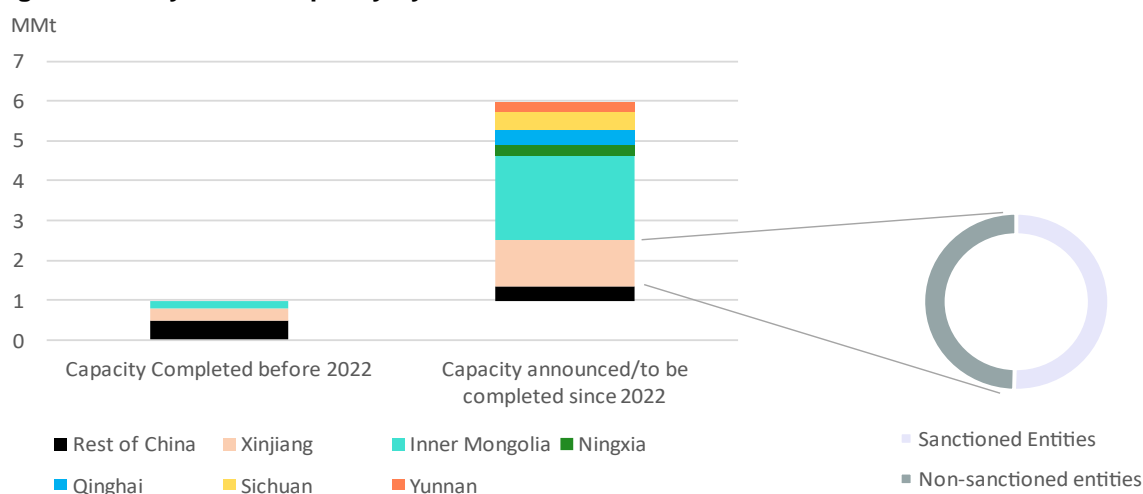


5.2 Reglobalisation by the Watts

5.2.1 Sanctions and Upstream Adjustment

US sanctions are already impacting China's upstream supply chain. For instance, an analysis of polysilicon projects completed or announced since December 2021 when the UFLPA was implemented indicates a strategic pivot: Inner Mongolia overtook Xinjiang as the preferred investment destination, despite the reduction of power subsidies being offered to polysilicon manufacturers in the former region.¹⁰⁰ In Xinjiang, approximately half of the new or planned capacity is attributed to already sanctioned entities. Yunnan, Sichuan, and Qinghai also emerged as alternative investment destinations. These data points may suggest that sanctions are discouraging new investments in Xinjiang, reflecting a shift in the geographical concentration of China's polysilicon production (Figure 10).

Figure 10: Polysilicon Capacity by Province¹⁰¹



Source: Corporate Announcements; Author's Calculation

5.2.2 US Reshoring Efforts

Since 2020, concepts such as 'friend-shoring'— the reshoring of manufacturing capacity to and from allied nations to reduce import reliance on geopolitical rivals — have gained significant traction in Western capitals.¹⁰² As the industry witnessed a slew of capacity expansion worldwide, this section assesses the scale of supply chain readjustment by comparing the existing and planned capacity. It demonstrates that the intensified tariffs and industrial policies are already having a considerable impact on reshaping global supply chains. The US successfully attracted the bulk of Western capital flows with the generous IRA subsidies while Chinese companies doubled down on overseas investment in Southeast Asia and began to offshore production to the Middle East.

The IRA notably catalysed a robust manufacturing reshoring on American soil, particularly within the downstream sectors. As of October 2024, the US possesses 45.1 GW of operational module capacity and an additional 37.3 GW of capacity in the pipeline, which combined is expected to position the US as the second-largest module producer globally by 2025, marking a substantial increase from a mere operating capacity of 7 GW before the passage of the IRA (Figure 11).¹⁰³

¹⁰⁰ The Paper (2022). Observation | How much impact does the preferential electricity price in Inner Mongolia have on photovoltaic manufacturing enterprises? https://www.thepaper.cn/newsDetail_forward_19875298

