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Government Support in the Solar and Wind Value Chains

The past two decades have witnessed profound changes in the value chain for solar modules and wind turbines. These changes have gone in hand with growing concerns about excess production capacity, concentration of supply, and the subsidies that some governments provide to their manufacturers of solar and wind equipment. Against this background, this paper provides detailed, firm-level evidence on the scope and scale of government support for the production of solar modules and wind turbines throughout the period 2005-23. The analysis finds subsidies to have been generally larger for producers of solar modules than for producers of wind turbines. Until recently, China-based producers had been the largest recipients of government support by a significant margin in both solar and wind but recent measures introduced in OECD countries have translated into a notable increase in 2023. These findings underscore the trade-offs governments can face between climate objectives and fair competition.

Key words: Subsidies; Industrial policy; Renewable energy; Trade policy

JEL codes: F13; H25; H81; O25; Q48

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Executive Summary

Combatting climate change requires the deployment of renewable energy capacity at scale and at relatively low cost. While international trade plays an important role in this regard, there are pressing concerns over producer subsidies distorting competition to favour certain manufacturers of renewable-energy equipment.

The past two decades have witnessed major changes in how and where solar photovoltaic modules and wind turbines are produced. Many of the different manufacturing stages have largely moved to the People's Republic of China (hereafter, China), which has come to dominate the global production of polysilicon, solar wafers, cells, and modules, as well as the global market for key components of wind turbines such as blades, nacelles, and gearboxes. China has also become the largest market for the installation of renewable energy capacity, adding every year more solar and wind generation capacity than all other countries combined. Partly as a response, these changes have coincided with the introduction of trade remedies by several other countries and the proliferation of local-content requirements seeking to spur the development of manufacturing capacity locally.

One important question is the extent to which the major changes above have resulted from policies rather than market forces. Granular evidence collected by the OECD shows investment in module production capacity to have accelerated dramatically since 2020, with the resulting capacity vastly exceeding current demand. In this context, concerns are mounting that falling prices and low capacity-utilisation rates may be a manifestation of systemic overcapacity in the solar module sector, with the problem worsening in recent years. Such structural overcapacity ultimately raises trade and competition concerns as capacity expansion on such a scale and unresponsive to market signals suggests the presence of policy incentives softening the budget constraints of producers.

Firm-level information collected by the OECD shows subsidies to have been generally larger for producers of solar cells and modules (more than 3% of firm revenue on average) than for producers of wind turbines (slightly less than 1% of firm revenue on average). Until recently, China-based producers had been the largest recipients of government support by a significant margin in both solar and wind but recent measures introduced in OECD countries have translated into a notable increase in 2023. Government grants, tax concessions, and below-market borrowings all appear to have played a role in supporting producing firms.

One key conclusion is that some governments have been conducting what might be called 'green industrial policy' for nearly two decades already. Amid growing calls for governments to support clean-technology manufacturing in the context of the low-carbon transition, it might be helpful to take stock of the policies that already exist in this domain and the effects they may have had. Evidence generally points to the role of government support in causing (at least partly) structural overcapacity along the solar value chain. One consequence of excess production capacity in the solar value chain has been the growing concentration of production activities across fewer companies, most of which are based in China. As a result, governments now face complex trade-offs requiring them to balance at times conflicting policy priorities. This includes the imperative to decarbonise their energy systems and sustain innovation while also ensuring a level playing field in global trade and improving energy security.

Meeting government targets for reaching net-zero emissions of anthropogenic greenhouse-gas emissions requires, among other things, the large-scale deployment of renewable energy capacity. This ambition necessitates that this capacity be available at scale and at relatively low cost to ensure widespread adoption across countries' energy systems. International trade plays an important role in this regard, enabling specialisation, economies of scale, the sourcing of equipment from the lowest cost and most efficient producers, and the dissemination of innovative technologies.

Many countries have, however, expressed concerns over the conditions under which international competition is currently taking place in the renewable energy sector.[1] Chief amongst these concerns are the subsidies that certain countries offer to their manufacturers of renewable energy equipment. On the one hand, subsidies can be a useful addition to the range of instruments used for climate change mitigation, particularly where they spur additional deployment of low-carbon power-generation capacity and foster innovation and adoption of cleaner technologies. Yet subsidies can also be a problem where they distort competition to favour certain producers of renewable-energy equipment.

The possible consequences of countries using subsidies to favour their own producers of renewable energy equipment include: the risk of an escalating subsidy race favouring countries with more fiscal space; loss of confidence in the benefits of international trade; resource misallocation due to the crowding out of more efficient or innovative producers by more subsidised but less efficient competitors; growing overcapacity dampening the ability for producers to engage in meaningful innovation efforts; and the concentration of manufacturing in one country or region, with possible consequences for energy security and supply-chain robustness and resilience.

Substantial work has already been conducted at the OECD, the IEA, and elsewhere on the benefits and limitations of demand-side policies for encouraging the deployment of renewable energy capacity. By contrast, much less work to date analyses subsidies on the supply side, which this report seeks to measure and discuss. The present report follows on earlier sector studies of industrial subsidies undertaken by the OECD (OECD, 2019[1]; OECD, 2019[2]; OECD, 2023[3]), adopting a similar model albeit in a reduced format. Section 1 provides a brief overview of how the supply of solar modules and wind turbines evolved over the period 2005-23, then Section 2 looks at the broader value chain landscape. Section 3 describes succinctly the larger policy environment affecting both sectors, with particular attention to trade policies. Section 4 provides estimates of government support for manufacturing solar cells & modules and wind turbines. Finally, Section 5 offers some conclusions and discusses possible policy implications from a trade perspective.

1. Major trends in the supply of solar modules and wind turbines

The past two decades have witnessed major changes in how and where solar photovoltaic (PV) modules and wind turbines are manufactured. While global production of solar PV modules stood at barely 1.5 GW in 2005, it exceeded 500 GW in 2023 and looks set to increase further at record pace (IEA, 2024[4]). Global data from the International Renewable Energy Agency (IRENA) show, meanwhile, that cumulative installed wind-power capacity grew from 181 GW in 2010 to 1 017 GW in 2023.[2] In addition to growing fast over a relatively short time span, there have been important shifts in the location of production of renewable energy equipment (Figure 1). This is particularly visible for solar PV modules, where producers based in China have come to dominate the sector, accounting in 2023 for more than 90% of global shipments by volume. This contrasts with once-dominant OECD-based producers (e.g. Germany, Japan, and the United

[1] As reflected in the number of trade remedies targeting solar PV products, wind turbines, and their components. See Section 3.

[2] See www.irena.org/Data/View-data-by-topic/Capacity-and-Generation/Statistics-Time-Series (accessed on 1 August 2024).

States), who have seen their combined share collapse over the second half of the 2000s to reach less than 10% in 2023.

While less dramatic, the wind-turbine sector has also seen China-based producers play a growing role even as OECD-based producers (e.g. Denmark, Germany, Spain, and the United States) continue to dominate global sales. That said, the data shown in Figure 1 do not include certain large producers of wind turbines based in China for which detailed information was not available at the time of writing.[3] As a result, the figures likely underestimate the extent to which China-based companies have grown their share of the wind-turbine market.

There are many factors behind the changes observed in both sectors, beginning with local market size across countries, itself tied in part to the generosity of government support for the generation of renewable-based electricity (Annex C). The largest markets for solar modules were thus initially Germany, Japan, Spain, and the United States, spurred by strong policy incentives such as feed-in tariffs and renewable portfolio standards.[4] Back in 2004, wind power capacity was similarly the largest in Germany, followed by Spain, the United States, and Denmark (REN21, 2005[5]). China's current position as the largest market for solar modules and wind turbines is, in that sense, a more recent phenomenon dating back to 2013-14 (Figure A C.1). China began producing solar modules as far back as the early 2000s, at a time when nearly all its output was destined for export to OECD markets. Only with the later introduction of demand-pull support mechanisms did local producers begin increasing their domestic sales. Today, China forms the largest solar and wind market globally by far, adding every year more renewable generation capacity than all other countries combined. With such high demand in a very large domestic market, it is not surprising to find that China-based producers have grown their market shares.

Production costs are another important determinant of where the manufacturing of renewable energy equipment takes place. While energy prices are very important in the upstream parts of the solar PV value chain – such as the production of polysilicon – materials are generally the largest cost component downstream in the production of both solar panels and wind turbines (Annex B) (IEA, 2022[6]; IEA, 2024[4]). For solar cells and modules, this corresponds largely to polysilicon (Figure 2; left) whereas materials used in wind turbines include steel, fibreglass, copper, and several others.[5] Not all producers face the same costs, however, with OECD-based producers of wind turbines having experienced more rapid increases in the cost of their intermediate inputs over the last ten years (Figure 2; right).[6]

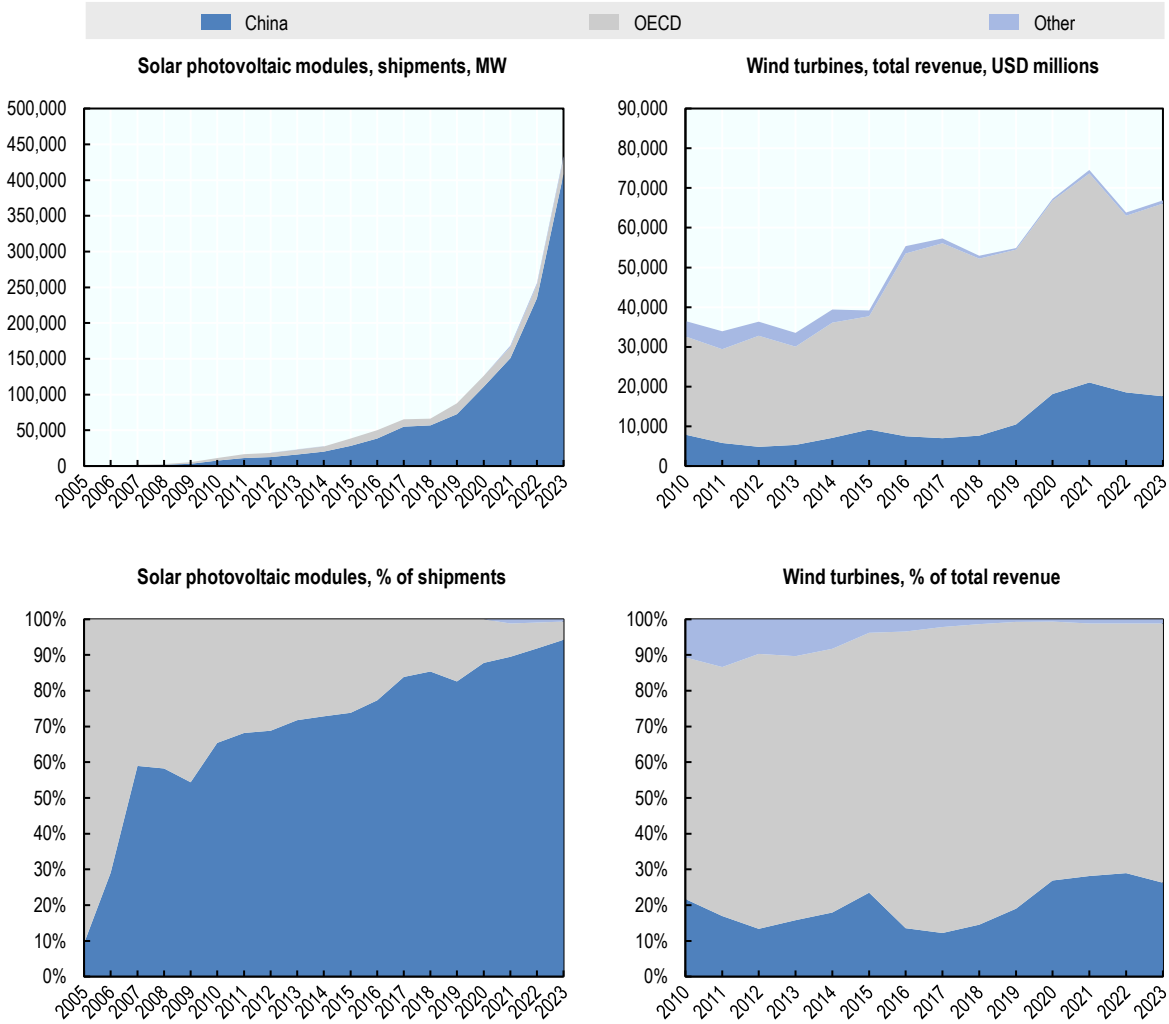
[3] This includes the wind-turbine subsidiaries of CSSC (the world's largest shipbuilder), CRRC (the world's largest producer of rolling stock), and Sany (a large producer of heavy machinery), as well as the Envision group (for which the data available only cover 2014-15).

