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BUILDING A GREEN, FAIR AND RESILIENT SOLAR PV SUPPLY CHAIN

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Project Europe 2050

ANALYSIS

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Preface by the editors

Europe stands at a critical juncture in its energy strategy, facing opportunities and challenges that demand a nuanced approach. It currently has a window of opportunity to both diversify its energy supply and strengthen its independence through new globalized partnerships. However, this transition is not without its risks, given the existing constraints of Europe's energy infrastructure and its geographic location.

The opportunities and challenges both also concern Europe’s green strategy alike. Since the onset of Russia’s war against Ukraine, the disruption of pipeline-bound gas trade has led to a resurgence of CO2-intensive fuel sources like lignite, while natural gas consumption has been scaled down. Simultaneously, there is a growing consensus on the need to prioritize renewable energy generation, with initiatives like the EU Green Deal. However, Europe faces substantial differences among member states in their energy and climate strategies, coupled with infrastructural and economic bottlenecks. This divergence still leaves Europe struggling to make a decisive shift toward a more sustainable energy infrastructure.

When it comes to specific components of this critical infrastructure, such as solar panels, which are the focus of this study, China's monopolies in the renewable energy sector pose a unique challenge of its own. Whilst a deviation of supply chains for renewable power sources may decrease political coercion risks, China's dominance in the production of renewable energy technologies, which also include wide-ranging capacities in the mining, smelting, and refinement industries that Europe does not have, creates a densely integrated power lever that continues to keep Europe under pressure even if it successfully de-risks in single key technologies.

That said, re-globalising supply chains for key technologies remains the way to go. Not only does Europe depend on imports that it can no longer rely on China to provide exclusively, but because its geographical positioning creates specific vulnerabilities, namely critical trade routes like the Suez Canal and the Strait of Hormuz, which expose it to potential disruptions of its international trade routes in general, not only for specific tech components. A diversification of stable collaborations, that are not only reliable in the long-term, but also geographically distributed throughout the globe, therefore helps alleviate a risk that is much greater than that of Europe’s energy transition alone.

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Executive Summary

→ **The global solar PV supply chain is deeply dependent on the People's Republic of China (PRC):** The PRC's global market share across the whole solar PV supply chain exceeds 80%, and stretches to over 97% at the silicon wafers stage of production.

→ **Dependence on PRC solar undermines energy security and puts net zero targets at risk:** The PRC has a track record of weaponizing its dominance of critical supply chains to achieve geo-political goals. This could undermine current targets to triple EU solar capacity by 2030, putting at risk a major component of the EU's future energy supply and restricting its strategic autonomy.

→ **PRC solar sanctions could impose major costs on EU energy bills:** Our modelling shows that the PRC bans on solar exports, for example, precipitated by geopolitical fallout following a conflict across the Taiwan strait, could cost the EU €46.18 billion by 2030 in increased energy bills, or €103 per capita. This would also provide a major setback to the EU's climate ambitions, with new solar installations falling far behind planned targets.

→ **The EU needs a robust solar strategy:** Building alternative solar PV supply chains outside of the PRC is challenging due to high capital costs, energy intensive production and extended lead times on new production facilities. This paper proposes an EU solar strategy based on three core principles:

- ***De-risking new solar installations:*** The EU should incentivise energy providers to diversify their supply chains by introducing minimum standards of supply chain resilience as a precondition for government support. Standards should ensure that EU providers are not overly reliant on the PRC's supply chain and have effective contingency plans in the event of supply chain disruption.

- ***Scaling up EU solar production:*** The EU has scalable capacity at most stages of the solar PV supply chain. Raising ESG and supply chain resilience requirements for new solar installations, as well as guaranteeing EU wide funds for new solar manufacturing projects, will help derisk the EU's solar PV supply.

- **Diversifying the global supply chain:** Countries in Latin America and South-East Asia are better placed than Europe to compete with the PRC's economies of scale and low energy costs – particularly at the earlier stages of the solar PV supply chain. The EU should use the Global Gateway and the G7's Partnership for Global Infrastructure and Investment to raise the necessary capital investments at key stages of the supply chain.

1. The PRC's role in the solar PV supply chain

1.1 Introduction

The last decade has seen a major reorientation of global solar PV supply chains. While once dominated by the US, Japan and Europe, firms belonging to the People's Republic of China (PRC) have emerged as today's preeminent market leaders. The PRC is the world's leading manufacturer at each stage of the solar PV supply chain, with its global market share across the whole value chain exceeding 80%.[1]

This surge in the PRC's production capacity is part of an intentional, decades-long push by the PRC government. The State Council named solar a "strategic emerging industry" in 2010 and has since promoted the sector with generous subsidies and fast-tracking the myriad of necessary bureaucratic procedures from land acquisition to industrial permits.[2] The PRC has invested over USD 50 billion in new PV supply capacity since 2011 – ten times more than Europe across the same period.

This section unpacks the PRC's dominance at each stage of the solar PV supply chain, analysing how and why PRC firms are outperforming their international peers.

1.2 Unpacking the solar PV supply chain[3]

The vast majority of solar panels are made up of the polysilicon-based crystalline silicon cells, with the remainder being predominantly thin-film cadmium telluride cells. This section will focus predominantly on polysilicon based panels, which account for over 95% of global production.[4]

The solar PV supply chain can be structured into six distinct stages. The process begins with the extraction and refinement of raw materials. Crucially, quartz rock (silica; SiO2) is mined from the earth and reduced to produce metallurgical grade silicon. Metallurgical grade silicon (MGS) is further refined to produce solar grade polysilicon, with a higher level of silicon purity. The next phase sees polysilicon turned into large cylinders (called ingots) which in turn are precision sliced into thin wafers. These early stages of the production are energy intensive and require large amounts of electricity. At the later stages, wafers undergo a sophisticated treatment regimen culminating in the creation of photovoltaic cells, capable of harvesting and converting sunlight into electrical energy. Finally, individual cells are assembled into panels by being encased within protective materials, resulting in fully-assembled solar panels.

Figure 1 | Production of solar panels

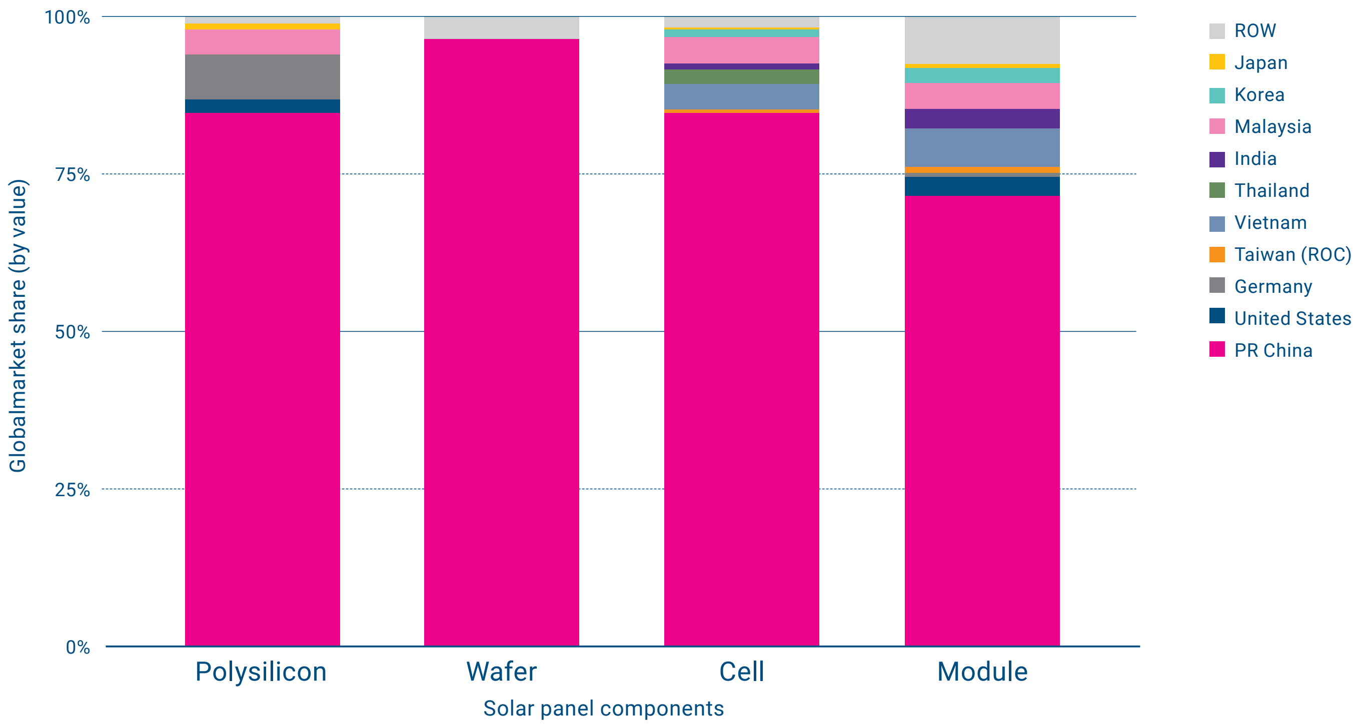
1 International Energy Agency, Special Report on Solar PV Global Supply Chains (OECD, 2022), 7, https://doi.org/10.1787/9e8b0121-en.