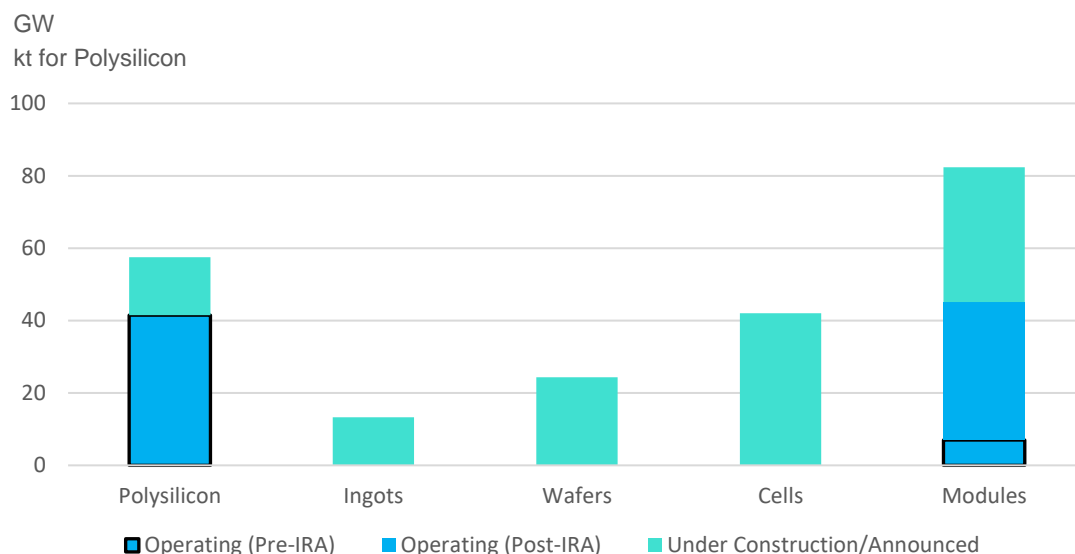
¹⁰¹ Announcements are subject to cancellation in the future; Existing capacity is subject to retirement; Data retrieved in January 2024 based on corporate announcements

¹⁰² In June 2021, the White House for the first time identified friend-shoring or ally-shoring as a tool to reduce supply chain vulnerability in a 100-day supply chain resilience review report. See <https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf>

¹⁰³ SEIA (2024). Solar and Storage Supply Chain Data, <https://seia.org/research-resources/solar-storage-supply-chain-dashboard/>



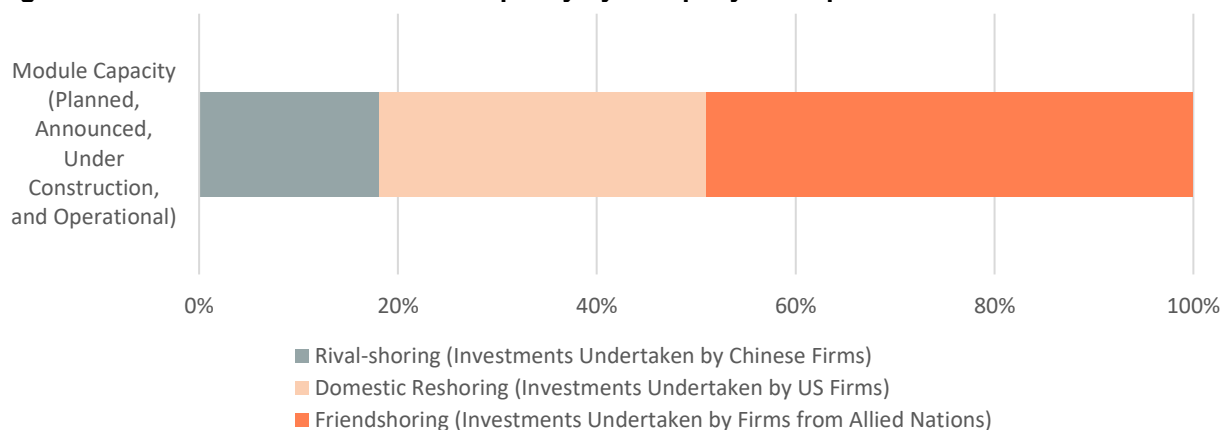
Figure 11: US Solar PV Manufacturing Capacity by Segment



Source: SEIA (2024)

An analysis of the post-IRA capacity additions by company headquarters indicates that Western firms spearhead these reshoring efforts (Figure 12). Six of the eight participating countries are members of the International Energy Agency (IEA), a Western energy security alliance.¹⁰⁴ ¹⁰⁵ The other two countries, India and Jordan, also maintain special ties with the US, as a Major Defence Partner and a Major Non-NATO Ally, respectively.¹⁰⁶

Figure 12: Share of Post-IRA Module Capacity by Company Headquarters¹⁰⁷



Source: SEIA (2023)

Despite the IRA's explicit target of reducing reliance on Chinese supplies, Chinese companies still play an important role, contributing ~20 GW of the planned capacity. These investments are often made in the form of joint investments with US companies that sought technology and expertise from leading

¹⁰⁴ The six countries are Canada, Italy, Norway, South Korea, Switzerland, and Turkey

¹⁰⁵ IEA (2024). History From oil security to steering the world toward secure and sustainable energy transitions. <https://www.iea.org/about/history>

¹⁰⁶ SEIA (2023). Solar and Storage Supply Chain Data. The data series was retrieved in December 2023 and revised by the author. Canadian Solar was counted as a Chinese company as most of its production capacity is based in China even though it is headquartered in Canada. Joint projects between a US company and its foreign partner are counted as projects delivered by a foreign company

