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De-risking and decarbonising: a green tech partnership to reduce reliance on China

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Executive summary

TRADE IN RENEWABLE energy goods is a global public good; all countries gain when others cut emissions, and all suffer from climate change if decarbonisation is delayed. Yet this trade depends on China, which controls most of the world's production of solar panels and electric vehicle batteries, and some of the global trade in wind turbines. These supply chains are vulnerable to disruption, natural disasters and weaponisation by China, which has already exercised its dominant position in some critical raw materials to put pressure on other countries.

PART OF THE EUROPEAN UNION and United States response to reduce reliance on China is reshoring production, but this is economically inefficient given their limited access to critical raw materials and high production costs. Moreover, Chinese firms are far ahead of the rest of the world in green tech manufacturing and innovation, and in extraction and processing.

TO REDUCE RELIANCE on China, incentive-aligned governments and businesses should form a green tech partnership. This would produce green tech with the aim of decarbonising faster, while ensuring greater diversification of resources and improving security of supply. Each partnership economy would use its comparative advantage within a new green-tech supply chain. The aim is to supplement, not substitute, the Chinese supply chain, since both will be needed to meet rising global demand for green tech, including in China.

ALTHOUGH SUCH INTERNATIONAL coordination is difficult, the partnership would offers benefits to many different countries. Emerging economies that are rich in critical raw materials and/or have moderate wages would gain economic development opportunities. The US and the EU should share technology and provide financing, as they will gain from reduced dependence on China and from sourcing than is still cheaper than reshoring. China would have more room to use its clean tech to meet its own decarbonisation targets.

THE PARTNERSHIP COULD be organised through a combination of trade and investment agreements, together with tech transfer and financial agreements, under some form of inter-governmental oversight. The dependence of all countries on China for green tech is so great that non-market incentives might also be needed, such as subsidies or, preferably, a system of carbon pricing within the partnership.

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1 Introduction

Greater alignment of the major economic powers is needed around a collective effort to improve security of supply for decarbonisation goods

Despite rising geopolitical tensions, Europe, the United States and China agree on one goal: the need for all countries to replace fossil fuels with renewable energy, in order to cut the greenhouse gas emissions that are causing global warming. However, it is difficult to cooperate on green tech trade in the context of geopolitical tension and geo-economic competition. Even worse, the scramble for critical resources to make the clean tech needed for decarbonisation is creating new tensions, becoming another source of rivalry.

To pursue decarbonisation as a global public good, greater alignment of the major economic powers is needed around a collective effort to accelerate the transition to renewable energy and electric vehicles. China wants to maintain its dominant position in global supply chains, while the US and European Union are focused primarily on increasing their own supplies of clean tech, rather than improving the overall security of supply for all countries.

We analyse two main risks to faster global decarbonisation. The first stems from the excessive concentration of green-energy supply chains in a single country. China dominates global supply chains for green-energy products, including solar panels, electric vehicle batteries and, to a lesser extent, wind turbines. For Europe to reduce this risk, supplementary supply chains would need to be built, rather than just reshoring critical raw materials and production, which has been the main theme of recently announced EU policies (Tagliapietra *et al*, 2023; Le Mouel and Poitiers, 2022). The second risk arises from China's own clean-tech needs. China's decarbonisation targets are a vital global interest because it is the largest emitter of greenhouse gases. Given China's massive investment in production capacity for renewables, the risk that China might be unable to supply sufficient green tech to the rest of the world appears currently to be low, but this risk could grow, and supply disruptions that would slow down global decarbonisation remain a problem.

To address both risks, a 'green tech partnership' should be put in place. This would be a network of countries that take responsibility for different parts of the supply chain, according to their comparative advantage – in other words, through coordinated specialisation. It aims at creating a supplementary supply chain that would increase the production of green tech over and above that of China, while ensuring that extraction, refining and innovation are less concentrated in a single country.

The main challenge in designing such a partnership is how to align incentives for the governments and private sectors of participating countries, and how to keep it inclusive. In other words, the aim is not to substitute the China-centric green supply chain, but to complement it by calling into the partnership resource-rich countries and those with innovation capabilities or low-cost extraction, refining or manufacturing infrastructure.

We first review Europe's dependence on China for decarbonisation goods and provide data on China's own needs for clean tech in the future, which will affect its export capacity. Next, we assess recent European and American attempts to reduce this reliance on China through the reshoring of production and seeking of bilateral deals with countries that can offer alternative raw material supplies. Neither the current situation of reliance on China nor the attempts at reshoring production are the best options for minimising the risks to global decarbonisation. We then set out our proposal for a green tech partnership.

2 How reliant is Europe on China for clean technology?

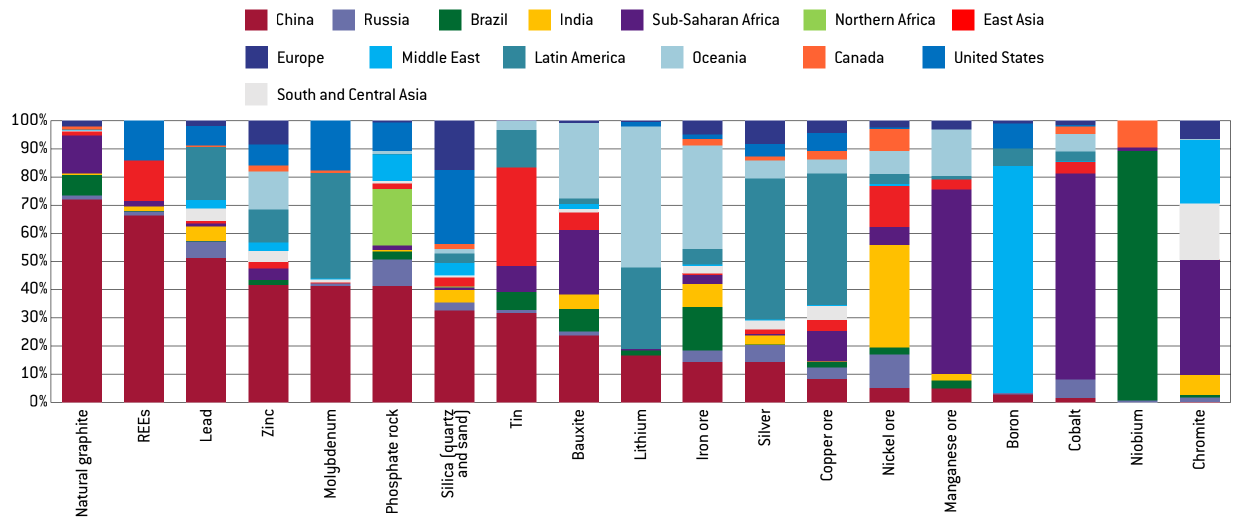
Work on the US and EU energy transitions tends to focus on access to critical raw materials or manufacturing capacity. However, clean-tech supply chains are complex and the input needs for clean tech are multi-faceted. These include reliable access to (i) critical raw materials, (ii) refining and processing capacity, (iii) low-cost manufacturing subject to limited tariffs and non-tariff barriers, and (iv) technological innovation to avoid resource bottlenecks and improve the efficiency of finished goods.

None of these needs can be met in the near term without China, neither within Europe nor globally. In this section, we present evidence on how reliant the EU is on China for clean tech, focusing on three sectors (solar panels, wind turbines and EV batteries), and on the four key components of each of these supply chains (extraction, refining, innovation and manufacturing).

2.1 China dominates mining and processing of key renewable energy minerals

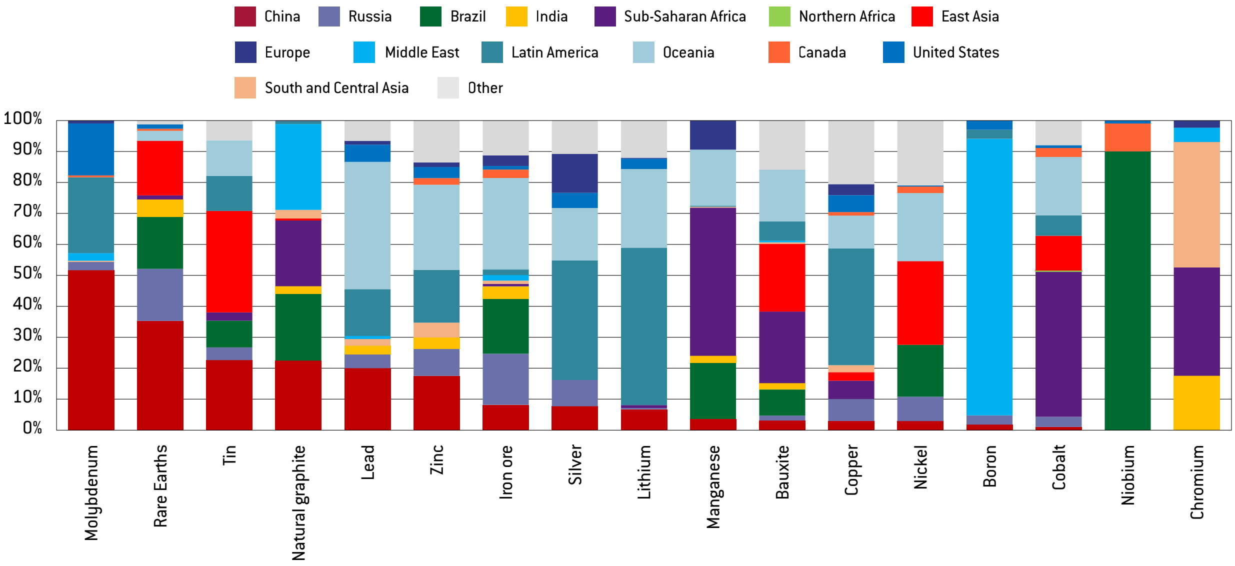
China's territory is rich in mineral resources, many of which are central to the production of clean-tech goods (Figure 1). Notably, China extracts 72 percent of the world's natural graphite and 66 percent of rare earth elements (REEs). On the whole, however, extraction of clean-tech minerals is dispersed across the globe, generally predicted by the location of deposits (Figure 2).