2 US-China Business Council, 'China's Strategic Emerging Industries: Policy, Implementation, Challenges, & Recommendations' (US-China Business Council, March 2013), https://www.uschina.org/sites/default/files/sei-report.pdf.

3 ConstantineShovel, *Comb Quartz from Montiferru*, 23 February 2019, 23 February 2019, Own work, https://commons.wikimedia.org/wiki/File:Comb_quartz_from_Montiferru.jpg; Hi-Res Images ofChemical Elements, *Pure Silicon, Rough Surface, 2 Grams, Size 2 Cm*, 20 December 2009, 20 December 2009, http://images-of-elements.com/silicon.php, https://commons.wikimedia.org/wiki/File:Pure_Pure_silicon,_rough_surface,_2_grams,_size_2_cm.jpg; Bjorn Wylezich, *High Purity Polycrystalline Silicon from Freiberg, Germany Isolated on White Background Stock Photo*, accessed 30 October 2023, https://stock.adobe.com/uk/images/high-purity-polycrystalline-silicon-from-freiberg-germany-isolated-on-white-background/191755963; frog, *Silicon Ingot Stock Illustration*, accessed 30 October 2023, https://stock.adobe.com/uk/images/silicon-ingot/47721432; Oregon Department of Transportation, Wafers on the Conveyor, 24 February 2009, 24 February 2009, *Wafers on the conveyor* Uploaded by Smallman12q, https://commons.wikimedia.org/wiki/File:Wafers_on_the_conveyor_(3346902863).jpg; Albert Lozano-Nieto, *Solar Cell Research Stock Photo*, accessed 30 October 2023, https://stock.adobe.com/uk/images/solar-cell-research/1000792.

4 International Energy Agency, Special Report on Solar PV Global Supply Chains, 13.

Figure 2 | Global market share of polysilicon, wafer, cell and module by value



Data source: IEA (2022), Solar PV Global Supply Chains, IEA, Paris. Reproduced with permission.

Metallurgical-grade silicon, polysilicon and raw materials

The PRC dominates both global MGS and solar grade polysilicon production, producing approximately 80% of the world's MGS and.[5] Polysilicon, the next stage in the value chain, makes up 35% - 45% of the average value of the finished solar panel.[6] The PRC is also the leader at this stage, being responsible for over 80% of solar-grade polysilicon in 2021. The PRC's market share is expected to increase further as hundreds of thousands of metric tonnes in additional capacity are slated to come online.[7]

The concentration of metallurgical grade silicon and polysilicon production in the Xinjiang Uyghur Autonomous Region (XUAR) raises significant ethical concerns. Approximately 35% of global polysilicon production and 44% of the PRC's total MGS output is produced in the XUAR.[8] State-sponsored forced labour is endemic to the XUAR and is present in practically all industrial activity in the region. Since 2016, the PRC government has interned upwards of one million Uyghurs and other minority ethnic and religious groups in the XUAR in so-called 'vocational training centres', with many detainees required to work at commercial factories built within or near the detention facility. Additionally, the PRC government has enlisted 2.6 million Uyghurs and other minority groups in 'labour transfer schemes' which send workers to farms and factories in the region or elsewhere in the PRC.[9] MGS and polysilicon produced in the region are also used by solar manufacturers elsewhere in the PRC, meaning that forced labour concerns are not restricted to the XUAR alone. While some manufacturers have shifted their polysilicon procurement to Inner Mongolia and other regions in the PRC, the MGS used in the production of polysilicon is still likely to be from XUAR.

Ingots and Wafers

Wafers are the most geographically concentrated segment of the solar PV supply chain, with the PRC holding 96.8% of global production capacity in 2022.[10] This dominance means that all subsequent stages of the supply chain are heavily dependent on the PRC's wafer production. This trend looks set to continue, with the PRC wafer manufacturers announcing plans to add a further 300 GW of capacity by 2024.[11]

5 'Everything You Need to Know about China's Industrial Silicon Market_SMM | Shanghai Non Ferrous Metals', SMM, 6 February 2023, https://news.metal.com/newscontent/102084821/Everything-You-Need-to-Know-about-China%E2%80%99s-Industrial-Silicon-Market/; Sadhna Gupta, 'Exploring the Factors Behind Volatility in the Silicon Market', Aranca, 28 April 2023, https://www.aranca.com/.
6 International Energy Agency, *Special Report on Solar PV Global Supply Chains*, 21.
7 Johannes Bernreuter, 'Tongwei and Xinte to Upgrade Polysilicon Production Capacities', 29 April 2021, https://www.bernreuter.com/newsroom/polysilicon-news/article/tongwei-and-xinte-to-upgrade-polysilicon-production-capacities/.
8 Alan Crawford and Laura T. Murphy, 'Over-Exposed: Uyghur Region Exposure Assessment for Solar Industry Sourcing' (Sheffield, UK: Sheffield Hallam University Helena Kennedy Centre for International Justice, 2023), 2, https://www.shu.ac.uk/helena-kennedy-centre-international-justice/research-and-projects/all-projects/over-exposed.
9 Laura T. Murphy and Nyrola Elimä, 'In Broad Daylight: Uyghur Forced Labour and Global Solar Supply Chains' (Sheffield, UK: Sheffield Hallam University Helena Kennedy Centre for International Justice, 2021), https://www.shu.ac.uk/helena-kennedy-centre-international-justice/research-and-projects/all-projects/in-broad-daylight.
10 International Energy Agency, *Special Report on Solar PV Global Supply Chains.*
11 International Energy Agency, 24.

This not only increases the PRC's dominance of the supply chain, but also discourages potential competitors by flooding the market. A further challenge is that the PRC is also the main producer of the machinery required to slice polysilicon ingots into wafers. PRC firms have made significant advances in slicing bigger and thinner wafers, allowing solar panels to make major efficiency and cost gains in recent years.[12]

Cells and Modules

While the PRC remains the undisputed global leader at the cell stage of production – accounting for approximately 82% of global solar cell manufacturing capacity – other countries are playing an increasingly important role.[13] South-East Asian countries including Vietnam, Malaysia and Thailand have all expanded production capacity in recent years. Together with Korea, South-East Asian countries now account for 18% of the global cell market.[14] However, it is important to note that much of the investment in South-East Asia's cell production capacity has been led by PRC firms using the PRC upstream inputs, often with a view to circumvent US import tariffs and the US Uyghur Forced Labour Prevention Act.[15] To take full advantage of South-East Asia's growing solar manufacturing capacity more investment is needed to increase local production of upstream inputs – a recommendation returned to later on in this paper.

The PRC also leads the world in module manufacturing, with 70% of global production capacity. However, its lead is less pronounced compared to other stages of the supply chain. While the polysilicon, wafers and cells stage of the supply chain sees significant benefits from economies of scale, modules can be manufactured profitably in smaller batches and do not entail as high capital investment. This means that module assembly is the most geographically diversified stage of the solar PV supply chain, with 38 countries possessing module assembly capabilities in 202. Aside from the PRC, the largest manufacturers by global market share are Vietnam (5%), Malaysia (4%), Korea (4%) and the United States (4%).[16]

1.3 Why is the PRC so dominant?

Low energy costs

An important factor in the PRC's dominance of the solar PV supply chain is its low energy costs. This is particularly relevant at the early stages of the supply chain, where the energy-intensive extraction processes for metallurgical grade silicon, polysilicon and other raw materials make the PRC an ideal producer. Energy costs contribute to approximately 40% of a polysilicon factory's operating costs.[17] Industrial electricity costs for businesses in the PRC are comparatively cheap, with energy costs in Europe are on average three times higher, in part due to high levels of taxation.[18] More specifically, cheap energy in the provinces of Yunnan, Sichuan, Inner Mongolia and the XUAR make them ideal locations for developing new solar manufacturing capacity.[19] The dependence on coal-generated electricity in the XUAR for MGS and polysilicon production has serious environmental implications, with a carbon footprint nearly four times larger than solar panels manufactured with cleaner energy in Europe.[20] The PRC is likely to retain its competitiveness on energy prices over the US and Europe due to its willingness to maintain coal as the main source of its electricity generation, rather than more expensive, greener fuels, and its comparatively low tax on energy costs.[21]

Economies of scale

Economies of scale describe the cost advantages achieved when producing a good in large quantities. PRC firms have been able to achieve economies of scale through receiving significant government support in raising high levels of capital investment to finance large scale solar production. Economies of scale are particularly important at the early stages of the supply chain. For instance, greenfield polysilicon are not usually bankable for capacities of less than 3 GW, while recent plants in the PRC range in size from 40,000 Mt to 100,000 Mt, almost tripling historical averages.[22] Further, the presence of large-scale production at all stages of the supply chain in the PRC has also allowed PRC manufacturers to benefit from vertical supply chain integration, with simplified logistics across the supply chain. These reduced costs have allowed PRC firms to undercut foreign rivals and dominate the global market.