[4] Feed-in tariffs and renewable portfolio standards belong to what this report refers to as 'demand pull support mechanisms' since these measures aim to increase the demand for renewable energy equipment. Feed-in tariffs guarantee the prices at which generators of electricity based on renewable energy sources are able to sell their output to regional or national grid operators. Renewable portfolio standards are requirements for power generators to supply a specified minimum proportion of their electricity from low-carbon or renewable-based energy. See, for example, www.eia.gov/energyexplained/renewable-sources/portfolio-standards.php (accessed on 17 September 2024).

[5] See Annex B for a short description of the value chain for solar PV modules and wind turbines.

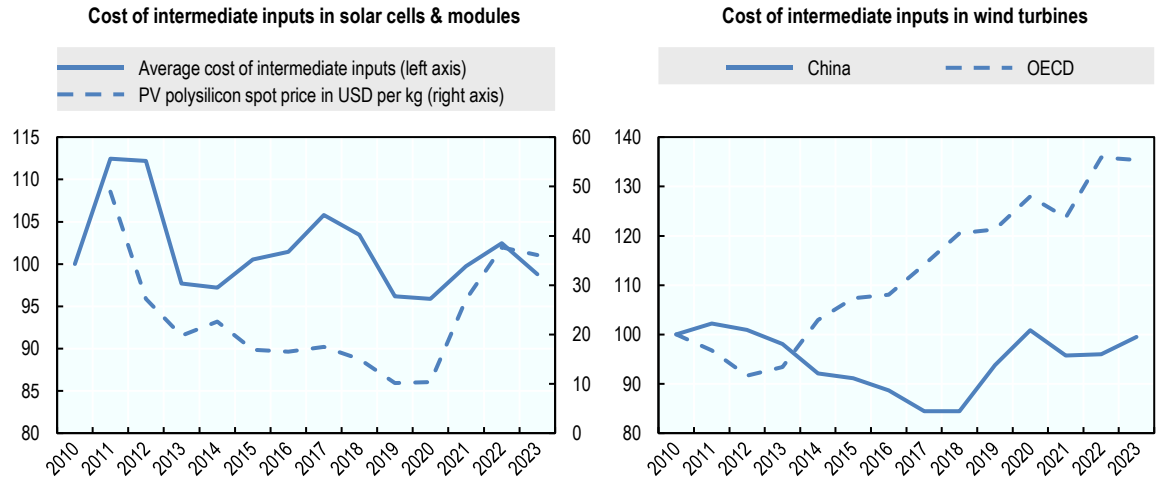
[6] Since about 80% of solar module production takes place in China, direct comparisons of average costs across jurisdictions are less meaningful in this sector given the relatively small number of large producers based outside China. See IEA (2024[4]) and IEA (2022[6]) for a discussion of the different cost components in an international context.

Figure 1. The past two decades have witnessed major changes in how and where solar panels and wind turbines are manufactured



Note: The graphs above are based on the sample of firms described in Annex A and therefore do not account for the entirety of sector shipments or sales. The geographical split is based on the jurisdictions in which firms are based, which can differ from where actual production takes place.
Source: OECD research and OECD MAGIC database. See Annex A.

Figure 2. Materials remain the largest cost component in the production of both solar panels and wind turbines



Note: The cost of intermediate inputs is expressed as 2010=100. It is approximated using firms' financial statements by deducting depreciation, amortisation, and staff costs from firms' cost of sales and dividing the resulting number by revenue.
Source: OECD MAGIC database for the cost of intermediate inputs and the Wind database for PV polysilicon prices.

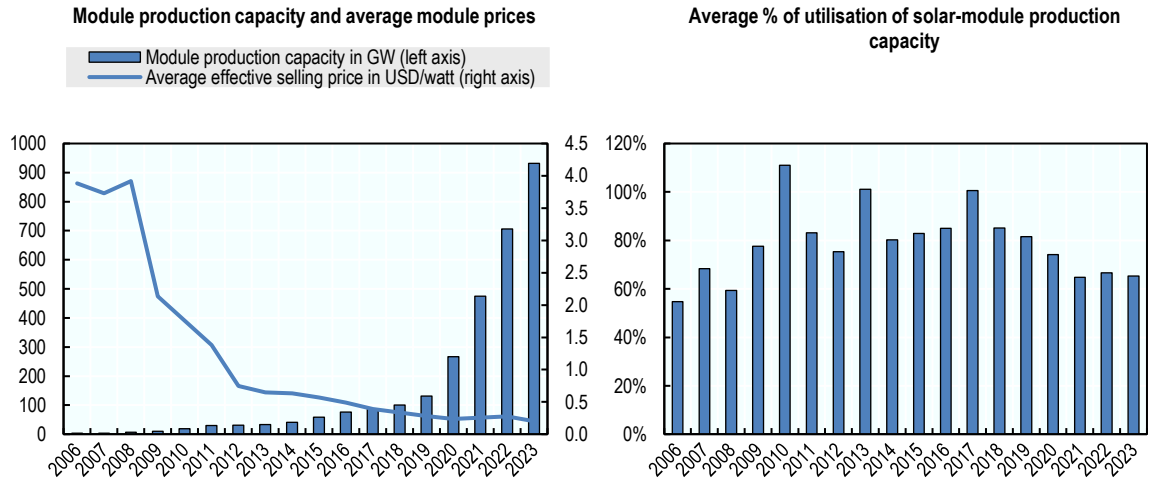
One important question is the extent to which the major changes described above have resulted from policies rather than market forces. A large range of policies can affect production costs and investment decisions, some more benign than others from a trade-policy perspective. Of key concern in this report are supply-side subsidies favouring certain producers, and which risk crowding out other, less-subsidised competitors. Addressing this issue requires understanding the drivers behind firms' expansion of their production capacity and sales, as well as the resulting effects on competition, prices, and trade flows.

Granular evidence collected by the OECD for all major producers of solar cells and modules (Annex A) shows their investment in module production capacity to have accelerated dramatically since 2020 (Figure 3).[7] Not adjusting for inflation, this has coincided with a fall in the average selling price of solar modules from USD 0.28 per watt in 2019 down to USD 0.20 per watt in 2023, after having rebounded slightly in 2022 in the context of supply-chain bottlenecks amplified by the COVID-19 pandemic. These developments also corresponded with a decrease in the sector's average capacity utilisation rate from more than 80% in 2019 to about 65% over the years 2021-23. More generally, the average price of solar modules has fallen considerably over the entire period studied, starting at around USD 3.9 per watt in 2005 and reaching as little as USD 0.2 per watt in 2023 (not adjusted for inflation).[8]

[7] Comparable data are, unfortunately, not available for the wind industry.

[8] At constant 2015 prices, this would correspond to a decrease from around USD 4.49 per watt in 2005 to USD 0.16 per watt in 2023.

Figure 3. The dramatic increase in solar production capacity since 2020 has coincided with falling module prices and lower capacity utilisation



Note: The graphs above are based on the sample of firms described in Annex A and therefore do not account for the entirety of solar-module capacity and prices. Prices are not adjusted for inflation. Volumes shipped can at times exceed capacity at the firm-level when producers meet additional demand by sourcing modules externally.
Source: OECD research. See Annex A.

While various factors could underpin the sharp decline in solar modules prices, such as significant reductions in the cost of intermediate inputs, economies of scale spurred by larger demand, or technological improvements, there is no compelling evidence that these factors alone explain this decrease. As shown in Figure 2, the price of intermediate inputs used in the production of solar cells and modules was highly volatile between 2005 and 2022. Meanwhile, although the efficiency of solar cells clearly improved over that period, these improvements remained gradual and limited.[9] According to some research, economies of scale brought by increases in the size of manufacturing plants have seemingly played a considerable role in the reduction of module prices since the early 2000s (Kavlak, McNerney and Trancik, 2018[7]). Such increases may not necessarily be a reflection of higher efficiency and improved yields, however. While the price of solar modules has dramatically fallen between 2008 and 2017 (Figure 3), solar module shipments appear to have gathered pace in the last six years (Figure 1), suggesting an important time lag between the fall in prices and the recent surge in shipments. The lack of concomitance between these two phenomena, together with the sustained low capacity utilisation of solar module manufacturing plants over most of the period 2005-23 (Figure 3) indicate that other factors than just economies of scale may be at play.

In this respect, concerns are mounting that falling prices and low capacity-utilisation rates may be a manifestation of systemic overcapacity in the solar module sector, with the problem worsening in recent years. The issue of overcapacity in China's clean energy sector is not new: it notably took a new turn after the 2008-09 global financial crisis, which prompted Chinese authorities to intervene in 2009 to rein in capacity expansions in various industrial sectors, including the production of solar-grade polysilicon and wind-power equipment (Li, Sun and Song, 2023[8]).[10] The issue of excess capacity nonetheless persisted

[9] See www.nrel.gov/pv/assets/images/cell-pv-eff-crysi.jpg (accessed on 3 September 2024).

[10] Driven by concerns that part of its RMB 4 trillion fiscal stimulus package (adopted in 2008), was leading to overinvestment in certain industrial sectors, the Chinese Government issued guidelines in 2009 to curb this trend. On this occasion, authorities notably recognised that "blind expansion" not only concerned traditional industries with overcapacity such as steel and cement, but also emerging industries such as wind power and polysilicon, which showed a tendency to duplicate construction. See (translated from Chinese) www.gov.cn/ldhd/2009-

in the following years, particularly in the polysilicon sector. During the period 2010-15, China's polysilicon manufacturing capacity expanded twice as quickly as in the rest of the world, resulting in a global supply glut and a major drop in the commodity's prices (Figure 2), as well as reportedly affecting downstream user segments (IEA, 2022[6]). As of 2024, judging by corporate disclosures and the Chinese Government's own declarations, the problem of excess capacity remains widespread in the solar module sector and across most of the value chain (Box 1),[11] resulting in fierce price competition and downward pressure on profit margins.

Box 1. Overcapacity in the solar module value chain is a concern for both governments and companies

Chinese authorities recognised in a report issued in March 2024 that overcapacity in some industries underpins, among other factors, a fragile economic recovery and slower growth in China.[1] The Ministry of Industry and Information Technology notably published draft regulations in July 2024 seeking to rein in the production of solar cells by guiding solar-cell companies to reduce "manufacturing projects that merely expand production capacity."[2] References to overcapacity in the annual reports of companies active in the solar sector further support the view that the solar value chain is suffering from overcapacity:

- **JA Solar**, a Chinese manufacturer of solar ingots, wafers, cells, and modules noted in its 2023 annual report that, "since 2021, the rapid growth of the global market has not only driven the capacity expansion of companies in the photovoltaic industry but also pulled the cross-industry entry of leading companies in other industries. […] With the release of production capacity and output, the photovoltaic industry has a clear trend of periodic overcapacity and structural overcapacity, and the prices of all segments in the photovoltaic industry have fallen."
- Similarly, **Canadian Solar**, which is active in the same value-chain segments as JA Solar, observed in its 2023 annual report that rapid capacity expansion of silicon production in recent years, coupled with the global financial crisis, led to an oversupply of high-purity silicon since the beginning of 2009. This situation "has contributed to an oversupply of solar wafers, cells and modules and resulted in substantial downward pressure on prices throughout the value chain."
- According to **Wacker Chemie**, a major German producer of polysilicon, the PV industry has built up vast excess capacity in China. Today, "Chinese competitors are investing heavily in new polysilicon capacity." As the company stated in its 2023 annual report, "massive excess capacity in China in the coming years at all points in the solar industry's value chain and, in particular, as regards polysilicon could result in intense price competition, putting pressure on margins."

[1] Report on the Work of the Government delivered at the Second Session of the 14th National People's Congress of the People's Republic of China on 5 March 2024, https://npcobserver.com/wp-content/uploads/2024/03/2024-Government-Work-Report_EN.pdf (accessed on 28 August 2024).
[2] See www.miit.gov.cn/jgsj/dzs/gzdt/art/2024/art_16a86cc6229d4cf8b52c54dd01df7a74.html, translated from Chinese (accessed on 1 September 2024).