¹⁰⁷ SEIA (2023). Subject to the same conditions described in the last reference



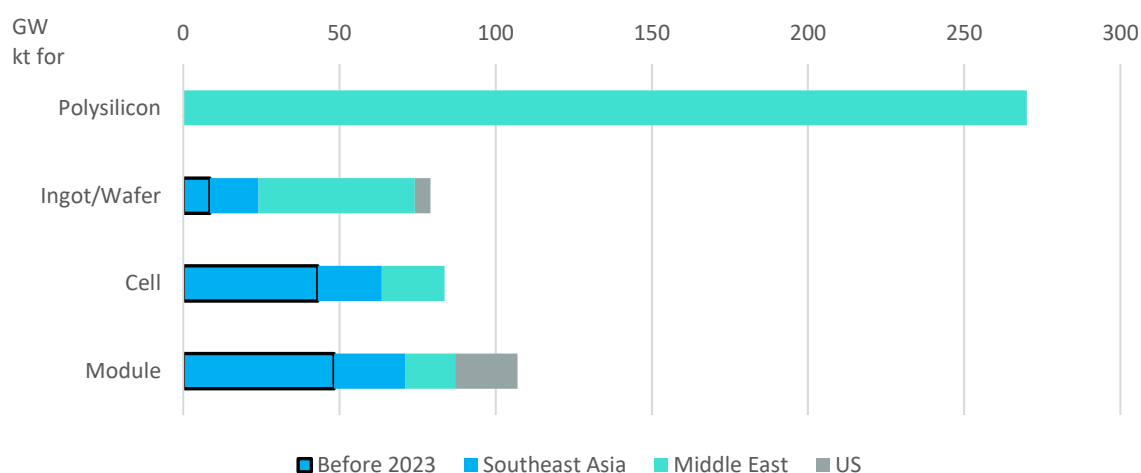
Chinese suppliers to help build up capacity. The phenomenon, described by the author as ‘rival-shoring’, is driven by both incentives and pressure from US policies: Major Chinese suppliers eyed IRA subsidies while leveraging a ‘Made in the USA’ labelling as a strategic hedge against the pending tariff risks.¹⁰⁸

The author’s interviews with multiple Chinese corporate strategists reveal that geopolitical risks create significant uncertainties for rival-shoring. Nearly all the announced capacity is in the module sector, a capital-light and tentative approach intended to gauge the feasibility of accessing IRA tax credits. In addition, most interviewees indicated that the 2024 US presidential election outcome and the incoming administration’s policies could impact their final investment decisions.

5.2.3 Chinese Offshoring Intensifies

Chinese companies are also actively adjusting their global footprints. Before 2023, Chinese companies operated less than 50 GW of cell and module capacity in Southeast Asia for tariff-jumping purposes. Since then, announced overseas capacity has far exceeded that number, with investment also flowing into upstream segments for the first time. As of July 2024, the capacity announced includes 270 kt for polysilicon, 70.6 GW for ingot/wafers, 40.5 GW for cells, and 58.8 GW for modules.¹⁰⁹ China’s offshoring effort is characterised by accelerated investments in Southeast Asia and the Middle East, with a heavier emphasis on upstream investments to complement its existing overseas supply chains (Figure 13).¹¹⁰

Figure 13: Chinese Outbound Investments by Market Segment and Region



Source: Corporate Announcements and Media Outlets

Chinese companies’ intensified commitments to Southeast Asia, especially increased midstream investments, mirror the more complex trade barriers imposed by the US. A moderate portion of the investments is directed to the ingot and wafer sectors. This is likely to take advantage of the circumvention tariff exemptions given to modules produced in Southeast Asia without using Chinese wafers. All the future capacity in Southeast Asia is slated for Malaysia, Thailand, Indonesia, Vietnam, and Cambodia, countries that notably have maintained robust relations with China.

The Middle East, led by Saudi Arabia, the UAE, and Oman, have emerged as another prime destination in China’s outbound investment strategies (Table 3). Announced projects span the entire value chain, with several projects under plans aiming to establish vertically integrated operations. Multiple industry practitioners indicated that these efforts are designed to forge a supply chain completely outside of

¹⁰⁸ Huxiu (2023). Behind Chinese photovoltaic enterprises going to the United States to build factories: helplessness, temptations and traps. <https://m.huxiu.com/article/2078533.html>

¹⁰⁹ Author’s calculation

¹¹⁰ Xinhua (2024). The transformation of photovoltaic products to ‘made globally, sold globally’ <http://www.news.cn/tech/20240131/d89101746ccc4d85946fc0aba1e8427d/c.html>