12 Dan Murtaugh, 'China Mulls Protecting Solar Tech Dominance With Export Ban', Bloomberg.Com, 26 January 2023, https://www.bloomberg.com/news/articles/2023-01-26/china-mulls-protecting-solar-tech-dominance-with-export-ban.
13 International Energy Agency, *Special Report on Solar PV Global Supply Chains*, 18.
14 International Energy Agency, 26.
15 Crawford and Murphy, 'Over-Exposed: Uyghur Region Exposure Assessment for Solar Industry Sourcing'.
16 International Energy Agency, *Special Report on Solar PV Global Supply Chains*, 27.
17 Dan Murtaugh et al., 'Secrecy and Abuse Claims Haunt China's Solar Factories in Xinjiang', *Bloomberg.Com*, 13 April 2021, https://www.bloomberg.com/graphics/2021-xinjiang-solar/.
18 Mauricio Belaunde et al., 'Ensuring Resilience in Europe's Energy Transition - The Role of EU Clean-Tech Manufacturing' (Agora Energiewende, September 2023).
19 Bloomberg News, 'China's Solar Industry Is Slowly Shifting Away From Xinjiang', *Bloomberg.Com*, 21 December 2021, https://www.bloomberg.com/news/articles/2021-12-21/china-s-solar-industry-is-slowly-shifting-away-from-xinjiang.
20 Seaver Wang and Juzel Lloyd, 'Sins of a Solar Empire' (Breakthrough Institute, 15 November 2022), 29, 35.
21 Jeromin Zettelmeyer et al., 'Beating the European Energy Crisis', International Monetary Fund, December 2022, https://www.imf.org/en/Publications/fandd/issues/2022/12/beating-the-european-energy-crisis-Zettelmeyer.
22 International Energy Agency, Special Report on Solar PV Global Supply Chains, 85.

Relaxed regulations

Solar production, particularly at the polysilicon and raw minerals stage, involves energy intensive and infrastructure-heavy ventures with high levels of safety risks, pollution and environmental impact. Compared to demanding safety, environmental and planning regulations in the US, Europe, Japan and elsewhere, solar producers in the PRC have benefited from less stringent safety and environmental regulations and the fast-tracking of the myriad of necessary bureaucratic procedures from land acquisition to industrial permits.[23] For these reasons the PRC's new polysilicon plants have had some of the world's shortest lead times for construction – as low as 12 months compared to a global average of three years.[24] Significant differences in the PRC design standards means that polysilicon plants designed for the PRC could not be directly replicated in other parts of the world with stricter regulations.

2. Why is the solar PV supply chain a strategic risk?

2.1 Solar and the EU's energy security

Expanding domestic solar power generation is a key component of the European Union's commitment to achieving carbon neutrality by 2050.[25] EU strategy documents make it clear that solar power is key to both meeting the EU's 2050 'net zero' target and for achieving greater energy security – the latter issue brought to the fore by the impact of Russia's invasion of Ukraine on global energy markets. It has been estimated that in 2022, solar power in the EU helped reduce demand for gas by 9 billion cubic metres of gas, saving €12 billion in gas costs.[26]

While solar currently only makes up 7.3% of the EU's electricity generation, the EU Solar Energy Strategy includes goals to scale up to almost 600 gigawatts of solar power capacity by 2030.[27] With 208.9 GW of solar panels installed by the end of 2022, this amounts to a near tripling of the current installed capacity, with solar energy projected to make up between 17% and 23% of the EU's electricity mix.[28] The costs of failing to meet this planned expansion of solar capacity is very high. This is due to solar energy being significantly cheaper than other energy sources – as demonstrated by our modelling in the next section.

Expanding solar capacity is intended to increase the EU's economic resilience. Domestic solar capacity reduces the need for imported energy and thus makes the EU less exposed to shocks in global energy markets. However, the PRC's dominance of the global solar PV supply chain means that the EU's growing solar ambitions also necessarily entail a growing dependence on the PRC. As EU Commissioner Thierry Breton warned, there is a danger that Europe replaces dependence on Russian gas with dependence on the PRC's solar PV supply chain.[29] This threatens to undermine the very energy security and strategic autonomy solar is meant to provide

2.2 Strategic risks posed by reliance on the PRC's solar PV supply chain

The EU's ambitious plans to triple solar capacity are highly dependent on importing solar PV. Our analysis estimates that approximately 70% of solar installations in 2022 were dependent on modules imported from the PRC, with EU domestic production able to satisfy at most 22.7% of planned installations.[30] However this figure underplays the PRC's critical role, with EU production of solar modules heavily dependent on PRC inputs. The PRC has near total dominance at the upstream stages of the supply chain, including 97% of the world's polysilicon wafers production capacity. Even for supply chains that mainly rely on non-PRC inputs, an increase or decrease in the PRC's supply are major determinants of the global market prices for polysilicon, wafers and other key components. As such, no solar PV supply chain is fully insulated from shocks in the PRC's production.

23 US-China Business Council, 'China's Strategic Emerging Industries: Policy, Implementation, Challenges, & Recommendations'.
24 International Energy Agency, *Special Report on Solar PV Global Supply Chains*, 65; Johannes Bernreuter, 'Polysilicon Market – Free Info on Size, Shares, Trends & China', 8 July 2022, https://www.bernreuter.com/polysilicon/market-analysis/.
25 European Commission, '2050 Long-Term Strategy', accessed 1 November 2023, https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en; European Commission, 'Energy and the Green Deal', 8 April 2022, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/energy-and-green-deal_en.
26 Sarah Brown, 'Wind and Solar Growth Save €12 Billion since Russia Invaded Ukraine', *Ember* (blog), 22 February 2023, https://ember-climate.org/insights/research/wind-and-solar-growth-save-e12-billion-since-russia-invaded-ukraine/.
27 Dave Jones, 'European Electricity Review 2023' (Ember, 31 January 2023), 46; European Commission, 'EU Solar Energy Strategy - COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS', Pub. L. No. SWD(2022) 148 final, COM(2022) 221 (2022), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A221%3AFIN&qid=1653034500503.
28 SolarPower Europe, 'New Report Reveals EU Solar Power Soars by Almost 50% in 2022 - SolarPower Europe', SolarPower Europe, 19 December 2022, https://www.solarpowereurope.org/press-releases/new-report-reveals-eu-solar-power-soars-by-almost-50-in-2022; European Commission, 'Non Paper on Complementary Economic Modelling Undertaken by DG ENER Analysing the Impacts of Overall Renewable Energy Target of 45% to 56% in the Context of Discussions in the European Parliament on the Revision of the Renewable Energy Directive' (European Commission, 20 June 2022), https://energy.ec.europa.eu/system/files/2022-06/2022_06_20%20RED%20non-paper%20additional%20modelling.pdf.
29 Thierry Breton, 'Launch of the European Solar Photovoltaic Industry Alliance', Text, European Commission - European Commission, 9 December 2022, https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_22_7619.
30 See the methodology annexe

The first challenge this presents is the risk of **supply chain disruption**. The solar PV supply chain is highly geographically concentrated, even beyond the country level. In 2021, 30% of the world's solar modules were produced in one PRC province, Jiangsu, with 14% of global production capacity of wafers located at a single PRC facility. The IEA and leading solar firms have warned that such concentration makes the solar PV supply chain highly vulnerable to shocks such as industrial accidents, natural disasters and pandemics.[31] A US National Renewable Energy Laboratory report outlines how a 2020 explosion at a plant operated by the PRC's GCL-Tech temporarily halted a tenth of the world's production capacity.[32] In total, technical issues at four major PRC polysilicon plants led to a 4% year-on-year decline in 2020 polysilicon production, which alongside the suspension of many PRC factories due to the COVID-19 pandemic, contributed to a near quadrupling of prices that year.[33]

The second challenge posed by the PRC's dominance is that of **supply chain weaponization**. As renewable energy becomes a larger part of the global energy mix, the geopolitical leverage the PRC gains from controlling a critical component of that supply chain will only increase. The PRC has already shown a willingness to weaponize trade for strategic benefit: in July, the country implemented export controls on germanium and gallium products, two metals used in semiconductor manufacturing, in response to US led export controls on chip making equipment.[34] PRC exports of the products plunged, catching many EU firms off-guard and exposing a vulnerability in their critical raw material supply chain.[35]

The PRC government is already contemplating how best to exploit its strategic advantage in the solar PV supply chain. The PRC's Ministry of Commerce and Ministry of Science are currently considering including advanced solar wafer manufacturing equipment in export bans.[36] This would constrain the ability of other countries to develop alternative supply chains, increasing their dependence on imports of PRC solar. While there remains a strong trade incentive for the PRC to continue exporting to the West, this is diminishing as the PRC seeks to diversify its export markets through the Belt and Road Initiative. While the EU and the US still account for nearly half of the total value of the PRC solar exports, the PRC has actively redirected its solar PV exports from developed nations to developing nations over the past five years.[37]

Increasing its ability to weaponize critical global supply chains is a stated long-term goal of the PRC government. The so-called 'dual circulation' strategy aims to increase self-sufficiency in critical supply chains while reducing reliance on exports to the West. This strengthens its hand in both imposing and responding to trade sanctions.[38] Earlier this year, Beijing passed a new Foreign Relations Law, designed to give more powers to respond to foreign sanctions, export controls and other measures that may be imposed upon it.[39] In such an event, it is likely that the PRC would seek to reduce the collateral damage of a sanctions package by targeting Western industries that rely heavily and asymmetrically on PRC inputs – such as the solar PV supply chain.