Figure 1: Global extraction of renewable energy minerals, % of total, 2019-2020



Source: Bruegel based on US Geological Survey.

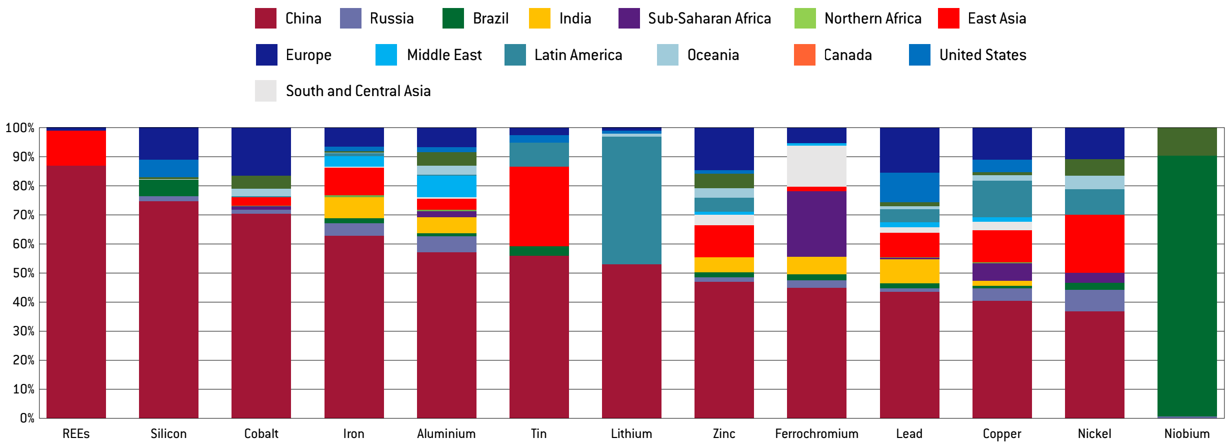
Figure 2: Global reserves of key minerals for renewable energy goods (2022)



Source: Bruegel based on US Geological Survey.

Beyond domestic extraction of key minerals, China commands a network of mineral supply agreements that feed its domestic refining industry, built through a series of cross-border acquisitions and trade agreements. These are primarily in southern and western Africa, Oceania and Latin America, but also with regional neighbours (Holden *et al*, 2022). China dominates the processing of REEs, with a market share above 85 percent, and of silicon and cobalt, all of which are integral to the production of high-energy-density batteries, wind turbines and solar panels[1].

Figure 3: Refining of renewable energy minerals, 2019-2020



Source: Bruegel based on US Geological Survey, IEA.

1 Charlie Cooper, Antonia Zimmermann and Sarah Anne Aarup, 'China Leaves EU Playing Catchup in Race for Raw Materials,' *Politico*, 10 March 2023, https://www.politico.eu/article/white-gold-rush-salt-lithium-batteries-raw-materials-chile-salar-atacama/.

That China's share of metals processing is higher than its share of extraction of those metals is a good indicator of how strategic the Chinese government has been in its long-standing aim to achieve dominance of the clean-tech industry. The US, EU and other advanced economies were for years content to see the processing of critical raw materials move to China because it is environmentally damaging and often depletes groundwater resources[2]. It would now be difficult for them to re-shore processing on a large scale because of domestic political opposition.

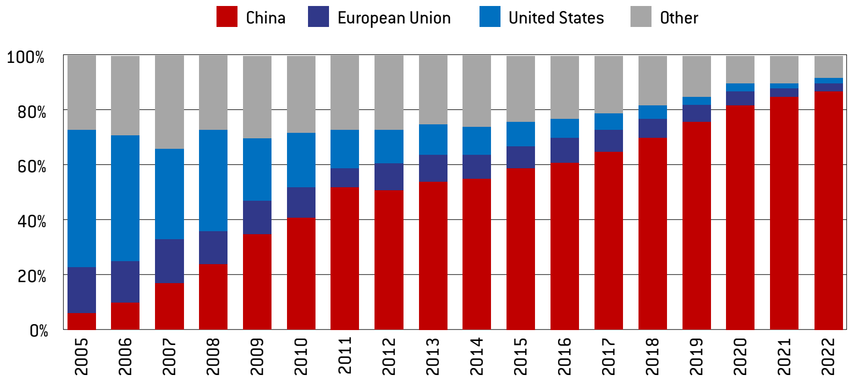
2.2 China is an advanced manufacturer of renewable energy goods

Much of Chinese manufacturing today is technologically advanced and grounded in a unique political, educational and infrastructural ecosystem. Economies of scale and leveraging of big data to fine-tune manufacturing routines put China ahead of the competition in producing many technically sophisticated goods. In the next sections we assess China's dominance of the manufacturing of three major types of clean tech: solar panels, wind turbines and EV batteries.

Solar panels

Chinese policymakers have succeeded in developing a leading solar PV industry that now holds a dominant share of the global market (Figure 4). Chinese solar panels are cheaper than the competition[3] – largely because of the country's command over raw material inputs – and are also the most efficient in terms of crystalline silicon panel technologies, which comprise the vast majority of the global market.

Figure 4: Share of solar panels all-components manufacturing



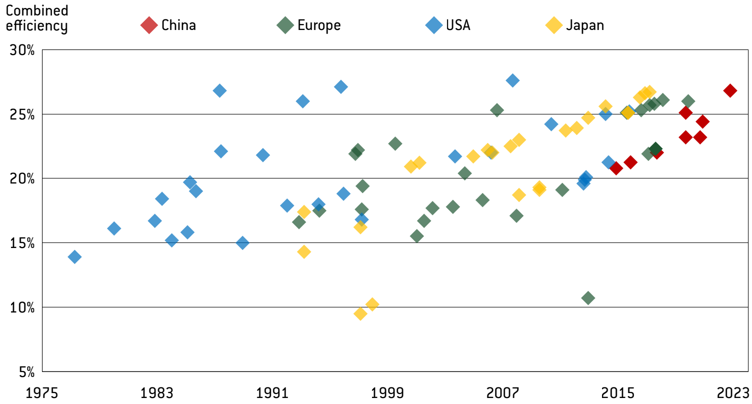
Source: Nataxis.

By fine-tuning their advanced, highly automated manufacturing processes, Chinese solar PV firms are able to manufacture with superior precision (Lin *et al*, 2023). This has enabled them to achieve record efficiencies for commercial silicon cells in the last five years (Figure 5).

2 Jaya Nayar, 'Not So "Green" Technology: The Complicated Legacy of Rare Earth Mining,' *Harvard International Review*, 12 August 2021, https://hir.harvard.edu/not-so-green-technology-the-complicated-legacy-of-rare-earth-mining/.

3 See Wood Mackenzie news release of 23 May 2023, 'China's solar exports booming, up 64% in 2022 despite global trade tensions,' https://www.woodmac.com/press-releases/chinas-solar-exports-booming-up-64-in-2022-despite-global-trade-tensions/.

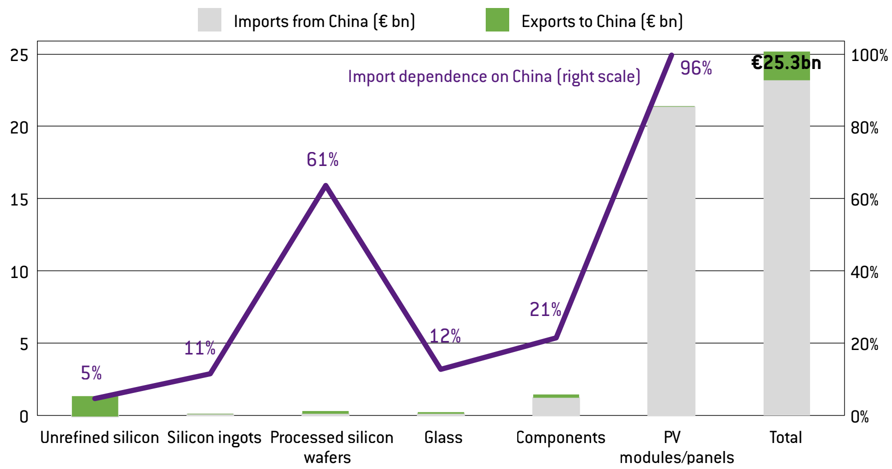
Figure 5: Solar PV efficiency records, crystalline silicon*



Source: NREL. Note: The figure shows the location of laboratories that have broken efficiency records for crystalline silicon solar panels over the last five decades. Chinese researchers have begun setting records in the last decade. Crystalline silicon solar modules are the most prevalent on the market. Efficiency refers to the share of energy received converted into electricity.