China serving the Middle East, the US, and other markets that may be subject to tariff risks.¹¹¹ The influx of capital into the Middle East is also driven by concessional policies for foreign investment, regulatory requirements on supply chain localisation, and an ambitious energy transition underway.^{112 113 114} It also underlines the growing strategic alignment between the Gulf and China, marked by a substantial increase in bilateral investment flows.^{115 116}

Table 3: Announced Chinese Solar PV Manufacturing Projects in the Middle East

Company	Country	Polysilicon (kt)	Ingot/Wafer (GW)	Cell (GW)	Module (GW)
TCL Zhonghuan	Saudi Arabia		20		
Trina	UAE	50	30	5	5
CGL	UAE	120			
TaleSun	Turkey				1
Shuangliang New Energy Equipment	Oman	100			
Jinko	Saudi Arabia			10	10
Drinda	Oman			5	

Source: Corporate Announcements

5.3 Technology Race

The technological landscape has almost completely reversed over the last decade. China now leads in the technologies of almost all solar components and manufacturing equipment.^{117 118} The NREL cell efficiency record chart shows that Chinese companies and research institutions managed rapid catch-ups with and surpassed the global efficiency records of many leading technologies.¹¹⁹ As the commercialisation of innovations also depends on the ability to scale production as well as a robust demand to bend the cost curve, China is already on track to achieve an unprecedented pace of technological upgrades to its existing capacity over the next five years while the West struggles with the pace of reshoring. The dominant technology in 2023, PERC cells, is expected to hold less than 10 per cent of the market share in 2026.¹²⁰ In contrast, the planned US cell production capacity — comprising both PERC and TOPCon technologies — is still in the pipeline and expected to be completed in 2025 (Figure 14). While new US tariffs against China's tariff-jumping practices can take years in legal proceedings to take effect, Chinese solar products may already be generations ahead of the fully US-manufactured products then, with significant efficiency improvements and cost reductions expected in the next five years.

¹¹¹ Securities Times (2023). TCL Zhonghuan will invest in the construction of Saudi Arabia's first photovoltaic industry chain. <http://www.stcn.com/article/detail/1007134.html>

¹¹² Sina Finance (2023). From signing large orders to building factories, photovoltaic industry chain enterprises aim at 'Middle East opportunities.' <https://finance.sina.com.cn/chanjing/cyxw/2023-09-22/doc-imznpfew8444606.shtml>

¹¹³ Caixin (2023). Saudi Public Investment Fund: Saudi Arabia is accelerating the localisation of renewable energy. <https://www.caixin.com/2023-11-03/102124227.html>

¹¹⁴ 36Kr (2023). The investors rushed to the Middle East one after another. Why are China's photovoltaics industry crazy about the Middle East? <https://36kr.com/p/2547149108158338>

¹¹⁵ Caixin (2023). In Depth: Chinese Firms Flock to Saudi Arabia in Middle East Gold Rush. <https://www.caixinglobal.com/2023-05-04/in-depth-chinese-firms-flock-to-saudi-arabia-in-middle-east-gold-rush-102042468.html>

¹¹⁶ Bloomberg (2024). Cash-Rich Mideast Firms Drive Record Investment Into China. <https://www.bloomberg.com/news/articles/2024-09-25/cash-rich-middle-east-firms-drive-record-investment-into-china>

¹¹⁷ European Commission (2023)

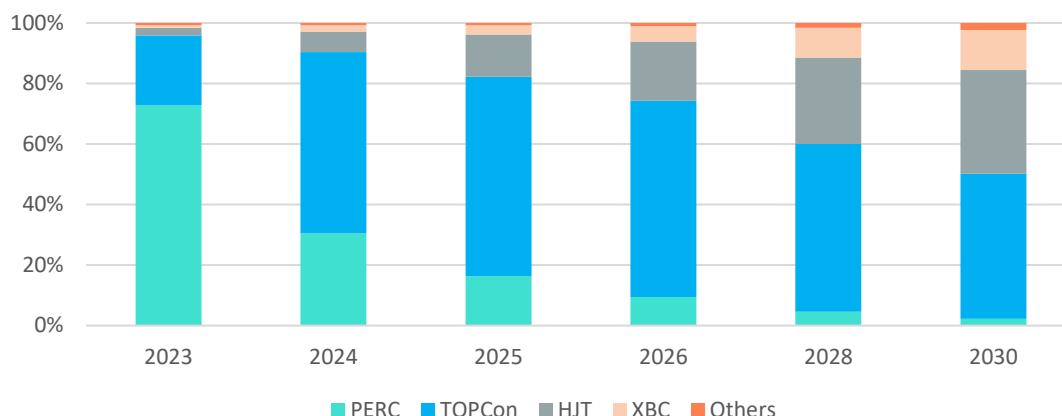
¹¹⁸ CPIA (2024) [Annual Report] Chapter 9: In 2023, the scale of China's photovoltaic equipment industry increased by nearly 70 per cent year-on-year, and the equipment in all major components was basically localized. https://mp.weixin.qq.com/s/thi34fvxVOXhHN-X_XhsZA