The most extreme scenario in which solar PV supply chains could both be disrupted and weaponized is conflict over the Taiwan Strait. The Taiwan Strait is the primary route for ships passing between East Asia and Europe, with almost half of the global container fleet and 88% of the world's largest ships by tonnage passing through the Taiwan Strait in 2022.[40] A PRC imposed economic blockade or military action against Taiwan could wreak havoc on the global solar PV supply chain, causing extensive shipping delays and driving price increases. Such conflict would also see a major escalation in sanctions and counter sanctions between G7 countries and the PRC – with an estimated US $3 trillion reduction in trade and financial flows.[41] In this context, the PRC government may choose to weaponize its dominance of the solar PV supply chain to counter foreign sanctions in other areas.[42]

However, as recent disputes have shown, even much less extreme scenarios could lead the PRC to take coercive economic action. Punitive trade sanctions imposed on Australia's agricultural and commodity exports in 2021 were triggered by the PRC's anger at Australia's call for an independent inquiry into the origins of COVID-19, while a wholesale ban on Lithuanian imports was triggered by the renaming of the Taiwan Representative Office in Vilnius. In an escalating dispute with the PRC, the EU's dependence on PRC solar constitutes a major vulnerability that threatens to undermine the EU's energy security.

31 International Energy Agency, *Special Report on Solar PV Global Supply Chains*, 58; Barney Jopson and Rachel Millard, 'Solar Supply Chains Must Diversify Away from China, Warns EDP', Financial Times, 25 September 2023, sec. Solar power, https://www.ft.com/content/6ecee5d2-e86b-49d3-9b7f-da937bf8b993.

32 David Feldman and Robert Margolis, 'Q1/Q2 2020 Solar Industry Update' (National Renewable Energy Laboratory, 1 September 2020), 43.

33 International Energy Agency, *Special Report on Solar PV Global Supply Chains*, 23.

34 Amy Lv and Dominique Patton, 'China Exported No Germanium, Gallium in August after Export Curbs', *Reuters*, 20 September 2023, sec. China, https://www.reuters.com/world/china/china-exported-no-germanium-gallium-aug-due-export-curbs-2023-09-20/.

35 Sarah Anne Aarup et al., 'China's Threat on Mineral Exports Knocks EU off Balance', *POLITICO*, 6 July 2023, https://www.politico.eu/article/eu-brussels-freezes-as-china-beijing-hits-back-in-trade-fight-germanium-gallium-computer-chips/.

36 Murtaugh, 'China Mulls Protecting Solar Tech Dominance With Export Ban'.

37 Lili Pike, 'Following the Green BRICS Road', *China Dialogue* (blog), 1 September 2017, https://chinadialogue.net/en/business/10036-following-the-green-brics-road/.

38 World Integrated Trade Solution, 'China Electrical Apparatus; Photosensitive, Including Photovoltaic Cells, Whether or Not Assembled in Modules or Made up into Panels, Light Emitting Diodes Exports by Country | 2022 | Data', accessed 27 October 2023, https://wits.worldbank.org/trade/comtrade/en/country/CHN/year/2022/tradeflow/Exports/partner/ALL/product/854140#; Yingzhe Guo and Chang Liu, 'Unrestrained Investment Creates Looming Glut for China's Solar Supply Chain, Analysts Say - Caixin Global', 6 December 2022, https://www.caixinglobal.com/2022-12-06/unrestrained-investment-creates-looming-glut-for-chinas-solar-supply-chain-analysts-say-101975040.html.

39 Dennis Kwok, 'Xi's National Security Agenda: How Can Governments and Businesses de-Risk?', *China Strategic Risks Institute* (blog), 21 June 2023, https://www.csri.global/research/xis-national-security-agenda-how-can-governments-and-businesses-de-risk.

40 Kevin Varley, 'Taiwan Strait: Tensions Raise Risks in One of Busiest Shipping Lanes - Bloomberg', 2 August 2022, https://www.bloomberg.com/news/articles/2022-08-02/taiwan-tensions-raise-risks-in-one-of-busiest-shipping-lanes?leadSource=uverify%20wall.

41 Charlie Vest and Agatha Kratz, 'Sanctioning China in a Taiwan Crisis: Scenarios and Risks', *Atlantic Council* (blog), 21 June 2023, https://www.atlanticcouncil.org/in-depth-research-reports/report/sanctioning-china-in-a-taiwan-crisis-scenarios-and-risks/.

42 Lv and Patton, 'China Exported No Germanium, Gallium in August after Export Curbs'.

3. Modelling the costs of the EU´s dependency

Modelling the economic impact arising from disruption to the EU's solar PV supply chain is a complex task that depends on a number of variables. Our model attempts to understand the cost in terms of the impact on household energy bills, the avenue by which ordinary EU citizens are most likely to feel a direct cost, in the event that the PRC blocks the export of solar goods to the EU.

Our model finds that a PRC export ban on polysilicon solar wafers – of which the PRC controls over 97% of world production capacity – could lead to the EU missing out on 328.04 GW of planned additions to solar capacity over a five year disruption period. This scenario could then lead to a corresponding increase in energy bills of "€46.18 billion by 2030, or €103 per capita. This is due to the cost savings associated with solar, which is cheaper than other forms of energy and projected to fall further in cost in the coming years.

Our analysis also models the impact on a selection of EU Member States. While the costs are high across all scenarios, the cost is comparatively higher for Germany and Spain – at €13.17 billion and €15.86 billion, or €158 and €335 per capita by 2030. This is due to the greater role that solar PV is expected to play in their respective energy mixes.

A number of other scenarios are also considered in our model. It is possible that the PRC chooses to impose weaker sanctions, with import bans at only the final solar modules stage of production. The EU's dependency here is lower, at approximately 70%, giving a smaller but still significant impact. This is likely to be an underestimate as the shock to global solar prices arising from PRC export bans could add further prohibitive costs to the EU's solar expansion. We also consider the costs associated with a minimum three year disruption period, this being the average time it takes for a new polysilicon plant to come online. However, it is likely that it would take longer for production to scale up to replace the PRC's capacity, particularly for plants built in the US and Europe. Hence why this model primarily considers a five year time disruption period, which is a more realistic time frame for the global supply chain to recover. In all scenarios, we assume that the PRC will impose a blanket export ban on all EU countries collectively.

Table 1 | Projected cumulative increased energy costs in the EU by 2030 in PRC solar export ban scenarios

		EXPORT BAN	
	EU, by 2030	**Solar modules**	**Solar wafers**
Disruption period	3 years	€24,634,243,473	€34,349,373,242
	5 years	€33,115,748,598	€46,175,771,952
	GERMANY, by 2030	**Solar modules**	**Solar wafers**
Disruption period	3 years	€8,785,114,486	€9,794,897,760
	5 years	€11,809,806,257	€13,167,255,252
	SPAIN, by 2030	**Solar modules**	**Solar wafers**
Disruption period	3 years	€11,268,124,909	€11,752,775,443
	5 years	€15,207,979,817	€15,862,086,475
	ITALY, by 2030	**Solar modules**	**Solar wafers**
Disruption period	3 years	€1,024,235,568	€4,174,405,467
	5 years	€1,377,598,563	€5,614,582,379
	FRANCE, by 2030	**Solar modules**	**Solar wafers**
Disruption period	3 years	€1,674,842,784	€3,130,245,667
	5 years	€2,251,486,743	€4,207,981,003

Our methodology is only a first attempt at modelling a very complex problem with a number of intermediate scenarios and alternative contingencies. The results here are only meant to be indicative of the scale of the challenge posed by the EU's dependency on the PRC's solar PV supply chain. The PRC's ability to weaponize its solar PV supply chain could have real costs on ordinary citizens in the EU, reducing the EU's strategic autonomy and undermining its economic security.

4. Strategic priorities for securing the solar PV supply chain

While European companies once led the industry, today PRC firms are world leaders in both manufacturing at scale and developing leading technologies. Scaling up existing European manufacturing capacity is an obvious place to start in safeguarding the EU's future energy security. However, Europe's higher energy and labour costs mean that further action will also be needed. In addition to EU-wide support for solar PV manufacturers, this paper also recommends an approach based on de-risking the EU's new solar installations and diversifying global solar PV production.