Chinese firms are the trusted suppliers of the European solar installation industry. More than 96 percent of EU imports of solar panels came from China in 2022, with a high degree of dependence across the whole supply chain (Figure 6). Notably, the EU is a sizeable net exporter of unrefined silicon to China, where it is processed and fed into the domestically captured value chain. Total EU-China all-components solar PV trade was €25.3 billion in 2022. Overall, the value chain is dominated by China, with European exports of unrefined silicon accounting for barely 5 percent of the total.

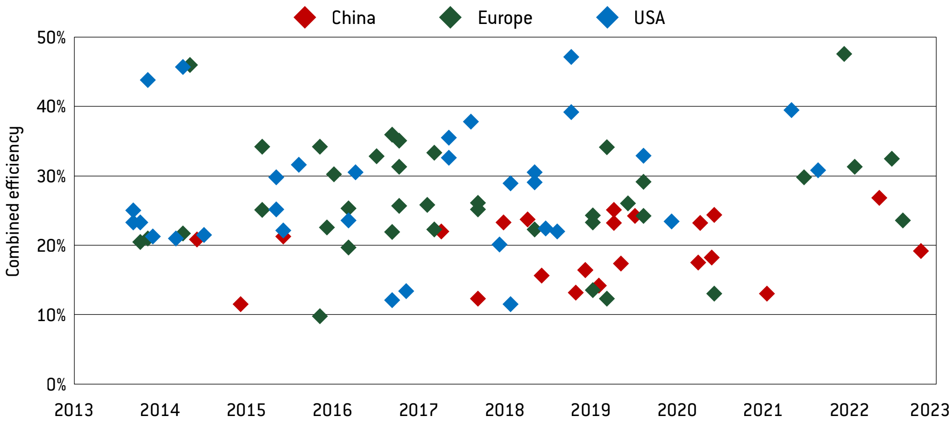
Figure 6: EU dependence on China in the solar PV supply chain, 2022



Source: Eurostat.

Chinese efficiency records in commercial silicon cells do not necessarily reflect technological innovation, but are likely the result of superior manufacturing precision enabled by economies of scale and high levels of investment. Moreover, Chinese firms lag behind the US and Europe in experimental solar PV technologies (Figure 7).

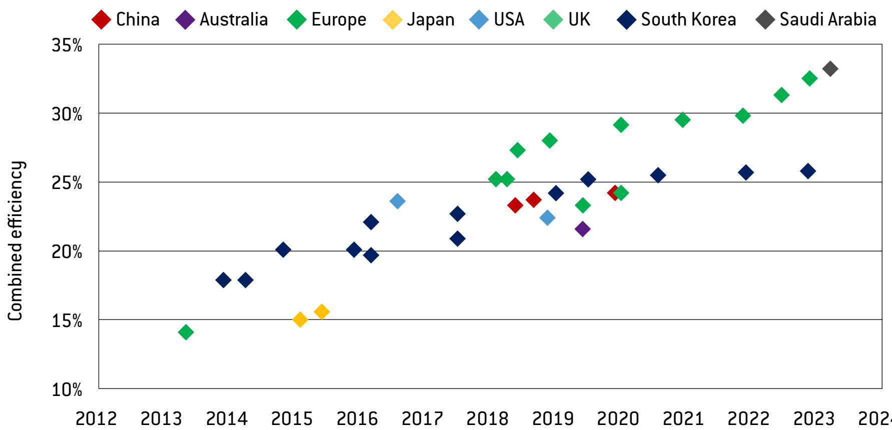
Figure 7: Solar PV efficiency records, all technologies (EU, US, China)



Source: NREL. Note: See note to Figure 5.

For instance, in the development of solar PV cells that incorporate perovskites[4], China lags behind other producers (Figure 8). There is a clear potential for a commercial breakthrough of solar panels produced with perovskites, which are considerably more efficient than currently dominant single-layer crystalline silicon panels, but scalability may be difficult outside China without government intervention.

Figure 8: Solar PV efficiency records, perovskite



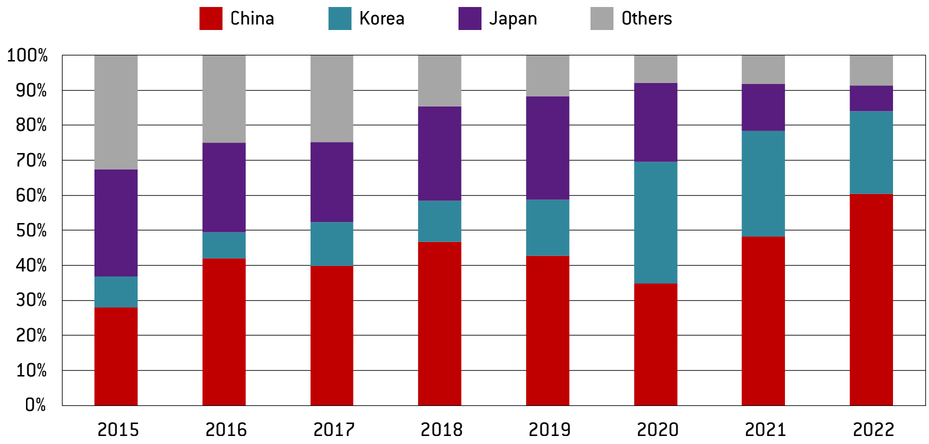
Source: NREL.Electric batteries.

EV batteries

Global EV lithium-ion battery production is principally located in China, Japan and Korea, with China having a 60 percent market share in 2022 (Figure 9). However, following major investments in EV battery factories in geographies including the EU and the US, manufacturing will become increasingly regionalised. Nevertheless, mineral extraction and refining may be harder to diversify and will likely remain centred on China in the near term.

4 Non-silicon compounds arranged in a particular crystalline structure often added as a secondary layer on top of a crystalline silicon base. See https://www.energy.gov/eere/solar/perovskite-solar-cells.

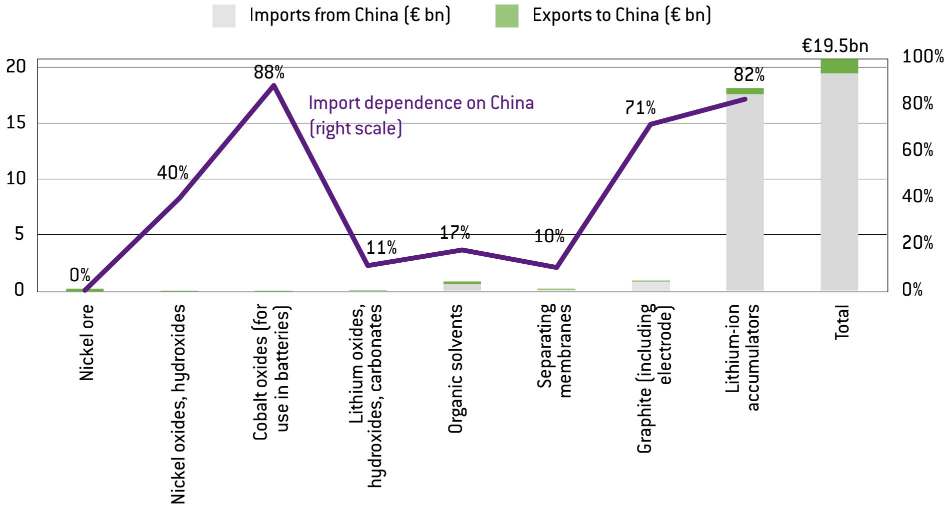
Figure 9: Market share of lithium-ion EV battery production by country



Source: Bruegel based on Natixis, SNE Research.

The EU's EV battery imports currently come mainly from China (Figure 10). Overall, 82 percent of finished lithium-ion accumulators imported into the EU in 2022 came from China. Moreover, certain inputs into the EV battery supply chain are also predominantly sourced from China, including cobalt oxides (88 percent) and graphite (71 percent). The EU is only a minor participant in this supply chain, both in terms of finished and intermediate goods.