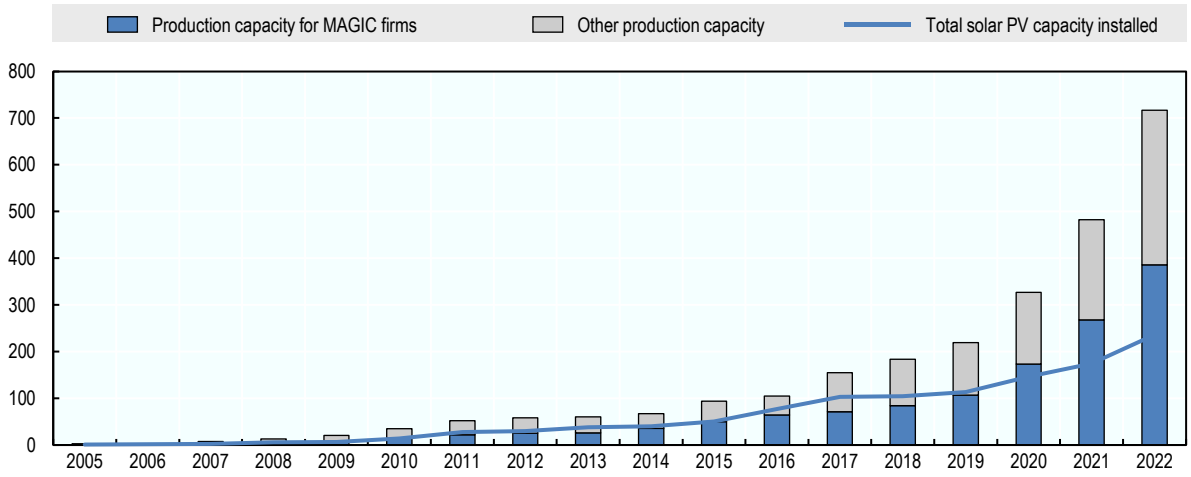
08/26/content_1402220.htm (accessed on 22 August 2024). The issue prompted Chinese state banks to reduce the loans they provided to these sectors by restricting lending conditions. See, among others, China Construction Bank (Annual Reports 2011, 2012, and 2013), Bank of Communications (Annual Reports 2011 and 2012), and China Merchants Bank (Annual Reports 2012 to 2016).

[11] The market for solar-grade polysilicon was, however, tighter and prices higher between 2020-22, partly due to disruptions caused by the COVID-19 pandemic (IEA, 2022[6]). See also Figure 2.

Although there is no single or definitive metric to measure overcapacity,[12] there are signs that the solar module sector is indeed experiencing overcapacity. While solar module production capacity has dramatically increased since 2020, capacity utilisation has fallen in the sector (Figure 3), thus revealing an important gap between companies' actual output and their production capacity. Using the total solar-module power capacity installed every year as a proxy for global demand shows that production capacity vastly exceeds current demand, with the production capacity of companies covered in the OECD MAGIC database (Annex A) alone already surpassing this level (Figure 4). Moreover, this significant imbalance between demand and the volume companies can produce does not appear to be temporary or cyclical, but rather more enduring and structural, resulting from companies' decision to maintain or grow their production capacity in excess of, and detached from, current and future demand. Such structural overcapacity may ultimately raise trade and competition concerns as capacity expansion on such a scale and unresponsive to market signals does not typically happen in a vacuum. This could suggest the presence of policy incentives softening the budget constraints of companies (Yu et al., 2021[9]; Boullenois, Kratz and Rosen, 2024[10]).

Figure 4. Production capacity for solar modules vastly exceeds global demand

Production capacity versus total capacity installed for solar PV modules (in GW)



Source: OECD research and IEA (2023[11]). See Annex A for a description of data sources.

2. A brief overview of recent developments in the solar and wind value chains

In the context of the significant changes noted above in relation to the supply of solar modules and wind turbines, it is important to understand the evolving composition, structure, and geography of the solar-module and wind-turbine value chains and how they have shaped trade in renewable energy equipment. A more in-depth presentation of the solar and wind value chains is available in Annex B.

[12] According to remarks made by the US Department of the Treasury Under Secretary for International Affairs Jay Shambaugh on Chinese overcapacity and the global economy, rather than a single test or condition to identify overcapacity, there are three different sets of indicators, which together or on their own could signal the existence of overcapacity, namely (i) an increase in capacity expansion inconsistent with even the most ambitious demand projections; (ii) the widespread presence of lossmaking and inefficient firms along with rising investment and production; and (iii) low or sharply declining capacity utilisation rates. See https://home.treasury.gov/news/press-releases/jy2455#_ftn1 (accessed on 29 August 2024).

Over the last 15 years, the geography of the solar PV value chain has dramatically changed as the different manufacturing stages (Annex B) have largely moved to China. Although China already dominated in 2010 the global production of solar wafers (80%), cells (60%), and modules (50%) (IEA, 2022[6]), its weight has further increased since, rendering the supply chain almost entirely dependent on producers based in China. In 2021, China represented 97% of global wafer manufacturing capacity while accounting for 80% and 70% of the global production of cells and modules, respectively (ibid). In that same year, China produced 70% of the world's silicon metal and 80% of the polysilicon used for solar PV modules manufactured globally (IEA, 2022[6]; Moon, 2024[12]).[13]

While the concentration of wind-turbine manufacturing capacity in China is not as significant as for solar modules Figure 1, the country has gradually built a large, scale-driven integrated supply chain. In addition to blades and nacelles, China dominates the global market for key wind turbine components such as gearboxes (80%), converters (82%), generators (73%), and castings. It has also become a global leader in the extraction and processing of key material inputs, such as steel, aluminium, and rare earth elements (REEs) used in permanent magnets (Rystad Energy, 2023[13]; GWEC, 2024[14]). China's lead is also significant further downstream in the construction of wind-power installation vessels for offshore wind farms. It is set to remain so in the near future as wind-turbine manufacturers vie for the ever-growing offshore wind market, thus increasing the demand for vessels with sufficiently large crane and lifting capabilities (IEA, 2023[15]; GWEC, 2024[14]; Rystad Energy, 2023[13]).[14] Despite recent efforts by several OECD governments to diversify away from China, announced capacity expansion plans in both the solar module and wind turbine value chains indicate that the manufacturing of key components across these value chains will remain geographically concentrated in China in the coming years.[15]

Many of the largest China-based manufacturers of solar modules have also become crucial actors all along the solar value chain, having integrated vertically over time by entering various – and in some instances all – segments of the value chain (Figure A B.2 in Annex B). While in 2005, more than 80% of the solar PV manufacturers covered in this study were active in less than two segments of the value chain, in 2023, more than half of them were active in three or more segments (Figure 5). Vertical integration in this sector has remained mostly confined to China-based firms, with the exception of Korean producer Hanwha Solutions. Various factors may explain these findings. First, by adopting a favourable regulatory and policy environment for producers along the entire solar value chain, Chinese authorities have played an important role in pushing for vertical expansion.[16] This may have prompted Chinese producers active in one value-

[13] China's market dominance along the solar value chain is exacerbated by the fact that minerals used throughout the manufacturing process of solar PV modules (e.g. copper and zinc), as well as other module components (e.g. glass, junction boxes, aluminium frames, encapsulants, and backsheets) are also mostly processed or produced in China (Annex B) (IEA, 2022[6]).

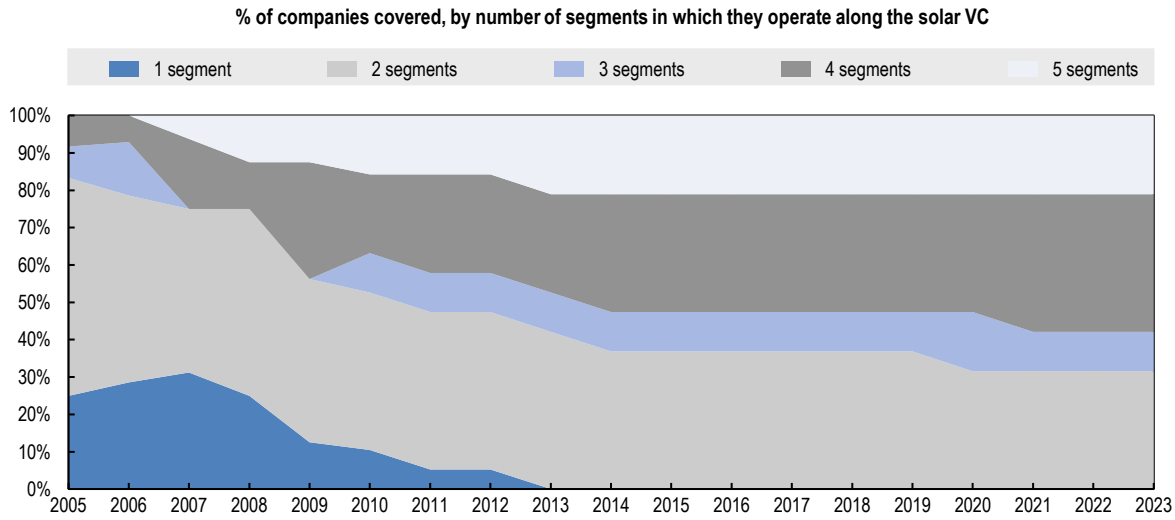
[14] In December 2023, according to press reports, there were more than 130 wind power installation vessels in operation worldwide, of which more than 100 were built in China. In addition, among the 37 orders for such vessels counted globally at the end of October 2023, 33 were being built by Chinese shipyards. See www.globaltimes.cn/page/202312/1304406.shtml (accessed on 25 August 2024).

[15] Once completed, announced capacity expansion plans could result in 95% of all solar module components being made in China by 2025 (US Department of Energy, 2022[45]). China could also be responsible for 56% (onshore) and 60% (offshore) of global manufacturing capacity of wind towers, 63% and 80% for onshore and offshore blades, as well as 64% and 70% for onshore and offshore nacelles, respectively (IEA, 2023[15]).

[16] After having included solar PVs on the list of strategic emerging industries in 2010, the Chinese Government designated the production of clean-energy technologies as a whole to be one of the seven strategic emerging industries for powering China's future economic development in its 12th five-year plan (2011-15). In addition, along with setting targets for solar powered installed capacity in successive five-year plans, the government also adopted a wide range of support policies to bolster the domestic supply of solar technologies, notably through local-content requirements, as well as to promote the demand for solar power, including through a feed-in tariff system.

chain segment to expand into other manufacturing stages. Many of these integration efforts, which took place at both ends of the value chain (Annex B), may have occurred also in response to price volatility in certain key components or inputs. Following a sudden surge in polysilicon prices in 2008 due to a global shortage, several Chinese module producers embraced a vertical integration strategy to secure their supply of polysilicon. Given the large amount of energy required for refining silicon metal, access to competitive, coal-based electricity prices in the Western Chinese provinces of Xinjiang and Inner Mongolia facilitated their entry into the segment (Annex B). In a similar fashion, original producers of polysilicon have capitalised on their cost advantage to integrate downstream into the value chain (e.g. in wafers, cells, and modules).

Figure 5. The largest China-based manufacturers of solar modules have integrated vertically over time



Note: The graph above is based on the sample of firms described in Annex A and therefore does not account for the entirety of solar-module-producing companies.
Source: OECD research. See Annex A and Annex B.

In contrast to the solar value chain, the scale of vertical integration in the wind value chain has remained limited due to the technical complexity attached to the manufacturing of wind turbines (BloombergNEF, 2021[16]). That said, most of the major manufacturers of wind turbines do produce nacelles and, to a lesser extent, blades in-house instead of outsourcing their production (BloombergNEF, 2021[16]; Rystad Energy, 2023[13]; David, 2021[17]).[17] Markets for these two components are thus somehow less fragmented than markets for other wind-turbine components although there remain some independent blade and nacelle manufacturers located predominantly in China (Rystad Energy, 2023[13]).[18]

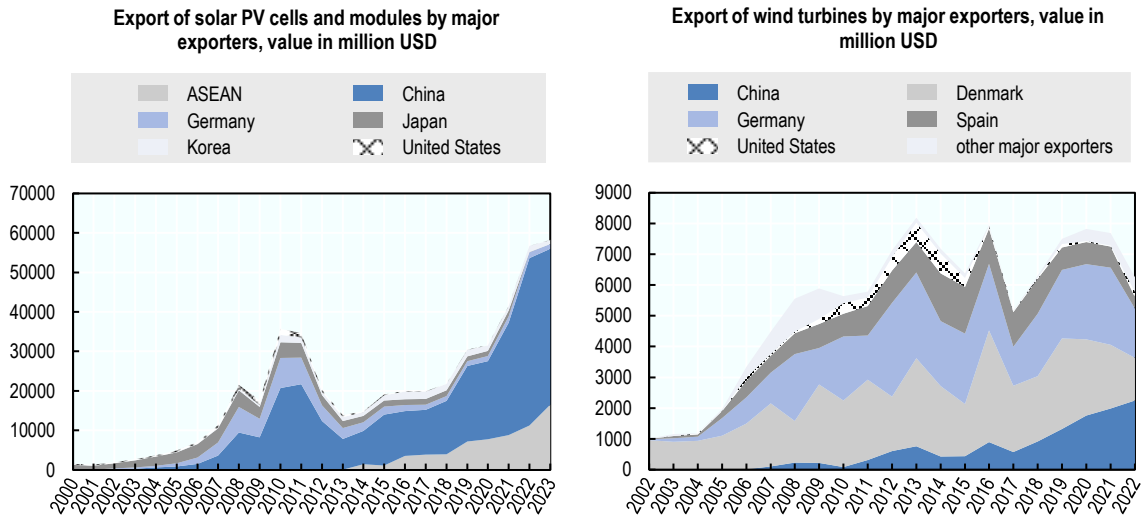
[17] In 2022, Vestas, Siemens Gamesa, and GE together produced 32% of the global blade manufacturing capacity while Vestas, Goldwind, Envision, Siemens Gamesa, GE, Nordex, and MingYang together manufactured 63% of the global nacelle manufacturing capacity (Rystad Energy, 2023[13]).