¹¹⁹ NREL (2024) Best Research-Cell Efficiency Chart. <https://www.nrel.gov/pv/cell-efficiency.html>

¹²⁰ CPIA (2024) Roadmap for the development of China's photovoltaic industry (2023-2024)



Figure 14: Technological Makeup of Cell Capacity in China



Source: CPIA (2024)

Increased trade tensions could also cost the US access to leading technologies and critical manufacturing equipment from China, leaving many reshoring projects vulnerable. Even as the US ramped up Section 301 tariffs on Chinese solar products in 2024, it explicitly acknowledged the difficulty of replacing Chinese solar manufacturing equipment by granting them tariff exemptions.¹²¹ However, Beijing may preempt this by cutting access to advanced technology. In December 2022, the Chinese Ministry of Commerce proposed significant amendments to its export control list, specifically targeting technologies for producing large solar wafers, black silicon materials, and both monocrystalline and multicrystalline silicon ingots.¹²² This move may reflect Beijing's concerns that cross-border technology transfers could cost China's technological lead, or it could be a countermeasure to the increasingly stringent US export controls on advanced technology.¹²³

6. Overcapacity: A Terawatt-sized Bubble

In 2024, nearly every segment of China's solar manufacturing is approaching or already exceeding an unprecedented 1 TW/y capacity — doubling the IEA's most ambitious forecast for solar installations in 2024 (Figure 15).¹²⁴ The sharp increase, despite intensified global trade tensions, may result from primarily domestic developments driven by a capital and technology rush. The industry is undergoing a rapid transition from mainstream PERC technology toward TOPCon capacity, a higher-efficiency and cost-competitive cell technology. Companies are also aggressively pursuing economies of scale and vertical integration to crowd out competitors from the market, enabled by substantial investments fuelled into the sector.¹²⁵ ¹²⁶ As of July 2024, the Chinese module price fell below \$0.1/W, a record low that even leading Chinese suppliers struggle to maintain profitability.¹²⁷ ¹²⁸ The overcapacity crisis is poised to wipe out many domestic players with higher cost bases, leading to a significant industry consolidation.

¹²¹ USTR (2024). Notice of Modification: China's Acts, Policies and Practices Related to Technology Transfer, Intellectual Property and Innovation. [https://ustr.gov/sites/default/files/Section%20301%20Modifications%20Determination%20FRN%20\(Sept%2012%202024\)%20\(FINAL\).pdf](https://ustr.gov/sites/default/files/Section%20301%20Modifications%20Determination%20FRN%20(Sept%2012%202024)%20(FINAL).pdf)

¹²² Ministry of Commerce (2022). Notice on the revision of the 'Catalogue of China's Export Restricted Technologies' for Public Comments, <http://fms.mofcom.gov.cn/article/tongjiziliao/202212/20221203376696.shtml>

¹²³ Securities Times (2023). The mystery and impact of photovoltaic technology export restrictions. <http://www.stcn.com/article/detail/783294.html>

¹²⁴ The IEA forecast the solar installations in 2024 to be around 500 GW in the accelerated case in its *Renewables 2024* report. See <https://iea.blob.core.windows.net/assets/45704c88-a7b0-4001-b319-c5fc45298e07/Renewables2024.pdf>

¹²⁵ 36Kr (2023) The three major promoters of photovoltaic production capacity leap forward. <https://36kr.com/p/2379390816972039>

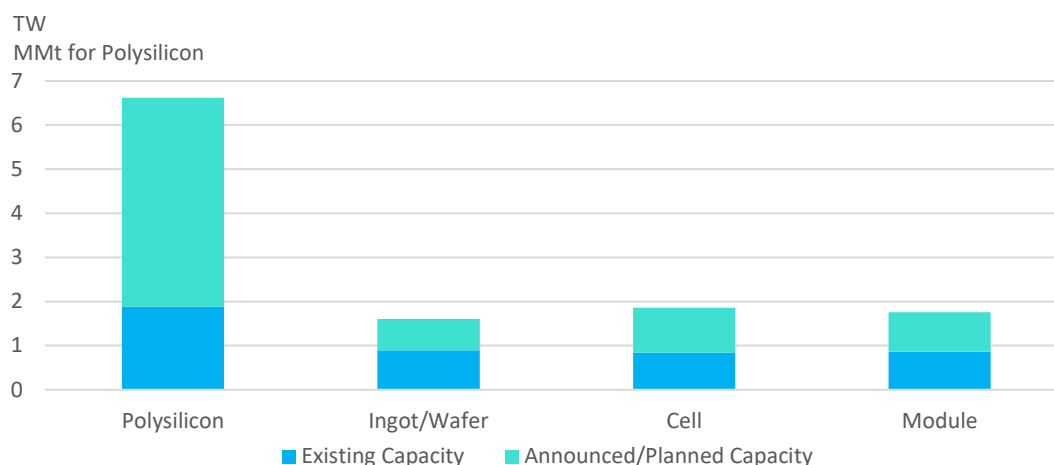
¹²⁶ Caixin (2023). Cover Story: Are Chinese Solar Giants Flying Too Close to the Sun? <https://www.caixinglobal.com/2023-09-04/cover-story-are-chinese-solar-giants-flying-too-close-to-the-sun-with-massive-expansion-plans-102099978.html>