Figure 10: EU dependence on China in the EV battery supply chain (2022)

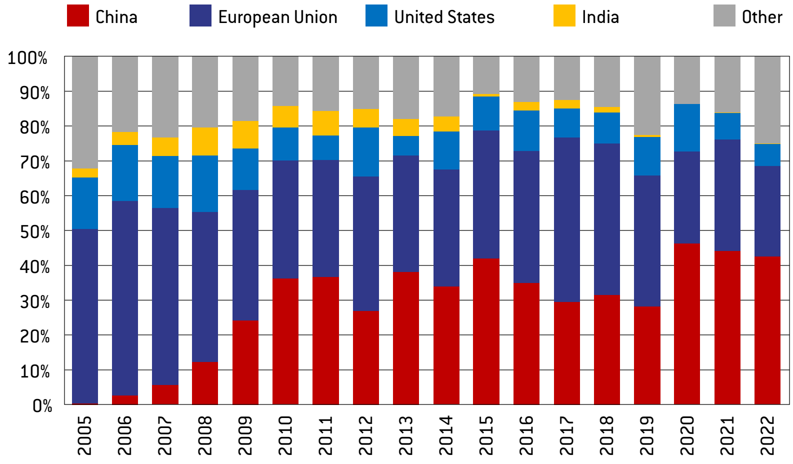


Source: Eurostat.

Wind turbines

EU-China trade in finished wind turbines is low relative to that in intermediate goods, because of the high cost of transporting wind turbine blades and towers between Europe and China. This favours localised production and has resulted in a regional fragmentation of the market. Therefore, Europe's diminishing and China's growing global shares (Figure 11) do not reflect directly competitive dynamics among Chinese and European firms, but mainly the levels of investment in wind farms across the respective regions in which European and Chinese firms are active.

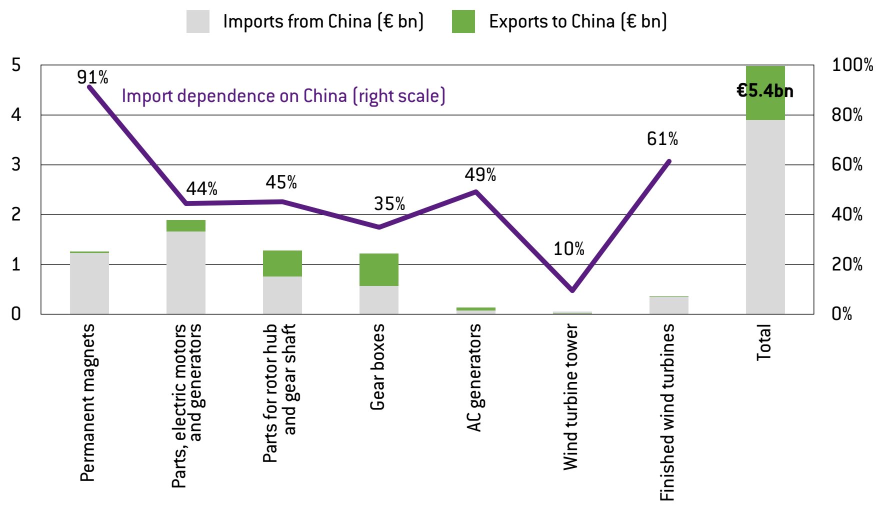
Figure 11: Shares of global wind turbine manufacturing



Source: Natixis.

Though EU-China trade in finished wind turbines is low, there is a sizeable volume of trade in intermediate turbine components (Figure 12). While the EU's reliance on China is generally only moderate for most components, 91 percent of EU imports of permanent magnets came from China in 2022, a dependence that extends to many other technologies, including electric motors[5].

Figure 12: EU dependence on China in the wind turbine supply chain (2022)



Source: Eurostat.

5 Barry van Wyk, 'China's Wind Power Companies Are Giants, But They Aren't Going to Take Over the World—Yet,' The China Project, 25 July 2023, https://thechinaproject.com/2023/07/25/chinas-wind-power-companies-are-giants-but-they-arent-going-to-take-over-the-world-yet/; Mary Hui, 'Why Rare Earth Magnets Are Vital to the Global Climate Economy,' *Quartz*, 14 May 2021, https://qz.com/1999894/why-rare-earth-magnets-are-vital-to-the-global-climate-economy; David Piper, 'Applications of Magnets in Wind Turbines,' *Wind Systems Magazine*, 15 March 2021, https://www.windsystemsmag.com/applications-of-magnets-in-wind-turbines/.

2.3 China's increasing dominance of green tech-related innovation

Chinese researchers have rapidly increased their output of scientific publications on solar PV, wind turbine and EV battery technologies, surpassing the US and the EU in 2022 (Figure 13). Currently, Chinese firms mainly lead on manufacturing processes and cost efficiency. By investing in domestic research on renewable energy technologies – where the West still mainly holds the lead – Chinese firms aim to reinforce their grip on exports of these goods. However, the quantity of output tells little of its quality, and the extent to which this research is novel and what share of it is applied as opposed to basic is not reflected in this breakdown.

Figure 13: Chinese scientific publishing on renewable energy tech

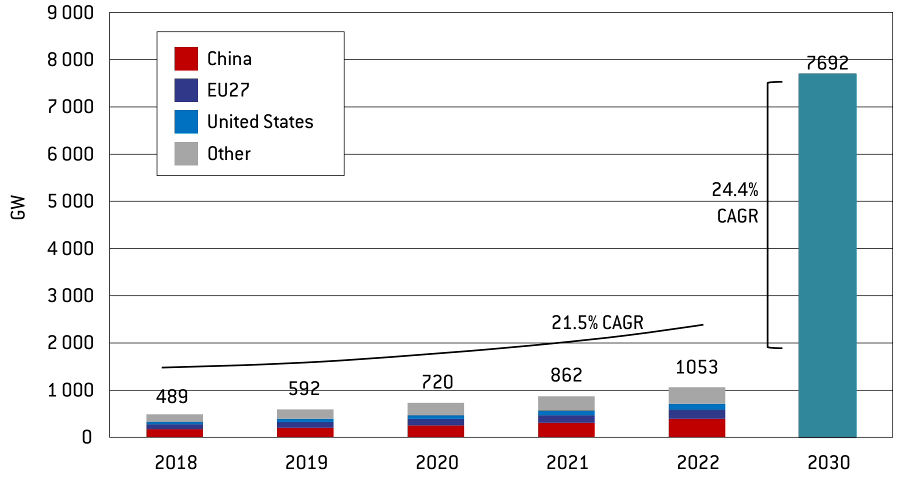
	Number of scientific publications - 2010			Number of scientific publications - 2021		
	1st	2nd	3rd	1st	2nd	3rd
Solar	🇪🇺	🇨🇳	🇺🇸	🇨🇳	🇪🇺	🇺🇸
Wind	🇨🇳	🇪🇺	🇺🇸	🇨🇳	🇪🇺	🇺🇸
Li-ion batteries	🇪🇺	🇨🇳	🇺🇸	🇨🇳	🇪🇺	🇺🇸
Heat pump	🇪🇺	🇨🇳	🇺🇸	🇨🇳	🇪🇺	🇺🇸
Carbon capture and storage	🇪🇺	🇺🇸	🇨🇳	🇨🇳	🇪🇺	🇺🇸

Source: European Commission presentation at Bruegel seminar on 21 June 2023. Reproduced with permission.

3 Ballooning global demand for green technology, including in China

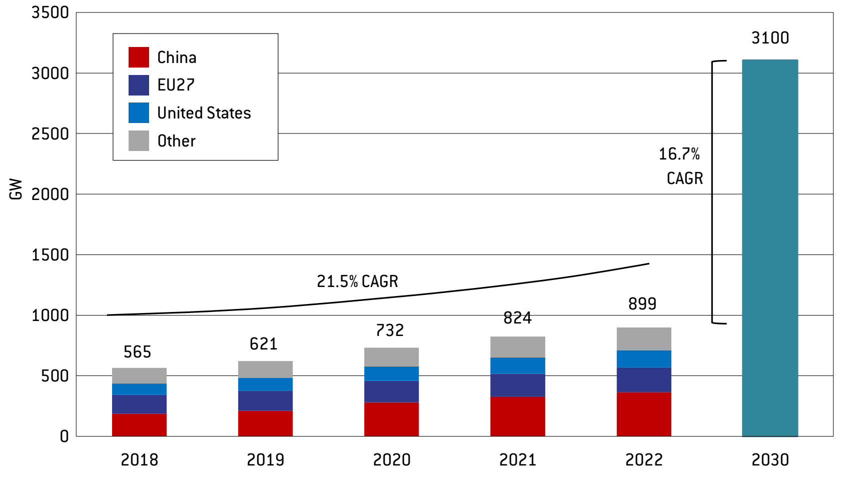
Global demand for green technology goods has and will continue to increase considerably to deliver the world's decarbonisation targets. The International Energy Agency projects six-fold and three-fold increases in installed solar panel and wind turbine capacity respectively, if targets for net-zero emissions by 2050 are to be met (Figures 14 and 15). It also projects EV battery demand to expand six-fold by 2030 under the sustainable development scenario outlined by the United Nations. (Figure 16) (IEA, 2020)

Figure 14: Solar PV installed capacity for net-zero, by region



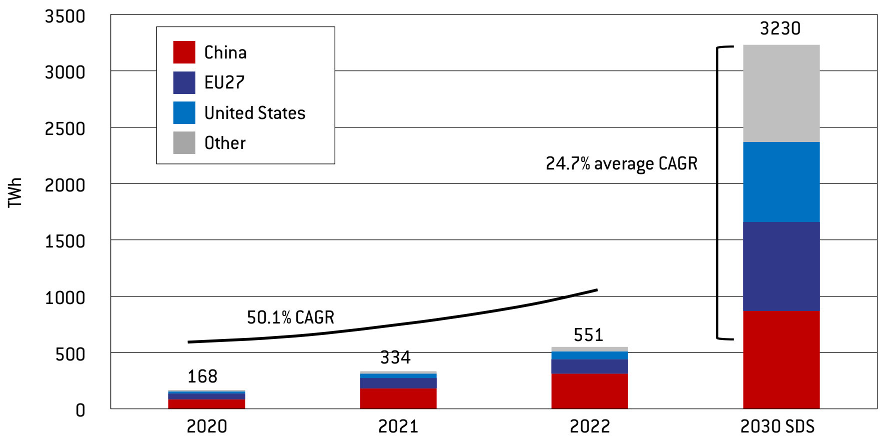
Source: Bruegel based on IRENA, IEA.