[18] China accounted in 2022 for 62% and 57% of, respectively, global blade and nacelle manufacturing capacity. Following the acquisition by GE of the Danish blade producer LM Wind in 2017, US-based TPI Composites is now the only remaining major independent blade manufacturer outside China and India (Rystad Energy, 2023[13]; BloombergNEF, 2021[16]).

Although manufacturing capacity in the solar module and wind turbine sectors has generally experienced a large-scale geographical shift toward China, some economic factors and government policies have nonetheless underpinned a certain degree of localisation. In this respect, the proliferation of national and subnational local-content requirements (LCRs) attached to renewable-energy support schemes (e.g. feed-in tariffs, contracts for difference, or tax credits) since the end of the 2000s, as well as the emergence of trade remedies in the solar module and wind turbine sectors, have incited manufacturers to establish manufacturing facilities locally (see next section). Moreover, as the size of wind turbines has increased – particularly offshore ones –, so have their components, requiring for logistical and economic reasons that these very large components be manufactured and pre-assembled in specifically designed port facilities before they are transported to, and erected at, their ultimate offshore location (GWEC, 2024[14]; CSIS and BloombergNEF, 2021[18]).

International trade forms an integral part of the solar and wind value chains, such that the changes described above have profoundly reshaped global trade in solar modules and wind turbines. Combining PV cells and modules for statistical purposes shows that the largest exporter by value has long been China, followed more recently by Southeast Asian countries, notably Viet Nam, Malaysia, Thailand, and to a lesser extent Cambodia (Figure 6; left). Of these, Viet Nam, Malaysia, and Thailand serve both their domestic market and the global market while Cambodia's solar PV production is almost entirely destined for export to the United States (ADB, 2023[19]). Against the backdrop of trade restrictions affecting Chinese exports (see next section), Southeast Asia has evolved into an export hub for solar modules, mainly directed at the European and US markets (IEA, 2022[6]). While part of this shift appears to concern China-based companies relocating their downstream activities to avoid trade barriers, it is unclear how much of Southeast Asia's growing exports are due to this relocation trend.[19]

Figure 6. China has become the largest exporter of solar cells and modules and, more recently, wind turbines



Note: See Annex A for a description of the data sources.
Source: OECD, based on national sources and the CEPII's BACI database. See Annex A.

[19] The IEA notes in this regard that many Chinese integrated solar manufacturers moved some of their manufacturing plants in Southeast Asian countries (IEA, 2022[6]).

On the import side, the largest importers of solar cells and modules are mainly found in the OECD. While Southeast Asia and Korea have, since the 2010s, gradually replaced China as the largest exporters to the United States, China remains a major source for imports of solar PV products for many countries, including the European Union (with even an increase through 2022), Japan, Korea, and India. The past few years have also seen China increase its solar PV exports to Africa (led by South Africa) and countries of the Gulf Cooperation Council. Saudi Arabia's solar PV imports from China surged, for instance, by USD 1 billion (i.e. a more than fourfold increase) between 2022 and 2023.[20] These shifts in trade may speak for the multiple roles China plays in the solar value chain: as a trading partner, more specifically a supplier of ready-made solar PV products; as an investor in local solar PV production; and as a co-investor in solar power-generation projects abroad, e.g. Saudi-Chinese solar projects in Uzbekistan (Al-Sulayman and Alterman, 2023[20]).

In the wind sector, leading exporters have long included Denmark, Germany, and Spain, together with Japan and the United States until their exports began to decrease around 2010 and 2015, respectively. China's exports of turbines have been steadily growing, with the country's total export value surpassing that of Spain in 2019, and that of Germany and Denmark in 2022 to become the largest global exporter that year (Figure 6; right). China's top destinations in 2022 for its exports of wind turbines were Colombia, Viet Nam, Argentina, Canada, Chile, and Brazil. In the European and US markets, Denmark and Germany continue to be major exporters, although China's growing presence is noticeable. India has also expanded its exports in recent years, partially aided by shifts in production location following supply chain disruptions caused by the COVID-19 pandemic and US-China trade disputes (GWEC and MEC+, 2023[21]).

3. The broader policy environment affecting the solar and wind value chains

Alongside market forces and producer subsidies (discussed in the next section), trade policies, renewable energy support schemes, and the domestic regulatory environment within countries have all played an important role in shaping the solar and wind value chains over the last two decades. Ambitious renewable energy targets have generally not been sufficient by themselves to induce sufficient investment in renewable energy capacity, leading governments to introduce a range of demand-pull measures, namely measures aimed at fostering the installation and deployment of solar and wind-based capacity. These measures have mainly taken the form of price-based support schemes – such as feed-in tariffs, feed-in premia, or contracts for difference[21] – and quantity-based support schemes – such as renewable portfolio standards and renewable energy auctions. In opting for either of these two types of support measures, governments have sought to stimulate demand for renewable-energy-based electricity by guaranteeing revenue for renewable electricity producers. Alongside tax credits and loans provided to renewable energy developers, these measures aimed to create certainty for producers of renewable electricity and, in turn, for investors, allowing them to earn a sufficient return for the electricity they generated or the investments they made.

Demand-pull support schemes have been a major driving force behind the increase in installed capacity of solar panels and wind turbines, which tends to closely track the evolution of government policies (Annex C). By steering demand, these government incentives have ultimately contributed to the

[20] This is according to the customs statistics of the General Administration of Customs of the People's Republic of China. See http://stats.customs.gov.cn/indexEn (accessed on 5 September 2024).

[21] Contracts for difference (CfDs) are increasingly being used by governments to support the deployment of renewable energy capacity. CfDs are based on the difference observed between wholesale market prices for electricity and a 'strike price' pre-agreed by utilities and renewable energy generators. If the strike price exceeds market prices, utilities (often government-owned) must pay the difference to generators. In the opposite case, generators must pay back the difference to utilities. See, for example, www.iea.org/policies/5731-contract-for-difference-cfd (accessed on 17 September 2024).

development of the solar module and wind turbine industries, including technological improvements and economies of scale. However, demand-pull policies may not fully account for the significant changes having occurred in the solar and wind manufacturing landscape over the last 15 years (see earlier sections). In this regard, it should be noted that the strength of China's manufacturers in both sectors pre-dated the surge in domestic installations, which only later grew at a very rapid pace (Annex C). This is particularly apparent for solar modules. China introduced its national feed-in tariff for solar modules only in 2011, which led to an increase – albeit limited in the first years due to a lack of long-distance transmission lines – in installed capacity. Yet module shipments by Chinese manufacturers had already experienced a significant surge during the period 2005-07, largely driven by generous demand-pull support schemes in OECD countries (Figure 1). This suggests that other factors in China, including cost competitiveness and producer subsidies, may have contributed to the early development of solar module manufacturing in the country.[22]

In apparent contrast with governments' efforts to deploy solar and wind energy within their territory through regulatory policies and demand-pull support mechanisms, government measures restricting trade in renewable energy products have also expanded significantly over the last 15 years. Solar modules and wind turbines have generally enjoyed low import tariffs, enabling the development of highly integrated value chains (Bahar, Egeland and Steenblik, 2013[22]). In response to concerns about subsidies and dumping practices, however, countries have introduced a growing number of trade remedies, i.e. anti-dumping duties (ADD) and countervailing duties (CVD), on solar modules, wind turbines, and their components. Since 2012, the number of such measures has significantly increased. In August 2024, there were 35 ADD and CVD in place affecting the imports of these products against 0 in 2011.[23] Among the duties in force today, 16 are levied against imports from China. In this respect, since they emerged in 2012, trade remedy investigations have mostly targeted Chinese exports of solar panels, wind turbines, and their components, after various WTO Members found evidence of dumping and subsidies practices in China in relation to these products.

In the presence of distortive, non-market practices, governments can use trade remedies to restore a level-playing field although these measures can contribute to increasing prices for downstream users. Not all trade remedies are tied to the presence of distortive, non-market practices, however. Although it may not always be easy to determine whether new AD or CVD investigations and import duties constitute an illegitimate retaliatory measure, various contextual factors seem to indicate that some of the 35 ADD and CVD which affected solar modules and wind turbines formed part of a retaliatory strategy on the part of the affected country.[24]

Beyond import tariffs and trade remedies, non-tariff measures (NTMs) may also contribute to hindering access to cheap renewable energy equipment and, ultimately, slow the deployment of renewable energy capacity. NTMs take various forms, including technical barriers to trade or quantitative measures, such as

[22] Recent research analysing the universe of China's regulations pertaining to solar photovoltaics has notably found that authorities began subsidising production before they began subsidising the installation of renewable energy capacity (Banares-Sanchez et al., 2024[35]).

[23] Number based on the authors' own research. Note that this only includes duties imposed on solar modules and wind turbines directly or their key components or inputs, notably polysilicon, solar glass, or ethylene vinyl acetate sheet for solar modules. It does not take account of duties imposed on imports of products, which although they are key inputs to solar modules or wind turbines, are sold to various end-users. This is notably the case of silicon metal, a raw material that is used to produce polysilicon for solar PV cells and modules (Annex B). In August 2024, there were seven duties levied on imports of silicon metal in place, thus bringing the total of ADD and CVD to 42.

[24] These factors are notably: (i) the proximity in time with the ADD and CVD imposed by the other country; (ii) the proximity of the products concerned, i.e. the fact that they affect another segment of the value chain and (iii) the time proximity of their termination, i.e. the fact that they are terminated soon after the ADD and CVD imposed by the other country are themselves terminated.

quotas, special safeguards, and price controls. In this respect, a forthcoming OECD report shows that NTMs targeting environmental goods have been on the rise since 1995. Chief among these are LCRs, which require both domestic and foreign firms to use a minimum level of domestically manufactured goods or domestically supplied services. Although they had been in use before, LCRs re-emerged after the 2008-09 global financial crisis (Hufbauer et al., 2013[23]); they have increased since then, partly as a response to unfair trade practices in other countries. They have notably played a growing role in government support mechanisms for renewable energy: since the late 2000s, both OECD and non-OECD countries, at the national and subnational levels, have increasingly used LCRs as a condition for benefitting from their demand-pull support mechanisms (OECD, 2015[24]; Bahar, Egeland and Steenblik, 2013[22]; Kuntze and Moerenhout, 2013[25]; Stephenson, 2013[26]). Some governments have, for instance, conditioned eligibility for their support schemes (e.g. feed-in tariffs or contracts for difference) upon the purchase of locally manufactured renewable energy equipment. Others have conditioned the payment of a premium on top of a feed-in tariff upon compliance with LCRs. More recently, along with the increase in renewable energy tenders, governments have incorporated local content as a qualification requirement for their tenders. As a result, between 2008 and 2023, at least 28 jurisdictions adopted LCRs at the national or subnational levels in the renewable energy sector, including 11 OECD economies and 17 non-OECD economies.

Governments generally introduce LCRs in the hope that they will spur the development of local manufacturing capacity (and associated jobs), increase the tax base, enhance domestic knowledge and innovation through learning by doing and capacity training (OECD, 2015[24]), as well as a response to unfair trade practices. Yet, by forcing renewable energy producers to purchase equipment manufactured domestically that is typically more costly than imported products, LCRs can hinder trade in renewable energy equipment and ultimately slow the deployment of renewable energy. Their discriminatory character can also aggravate trade tensions and generate tit-for-tat trade responses. Since 2010, WTO Members have brought eight requests for consultations before the dispute settlement system in relation to LCRs attached to solar and wind support schemes. In the three disputes which led to the establishment of a panel, the WTO adjudicatory body found that the LCR measures were inconsistent with WTO rules. Despite the wide use by governments of LCRs in relation to renewable energy, the manufacturing of solar modules and wind turbines, as noted earlier, has nevertheless grown more concentrated.

As demand for solar panels and wind turbines is set to expand considerably in the next decades, so will demand for their respective components and the necessary key metals and minerals (Annex B). Security in the supply of these key materials has therefore become an issue of shared concern (IEA, 2021[27]; Kowalski and Legendre, 2023[28]). This is particularly the case for certain REEs, which are crucial inputs into permanent-magnet synchronous generators currently dominating the offshore wind-turbine market (Annex B). Due to the geographical concentration of these materials, political risks, trade restrictions, external shocks, or new regulatory requirements in countries where the upstream stages of the value chain are preponderantly located may all adversely affect the wind and solar value chains (IEA, 2021[27]). Export restrictions are a case in point, with the incidence of measures affecting REEs having seen a relatively large increase between 2009 and 2020 (Kowalski and Legendre, 2023[28]). By lowering local prices relative to world market prices, export restrictions will typically penalise local REE producers but benefit local downstream users of the materials concerned, at the expense of foreign competitors lacking access to cheaper resource. In the case of REEs used for manufacturing renewable energy equipment, this would imply that export restrictions could end up favouring local producers of wind turbines to the detriment of foreign producers. As in the case of stages further downstream in the solar and wind value chains (see earlier section), concerns revolve around the central role of China in the mining and processing of REEs (Annex B).