4.1 De-risking new solar PV installations

The EU must work with solar providers to ensure that new installations are based on supply chains which are resilient, diverse and take into account the risks posed by the PRC's dominance over the solar PV supply chain. With ongoing reforms to Europe's electricity markets, the EU has several levers of influence to help energy companies avoid over-reliance on the PRC's solar PV supply chains as they ramp up solar generation capacity. By establishing supply chain resilience criteria as a pre-condition for receiving further support, policymakers can encourage energy suppliers to move towards more diverse supply chains.

Setting minimum standards for supply chain resilience

The Net-Zero Industry Act (NZIA), currently under consideration by the European Parliament, has led the way in establishing resilience as a factor for consideration in determining government support. The Act states that authorities should consider sustainability and resilience when awarding contracts or ranking bids for the deployment of net-zero technologies. Importantly, dependency on a single source of supply should be a factor for consideration for technologies where the EU imports more than 65% of supply – which would include solar PV.[43]

The NZIA also allows technologies which reduce strategic import dependencies in key net zero technologies to be considered eligible for streamlined manufacturing permitting. These provisions are welcome and should be supported with additional guidance from the Commission on specific criteria that should be considered when assessing resilience, which at a minimum should include:

- **Supply chain diversity:** Bids should declare what proportion of the value of their supply chain originates from a single source. This should include not only the origin of the final purchased product, but also the origin of major upstream inputs.
- **Geopolitical risk assessment:** Bids should be assessed for their exposure to risks including trade sanctions and coercive economic diplomacy. In this respect not all sources of supply should be considered equal levels of risk. For example, supply chains based in Europe or a trusted group of partner countries may be considered at lower risk, while providers which are heavily reliant on the PRC may be considered at higher risk.
- **Contingency planning:** Bids should demonstrate their ability to continue their project plans in the face of adverse contingencies including supply chain disruptions and geopolitical fallout, such as using stockpiles or locating alternative sources of supply.

Modelled on the NZIA, resilience criteria should also be included for consideration within other government support initiatives relevant to solar PV deployment. For example, resilience criteria could also be instituted through the European Investment Bank, which has currently earmarked up to €45 billion for projects supporting the manufacturing or deployment of strategic green technologies.[44] Similarly, bids for government support under proposed 'Contracts for Difference' schemes – whereby governments pay a guaranteed minimum price for renewable energy generation – should incorporate resilience criteria into the assessment process. As with the above, criteria should take into account supply chain diversity, contingency planning and geopolitical risk assessment.[45]

Raising environmental and ethical standards

Another avenue for de-risking the EU's solar PV supply chain is by raising the ethical and environmental standards for solar PV imports. As noted above, the PRC's solar PV supply chain is deeply integrated with forced labour programmes in the XUAR and has a significantly higher environmental

43 European Parliament, 'Net-Zero Industry Act | Legislative Train Schedule', European Parliament, accessed 3 November 2023, https://www.europarl.europa.eu/legislative-train/package-green-deal-industrial-plan-for-the-net-zero-age/file-net-zero-industry-act; 'Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on Establishing a Framework of Measures for Strengthening Europe's Net-Zero Technology Products Manufacturing Ecosystem (Net Zero Industry Act)' (2023), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023PC0161.

44 European Investment Bank, 'REPowerEU and the EIB', accessed 7 November 2023, https://www.eib.org/en/projects/sectors/energy/repowereu; European Investment Bank, 'EIB to Support Green Deal Industrial Plan with €45 Billion in Additional Financing', European Investment Bank, 12 July 2023, https://www.eib.org/en/press/all/2023-270-eib-to-support-green-deal-industrial-plan-with-eur45-billion-in-additional-financing.

45 European Commission, 'Q&A EU's Internal Electricity Market Design Revision', Text, European Commission - European Commission, 14 March 2023, https://ec.europa.eu/commission/presscorner/detail/en/qanda_23_1593; European Council, 'Electricity Market Reform', 23 October 2023, https://www.consilium.europa.eu/en/policies/electricity-market-reform/.

impact than production elsewhere due to the high prevalence of coal in its energy mix. By raising environmental and ethical standards, policymakers can provide a strong demand side incentive for EU energy providers to explore alternative solar PV supply chains that have a lower carbon footprint and are less at risk of complicity in human rights abuses.

The European Parliament is currently reviewing a draft regulation that seeks to ban and withdraw from the market goods which are made with forced labour. Crucially, amendments inserted by the Internal Market and International Trade committees require companies operating in areas at high risk of forced labour to prove that their supply chains are not implicated. By reversing the burden of proof from authorities to companies, these amendments serve to make the regulation far more effective by forcing companies to adopt a proactive and preventative approach. If passed, these regulations would give companies an incentive to diversify their supply chains away from heavy dependence on the XUAR, which in turn would lower risk of supply chain disruptions.

In terms of raising environmental regulations, the Carbon Border Adjustment Mechanism (CBAM) could be further expanded to help diversify the solar PV supply chain. CBAM aims to incentivise cleaner industrial production in non-EU countries by levying additional fees on carbon-intensive goods entering the EU. CBAM entered its transitional phase in October 2023 and has initially been applied to the imports of a limited range of carbon-intensive goods, including cement, iron and steel.[46] Including solar panels and components in CBAM would not only encourage cleaner production in the global solar PV supply chain, but would also ensure that European firms are not unfairly undercut by cheaper but more carbon intensive production – particularly in the PRC. Further, tax revenue raised by CBAM could be distributed back into EU funds supporting the manufacturing and deployment of green technologies.

4.2 Scaling up EU manufacturing capacity

The EU Net-Zero Industry Act sets an indicative target of meeting 40% of solar PV demand through domestic manufacturing by 2030.[47] While a worthy target, this will require a significant expansion on existing capacity, with EU manufacturers reaching 2%, 4% and 28% of demand in wafers, cells and modules production respectively in 2023.[48] Achieving this will require adopting a union-wide approach that takes into account the competitive advantage of various member states to build a resilient and viable European supply chain.

The case for an EU wide funding

A number of initiatives have attempted to boost Member State level spending to speed up investment in renewable energy to meet climate targets and lower energy prices in the light of Russia's invasion of Ukraine. Most significantly, the EU's **Temporary State aid Crisis and Transition Framework (TCTF),** announced in March 2023, relaxes state aid rules to enable governments to support the roll-out of renewable energy through investments, tax benefits, loans or guarantees with maximum caps between €150-350 million.[49] This has been complemented by the **General Block Exemption Regulation (GBER)**, which permits member nations to provide investment aid without prior notification to the Commission. These initiatives, while beneficial, have drawbacks compared to a Union wide approach. Differing levels of state support provides an advantage to firms in financially stronger states. This disincentivizes firms from locating production elsewhere, distorting the comparative advantage that other states may have through lower labour and energy costs. Already, signs of inequality have begun to show, with Germany (53%), France (24%), and Italy (7.65%) granted the majority of all extraordinary aid approved by the European Commission.[50]

In contrast, an EU wide 'Clean Tech Manufacturing Fund' could see support for projects prioritised based on commercial viability, wherever they take place. Research from Agora Energiewende finds that EU-wide investment coordination could save 12 percent in overall costs for scaling up green tech manufacturing compared to scenarios primarily driven by national policies.[51] Crucially, such a fund would need to cover operational costs as well as grants for capital costs. The former could take place through so-called 'Contracts for Difference', in which variable levels of government compensation should the market price of a product fall beneath a predetermined value. Research and development costs are already well covered by existing EU funds, including Horizon Europe and the Innovation Fund.

Drawing on analysis from Agora Energiewende, we suggest a dedicated solar PV budget of approximately €1.15 billion annually within an EU Clean Tech Manufacturing Fund, with a rough 30/70 split between capital and operational expenditure respectively. This is calculated from Agora Energiewende's analysis that meeting the EU's Net-Zero Industry Act solar PV manufacturing targets would require government support at a rate of 30% of the industry's additional expenditure, which equates to €13.9 billion by 2035. [52]

46 European Commission, 'Carbon Border Adjustment Mechanism', accessed 7 November 2023, https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en.
47 European Commission, 'The Net-Zero Industry Act', accessed 7 November 2023, https://single-market-economy.ec.europa.eu/industry/sustainability/net-zero-industry-act_en.
48 Belaunde et al., 'Ensuring Resilience in Europe's Energy Transition - The Role of EU Clean-Tech Manufacturing'.
49 European Commission, 'Temporary Crisis and Transition Framework', accessed 7 November 2023, https://competition-policy.ec.europa.eu/state-aid/temporary-crisis-and-transition-framework_en; Cleary Gottlieb, 'Commission Adopts State Aid Temporary Crisis and Transition Framework', 17 March 2023, https://www.clearygottlieb.com/news-and-insights/publication-listing/commission-adopts-state-aid-temporary-crisis-and-transition-framework.
50 Stavros Makris, 'Temporary Crisis and Transition Framework: Dealing with Crisis and Transitioning to a Net-Zero Economy - But At What Cost?', *Kluwer Competition Law Blog*, 4 April 2023, https://competitionlawblog.kluwercompetitionlaw.com/2023/04/04/temporary-crisis-and-transition-framework-dealing-with-crisis-and-transitioning-to-a-net-zero-economy-but-at-what-cost/.
51 Belaunde et al., 'Ensuring Resilience in Europe's Energy Transition - The Role of EU Clean-Tech Manufacturing'.
52 Belaunde et al., 54–55.