Figure 15: Wind installed capacity for net-zero, by region



Source: Bruegel based on IRENA, IEA.

Figure 16: Annual EU battery demand projections, by region



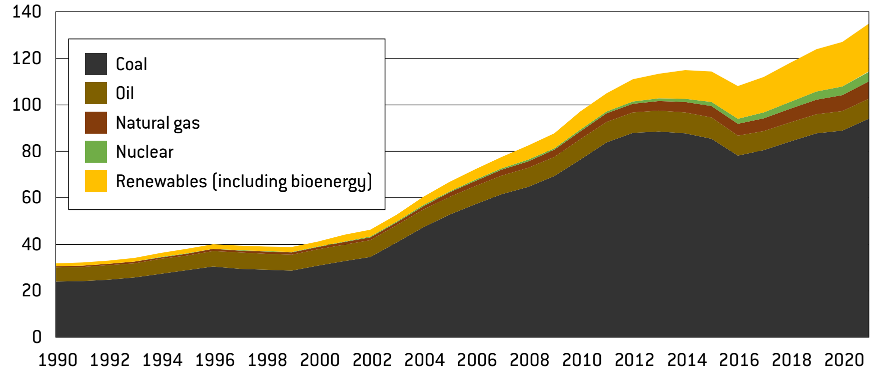
Source: IEA.

3.1 China will need a massive increase in renewable energy capacity to meet its targets

While China has steadily cemented its dominant role as the largest exporter of green tech globally, the country's own decarbonisation needs are vast. It is the world's largest greenhouse gas emitter and has targets of peaking emissions in 2030 and reaching net zero by 2060.

Over the last two decades, China has addressed its rapidly growing energy needs by expanding its coal energy infrastructure (Figure 17). This expansion, which is still ongoing[6], will need to cease and ultimately be reversed through substitution by non-fossil power generation. This will require China to expand its renewables base on an enormous scale if its energy supply is to remain sufficient while emissions are being cut and if its decarbonisation targets are to be delivered on time.

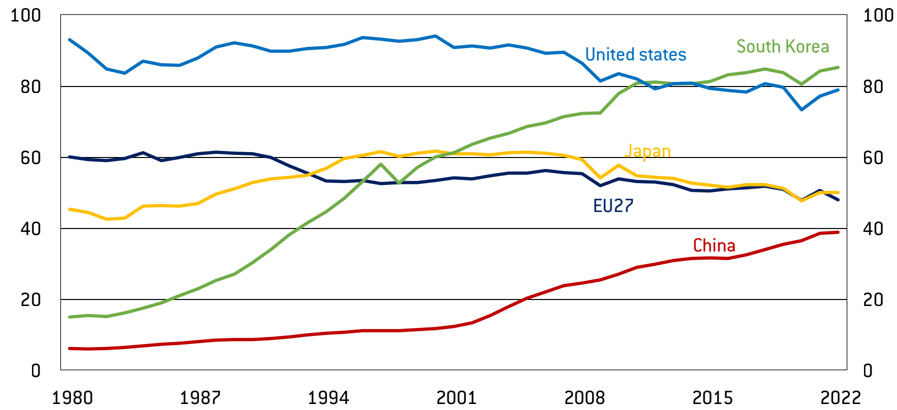
Figure 17: China, total energy consumption by source



Source: China National Bureau of Statistics. Note: the unit of measurement is quad BTU (quadrillion British thermal units). One quad BTU is roughly equivalent to one exajoule (EJ) of energy. Global primary energy consumption was 617 EJ in 2019 (https://www.iea.org/reports/world-energy-balances-overview/world).

China's renewable energy needs are highly dependent on how its *per-capita* energy demand develops over the next few decades. Assuming only a moderate increase in *per-capita* energy demand (Figure 18), the average annual installation needs for solar panels and wind turbines will easily exceed 400GW and 75GW annually, under the target set by China's Ministry of Ecology and Environment of 68 percent renewable primary energy by 2060[7].

Figure 18: Primary energy consumption *per capita*, MW



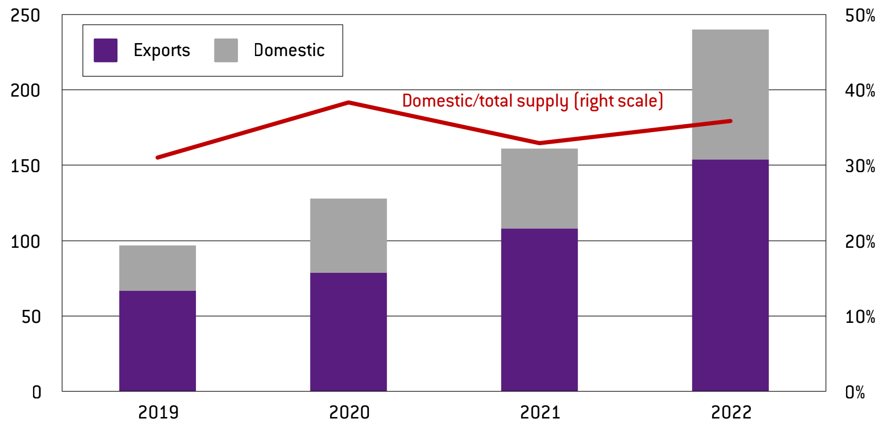
Source: Energy Institute

6 David Stanway and Muyu Xu, 'Analysis: China's New Coal Plants Set to Become Costly Second Fiddle to Renewables,' *Reuters*, 22 March 2023, https://www.reuters.com/business/energy/chinas-new-coal-plants-set-become-costly-second-fiddle-renewables-2023-03-22/.

7 See https://climateactiontracker.org/countries/china/.

Despite this, the Chinese solar PV industry remains predominantly geared towards exports, with only about a third of total supply installed domestically (Figure 19). This is despite China's large reliance on coal, phase out of which is a global priority. In a scenario in which China is pushed to install renewables even faster, for instance a climate crisis, there is a major question about whether China could remain the globally predominant supplier while addressing its domestic needs. The answer will depend on investment decisions made today, which are subject to a number of factors, including the return on investment in the various renewable sectors in China.

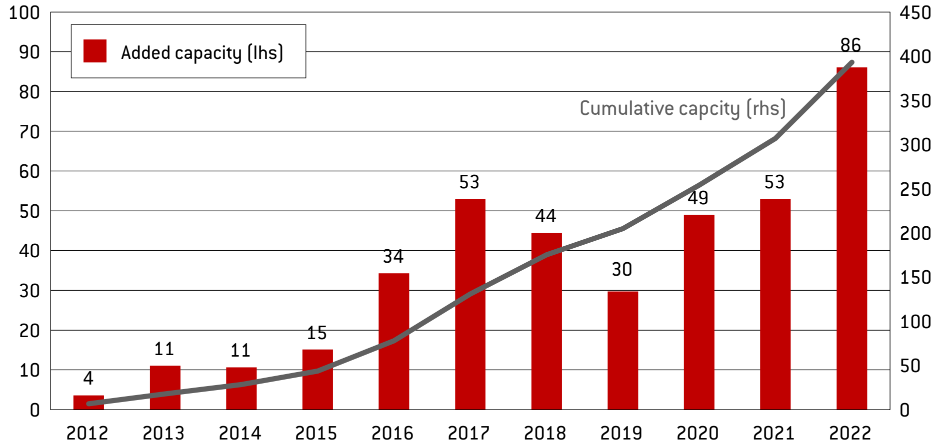
Figure 19: Chinese solar PV exports vs domestic installation, GW



Source: Bruegel based on IRENA, Wood Mackenzie.

Chinese installation of solar PV has accelerated in the last three years, and is projected to exceed 140GW in 2023, equivalent to just over 0.3 percent of China's total primary energy demand, if utilised at historical levels[8]. But the pace of installation has varied in the last decade (Figure 20). Moreover, even if the current trend were to continue, China would need to more than triple its annual average rate of solar PV installations, using the record projections for 2023 as base, and continue it until 2060 to deliver an annual average of over 400GW of installed solar PV capacity in line with decarbonisation targets.