4. Quantifying manufacturing subsidies for solar and wind equipment

The approach taken in this report is to measure producer subsidies at the level of individual manufacturing firms. As in earlier OECD work on industrial subsidies (OECD, 2023[29]), this stems from the lack of transparency of most governments regarding the amount and types of subsidies they offer to their industrial producers. The data used to that end come from the OECD MAGIC database (Annex A), which provides unparalleled granularity on the support that the largest industrial producers receive from governments across 14 key industrial sectors and over the years 2005-23. The sectors covered by the database notably include the production of solar cells and modules and the manufacturing of wind turbines.

Version 1.0 of the OECD MAGIC database includes 24 companies involved in the production of solar cells and modules and 16 involved in the production of wind turbines (Table A A.1). Collectively, these firms accounted for more than 80% of global shipments of solar modules in recent years and around two-thirds of wind capacity installed globally in 2023, respectively. In terms of solar-module production capacity – which largely exceeds demand (Figure 4) – the companies covered in the OECD MAGIC database represented more than half of global production capacity in 2022. While the sample is not representative of smaller companies operating in these two sectors, it is economically significant and meaningful in its coverage of global sales and production.

Thus far, subsidies appear to have been considerably larger for producers of solar cells and modules than for producers of wind turbines (Figure 7). All three types of subsidies investigated here – namely, government grants, corporate income tax concessions, and below-market borrowings – have played a role in supporting producing firms, although the contribution of corporate tax concessions and below-market borrowings is generally larger. In the case of solar cells and modules, several peaks in support are discernible around the financial crisis of 2008-09, 2015, 2018, and more recently 2023. The latter peak is largely attributable to the entry into force of production tax credits awarded to producers of solar modules in the United States under the Inflation Reduction Act.[25] Until then, China-based producers had been the largest recipients of government support by a significant margin in both solar and wind throughout the period covered. Although OECD-based producers of wind turbines have seen an increase in government support in 2023 (partly in relation to the US Inflation Reduction Act), this increase is more modest than for producers of solar equipment.

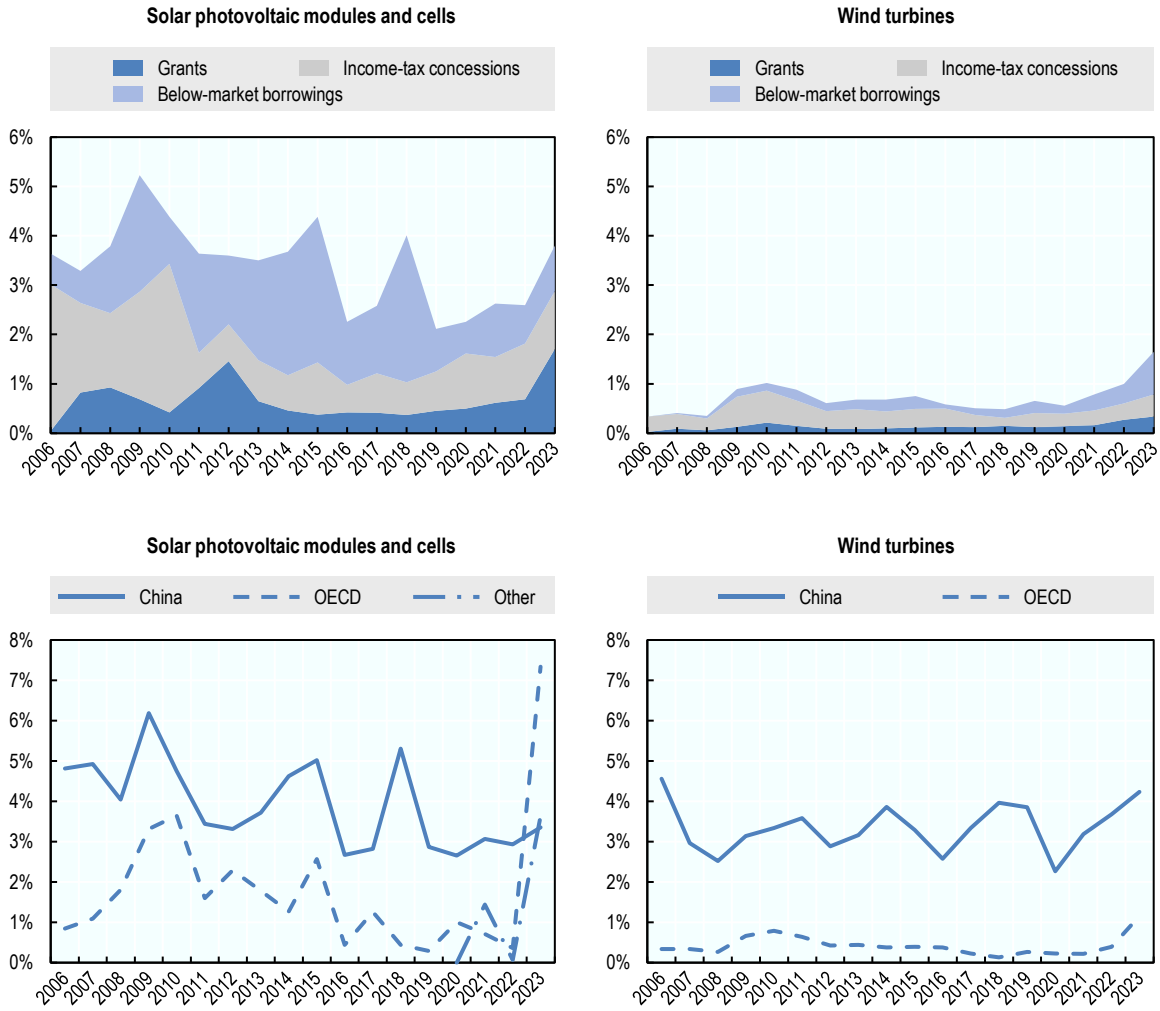
The relatively large contribution of tax concessions even before 2023 finds its source in a combination of: preferential tax rates awarded to certain subsidiaries of China-based producers; tax incentives for R&D spending; tax holidays benefitting producers with operations in Malaysia and certain other Southeast Asian economies; and various other tax measures. Preferential tax rates are common in China, where companies can obtain from local authorities the “high and new technology enterprise” status for a duration of three years (renewable), which lowers their rate of corporate income tax from the regular 25% rate to 15%. A similar benefit is also available to subsidiaries located in certain Western provinces of China (e.g. Gansu, Inner Mongolia, Qinghai, and Xinjiang), where much polysilicon production takes place.[26] In the case of solar cells and modules, the growing localisation of manufacturing activities in Southeast Asia, including by China-based companies, has been accompanied by the provision of tax incentives, some of which have granted beneficiaries a full exemption from corporate income tax.

[25] Note that production tax credits awarded under the Inflation Reduction Act are often recorded by companies as grants in their financial statements since recipients can opt to receive the credits as direct payments or sell them to other companies in exchange for a payment. See www.energy.gov/eere/solar/federal-tax-credits-solar-manufacturers (accessed on 29 August 2024). This explains why the increase for OECD-based firms in 2023 largely takes the form of grants.

[26] The IEA (2022[6]) notes that “China’s Xinjiang province accounts for 40% global polysilicon manufacturing.”

Figure 7. Subsidies have been considerably larger for producers of solar PV cells and modules than for producers of wind turbines

Top graphs: Total subsidies by type, % of firm revenue;
Bottom graphs: Total subsidies by jurisdiction or region, % of firm revenue



Note: All results above are expressed as a percentage of annual firm revenue. The two bottom graphs concern the sum of grants, tax concessions, and below-market borrowings. The geographical split is based on the jurisdictions in which firms are based, which can differ from where actual production takes place (e.g. some OECD-based firms producing in Southeast Asia).
Source: OECD MAGIC database.

Below-market borrowings are another relatively important form of government support observed in this study. Although generally larger in China, OECD-based companies have also at times obtained favourable loans from state-affiliated financial institutions. Wind-turbine manufacturer Vestas, for example, received in 2022 a "green loan" from the European Investment Bank for investing in "research, development and innovation (RDI) in the field of wind power technology."[27] Former German producer of solar modules QCells obtained a below-market loan from Malaysian authorities back in 2009 while its successor company, Korean group Hanwha Solutions, has obtained financing from the Korean Development Bank. First Solar,

[27] See www.eib.org/en/projects/all/20210533 (accessed on 30 August 2024).

the largest producer of solar modules in the United States, also received early on a loan from the Director of Development of the State of Ohio, which it finished repaying in 2013.

These examples notwithstanding, companies based in China have obtained the largest amounts of below-market borrowings throughout the period considered. There are two major reasons behind this finding. First is the extent to which China's financial sector is dominated by state financial institutions, with most corporate loans originating from the 'Big six' state-owned commercial banks, policy banks, and the 12 national joint-stock commercial banks, in which authorities often retain a controlling interest (OECD, 2024[30]). This has enabled companies such as Canadian Solar, JA Solar, and Jinko Solar to obtain loans from the China Development Bank, the China Construction Bank, and the Industrial and Commercial Bank of China. In some cases, the loans were also obtained directly from authorities, as was the case for Jinko Solar receiving an interest-free loan of CNY 20 million from Jiangxi Guochuang Investment, a "government background entity", in order to "support [the company's] daily operations", as well as another CNY 20 million loan at 3% interest from the Finance and Investment Management Centre of Jiangxi Province.[28]

Another reason behind the larger amounts of below-market borrowings seen in China concern Chinese companies' reliance on bank acceptances or bank acceptance drafts (henceforth "BAs"). BAs are a type of short-term financing instrument originally meant to facilitate commercial transactions. Simply put, corporate buyers of inputs can request banks to issue BAs, under which the issuing banks promise payment to the suppliers by a certain date in the future. BAs thus shift credit risk from buyers to issuing banks, with issuing banks bearing the responsibility for collecting repayment from the buyer at maturity. Although limited to certain jurisdictions, traditional forms of BAs have existed, for example, in London markets, in the United States, and in Canada (McMahon, 2022[31]; McRae and Auger, 2018[32]).[29] BAs in China have attracted particular attention for their extensive use, including in shadow banking, where they have enabled banks to provide credits outside their regulatory quotas, but also for their occasional issuance in the absence of underlying trade transactions. BAs in China are commonly used as a substitute for cash payments in trade transactions (until their maturity) and, despite being promoted as lending tools for SMEs, beneficiaries have often included large firms and state enterprises (McMahon, 2022[31]).

Unlike what can be seen in most other sectors covered by the OECD MAGIC database, the share of BAs in total debt stands out for solar and wind firms based in China: for those companies using BAs, they accounted on average for 38% of their total debt in 2023 in the solar sector and 44% in the wind sector, including one wind company for whom BAs represented as much as 80% of its outstanding debt. In Canada, the cost of BAs refers to the Canadian Dollar Offered Rate plus a stamping fee, which depends on clients' credit rating, together with standby, commitment, arrangement and agency fees (McRae and Auger, 2018[32]). Trade defence investigations by the European Commission have found, however, that BAs in China generally costed 0.05% of their face value, charging only a commission fee.[30] As such, the extensive use of this low-cost financing tool by firms based in China partly explains their larger below-market borrowings (Figure 8).

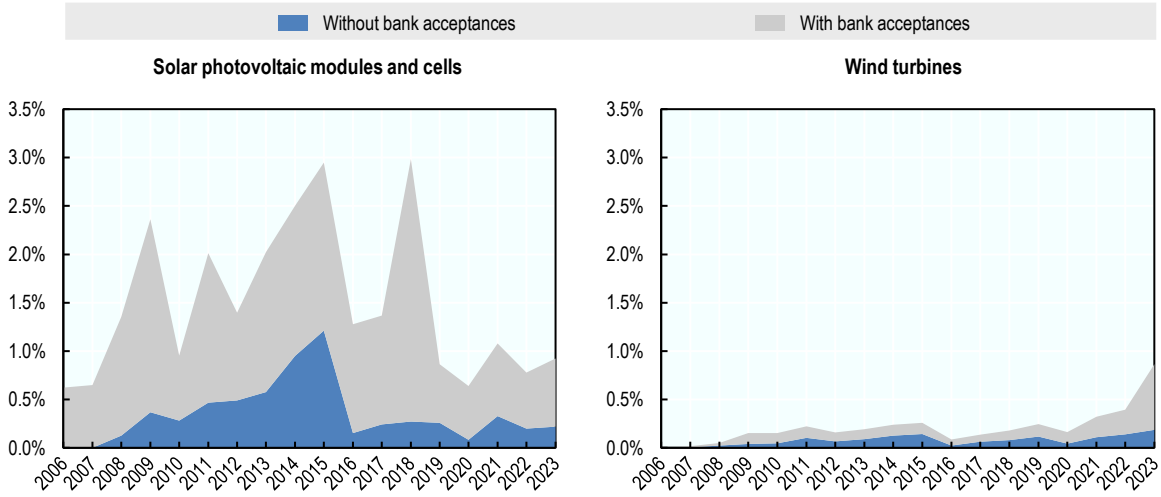
[28] See, for example, Jinko Solar's 2017 20-F filing to the US Securities and Exchange Commission.