One revenue stream that could be diverted towards developing an EU Clean Tech Manufacturing Fund is the European Union Emissions Trading System (EU ETS). This generated €31 billion in 2021, of which €25 billion went directly to the EU Member States.[53] Given that this funding is already earmarked for climate change and energy-related purposes, there is a strong case for allocating a greater proportion of this fund for EU-wide clean tech manufacturing support. Another potential funding stream is the revenue generated by the Carbon Border Adjustment Mechanism (CBAM). CBAM is projected to raise €1.5 billion per year by 2028, of which 75% of the revenues from the mechanism will be allocated to the EU budget. Expanding CBAM, in line with the proposals made in this paper, would further increase funds available.

4.3 Diversifying global solar PV production

While scaling up domestic solar production must be a priority, it is likely that Europe will continue to rely on a large degree of solar PV imports to meet its energy needs. This is particularly true for the energy intensive upstream of the solar PV supply chain, where Europe's high energy costs reduce its competitiveness and where the PRC currently dominates global production.

It is thus in the EU's strategic interest to ensure that solar PV production outside of Europe is not overly reliant on the PRC, allowing for a diverse and resilient supply chain. This section makes the case for investment in strategically important and commercially viable stages of the solar PV supply chain outside of the EU. Investing in the upstream stages of the solar PV supply chain (polysilicon, ingots and wafers) in countries with low energy and capital costs (such as Vietnam and Malaysia) emerges as the best option on this calculus.

We describe this initiative as a so-called 'friendshoring' strategy, whereby production that cannot be 'on-shored' is instead moved to friendly, allied third countries. While the EU will likely continue to import a substantial proportion of its solar panels from the PRC, building a combination of scaling up domestic supply and building a 'friendshore' will increase the resilience of the supply chain as a whole and reduce the PRC government's ability to weaponize it. Alternative sites of production will give greater opportunities for scaling up production should the PRC's supply chains be suddenly cut off, allowing the supply chain to respond more quickly to geopolitical shocks.

Building an effective friendshore

In order to ensure best value for taxpayer money, government support for friend-shoring initiatives should take a targeted approach, taking into account both the strategic need and the commercial viability of a project.

There is a strong strategic case for prioritising friend-shore investments at the earlier stages of the solar PV supply chain. It is at these stages where the PRC's dominance is most pronounced and where EU companies will most struggle to offer a competitive alternative. The earlier segments of the supply chain are also more effectively weaponised, with the potential to put a stranglehold on all subsequent stages. The comparatively long lead times for new plants at the earlier stages of the supply chain also add to the strategic risks at the upstream of the supply chain. While cell and module factories can be deployed in 6-12 months in most parts of the world, new polysilicon plants' range from 30-40 months. On average, new plants in the US and Europe have the longest lead times across all stages of production, while those in the PRC and South-East Asia can be built considerably quicker.[54]

In order to ensure commercial viability, 'friend-shoring' projects should be targeted on countries that have competitive capital and operational costs. According to IEA analysis, average investment costs per GW of solar production capacity are more than twice as expensive in the US and Europe compared to the PRC across all segments of the supply chain. In contrast, investment costs in South-East Asian countries are much more cost competitive, being only 10-20% higher than the PRC at the polysilicon, and ingots and wafers stage, while investment costs in India at the modules stage are on par with the PRC's.[55]

A capital investment of US$ 700 - 800 million could build a 10GW solar grade polysilicon or wafers production facility in South-East Asia of a comparable size to leading PRC firms.

To achieve commercially viable operating costs, the friendshore should be targeted at countries with low energy prices. Notably, South-East Asian countries such as Vietnam and Malaysia, as well as Korea, and India, have energy costs comparable to the PRC. These countries already collectively account for 12% of the globe's module production capacity, and so could benefit from vertical integration if new capacity could be built at the upstream stages of production. Although solar PV manufacturing in Latin America and Africa is still developing, the region has huge potential for developing greater manufacturing capacity with its cheap and clean energy and its burgeoning demand for solar PV as countries seek affordable ways to increase electricity output and consumption.

53 European Environmental Agency, 'Use of Auctioning Revenues Generated under the EU Emissions Trading System', 3 February 2023, https://www.eea.europa.eu/en/analysis/indicators/use-of-auctioning-revenues-generated.
54 International Energy Agency, Special Report on Solar PV Global Supply Chains, 65.
55 International Energy Agency, 87.

Table 2 | Solar PV manufacturing

.Country	**Average business electricity price** (USD/kWh)[56]	**Carbon intensity of electricity** (g/kWh CO2)[57]	**Existing PV-related manufacturing**
P.R. China	$0.09	531.15	Polysilicon, wafers, cells and modules
		EUROPE	
France	$0.24	257.38	Cells and modules [58]
Germany	$0.44	385.47	Polysilicon, cells and modules
		LATIN AMERICA	
Argentina	$0.04	338.28	Limited existing manufacturing
Ecuador	$0.09	188.71	
		ASIA	
Vietnam	$0.07	376.83	Wafers, cells, and modules[59]
Malaysia	$0.13	543.74	Polysilicon, wafers, cells, and modules[60]
		AFRICA	
Ethiopia	$0.022	25.19	Modules[61]
Nigeria	$0.046	368.22	Polysilicon, ingots, wafers, cells, and modules (under development)[62]
Kenya	$0.149	100.57	Modules[63]

Finally, building an effective friendshore will require investing in projects which have a realistic chance of competing with the advantages that have allowed PRC firms to dominate the global market. Most significantly, viable projects must be able to raise enough capital investment to achieve the economies of scale utilised by leading PRC firms. While there is no precise scale threshold for an individual plant to achieve, analysts have found that leading firms typically have 3 to 5 GW capacity plants at the downstream cell and module level, and around 10 GW at the upstream polysilicon, ingot and wafer level.[64] Industry trends point towards ever larger scales of production, with 20 to 40+ GW capacity at the ingot and wafer stage and 10 to 30 GW at the cells and modules becoming increasingly common.

Financing the friendshore

The European Union's Global Gateway programme is the centrepiece of the EU's strategic engagement in infrastructure development within low- and middle-income countries, presented as an answer to the need for sustainable and comprehensive infrastructure and a counterbalance to the PRC's Belt and Road Initiative (BRI). The Global Gateway aims to mobilise significant public and private investment, targeting critical areas such as climate change mitigation and adaptation, digital transformation, and health resilience. The EU has planned to mobilise €300 billion through EU funding and private capital, though much of this relies on repackaging existing development funding.[65] The Global Gateway is also

56 GlobalPetrolPrices.com, 'Electricity Prices around the World - Mar 2023', *GlobalPetrolPrices.com*, accessed 7 November 2023, https://www.globalpetrolprices.com/electricity_prices/.
57 Our World in Data, Ember, and Energy Institute Statistical Review of World Energy, 'Carbon Intensity of Electricity', *Our World in Data*, accessed 7 November 2023, https://ourworldindata.org/grapher/carbon-intensity-electricity?tab=table.
58 Will Norman, 'PV Startup Carbon Selects Location for Planned 5GW/3.5GW Cell and Module Factory in France', *PV Tech*, 7 March 2023, https://www.pv-tech.org/pv-startup-carbon-selects-location-for-planned-5gw-3-5gw-cell-and-module-gigafactory-in-france/.
59 Willie Jiang, 'Top 12 Solar Manufacturers in Vietnam 2022', *SolarFeeds Magazine* (blog), 26 June 2023, https://www.solarfeeds.com/mag/top-solar-manufacturers-in-vietnam/.
60 Adam Aziz and Jia Teng Liew, 'Cover Story: US Tariffs Shine Spotlight on Malaysian Solar Panel Industry', *The Edge Malaysia*, 8 June 2023, https://theedgemalaysia.com/node/669102; Solar Magazine, 'Malaysia Solar Energy Profile', Solar Magazine, accessed 7 November 2023, https://solarmagazine.com/solar-profiles/malaysia/; E. Borensztein, J. De Gregorio, and J-W. Lee, 'How Does Foreign Direct Investment Affect Economic Growth?', *Journal of International Economics 45*, no. 1 (June 1998): 115–35, https://doi.org/10.1016/S0022-1996(97)00033-0.
61 Ethiopian News Agency, 'Precise Consult to Assemble, Manufacture 250,000 Solar Home Systems in Ethiopia', *ENA English*, accessed 7 November 2023, https://www.ena.et/web/eng/w/en_37900.
62 Jonathan Touriño Jacobo, 'Nigeria Breaks Ground on US$171 Million Solar Cell Production Plant', *PV Tech*, 28 March 2023, https://www.pv-tech.org/nigeria-breaks-ground-on-us171-million-solar-cell-production-plant/; Uchechukwu Okoro, 'Nigerian PV Panel Production Gets Going at New Lagos Plant', *Energy & Utilities*, 24 October 2023, https://energy-utilities.com/nigerian-pv-panel-production-gets-going-at-new-news122767.html.
63 Dinfin Mulupi, 'Manufacturing Solar Panels in East Africa: Rising Demand, but Challenges Remain', How we made it in Africa, 28 March 2016, https://www.howwemadeitinafrica.com/manufacturing-solar-panels-east-africa-rising-demand-challenges-remain/53859/; Penninah Munyaka and Anna-Lena Becker, 'Solar Power, the next Frontier for Kenya's Renewable Energy...', *Rödl & Partner* (blog), accessed 7 November 2023, https://www.roedl.com/insights/renewable-energy/2016-07/solar-power-frontier-kenya-renewable-energy-sector.
64 Alberto Bettoli et al., 'Rebuilding Europe's Solar Supply Chain' (McKinsey, 13 December 2022), https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/building-a-competitive-solar-pv-supply-chain-in-europe.
65 Michele Barbero, 'Europe Is Trying (and Failing) to Beat China at the Development Game', *Foreign Policy* (blog), 10 January 2023, https://foreignpolicy.com/2023/01/10/europe-china-eu-global-gateway-bri-economic-development/; Josep Borrell, 'Global Gateway, EU's Proposal in the Global "Battle of Offers"', *European Union External Action* (blog), 27 October 2023, https://www.eeas.europa.eu/eeas/global-gateway-eus-proposal-global-battle-offers_en.