Figure 20: Solar PV installed capacity growth, China, GW

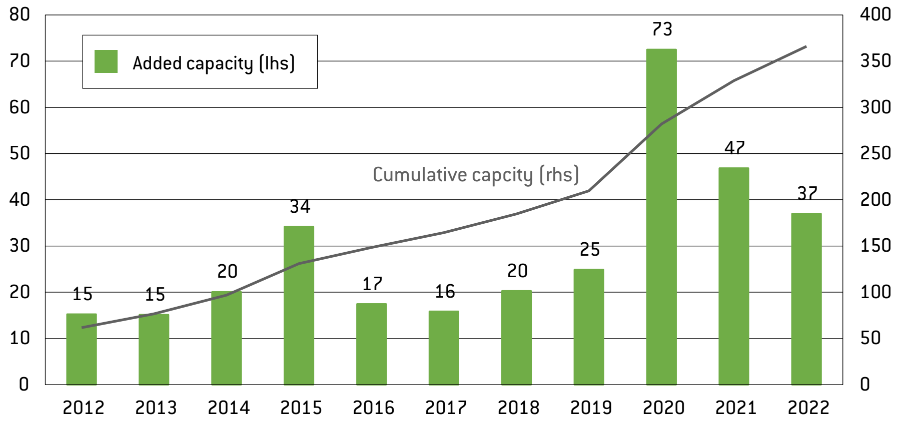


Source: IRENA.

8 Yujie Xue, 'Solar to Jump into Renewable Energy Driving Seat at Home and Abroad, as China's Capacity Just Keeps Expanding, Analysts Say', *South China Morning Post*, 26 May 2023, https://www.scmp.com/business/china-business/article/3221970/solar-jump-renewable-energy-driving-seat-home-and-abroad-chinas-capacity-just-keeps-expanding.

The same variability holds for wind (Figure 21). Annual average additions would have to be 50 percent greater than the mean added capacity between 2020 and 2022 (52 GW) until 2060 to meet government decarbonisation targets.

Figure 21: Wind installed capacity growth, China, GW



Source: IRENA.

Based on projections of Chinese capital expenditure in green-tech sectors, China should, in principle, manage to cover its own decarbonisation needs and maintain its highly lucrative export share. However, the ongoing deceleration of the Chinese economy makes it difficult to determine whether such substantial increases in capital expenditure will be feasible in the long run[9].

4 Mapping the risks of over-concentrated supply chains

Our analysis of the high reliance of the EU and the rest of the world on China for clean tech shows clearly why it is so difficult to reduce reliance on Chinese supply chains. In current circumstances, it is close to impossible for any country to achieve decarbonisation without importing a very large proportion of materials and finished products from China.

There are two different kinds of risk associated with the concentration of production: risks independent of the Chinese government and risks arising from decisions made in Beijing. Among the former, the effects of climate change itself in causing natural disasters and extreme weather events are increasingly important. The latter kind of risk may stem from active policy decisions or from shifts in economic and political priorities.

4.1 Types of risk created by over-concentrated supply chains

Many non-political and serendipitous risks could see exports from China impeded. These include climate-related disasters, pandemics or conflicts in mining regions (Van de Graaf *et al*, 2023). For example, in the summer of 2021, severe drought in Taiwan disrupted the delivery of

9 García-Herrero and Kaellenius (2023) present different scenarios for China's energy demand and clean-tech production, with consequences for the rest of the world in terms of the ability to import the necessary amounts of renewables for decarbonisation.

semi-conductors to the rest of the world, causing sharp increases in chip prices[10]. This type of *force majeure* event can cause immense disruption to global trade, and are a much bigger risk if there is heavy concentration of supply chains in single countries.

Among the second group of risks associated with decisions made in Beijing, there are two broad categories: economic policy and political decisions. Among the former, China's own decarbonisation efforts figure most prominently. The country's domestic needs are considerable and will require a ramping up of production capacity and consistent pace of expansion of renewable energy infrastructure (section 3.1). At the moment, Chinese production is growing in response to increasing global demand. However, at some point, it might become difficult to meet the EU's demand for decarbonisation goods if China cannot invest enough to keep on growing the supply of renewables, or decides to put its own needs first or serve other trading partners with which it may have signed preferential agreements.

The second type of decision made by Beijing is retaliation. There are clear instances, some very recent, of potential green-tech relation from China. For example, the introduction by the Netherlands of export controls on semiconductor components (lithography machines) in 2023 provoked retaliation by China in the form of a stop to exports of gallium and germanium, which are essential inputs into high-end semi-conductors[11]. China previously leveraged its dominant position in the minerals supply chain in 2010 when it stopped rare earth element exports to Japan after a stand-off over disputed islands[12]. Finally, China's ambiguous position over the war in Ukraine, particularly the possibility of the EU imposing sanctions on Chinese companies exporting dual-use technology to Russia, could trigger retaliation.

There are clear instances, some very recent, of green-tech retaliation from China

Beyond potential exogenous shocks and actions taken by Beijing, a scenario could also arise in which national security concerns become even more important, for example around the Taiwan Straits. Economic priorities might then be re-arranged, potentially hitting EU sourcing of renewable technologies.

Faced with these multiple risks, the EU has developed measures to handle any retaliation. However, applying them could be politically difficult because of the sheer scale of China's leverage in certain areas and because of internal political division over how to respond to trade aggressions. For example, China could limit exports of permanent magnets to Europe, seriously impeding the wind and EV industries. Although they are vital components, permanent magnets account for only a very small part of the EU's total trade with China. This could lead to EU countries with limited industrial exposure to permanent magnets to object to the EU retaliating to these measures, and to argue for giving in to Beijing's demands in the hope of sustaining other lines of trade and economic interests.

4.2 Responses so far

The EU's aim of *"de-risking"*, or reducing its dependence on its relationship with China, as proposed by European Commission President Ursula von der Leyen in May 2023 (von der Leyen, 2023), has gained widespread support among European countries and from the Biden Administration (Yellen, 2023; Sullivan, 2023). Von der Leyen presented de-risking as distinct from de-coupling. One part of the policy is to diversify the sources of supply, as set out in the proposed EU Critical Raw Materials Act (CRMA, European Commission, 2023a), while the second is to reshore manufacturing to Europe, as set out in the proposed Net Zero Industry Act (NZIA, European Commission, 2023b). While the EU, for decarbonisation purposes,

10 Sean Ashcroft, 'Timeline: Causes of the Global Semiconductor Shortage,' *Supply Chain Digital*, 11 January 2023, https://supplychaindigital.com/top10/timeline-causes-of-the-global-semiconductor-shortage. Other examples include the Evergreen cargo ship blocking the Suez canal in July 2021 and the closure of rail freight lines through Russia after its invasion of Ukraine.

11 Qianer Liu and Tim Bradshaw, 'China Imposes Export Curbs on Chipmaking Metals,' *Financial Times*, 3 July 2023, https://www.ft.com/content/6dca353c-70d8-4d38-a368-b342a6450d95.

12 Mai Nguyen, 'China's Rare Earths Dominance in Focus After it Limits Germanium and Gallium Exports,' *Reuters*, 5 July 2023, https://www.reuters.com/markets/commodities/chinas-rare-earths-dominance-focus-after-mineral-export-curbs-2023-07-05/.

needed to respond to the risks of excessive reliance on China, these two proposed laws are unfortunately unlikely to achieve this goal.

The CRMA would set targets for domestic mining, refining and recycling that are unlikely to be achieved because reshoring would be expensive and, in some cases, unfeasible because of European environmental protection rules. Furthermore, the bottlenecks in the supply chain for different types of green tech are so large that the EU's dependence on China cannot be solved exclusively through more access to refined critical raw materials. Even with such access, which so far remains elusive, reshoring the manufacturing of solar panels would not be cost effective, thus, driving up prices of clean tech and making the energy transition even more costly.

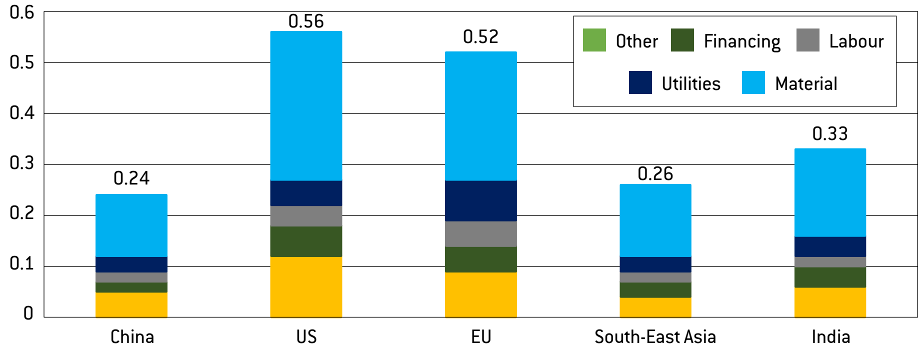
European countries might also increase costs even further by implementing narrowly defined plans to secure critical raw materials for their own use, instead of sharing the procurement for the whole EU or beyond. Le Mouel and Poitiers (2023) proposed that the EU creates an international strategy for critical raw materials, using instruments such as investment and export credits to diversify global supply chains. This is a worthy aim, but would take much longer than the timescale allowed for the energy transition. The lead times for mining projects are very long, with a global average of 17 years, while new refining plants can be built more quickly but can still be a major bottleneck (Energy Transitions Commission, 2023). Moreover, the EU's negotiation of trade agreements tends to be extremely slow, and ratification can run into political opposition. All in all, a rapid building up of access to CRMs seems unrealistic for the EU to achieve alone.