¹²⁷ IEA (2024)

¹²⁸ In March 2024, Longi, the world's largest module producer, began layoffs due to overcapacity and price crunch. See: <https://www.reuters.com/technology/chinas-longi-says-it-will-lay-off-about-5-employees-2024-03-19/>



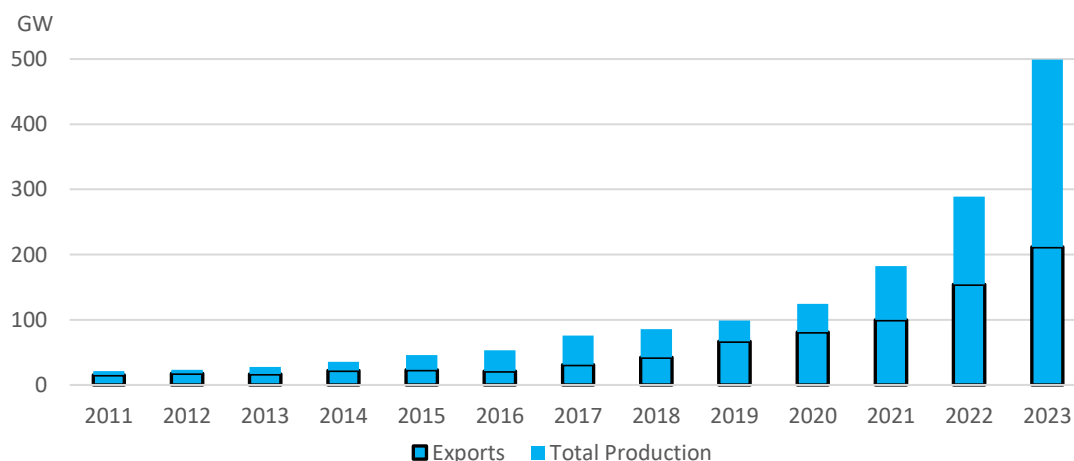
Figure 15: End-2023 Chinese Manufacturing Capacity by Segment^{129 130}



Source: CPIA, International Energy Website (2024), Author's Calculation Based on Historical CPIA Data Referenced in Media Reports

Exports in the past ten years have accounted for 40-60 per cent of China's total production (Figure 16). Even though China installed over 200 GW of solar capacity in 2023, over half the global market for PV and more than double what China installed the entire year prior, the prevailing industry consensus views international expansion as the only viable solution to absorb China's massive overcapacity.^{131 132} For the top five module manufacturers, overseas revenues already contribute over half of their total revenue as they have prioritised their globalisation strategy (Figure 17). The tariff-protected US market is even the most important destination for Chinese producers, as it is currently the only market with a price significantly above their costs. Consequently, China's domestic overcapacity has significant spillovers on the global solar industry.

Figure 16: Chinese Module Production and Exports, 2011-2023^{133 134}



Source: Energy Magazine (2024); Caixin (2023)

¹²⁹ International Energy Website (2024). Wang Bohua, Honorary Chairman of the Photovoltaic Industry Association: 190-220GW of new installed photovoltaics in China in 2024. <https://m.in-en.com/article/html/energy-2330796.shtml>

¹³⁰ Existing capacity is subject to retirement and announced/planned capacity may not be exhaustive

¹³¹ 21 Economy (2023). 110 GW was added in August. What is the upper limit of new photovoltaic installations this year? <https://www.21jingji.com/article/20230923/herald/f007b0cb7ce0aef2f34502b933c4bc10.html>