part of the G7 led Partnership for Global Infrastructure and Investment (PGII), which aims to mobilise $600 billion in public and private financing.[66]

Dedicating even a small proportion of Global Gateway or PGII budget could make a significant impact on the solar PV supply chain if invested in countries with low capital and operational costs. The IEA estimates that the minimum investment required for new polysilicon capacity in the South-East Asia region is approximately US$ 80 million/GW, and US$ 70 million/GW for solar wafers.[67] This means that a US $3.2 billion and US $1.75 billion investment in Vietnam or Malaysia could build 40GW of polysilicon production and 25GW of wafer production capacity respectively, equivalent to over 10% of global production in 2022. Together these initiatives would total to just under US $5 billion – less than 1% of the PGII finance target.

Using Global Gateway and PGII funds to funnel investments into building solar production capacity in low and middle income countries could meet important development goals. As highlighted above, countries in South-East Asia, Africa, and Latin America could all be viable sites for upstream solar production. By channelling investments into these areas, the Global Gateway can stimulate the local economies, potentially creating approximately 1,300 manufacturing jobs per gigawatt of solar production capacity, as estimated by the International Energy Agency (IEA).[68] The EU's funding through the Global Gateway is envisioned to be contingent upon adherence to high environmental and labour standards. This approach not only elevates the ethical framework within which infrastructure projects operate but also addresses concerns over the solar PV supply chain link to forced labour abuses in the XUAR.

66 The White House, 'FACT SHEET: President Biden and G7 Leaders Launch Build Back Better World (B3W) Partnership', *The White House* (blog), 12 June 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/06/12/fact-sheet-president-biden-and-g7-leaders-launch-build-back-better-world-b3w-partnership/; Patsy Widakuswara, '"Build Back Better World": Biden's Counter to China's Belt and Road', *Voice of America*, 4 November 2021, https://www.voanews.com/a/build-back-better-world-biden-s-counter-to-china-s-belt-and-road/6299568.html; European Commission, 'EU Commitment to Partnership for Global Infrastructure', Text, European Commission - European Commission, 9 September 2023, https://ec.europa.eu/commission/presscorner/detail/en/ip_23_4421.

67 International Energy Agency, *Special Report on Solar PV Global Supply Chains*, 22, 24, 86.

68 International Energy Agency, 94.

5. Policy recommendations

Securing Europe's solar PV supply chain is critical to strengthening its energy resilience and upholding its strategic autonomy. We propose a set of policies designed to de-risk new solar installations, scale up European solar PV manufacturing and diversify global supply chains.

1. De-risking new solar PV installations

→ **Publish further guidance under the Net Zero Industry Act:** The inclusion of supply chain resilience as a consideration for government procurement and expedited permitting is welcome. Once adopted, the Commission should publish further guidance on what specific criteria governments can use to assess supply chain resilience. This should include requirements for a geopolitical risk assessment to consider sources of origin at higher risk of supply chain disruption and weaponization.

→ **Establish resilience criteria as a pre-condition for other forms of government support:** EU and Member State support for energy companies through proposed Contracts for Difference and green financing such as the European Investment Bank should be conditional upon meeting minimum requirements for supply chain resilience. We suggest that this includes criteria on supply chain diversity, a geopolitical risk assessment and contingency plans for supply chain disruption.

→ **Adopt an area based approach to forced labour regulation:** The European Parliament should accept the amendments made by the Internal Market and International Trade committees on the draft regulations Prohibiting products made with forced labour on the Union market. Reversing the burden of proof for companies importing goods from areas at high risk of forced labour abuses is critical to ensuring the effectiveness of anti-forced labour regulation.

→ **Include solar PV within the Carbon Border Adjustment Mechanism (CBAM):** Including solar PV in the CBAM scheme will encourage importers to find cleaner, more diverse supply chains, while ensuring EU producers are not undercut by cheaper but more polluting production methods. Tax revenue collected can be re-distributed to support additional clean energy manufacture and deployment.

2. Scaling up EU manufacturing capacity

→ **Establish a EU Clean Tech Manufacturing Fund:** A centralised EU fund can help allocate resources most efficiently across the single market, allowing for expanded and more cost competitive production. We propose an annual solar budget of €1.15 billion in order to meet 2030 targets, split 30/70 between capital grants and operational support through Contracts for Difference schemes. This budget could be funded through re-allocation of revenue from the European Union Emissions Trading System, or the Carbon Border Adjustment Mechanism.

3. Diversifying global solar PV production

→ **Invest in viable, large-scale, upstream solar production in third countries:** The EU should work through the Global Gateway Initiative and the Partnership for Global Infrastructure and Investment (PGII) to raise public and private finance for new solar production facilities in low and middle income countries. In order to be commercially viable, capital investment must be sufficiently high to achieve economies of scale, and take place in countries with competitive energy costs. Such funding would be most effectively targeted at the strategically vulnerable polysilicon, ingots and wafers stage of the supply chain, with Vietnam and Malaysia emerging as attractive candidates. An investment of US $5 billion – less than 1% of the PGII finance target – could build up to 40 GW of polysilicon production and 25 GW of wafer production capacity.

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Methodology annexe

Methodology

Our model aims to project:

A) The impact of PRC export bans on the EU's ability to install new solar capacity in a particular year;

B) The corresponding additional cost of electricity generate via other sources compared to generating the same amount via solar over that year; and

C) The corresponding cumulative impact over a three or five year period, and totalled on the national level or divided per household.

The EU both manufactures and imports solar panels. Latest figures show the EU has a capacity of manufacturing 9.4 GW of solar modules.[69] In 2022, the EU added 41.4GW of solar power capacity.[70] Assuming that all of the manufacturing capacity is used, all European manufactured panels are consumed domestically, 22.71% of the panels Europe consumes are manufactured domestically, with the remaining 77.29% being imports. According to the World Bank, 90% of the solar modules imported into Europe are from China, which gives us an estimate of 70% of solar modules installed in Europe being from China.[71]

To calculate A), our model multiplies the EU's dependence on PRC imports for the solar product subject to export ban (modules or polysilicon wafers) by the EU's 2030 Solar Strategy targets and individual member states' 2030 NECP targets for new solar capacity installation in that year.

E.g. 70% * 67.64GW = 47.35 GW of missing new solar capacity installations.

To calculate B), our model multiplies the amount of missing new solar capacity installation by the 'load factor' (i.e. the projected average efficiency per GW of solar installation per hour) by the number of hours in a year to to calculate the amount of electricity that will have to be generated by other sources, which is then multiplied by the difference between government projections of wholesale energy prices for that year and government projections for solar energy prices for that year.

E.g. 47.35 GW * 13% load factor * 8760 hours * (€100000/GWh-€72020/GWh) = €1.51 billion additional cost

To calculate C), the figures for B) of each year are summed over the specific three or five year time period and up to 2030. The cost is added together to create a total EU cost by 2030, or divided by the population size in the EU to create a per capita cost.