The most recent innovation in EU green industrial policy, the proposed NZIA, aims to encourage domestic manufacturing, mainly by easing permitting and setting a 40 percent self-sufficiency target for clean-tech sectors. However, this target is unlikely to be met since the costs of such reshoring are substantial and access to resources for such production remains elusive. Moreover, the funding strategy relies on national allocations of state subsidies, likely to result in fragmentation, and there is no governance structure to enforce it (Tagliapietra *et al*, 2023).

The US has taken a different approach with its Inflation Reduction Act (IRA), which offers large public subsidies to encourage reshoring of production to reduce reliance on China. This approach is too costly for other economies to replicate; although estimates vary widely, some project the total cost of the IRA will top $1 trillion over the next decade, mainly because tax credits under the act are uncapped (Evenett and Hufbauer, 2023). Moreover, China can make de-risking even more expensive for Europe if it retaliates, either by imposing export controls on intermediate products or by stockpiling.

Finally, comparisons of the average costs of producing green tech in different parts of the world show that reshoring to the US or the EU would make decarbonisation much more expensive. This would, however, not necessarily be the case if renewables were manufactured in other emerging economies, such as India and other ASEAN countries, since their prices are comparable to those of China (Figure 22).

Figure 22: Solar PV module manufacturing cost per region, $/watt



Source: Wood Mackenzie.

5 A novel approach: from reshoring to a green tech partnership

While reshoring the production of renewables would be very costly and may not be feasible in a reasonable amount of time, a green tech partnership could serve the purpose of derisking the production of green tech from China while decarbonizing, but at a much lower cost. Our proposal aims at bringing together every country which has both a comparative advantage and decarbonisation goals. A partnership based on G7 members alone would not be enough. It would lack the ability to secure raw materials (beyond Canada), let alone refine and/or manufacture at low cost, for which countries with low manufacturing costs and economies of scale are needed, such as India. To attract partners to join, the partnership needs to offer more advantages than either of the alternatives – China continuing to dominate the global supply chain of green tech, or trying to set up a separate supply chain in just one market. Our proposal therefore offers benefits for both high and low-income partners.

The efficiency gains from such partnership hinge on the ability to attract members that bring a diversity of comparative advantages but whose interests in decarbonisation are aligned. Coordinated specialisation would allow the partnership to cover the full supply chain, which is necessary since critical dependences from China exist for all aspects, from extraction and refining to manufacturing and even innovation. Coordinated specialisation would also help with economies of scale so that such de-risking from China makes sense economically in the medium term.

This partnership should be envisaged as a supplementary supply chain, which necessarily excludes China in order to diversify supply to reduce risks. The partnership is not intended to replace the existing China-centric supply chain but to complement it. With this objective in mind, the EU should aim at bringing in the US as major consumer of green tech, but also with the necessary innovation and financing capacity, as well as resource-rich countries and low-cost manufacturers, all of which are currently too dependent on China for their decarbonisation.

5.1 Objectives and advantages

A green tech partnership based on coordinated specialisation would aim at creating a cross-border supply chain to produce renewables technologies among incentive-compatible countries. The advantages would include: (i) reducing the risks of concentration by diversifying extraction, refining and production sites through a strategy of coordinated specialisation;

(ii) lowering the cost of reduced reliance on China compared to alternative approaches, such as reshoring, (iii) securing enough manufacturing of green tech to meet decarbonisation targets; and (iv) widening the range of technologies used for clean tech by coordinating investment in innovation, so that decarbonisation becomes as cheap as possible. Only through a partnership of countries with different comparative advantages can a fully integrated supply chain be created at a reasonable cost. This is because different economies with different comparative advantages can work together to take up various parts of it. This does not necessarily imply friend-shoring, as long as the members share the common objective of decarbonising with lower risks and therefore their incentives in joining it are aligned, despite their different comparative advantages.

For China to participate in the partnership would go against the objective of creating a supplementary supply chain to reduce reliance on China. In fact, given China's global dominance of green tech, its participation would imply that the new supply chain would collude with the existing one, defeating the partnership's purpose.

For those countries with large reserves of critical raw materials, the partnership would reduce their dependence on a single buyer (monopsony) and give them more bargaining power in selling their natural resources to partners that also offer help in moving up the value chain in clean-tech production. They could also be in charge of refining and/or manufacturing. For developed economies with critical materials, such as Australia and Canada, it is particularly attractive to have a complementary value chain to China's since they would have more bargaining power to seel their critical raw materials in a supply chain the co-lead than in the current China-centric one which, in some instances, could act as a monopsony.

Countries with reserves of relevant critical materials are increasingly unwilling to export them without refining them or even using them for manufacturing themselves. They want opportunities to move up the value chain, not just the extraction of their natural resources for immediate export, but engagement themselves in processing and manufacturing. This incentive for cooperation must be a cornerstone of any international strategy and could be a great motivation to engage in a decarbonisation partnership.

Moreover, the EU should welcome the desire of mineral-rich countries to move up the value chain because their expansion into refining would reduce the excessive concentration of mineral processing in China. Moreover, it would offer a basis for producing green-energy components outside of China at low cost. Furthermore, one would expect the private sector to be willing to finance new venues for refining of critical raw materials given the demand.

For countries with few natural resources but abundant low-cost manufacturing capacity, including India, Mexico, Turkey and other countries in Southeast Asia, the partnership would offer access to both raw materials and markets for finished goods. Partner countries where innovation is more developed would need to offer pooling of intellectual property, such as patents, so that more countries can be involved in manufacturing clean tech.

For the EU, an international partnership would be more attractive than trying to reduce reliance on China by itself

For the EU, a broader international partnership would be more attractive than trying to de-risk on its own. It is even harder for the EU to try to reshore production than it is for the US, which is making available large subsidies to this end under the IRA. By contrast, in the EU, public funds for industrial policy to support reshoring of clean tech are mainly held at national level, which creates other problems. In particular, the EU's largest countries, in particular those with more fiscal space such as Germany, are clearly in a better position than smaller or more indebted states to subsidise the reshoring of production of renewable technologies. This is bound to fragment the single market, which is essential for the good functioning of the EU project.

The overall benefit for all partners in the green tech partnership would be greater security of supply by increasing overall production and reducing the risk of supply-chain disruption stemming from excessive concentration. This would be particularly important should China decide to use its leverage or, simply to ramp up its own domestic installed capacity instead of exporting green tech in the next decade.

Finally, the partnership should help mitigate technological path dependence, which may arise from the excessive concentration not only of production, but also R&D in one country. China's large efficiency gains have come from its economies of scale and its innovation, with the great benefit of reducing the costs of green tech. However, the downside is that such high concentration discourages innovation in new technologies. Members of a green tech partnership would have an interest in leapfrogging existing technologies to create even more cost-effective alternatives. This would be beneficial not only for the members of the partnership, but for the world as a whole. The current relatively limited competition means dependence on specific technologies that are narrowly controlled by a single country. By contrast, the existence of two or more main supply chains that are jointly innovating, as well as competing to reduce production costs even further, helps everyone.

Even though China would not be a member, the green tech partnership would not be a threat to China's exports of clean-tech products, because the demand is set to grow so much that all global production will be needed. However, China would also benefit from the technological diversification the partnership could generate, given that Chinese producers are also dependent on raw materials that may not be available in sufficient quantities, even from the supply chains China currently dominates. Examples are the silver required for solar PV in current technology, and the lithium required for batteries for electric vehicles. In these cases, the only way out of raw material shortages is technological substitution. Chinese producers can and are developing new technology that uses other raw materials, but innovation is more likely to succeed when many scientists and companies work in parallel in many countries. China should not fear the creation of alternative technologies that will compete with its products, because the future market will be so huge that all suppliers will have demand to meet, provided there are some common standards for product performance.

6 How to start building the green tech partnership

Setting up a new green tech partnership won't be easy, especially if many countries are included. The most obvious form of the green tech partnership would be a new kind of climate club. This type of partnership should focus on greater security of supply of green tech to cut emissions, with the key objective of aligning objectives in a way that each member has a clear sense of its role and the net gains from participating in the club.

Existing agreements on critical raw materials between countries are mainly bilateral (Japan and Saudi Arabia's recent deal is an example[13]). Now the EU is seeking similar bilateral ways to secure access to critical minerals, but multilateral agreements would be better – bilateral deals tend to drive up prices for raw and refined materials without necessarily creating long-term incentives for cooperation. In addition, bilateral deals can hardly cover all aspects of the supply chain in green technologies, including extraction, refining, innovation and manufacturing.