[29] BAs were historically found in London markets. The United States began using them in the early 20th century until they declined in the early 1990s as other financial products emerged (McMahon, 2022[31]). Canada also introduced BAs in the 1960s for money-markets purposes (McRae and Auger, 2018[32]).

[30] See https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R2287&from=EN (accessed on 4 September 2024).

Figure 8. Bank acceptances account for a large share of all below-market borrowings in solar and wind

Below-market borrowings with and without bank acceptances, % of firm revenue



Source: OECD MAGIC database.

Even before 2023, the support that producers of solar cells and modules received from governments already made the sector the most subsidised as a percentage of revenue among all sectors covered by the OECD MAGIC database (Figure 9). This was not the case for wind turbines, however, which sat among the sectors receiving relatively less support. It is nevertheless important to consider the possibility that support for other sectors upstream (and the excess capacity that might result) might have indirectly supported the solar and wind industries. Although this channel of support is very challenging to quantify,[31] it remains true that steel constitutes a crucial input into the production of wind turbines (e.g. for the mast) while both aluminium and glass are key materials used in the production of solar modules (e.g. for the frame). Considering that the production of all three materials attracts government support (particularly steel and aluminium), some amount of subsidies could have passed through in the form of cheaper inputs. Likewise, government support for the production of polysilicon is likely to have affected the cost structure of solar cells and modules, given that it accounted for as much as 30% of module production costs in 2022 (IEA, 2022[6]).

There are other forms of government support that this study is not able to quantify, including: government land sold or rented to producers at below-market cost; the provision of electricity and other energy inputs (e.g. coal) by state enterprises at below-market prices; and the provision of government equity on non-market terms. Estimation methods exist for all three subsidy types but would require considerably more data than is presently available to the OECD for this study.[32] There is nonetheless some evidence suggesting these forms of support to have benefitted certain producers of solar modules (Corwin and Johnson, 2019[33]). This includes subsidiaries of Jinko Solar (e.g. Haining Jinko and Sichuan Jinko)

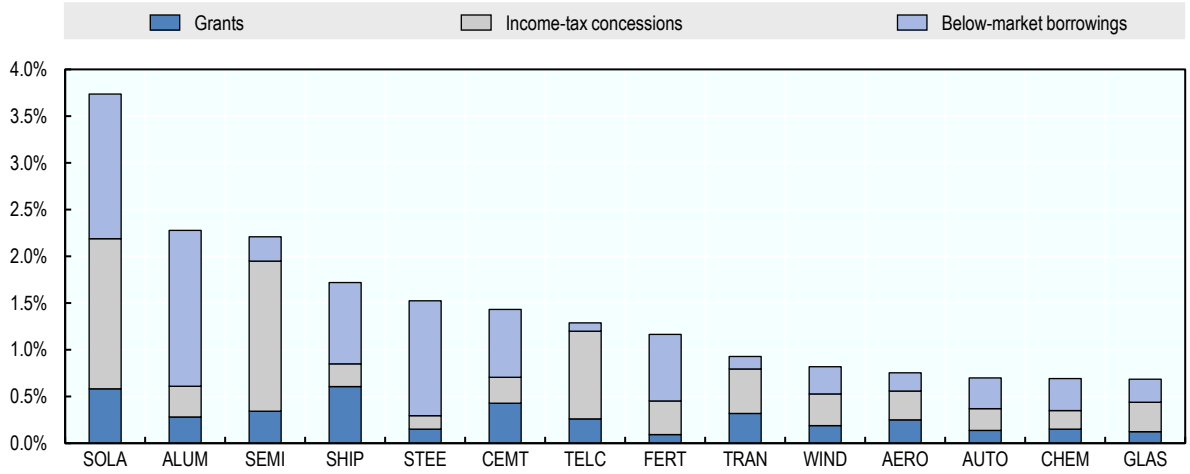
[31] See Liu (2019[43]) for an example.

[32] See, for example, OECD (2021[46]) for older estimates of below-market equity and OECD (2023[44]) for illustrative estimates of below-market energy inputs in heavy industries (steel, aluminium, cement, chemicals, and fertilisers).

receiving several capital injections from “government background funds” for the production of photovoltaic products.[33]

Figure 9. Solar cells and modules were the most subsidised sector in the OECD MAGIC database between 2005 and 2022

Industrial subsidies by sector (% of revenue)



Note: The data above are weighted averages by sector for the entire period 2005-22.
Source: OECD MAGIC database.

5. Conclusions and policy implications

A first conclusion drawn from the findings above is that some governments have been conducting what might be called ‘green industrial policy’ for nearly two decades already. Amid growing calls for governments to support clean-technology manufacturing in the context of the low-carbon transition, it might be helpful to take stock of the policies that already exist in this domain and the effects they may have had on manufacturing output, trade, competition, and the deployment of renewable energy equipment.

These effects are not easy to attribute causally to producer subsidies, nor is their quantification evident. Aided by new sources of data, empirical research is only now starting to confront questions about industrial subsidies and their impacts (IMF et al., 2022[34]). Numerous challenges make such analysis complex and difficult, reflecting partly the fact that the effects of subsidies depend on their design and on the broader context in which they are provided. In the case of the firms covered in this study, some subsidies have gone to producers of solar modules in distress, helping them to stay longer in business than they might have otherwise. As several such producers exited the market anyway – either through bankruptcy or acquisition by more successful competitors –, this could suggest that subsidies have had little effect. On the other hand, those module and wind turbine producers that have grown and gained market share the most also received generous government support, often tied directly to their investments in equipment and machinery. This suggests the impact of subsidies to be ambiguous and multifaceted, depending on their design and on the context in which they are being provided.

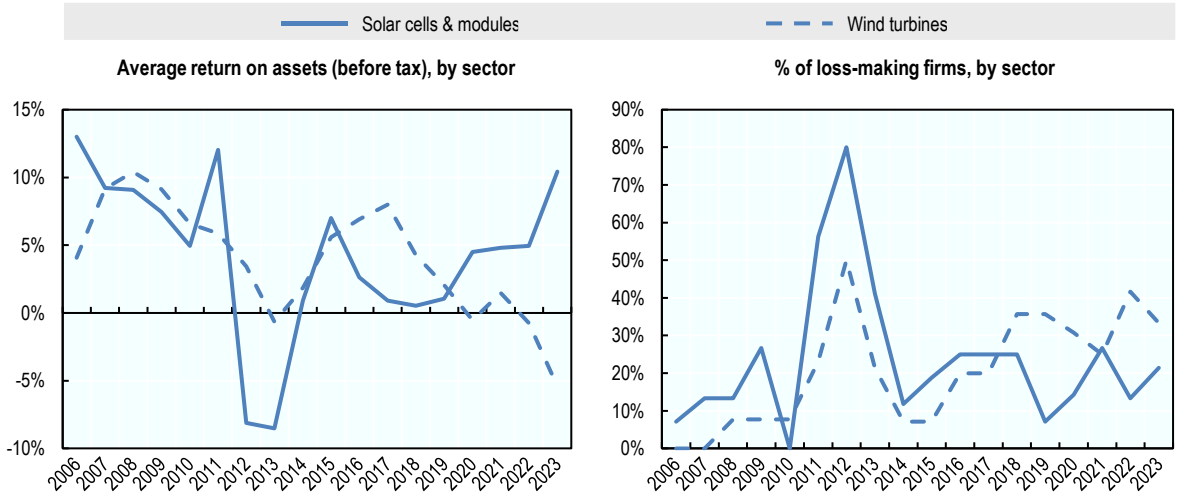
The evidence we have thus far suggests, overall, that producer support can increase firms’ investment in production capacity. A recent study of China’s solar panel industry concluded, for example, that subsidies introduced by local authorities had significantly increased module production capacity at the city level, and

[33] See, for example, Jinko Solar’s annual filings to the US Securities and Exchange Commission.

that this effect was much stronger for producer subsidies than for demand-side subsidies (Banares-Sanchez et al., 2024[35]). Together with the findings in this report (Section 1), the evidence thus points to the role of government support in causing (at least partly) structural overcapacity along the solar value chain.[34]

The presence of excess production capacity along the solar value chain raises important questions, notably regarding the drivers behind the observed fall in the average price of solar PV modules over the period considered (2005-23). It suggests that there is more to falling prices than just economies of scale and technological progress. As noted in Section 1, there is little doubt that learning-by-doing in manufacturing and improvements in solar-cell efficiency have played an important role in decreasing the price of solar modules, resulting in cheaper and better PV-based equipment. The inability of several producers to make a profit (Figure 10) – and this despite the sector attracting relatively large amounts of government support – could imply, however, that the larger volumes shipped did not necessarily translate into lower unit costs but rather thinner margins.[35]

Figure 10. A combination of falling output prices and higher input costs have lowered the profits of producers of solar modules and wind turbines



Note: The graphs above consider profit before tax and only cover companies covered by the OECD MAGIC database, which may under-estimate the proportion of loss-making companies due to a survivor bias.
Source: OECD MAGIC database.

One consequence of excess production capacity in the solar value chain has been the growing concentration of production activities across fewer companies, most of which are based in China.[36] The exit of higher-cost producers from the market is usually no cause for concern and a normal feature of

[34] It is more difficult to make that judgment for the wind-turbine industry due to data gaps and the wider dispersion in product characteristics and prices.

[35] The proportion of loss-making firms in both sectors in Figure 10 saw a peak in 2012 following a reduction in demand support schemes for renewable energy after the global financial crisis and the introduction of trade-defence measures in several jurisdictions. After having incurred a marked, sustained fall in profit, producers of solar cells and modules appear to have experienced larger average profit over the past few years, partly because of larger subsidies in 2023.

[36] Using revenue shares derived from the OECD MAGIC database, a calculation based on the Herfindahl-Hirschman index of market concentration shows the index decreasing between 2005 and 2010 as entry into the solar sector grew, before increasing again starting around 2019.

healthy competition, with the added benefit in this case of bringing about cheaper low-carbon energy. The complication comes, however, in this case from the pervasive support that some producers have enjoyed from governments, and which may have enabled them to better withstand the low prices partly caused by excessive investment in production capacity. Over the period covered by this report, numerous producers based outside China have either exited the market, downsized operations, or sold themselves to competitors,[37] leaving most of the market in the hands of the largest China-based producers.

As of 2024, it is an open question whether the new subsidies introduced by some OECD countries will be able to reverse the trend and durably increase solar-module manufacturing capacity outside China. A complicating factor in this regard is that China has come to dominate the entire value chain from the production of solar-grade polysilicon to the assembly of modules, while the country also leads in solar power capacity installation. In this regard, there may be lessons to be drawn from the solar case for the wind industry and other sectors. One such lesson would be to address early on the market distortions caused by industrial subsidies before they entrench a competitive advantage durably throughout the entire value chain. This is easier said than done, however, with a full understanding of how subsidies shape value chains still lacking. The range of policy tools needed to tackle excess capacity and its consequences is also unclear as the problem goes beyond individual trade flows or product codes.

Compared with other sectors, the market distortions caused by subsidies to producers of solar modules and wind turbines pose additional challenges in relation to climate change and energy security. As a result, governments face certain trade-offs requiring them to balance at times conflicting policy priorities. The imperative to decarbonise energy systems calls for cheaper renewable energy equipment, which requires sourcing from producers offering the lowest prices. Yet the concentration of the value chain in one jurisdiction or region can generate critical chokepoints, thus endangering energy security. At the same time, the market distortions caused by producer subsidies may lead governments to adopt trade-defence measures to remediate any injury to their own producers, which may have the effect of making renewable energy equipment more expensive. Governments may also opt to respond with subsidies of their own. Finally, sustaining innovation efforts in low-carbon technologies requires that producers enjoy sufficient profit margins, which can go against the objective to lower prices, at least in the short term. There is no single way to strike a balance between these competing priorities, with countries likely differing in the weights they assign to them.

Not all subsidies are harmful for trade. In some cases, subsidies may constitute a useful addition to the mix of policy instruments necessary for the low-carbon transition (Stechemesser et al., 2024[36]). Concerns over the market distortions caused by producer subsidies should not be conflated with the potential contribution of non-discriminatory market-pull subsidies on the demand side – which despite any possible trade concerns, can also help deploy renewable energy capacity, and encourage the development of innovative and competitive markets – or that of well-designed R&D subsidies – which have the potential to help in the discovery of new decarbonisation tools. Discussions of the most distorting subsidies in the solar and wind industries form, in this regard, only one part of a much broader policy debate around how to achieve a mutually beneficial transition to low-carbon economies.