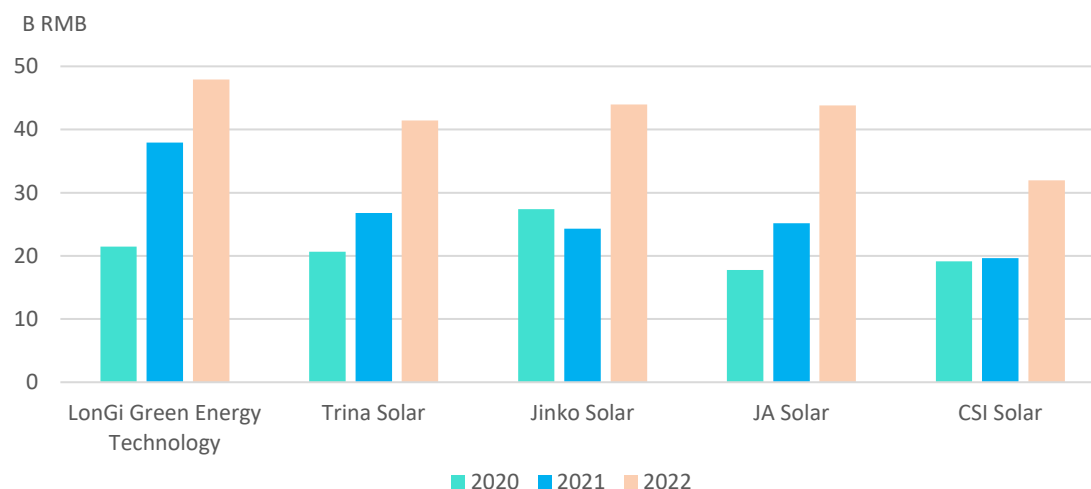
¹³² Yicai (2023). The trend of photovoltaic globalisation is difficult to change, and industry giants are hotly discussing the challenges of offshoring production capacity. <https://m.yicai.com/news/101818496.html>

¹³³ Energy Magazine (2024). 1.75 trillion yuan! China's photovoltaics hit a new high! <https://www.inengyuan.com/light/12322.html>

¹³⁴ Reuters (2024). China solar industry faces shakeout, but rock-bottom prices to persist. <https://www.reuters.com/business/energy/china-solar-industry-faces-shakeout-rock-bottom-prices-persist-2024-04-03/>



Figure 17: Overseas Revenue of Top Five Module Manufacturers



Source: Corporate Financial Reports

7. Made in China, Borne by the World

The 2010s trade war resulted in two distinct markets in the US and EU. The US continued to strengthen its tariff regime, relatively segmenting its solar market from the ROW by paying a significant premium for every module installed. Its domestic industry, however, continued to struggle to scale and compete with tariff-jumped imports. The industry did not revive until the IRA introduced large-scale subsidies. In contrast, the EU chose a different path, prioritising solar installations by lifting the AD/CVD in 2018. The decision led to a further decline in the market share of European manufacturers, leaving Europe as the largest open market for cheap and abundant Chinese exports.¹³⁵

Today's supply imbalance makes it an even more challenging environment for Western manufacturers. In 2011, when the initial trade war began, China's module production capacity was between 30 and 40 GW as the ROW had a total capacity of less than 20 GW.^{136 137} In 2024, the West still struggles to exceed the double-digit GW range while China's capacity is surging past 1 TW.

It is no coincidence that as of October 2024, European manufacturers are experiencing significant layoffs, debt restructuring, and bankruptcies. The European Commission has so far been slow in responding to industry appeals for more trade barriers or large-scale bailouts.¹³⁸ In contrast, Washington is further tightening its tariff regime through multiple avenues — lifting exemptions, addressing tariff-jumping, and hiking existing tariffs — setting the stage for a renewed trade war.^{139 140 141}

The expected influx of loss-making Chinese solar products in the years to come will likely reinforce the urgency for the US to sustain its existing policy approach of subsidising domestic manufacturing and restricting imports. Tariffs will be necessary to protect nascent industries and subsidies are essential to bridge the cost gap with Chinese products. It will be a costly and challenging game to preserve the subsidy and tariff regime, in addition to successfully nurturing a competitive industry. For countries that fail to implement robust trade defences — or even those too slow to do so — Chinese supplies could

¹³⁵ European Commission (2023)

¹³⁶ National Energy Administration (2012). The photovoltaic industry prepares for the domestic market development. http://www.nea.gov.cn/2012-02/09/c_131400162.htm

¹³⁷ US Energy Information Administration (2015). Global solar photovoltaic manufacturing production slows in recent years. <https://www.eia.gov/todayinenergy/detail.php?id=22912>

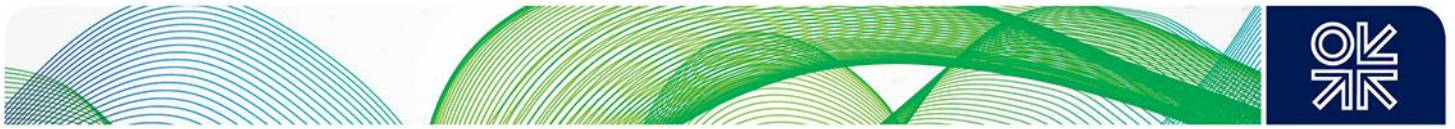
¹³⁸ European Commission (2024)

¹³⁹ Reuters (2024). US solar panel makers seek import tariffs to protect new domestic factories.