The green tech partnership would be a new kind of climate club that focuses specifically on reducing the risks of disruption to decarbonisation[14]. It should be noted that the idea of

13 Julian Ryall, 'Japan-Saudi Arabia Ties: a Green Energy Gambit or "Was Everything About China"?' *South China Morning Post*, 18 July 2023, https://www.scmp.com/week-asia/economics/article/3228001/japan-saudi-arabia-ties-green-energy-gambit-or-was-everything-about-china.

14 The understanding that cooperation is needed to deal with supply-chain resilience was clear in the 20 May 2023 G7 communiqué, and in a proposal from the Japanese G7 presidency, but these ideas would be much more limited than our proposal to set up a partnership to cover all aspects involved in the production of green tech production. See The White House, 'G7 Hiroshima Leaders' Communique,' https://www.whitehouse.gov/briefing-room/statements-releases/2023/05/20/g7-hiroshima-leaders-communique/, and Government of Japan, 'How to build responsible supply chains for the green transformation,' https://www.ft.com/partnercontent/government-of-japan/how-to-build-responsible-supply-chains-for-the-green-transformation.html.

climate clubs has evolved over time. Originally put forward by William Nordhaus in 2015 (Nordhaus, 2015), several proposals have appeared since around the idea of groups of countries, usually focused on emission reductions, imposing coordinated tariffs on imports that do not meet the club's green standards, in order to encourage others to join (Vangenechten and Lehne, 2021). German Chancellor Olaf Scholz pushed the idea during his country's G7 presidency in 2022, based on a government white paper on how to overcome the risk of carbon leakage through cooperation on industrial decarbonisation, coordination of carbon leakage measures and joint creation of lead markets for low carbon products (BMF, AA, BMWi, BMU, BMZ, 2021).

While the green tech partnership will need to be shaped by the interested parties, below are suggestions on: (1) where to start with the institutional framework; (2) how to align incentives; and (3) different rationales for membership.

6.1 Where to start with the institutional framework?

The green tech partnership could be organised through mini-lateral agreements on trade and investment

The design of a green tech partnership must rely on the alignment of incentives, either through good will or, possibly, a formal agreement. While the latter would be preferable, it would still need to remain open to allow for market forces to operate.

The first question is what might be the best group or institution to discuss the creation of such a partnership. The G7 has already started discussing cooperation on de-risking, especially under the Japanese presidency in 2023. While certainly more cohesive than other, larger groups, as shown clearly after Russia's invasion of Ukraine, its members are not diverse enough in terms of comparative advantage for the G7 to be the right group to start the green tech partnership. Even if the intention was to expand the partnership from the G7 to a larger group, the choice of the G7 as founding members could put developed countries in a central role, with countries of the Global South remaining on the periphery as providers of critical raw materials and low wage manufacturing. This model is unlikely to be politically sustainable, especially if China reacts by luring the Global South through its own outbound investment to manufacture green tech outside of China. This process is already starting, as Chinese producers aim to offshore production to avoid barriers to Chinese green energy exports stemming from the IRA and other initiatives, which makes it essential to come up with a more inclusive design for a green tech partnership.

With larger groupings, such as the G20 or the Conference of the Parties to the United Nations Framework Convention on Climate Change, China's reaction to the creation of a supplementary supply chain that it does not dominate could be a problem. This is because Chinese producers see themselves as major beneficiaries of the *status quo* in terms of huge exports and related profits, especially given the quasi-monopoly situation at least for solar panels. Beyond the revenue it brings, China's dominance of green tech offers huge leverage to China's leadership, given the importance of decarbonisation plans all over the world.

Given these considerations, and the urgency of reducing reliance on China while maintaining decarbonisation goals, the most pragmatic approach might be to 'mini-lateralise' current frameworks for discussion and decision-making. These include the trade and technology councils (TTCs) already set up by the US and EU, and those used by the EU and Japan and the EU and India. The starting point would already be different from the G7, since India could become one of the founding members through its presence in TTCs, including with the EU.

More specifically, a subcommittee of the different bilateral TTCs could be created and merged into a single unit, with the objective of creating the foundation for a green tech partnership. This merged committee would aim to agree a network of memorandums of understanding that would provide consistent terms and conditions for a partnership. From this narrow group of core countries with existing TTCs, other countries may step into the partnership based on objective criteria, such as having a relevant comparative advantage, and also being incentive-aligned.

6.2 Tools to align incentives

While governments will be in charge of providing the general framework, companies will need to implement the strategy agreed under the green tech partnership. For that, the benefits need to be clear to companies, including greater certainty of supply, less technological path dependence and lower risk of disruption. These are system-level benefits that are not necessarily obvious at the company level. Incentives will need to be created for companies to prefer to extract, refine, innovate and/or produce green tech, rather than import it from China.

Incentives for companies need to include tech transfer and sharing patents

The first set of incentives relates to access to resources through reduced barriers, such as trade and investment agreements. While major economies – certainly the US and the EU – are already setting up strategic alliances with countries rich in critical materials, doing so at the level of the partnership would be much more effective and cost efficient. The partnership would offer access to the partnership's combined markets free of tariffs and other trade barriers. For the US, though, this might not be feasible for the foreseeable future, given a bipartisan preference for the *status quo*, in terms of trade and investment agreements.

Other incentives would thus need to be explored, such as offering free transfer of technology to those partners that aim at extracting, refining or/and manufacturing. Long-term contracts could be offered to green producers in this new ecosystem for public procurement of clean tech in partner countries. Finally, patents should be shared inside the partnership, but some form of investment screening might be needed to avoid leakage of new technologies to production sites where dirty energy is used.

Beyond the industrial policy concerns of tech transfer leakage, a second rationale for patent-sharing would be the need to reduce the technological path-dependence that might occur if China were to adopt the technologies developed by the partners. Finally, access to finance would be another important asset which could be put in common in this partnership. This could be achieved through foreign direct investment into the countries where green tech will be manufactured, or other sources of funding related to the green transition.

It is hard to tell whether the above measures will be enough for such a partnership to take shape. As a second best, given the importance of reducing reliance on China while decarbonising, two instruments come to mind, which are being used by the US or the EU in the context of de-risking: subsidies and carbon taxes.

Of the two, taxes are known to be superior, but that does not mean they will be more feasible (Gugler *et al*, 2021). The US IRA is already based on subsidies, while the EU prefers carbon pricing. When moving to a partnership, rather than reshoring as an objective, incentivising green tech production using subsidies will probably lead to a spaghetti bowl of subsidies, at high cost and yielding large inefficiencies.

Carbon pricing is not perfect either, because it is hard to make it compatible with World Trade Organisation rules. This would make it hard to impose at the partnership level, because of the significant income differences between the countries likely to be involved. More specifically, carbon pricing could be used to bring the pricing of renewable technologies produced outside the partnership to par with those manufactured inside, if production of the non-partnership technologies uses fossil fuels for which the emissions are not taxed. This would be the case for all the renewable technologies imported from China.

7 Conclusions

The EU is hugely dependent on China for the green tech needed for decarbonisation. It is very risky to depend on a single source of production of key renewable technologies because of the potential for weaponisation of this dependence, and because of China's own needs and factors beyond the government's control, including climate disasters.

An alternative solution to country-by-country de-risking (ie reshoring) would be creation of a green tech partnership aimed at increasing both the scale and diversity of the supply of renewable energy technologies. Members of the partnership would be chosen based on incentive alignment and buy-in to a common goal of meeting decarbonisation targets. The guiding principle would be coordinated specialisation, under the principle of comparative advantage.

Because China's current dominance of the supply chain is based on lower production costs as well as the control of extraction and refining and top-notch innovation, the only way for a supplementary supply chain to be sustainable is to introduce policies that will generate interest in this supplementary supply chain. Those policies should free-up the transfer of technologies within the partnership. Nevertheless, given the importance of reducing excessive dependence on China, while maintaining the pace of decarbonisation, more aggressive options might be needed. Of the two most obvious, production subsidies and carbon pricing, the latter seems less harmful, especially if designed to take into account differences in income levels and to be WTO compatible.

On membership, given the diversity needed to build a cost-effective and complete supply chain, a G7 club would not be the best option. Rather the membership should be wider, including producers of critical materials and low-cost manufacturers, as long as they have the same common goal, ensuring incentive compatibility.

Finally, the choice of countries based on comparative advantage will be important, as along with aligning incentives. Other than job creation through the offshoring of refining and, especially, manufacturing, there are the benefits of access to financing and tech transfer for resource-rich or low-cost countries, especially for those with large economies of scale to which FDI might flow more easily. For the US and the EU, the advantages come from pushing their strategies to reduce reliance on China without incurring the huge costs of reshoring.

De-risking decarbonisation is about increasing production of green tech, with the best possible technology and reducing concentration risk. No country can do this alone. While any form of multilateral agreement is now difficult to achieve, it is vital to try to find coordinated solutions to this most global of problems, as neither the *status quo* of Chinese dominance nor reshoring by individual countries offer sustainable solutions.

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