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Figures used and sources

Table 3 | Outlook

Variable	Description	Data source
Solar Capacity Needed by 2030	**EU** The European Union set a target of almost 600 GW in total for solar energy by 2030.	EU Solar Energy targets for 2030[72]
	With 208.9 GW installed by June 2022, the UK needs to install 48.89 GW of solar capacity per year from.	SolarPower Europe[73]
	MEMBER STATES Each member state has its own national energy and climate plans (NECPs), which outline how it intends to meet the EU energy and climate targets for 2030. Each NECP contains a target installed capacity for solar and other renewable sources. As of this report's publication, only the data from Spain and Italy among the countries we are considering have submitted their NECPs, setting targets of 76.4 GW and 79.9 GW of installed solar capacity by 2030 respectively.	Ember's Live EU NECP tracker[74]
	France and Germany have respectively set targets of 44 GW by 2028 and 215 GW by 2030.	French government[75] German government[76]
Dependence on the PRC	**Scenario 1:** PV module export ban → Latest figures show the EU has a capacity of manufacturing 9.4 GW of solar modules. → In 2022, the EU added 41.4GW of solar power capacity. Assuming that all of the manufacturing capacity is used all European manufactured panels are consumed domestically, 22.71% of the panels Europe consumes are manufactured domestically, with the remaining 77.29% being imports. This is in line with other industry estimates. → According to the World Bank, 90% of the solar modules imported into Europe are from China → Multiplying 90% and 77.29% gives us an estimate of 70% of solar modules installed in Europe being from China.	SolarPower Europe[77] Energy Monitor[78] Energypost.eu[79] World Integrated Trade Solution[80]

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<table>
<tr><td></td><td>Scenario 2: Polysilicon wafer export ban - the PRC controls 96.8% of polysilicon wafer manufacturing worldwide</td><td>IEA[81]</td></tr>
<tr><td>Projected Price Difference</td><td>Wholesale electricity prices
→ Wholesale electricity prices averaged €122/MWh in Q1 2023
→ We assume that wholesale electricity prices will fall by 50% over the next 10 years, roughly in line with industry estimates.</td><td>European Power Benchmark[82]
Institute of Energy Economics at the University of Cologne[83]
S&P Global[84]</td></tr>
<tr><td></td><td>Solar energy generation costs
→ Solar power purchase agreement prices from Q1 2023 are used. When country-specific data is unavailable, we resorted to the EU-wide average figure
<table><tr><th></th><th>EUR/MWh</th></tr><tr><td>Spain</td><td>50</td></tr><tr><td>Italy</td><td>70</td></tr><tr><td>EU-wide</td><td>73.2</td></tr></table></td><td>Argus Media[85]</td></tr>
<tr><td></td><td>→ We assume that solar prices will fall by 60% from now to 2030, in line with IRENA projections.</td><td>IRENA[86]</td></tr>
<tr><td>Solar PV Load Factor</td><td>The solar load factors for each country and the EU are calculated by dividing the actual output (in TWh) from installed solar capacity by the maximum possible output

Load factor =
Actual output per year (TWh/y) * 1000/ Installed solar capacity (GW) * Number of hours in a year (h)
<table><tr><th></th><th>Capacity (GW)</th><th>Output (TWh)</th><th>Load factor</th></tr><tr><td>Germany</td><td>67.5</td><td>60.1</td><td>10.15%</td></tr><tr><td>Spain</td><td>18.2</td><td>32.77</td><td>20.55%</td></tr><tr><td>Italy</td><td>27.3</td><td>27.73</td><td>11.60%</td></tr><tr><td>France</td><td>17.1</td><td>19.98</td><td>13.34%</td></tr><tr><td>EU-wide</td><td>208.9</td><td>245.63</td><td>13.42%</td></tr></table></td><td>Capacity:
BSW Solar[87]
Ember[88]
PVTech[89]
EurObserv'ER[90]
SolarPower Europe[91]

Output:
Ember[92]</td></tr>
</table>

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Population	Population size on 1 Jan 2022		Eurostat[93]
		Population (million)	
	Germany	83.2	
	Spain	47.4	
	Italy	59.0	
	France	67.9	
	EU-wide	446.7	
	Constant at 67.0 million (2021) or 28.1 million households		

Assumptions

Here is a breakdown of our key assumptions and the reasons behind them:

- **Rate of new solar capacity installations:** We assume each EU member state will install the solar capacity needed to reach their 2030 targets at a constant rate each year.

- **Impact of sanctions:** We assume that the impact on the EU's solar PV installation rate during the disruption period will be of equal proportion to the dependence on the PRC for the product on which sanctions are imposed (i.e. a 70% decrease for 'weak' export bans on solar modules, or a 96.8% decrease for 'strong' export bans on polysilicon wafers). We believe this is a conservative estimate as it assumes that non-PRC supply is not disrupted, when in reality the affordability and availability of non-PRC supply would likely decrease significantly in response to this shock.

- **End of disruption period:** We assume that the solar PV installations in the EU and each of the member states after the disruption period has ended will return to the previous annual new capacity rate in line with the original 2030 targets. This could be an overestimate if solar PV prices never fall back to normal, thereby prohibiting installation at the previously planned rate. This could be an underestimate if energy providers decide to install at a higher rate to fill the gaps in their missing solar capacity.

- **Beginning of disruption period:** Our model calculates on the basis that the 3 or 5 year disruption period will begin in 2024. Moving the beginning of the disruption period to other years would give different results due to the changing costs of both solar electricity generation and wholesale electricity generation.

- **Projected Price Difference:** We assume wholesale electricity prices will halve over a decade, in line with industry estimates. As for solar prices, we adopt a more conservative estimate than IRENA and assume generation costs will fall by 60% from now to 2030. We acknowledge that disruptions might influence broader energy prices, particularly as the expansion of renewables depress wholesale electricity prices, but do not model such disruptions, which may underestimate the price difference.

- **Solar PV Load Factor:** We assume constant load factors, in line with usual practice.

- **Population:** We assume a constant population size, using 2022 figures, while recognising that these assumptions could understate per capita impacts due to expected population decrease.

The following tables summarise the impact of disruptions:

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Table 4 | The Impact of Disruptions

OUTPUT TABLES (3-YEAR SCENARIOS)

WEAK SANCTIONS	GERMANY	SPAIN	ITALY	FRANCE	EU
How many GW of planned installation solar capacity would be missed? (GW)	48.121875	20.29725	4.69455	6.98055	102.026087
Price difference between wholesale energy price and solar energy (EUR/MWh)	€42	€62	€44	€42	€42
National cumulative loss after three years (2026) (EUR)	€3,495,468,314	€4,395,438,301	€406,475,212	€666,395,400	€9,801,604,480
Per capita cumulative loss after three years (2026) (EUR)	€42	€93	€7	€10	€22
National cumulative loss by 2030 (EUR)	€8,785,114,486	€11,268,124,909	€1,024,235,568	€1,674,842,784	€24,634,243,473
Per capita cumulative loss by 2030 (EUR)	€106	€238	€17	€25	€55
STRONG SANCTIONS					
How many GW of planned installation solar capacity would be missed? (GW)	53.653125	21.17025	19.13325	13.0465	142.262625
Price difference between wholesale energy price and solar energy (EUR/MWh)	€42	€62	€44	€42	€42
National cumulative loss after three years (2027) (EUR)	€3,897,246,281	€4,584,489,411	€1,656,642,672	€1,245,478,879	€13,667,112,247
Household cumulative loss after three years (2027) (EUR)	€47	€97	€28	€18	€31
National cumulative loss by 2030 (EUR)	€9,794,897,760	€11,752,775,443	€4,174,405,467	€3,130,245,667	€34,349,373,242
Per capita cumulative loss by 2030 (EUR)	€118	€248	€71	€46	€77

OUTPUT TABLES (5-YEAR SCENARIOS)

WEAK SANCTIONS	GERMANY	SPAIN	ITALY	FRANCE	EU
How many GW of planned installation solar capacity would be missed? (GW)	80.203125	33.82875	7.82425	11.63425	170.0434783
Price difference between wholesale energy price and solar energy (EUR/MWh)	€42	€62	€44	€42	€42
National cumulative loss after five years (2028) (EUR)	€7,796,939,230	€9,930,533,457	€908,187,274	€1,486,451,592	€21,863,312,042
Per capita cumulative loss after five years (2028) (EUR)	€94	€210	€15	€22	€49
National cumulative loss by 2030 (EUR)	€11,809,806,257	€15,207,979,817	€1,377,598,563	€2,251,486,743	€33,115,748,598
Per capita cumulative loss by 2030 (EUR)	€142	€321	€23	€33	€74
STRONG SANCTIONS					
How many GW of planned installation solar capacity would be missed? (GW)	89.421875	35.28375	31.88875	21.74416667	237.104375
Price difference between wholesale energy price and solar energy (EUR/MWh)	€42	€62	€44	€42	€42
National cumulative loss after five years (2028) (EUR)	€8,693,139,141	€10,357,653,175	€3,701,435,530	€2,778,146,520	€30,485,655,729
Per capita cumulative loss after five years (2028) (EUR)	€104	€219	€63	€41	€68
National cumulative loss by 2030 (EUR)	€13,167,255,252	€15,862,086,475	€5,614,582,379	€4,207,981,003	€46,175,771,952
Per capita cumulative loss by 2030 (EUR)	€158	€335	€95	€62	€103