<https://www.reuters.com/business/energy/us-solar-panel-makers-see-new-tariffs-protect-domestic-factories-2024-04-24/>

¹⁴⁰ White House (2024)

¹⁴¹ USITC (2024)



end up wiping out their manufacturing industries for the foreseeable future. However, from a climate perspective, a glut of cost-effective Chinese modules is a significant boon to the ROW in urgent need of an accelerated energy transition.

The development of the solar industry today is becoming increasingly shaped by policy interventions and corporations respond accordingly. Western companies may opt to relocate to the US to shield themselves from the cut-throat competition from Chinese companies.¹⁴² In contrast, Chinese companies, facing a more complex tariff regime, will continue pursuing friend-shoring in a global market with a massive installation demand. The dividing line between the Western and Chinese PV sectors is not clear-cut: As China leads in PV technology, Western firms are exploring creative partnerships such as joint ventures to access top-performing cells while navigating geopolitical headwinds. Chinese firms may also continue rival-shoring incentivised by the high premium in the US market.

A reshoring completely driven by policy interventions also carries its risks. As the profitability of US-produced modules completely hinges on subsidies and tariffs, a potential repeal of the IRA subsidies could erase the financial viability of many planned reshoring projects. Even though the IRA sets a subsidy phaseout deadline of 2032, companies were responding to immediate risks and considering cancelling US investments in the event of a second Trump administration.¹⁴³ Consequently, policy uncertainties could significantly hinder the pace and magnitude of reshoring. In a similar vein, the intensification of US tariffs against imports from Southeast Asia is also aborting Chinese investments in Southeast Asia.¹⁴⁴

Conclusion

Amidst vigorous discussions in the West regarding trade actions to counter China's overcapacity and efforts to enhance supply chain resilience, trade barriers and industrial policies became a favoured choice among many major economies. This paper examines the efficacy of such policy designs by first reviewing the successes and failures of Western trade actions initiated in the early 2010s: The US failed to boost domestic manufacturing due to frequent tariff-jumping practices by Chinese companies as well as its inability to match the speed of Chinese innovation and cost reductions. The EU gave up its tariffs regime as it faced a greater priority of decarbonisation than preserving tariffs.

Today, Western policymakers still face the same challenges on tariffs. Even with the unprecedented subsidies provided by the IRA, Washington may have to acknowledge that China is innovating and scaling at a much faster pace, rendering US-manufactured PV modules uncompetitive in the global or even the domestic market. In addition, many of the reshoring projects will be vulnerable if Washington fails to sustain a robust subsidy and tariff regime. Brussels may have to concede that it lost the battleground in solar PV manufacturing, as it lacks the political and economic capacity to launch similarly substantial market interventions and trade restrictions. With the NZIA's target of 40 per cent self-sufficiency in manufacturing becoming increasingly unattainable, Brussels needs to set realistic strategies to preserve some domestic manufacturing capacity while accepting its heavy import reliance on China.

Chinese policymakers face the dual challenge of continuing to promote solar PV installations while addressing supply-side overcapacity. Unlike previous episodes of overcapacity in heavy industries, where government interventions often involved direct executive actions to retire state-owned capacity, the solar PV sector is dominated by private companies, requiring unique, innovative, and prompt policy responses.

¹⁴² On 17 January, 2024, Meyer Burger, a leading Swiss solar manufacturer, announced the decision to close its loss-making module factory in Germany and focus on investments in the US market instead. See <https://www.meyerburger.com/en/newsroom/artikel/european-market-distortion-impacts-2023-financials-meyer-burger-to-focus-on-manufacturing-footprint-in-the-us-and-prepare-for-closure-of-german-module-manufacturing>

¹⁴³ Reuters (2024). Trump effect in clean-tech sector deepens angst in Europe's boardrooms. <https://www.reuters.com/sustainability/boards-policy-regulation/trump-effect-clean-tech-sector-deepens-angst-europes-boardrooms-2024-07-29/>

¹⁴⁴ 36Kr (2024). The PV industry is in distress. <https://www.36kr.com/p/2814645896399113>



While the early 2010s trade war only shifted a modest proportion of Chinese downstream capacity to Southeast Asia, the current trade war is offering a glimpse of a potential economic decoupling underway. China is committing significant friend-shoring investments to Southeast Asia and the Middle East while the US is attracting a surge of inbound friend-shoring investments from Western allies. However, many of these policy-driven investments may yet be cancelled due to significant policy uncertainties. These diverging capital and trade flows represent a departure from the previous economic norms, where global supply chains were configured solely on cost and efficiency optimisation.

Despite the global imperative for decarbonisation, increasing government interventions are set to further fragment the global solar PV supply chain. It will add inefficiency, inflation, and complexities to an already challenging energy transition.