[37] Well-known examples of relatively large companies include: Solyndra (United States), which filed for bankruptcy in 2011 despite receiving support from the US Federal Government; SunPower (United States), which in 2019 spun off its manufacturing business to Singapore-based Maxeon; SolarWorld (Germany), which filed for insolvency twice in 2017 and 2018; QCells (Germany), which was acquired by Korean Group Hanwha in 2012 after having filed for bankruptcy; Sharp (Japan), which was acquired by Hon Hai Precision Industry (Foxconn) in 2016; and Kyocera (Japan), which has downsized its production of solar modules. See, for instance, www.greentechmedia.com/articles/read/rest-in-peace-the-list-of-deceased-solar-companies (accessed on 3 September 2024).

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Annex A. Data sources and firm sample

Description of data sources

Data on capacity, shipments, and prices of solar modules were collected manually from the annual reports of the firms covered, complemented with other corporate disclosures. To broaden the sample beyond just those firms covered in the OECD MAGIC database, data on capacity and shipments were also obtained from the national survey reports of the IEA's Photovoltaic Power Systems Programme, from Japanese website *PVeye*, and from the annual editions of the *PV Status Report* published by the European Commission's Joint Research Center.

For the trade data used in this report, several adjustments are made to improve measurement. Exports of solar PV products are normally counted under the six-digit HS code 854140, where they are mixed with non-solar products such as light-emitting diodes in versions of the Harmonized System predating 2022. To remedy this problem, export flows are measured using eight- to ten-digit national codes for solar PV cells and modules, using national government sources for the main exporters and importers. China only publishes eight-digit export-import data from 2015 onwards, however. Prior to this year, China's export data are thus replaced with an aggregate series of the value of imports from China reported by the European Union, the United States, Japan, and ASEAN countries, for which data by country of origin are available at the eight- or ten-digit level of the HS. Exports of wind turbines are, meanwhile, based on HS code 850231 and obtained from the CEPII's BACI database.

The OECD MAGIC database and the firm sample

The OECD MAGIC (MAnufacturing Groups and Industrial Corporations) database is a confidential firm-level database combining basic financial and economic data and estimates of government support at the level of each industrial group covered. It is meant to help improve understanding of the scope and scale of government support in manufacturing and to enable analysis of how this support affects firms' decisions and markets.

The database covers more than 480 firms of the world's largest manufacturing groups across 14 key industrial sectors and over the period 2005-23. For each sector, the firm sample is selected starting from the top firms by revenue or capacity such that the resulting coverage accounts for at least two-thirds of global sales or capacity. The geographical origin of firms in each sector is therefore largely determined by which jurisdictions occupy relatively large shares of global production. Table A A.1 below shows the firm sample used in this study, which covers both solar cells & modules and wind turbines.

The OECD MAGIC database focuses on those industrial sectors that produce either durable goods (e.g. capital goods) or industrial raw materials (e.g. aluminium, steel, and chemicals). Preference is given to products destined for other businesses (B2B), with the notable exception of automobiles, which are purchased by both businesses and final consumers. The resulting choice of sectors is as follows: aerospace & defence; aluminium; automobile; cement & building materials; chemicals; fertilisers; glass, ceramics & refractories; semiconductors; shipbuilding; solar photovoltaic cells & modules; steel; telecommunications network equipment; rolling stock & signalling; and wind turbines.

As of 2024, the OECD MAGIC database includes estimates of government support taking the form of governments grants, corporate income-tax concessions, and below-market borrowings. Estimates for government grants are generally obtained directly from corporate disclosures (or more rarely government sources) and not subject to assumptions or adjustments. Estimates for tax concessions are normally based on corporate disclosures but can at times involve judgment and interpretation on the part of the OECD when quantifying the amount of tax savings that companies enjoy as a result of particular tax provisions (e.g. a preferential rate of tax for certain subsidiaries of a company). Estimates for below-market borrowings, on the other hand, involve complex calculations and assumptions by the OECD given the lack of government and corporate disclosure on the subsidy component of firms' borrowings.

Table A A.1. Firm sample

Sector	Firm name	aka	Home base	Notes
Solar cells & modules	Meyer Burger	Meyer Burger Technology AG	CHE	Started production of solar cells and modules in 2021
Solar cells & modules	Chint Group	Chint Group Co., Ltd.; 正泰集团股份有限公司	CHN	Covers Astronergy as part of the whole group before 2016
Solar cells & modules	Canadian Solar	Canadian Solar Inc.	CHN	
Solar cells & modules	Tongwei	Tongwei Co., Ltd.; 通威股份有限公司	CHN	Entered the solar business in 2016
Solar cells & modules	Yingli	Yingli Green Energy Holding Company Limited; 英利绿色能源控股有限公司	CHN	
Solar cells & modules	Suntech Power	Suntech Power Holdings Co., Ltd.; Wuxi Suntech Power Co., Ltd.; 無錫尚德太陽能電力有限公司	CHN	
Solar cells & modules	LONGi	LONGi Green Energy Technology Co., Ltd.; 隆基绿能科技股份有限公司; 隆基股份; Xi'an LONGi Silicon Materials Corp	CHN	
Solar cells & modules	Chint Electrics	Zhejiang Chint Electrics Co., Ltd.; Astronergy; 浙江正泰电器股份有限公司	CHN	Incorporates the solar PV business (Astronergy) starting in 2016
Solar cells & modules	Hanwha SolarOne	Hanwha SolarOne Co., Ltd.; Solarfun Power Holdings Co., Ltd.; SolarOne Qidong	CHN	Acquired by Hanwha in 2010 to become Hanwha SolarOne
Solar cells & modules	Jiangsu Zhongli Group	Talesun Solar Technologies Co., Ltd.; 江苏中利集团股份有限公司	CHN	Entered module production in 2010
Solar cells & modules	GCL System	GCL System Integration Technology Co., Ltd.; Shanghai Chaori Solar Technology Co., Ltd.; 协鑫集成科技股份有限公司	CHN	Listed subsidiary of GCL Group specialised in solar modules and cells
Solar cells & modules	Trina Solar	Trina Solar Co., Ltd.; 天合光能股份有限公司	CHN	
Solar cells & modules	JinkoSolar	Jinko Solar Co., Ltd.; JinkoSolar Holding Co., Ltd.; Jiangxi Desun Energy Co., Ltd.; 首页; 晶科能源股份有限公司	CHN	
Solar cells & modules	SFCE	Shunfeng International Clean Energy Limited; Shunfeng Photovoltaic International Limited	CHN	Entered module production in 2011; acquired Suntech in 2014; disposed of the solar PV manufacturing business in 2019
Solar cells & modules	JA Solar	晶澳太阳能; JA Solar Technology Co. Ltd., 晶澳太阳能科技股份有限公司, 晶澳科技; JingAo Solar Co. Ltd.; 晶澳太阳能有限公司; 晶澳太阳能; 晶澳太阳能控股有限公司; JASO	CHN	
Solar cells & modules	Risen	Risen Energy Co., Ltd.; 东方日升新能源股份有限公司, 东方日升	CHN	
Solar cells & modules	QCells	Q-Cells SE	DEU	Acquired by Hanwha in 2012
Solar cells & modules	SolarWorld	SolarWorld AG	DEU	
Solar cells & modules	SESJ	Sharp Energy Solutions Corporation; SESJ; シャープエネルギーソリューション株式会社	JPN	

Sector	Firm name	aka	Home base	Notes
Solar cells & modules	Hanwha Solutions	Hanwha Solutions Corp.; Hanwha Chemical Corp.; 한화솔루션	KOR	Consolidates the solar business segment starting in 2018 after delisting of Hanwha Q Cells
Solar cells & modules	Hanwha Q Cells	Hanwha Q CELLS Co., Ltd.; Q-Cells SE	KOR	Formed after the merger of Hanwha SolarOne (CHN) and QCells (DEU) in 2015
Solar cells & modules	Maxeon	Maxeon Solar Technologies, Ltd.	SGP	Manufacturing activities spun off from SunPower in 2020
Solar cells & modules	First Solar	First Solar, Inc.	USA	
Solar cells & modules	SunPower	SunPower Corporation	USA	Solar PV-manufacturing activities were transferred to Maxeon Solar in 2020
Wind turbines	Sinovel	Sinovel Wind Group Co., Ltd.; 华锐风电科技（集团）股份有限公司	CHN	
Wind turbines	Dongfang	Dongfang Electric Co., Ltd.; 东方电气股份有限公司	CHN	Started wind turbines in 2007
Wind turbines	Shanghai Electric	Shanghai Electric Wind Power Group Co., Ltd.; 上海电气风电集团股份有限公司	CHN	
Wind turbines	Goldwind	Xinjiang Goldwind Science & Technology Co. Ltd.; 金风科技, 新疆金风科技股份有限公司	CHN	
Wind turbines	Envision	Envision Energy International Ltd.; 远见能源国际有限公司	CHN	
Wind turbines	Mingyang	Mingyang Smart Energy Group Co., Ltd.; 明阳智慧能源集团股份公司	CHN	
Wind turbines	Zhejiang Windey	Zhejiang Yunda Wind Power Co.,Ltd.; 浙江运达风电股份有限公司	CHN	
Wind turbines	XEMC	Xiangtan Electric Manufacturing Co.Ltd.; 湘潭电机股份有限公司, 湘电股份	CHN	
Wind turbines	UEE Holding	Enercon GmbH; Enercon	DEU	
Wind turbines	Siemens Energy	Siemens Energy AG; Siemens Gamesa Renewable Energy S.A.U.	DEU	Obtained full ownership of Gamesa and spun off from Siemens in 2023
Wind turbines	Senvion	Senvion S.A.; Senvion S.à r.l.; REpower Systems	DEU	Owned by Suzlon before 2016
Wind turbines	Nordex	Nordex SE; Nordex Acciona	DEU	Acquired Acciona Windpower in 2016
Wind turbines	Vestas	Vestas Wind Systems A/S	DNK	
Wind turbines	Siemens Gamesa	Siemens Gamesa Renewable Energy S.A.; Gamesa Corporación Tecnológica S.A.	ESP	Fully acquired by Siemens Energy in 2023
Wind turbines	Suzlon	Suzlon Energy Ltd.	IND	Owned Senvion before 2016
Wind turbines	GE	GE Renewable Energy; General Electric Co.	USA	Before split into GE Vernova

Annex B. A brief description of the value chains for solar PV modules and wind turbines

The value chain for solar PV modules

While there are different types of solar PV modules, crystalline PV modules – also called conventional PV modules or panels – are the most common. While other solar module technologies exist (e.g. thin-film) or are in development, crystalline silicon technology has thus far dominated the solar PV market. This dominance is set to remain given past and future expected improvements in efficiency as well as current and planned investments in manufacturing capacity (IEA, 2022[6]). Figure A B.1 below shows the five different manufacturing stages involved in the production of solar modules.

Figure A B.1. The five manufacturing stages involved in the production of solar modules



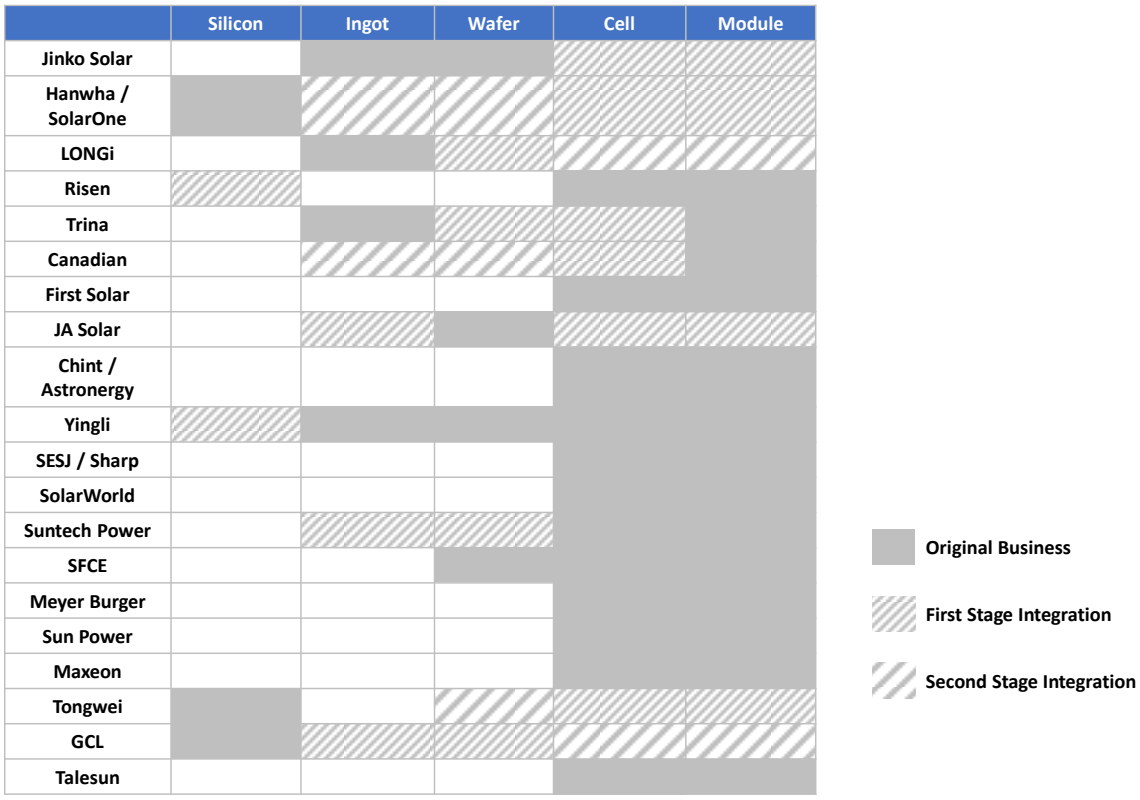
Source: Authors' elaboration.

- Polycrystalline silicon, commonly called **polysilicon**, is the main raw material used in the production of crystalline PV modules. It is a purified form of silicon dioxide (SiO_2) found in quartz sand. While polysilicon is also used in the semiconductor industry to produce electronic-grade polysilicon at a higher level of purity, most of the polysilicon production worldwide serves today the PV industry. The first manufacturing stage consists in purifying polysilicon through heavy and energy-intensive chemical processes, notably the Siemens process, to satisfy the ultra-high level of purity (> 99.999%) that the production of crystalline PV modules requires. The metallurgical grade silicon obtained is then converted into a gas named silane, which is, in turn, transformed into pure rods of silicon (BloombergNEF, 2021[37]). The cost of producing polysilicon is largely driven by the cost of silicon dioxide as well as electricity, which can represent 40% of the costs of producing polysilicon (IEA, 2022[6]).[38]
- The pure rods of silicon are subsequently broken into chunks and melted to form **ingots** of single silicon crystal – also called monocrystalline silicon or monosilicon – or multiple silicon crystals – called polycrystalline silicon or polysilicon. While the former type of ingots yields higher solar cell efficiencies, they are also more costly. Costs for monosilicon ingots have, however, fallen in recent years following an increase in demand from solar cell manufacturers and the upgrade or establishment since 2017 of polysilicon facilities in China to produce polysilicon of the quality required for monosilicon ingots (BloombergNEF, 2021[37]). As a result, the share of monosilicon ingots has grown since 2017 and currently dominates the market to the detriment of polysilicon ingots (ibid).
- Ingots are in turn cut into bricks and then further sliced into layers named **wafers**, which are each doped with one chemical (i.e. either phosphorus (p-type) or boron (n-type) so as to change their electrical properties.

[38] Most of the polysilicon production facilities in operation today are located in the Chinese provinces of Xinjiang and Inner Mongolia, where they benefit from low electricity prices due to local access to relatively cheap coal, which accounts in each of these provinces for approximately 75% of the power-generation mix (IEA, 2022[6]).

- To produce solar PV **cells**, two differently doped wafers, namely p-type and n-type wafers are assembled together. The p-n junction is responsible for the photovoltaic effect.
- The last manufacturing stage consists in assembling cells together through an electrical junction. The cells are then encapsulated in glass sheets and cooked to form solar PV **modules**.

Figure A B.2. Value-chain segments occupied as of 2023, by company covered

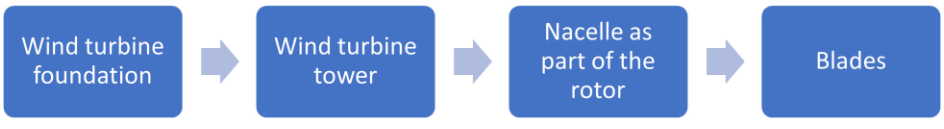


Source: OECD research.

The value chain for wind turbines

While wind turbines are composed of approximately 25 000 components, their final assembly depends on five main products: the **blades** form part of the **rotor**, which is connected to the **nacelle** sitting on top of the **tower**, which is itself attached to the wind turbine **foundation** (Figure A B.3) (Carrara et al., 2020[38]).

Figure A B.3. The final assembly of wind turbines depends on five main products



Source: Authors' elaboration.

- The **foundation** of a wind turbine must be able to withstand challenging environmental and extreme weather conditions, including strong waves, currents, corrosion through salt, and winds in the case of offshore projects (Rystad Energy, 2023[13]). The materials used must thus be chosen accordingly. In that regard, foundations traditionally use cement and gravel for onshore installations and steel for offshore structures.
- Attached to the foundation, the **tower** must be sufficiently high to enable the wind turbine to capture the best wind conditions. It is mainly composed of steel, concrete, zinc, and hybrid materials to withstand difficult weather conditions.
- As part of the **rotor**, the **blades** are one of the most important and expensive components of a wind turbine. Measuring today more than 100 metres, they must be sufficiently flexible, sturdy, and resistant to endure wind forces and other environmental phenomena. In this respect, most blades are made with lightweight, composite materials, including fiberglass reinforced plastic, such as polyester or epoxy, and carbon-fibre reinforced plastic (Rystad Energy, 2023[13]; Carrara et al., 2020[38]).
- The **nacelle** hosts critical components, such as the generator, gearbox, and other electrical equipment permitting wind turbines to generate power. To protect these components, nacelles are made of strong and durable materials, including steel and aluminium. Within the nacelles, generators may be based on permanent magnets, thus requiring the use of REEs, including neodymium, praseodymium, and dysprosium. Offshore wind turbines commonly use this type of generators given their lower maintenance costs, higher efficiency, and lighter weight (IEA, 2021[27]). According to the IEA, demand for REEs in the wind energy sector, notably neodymium and praseodymium, is expected to more than triple by 2040 as annual capacity additions accelerate and the wind turbine market shifts to permanent-magnet generators (ibid).

The importance of metals and minerals along the solar and wind value chains

Solar PV modules and their components require a wide range of minerals, metals, and chemicals, including copper, zinc, glass, junction boxes, aluminium frames, encapsulants, and blacksheets. Many of these materials are mostly processed or produced in China.

In the case of wind turbines, various materials and minerals enter into the production of the necessary components, including steel, iron, fiberglass, polymers, aluminium, copper, zinc, nickel, and REEs (IEA, 2021[27]), although steel and stainless steel is by far the most important input, feeding into most key components. The importance of steel in the manufacturing of wind turbines, together with the use of minerals such as REEs, explains in part the ever-growing place China occupies in the value chain, as it is able to tap into its vast reserve of minerals and its sizeable steel industry. REEs are important for the manufacturing of permanent-magnet generators located inside the nacelles, including neodymium, dysprosium, and (albeit in relatively smaller amounts) praseodymium.

China's central role in the mining and processing of rare earth elements (REEs) and implications for the wind value chain

Demand for REEs is set to increase significantly in the next decades in line with demand for permanent magnets used in wind turbines generators.[39] Although alternative technologies or technologies requiring a smaller volume of rare earths do exist in the wind turbines sector, they remain at this juncture less efficient and have lower performance, and thus cannot constitute competitive alternatives or substitutes (Andrews-Speed and Hove, 2023[39]; Carrara et al., 2020[38]).

Today, China dominates both the production and processing of REEs, making the supply of these materials overwhelmingly dependent on one single country. According to the IEA, China accounted in 2019 for 60% of global REE production and 90% of global processing and refining capacity (IEA, 2021[27]). The country's share has reportedly grown since then, notably at the production stage: in 2022, with 210 000 tonnes of REE mine production, China produced 70% of the global output (Andrews-Speed and Hove, 2023[39]). As a result, although a few countries have retained some mining capacity for REEs, most mined products are exported to China for separation and refining.

China's near monopoly in the upstream level of the wind turbine value chain compels companies producing downstream components, notably wind turbine generators, to rely mostly, if not exclusively on Chinese inputs. As a result, the supply of REEs and their prices are heavily influenced by government policies and market conditions in China. Any disruption in the supply of REEs, be it policy-induced or driven by unexpected shocks, may thus affect the entire wind supply chain. Prices for REEs appear, in this regard, to have been highly volatile. Besides external factors, such as the COVID-19 pandemic, prices have largely varied according to the Chinese Government's regulatory interventions in the sector, including through production quotas, environmental requirements, and export restrictions. The Chinese state retains significant control over the global supply and price of REEs, with the potential to impede the entry of new market participants outside China. China Rare Earth Corporation, a large central state enterprise recently created through the merger, led by China's state assets regulator, of three rare-earth state enterprises, accounts for 70% of the country's REEs output. This consolidation further cements the Chinese Government's pricing power in the sector.[40] In addition, Chinese authorities are also using regulatory tools to safeguard government ownership of the industry and protect it from foreign investment.[41]

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[39] According to the IEA's Sustainable Development Scenario, demand for rare earth elements in wind turbines is expected to increase from approximately 4 000 tonnes in 2020 to 12 000 tonnes in 2040 driven by the increase in annual capacity additions of wind turbines and a shift toward permanent magnet generators. Demand may be lower under a scenario of constrained supply of rare earth elements, reaching only 6 100 tonnes in 2040 (IEA, 2021[27]).

[40] This merger forms part of a consolidation wave in China, which in recent years has led to the emergence of large central state enterprises in various industrial sectors through mergers and acquisitions orchestrated by the State-owned Assets Supervision and Administration Commission (OECD, 2024[30]). In merging the rare earth units of three of the big six state enterprises that dominated the rare earth industry - Aluminium Corporation of China (Chalco), China Minmetals Corporation, and Ganzhou Rare Earth Group – China will likely maintain its market dominance in both the production and processing of REEs, through enhanced competitiveness and increased pricing power (Moon, 2024[12]). See also www.china-briefing.com/news/china-merges-three-rare-earths-state-owned-entities-to-increase-pricing-power-and-efficiency/ (accessed on 26 August 2024).

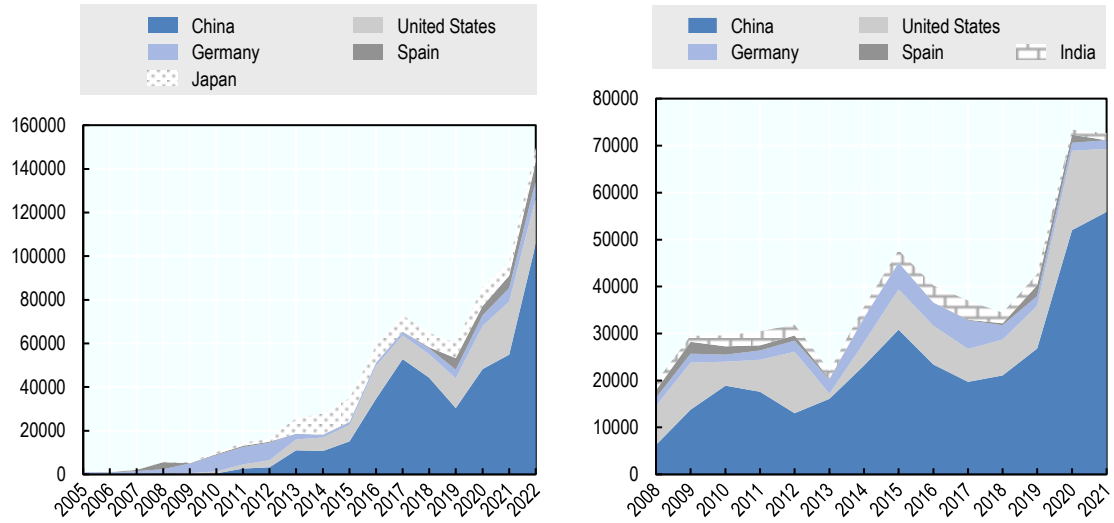
[41] Since 2015, the Chinese government regulates foreign investment in China and in Pilot Free Trade Zones (FTZ) through the Special Administrative Measures for Foreign Investment Access – also known as the Foreign Negative List – and the Special Administrative Measures for Foreign Investment Access in Pilot FTZ – also known as the FTZ Negative List (OECD, 2024[30]). In the last revision of the two negative lists in December 2021, authorities retained the prohibition on investment by foreign investors in the exploration, mining, and so-called 'beneficiation' of rare earths, radioactive materials, and tungsten. In addition, the negative list for FTZs specifies that foreign investors are prohibited from entering rare-earth mines or from obtaining relevant data samples, or production process technology (Moon, 2024[12]). See www.ndrc.gov.cn/xxgk/zcfb/fzggwl/202112/P020211227540591870254.pdf and www.ndrc.gov.cn/xxgk/zcfb/fzggwl/202112/P020211227540530036342.pdf (in Chinese Mandarin only) for the two negative lists (accessed on 27 August 2024).

Annex C. Additional supporting material

The installed capacity of solar modules and wind turbines has closely tracked the evolution of government policies, notably demand-pull support schemes. For instance, the installation of solar panels in Europe and Japan, as well as the installed capacity of wind turbines in Europe and the United States increased in the mid-2000s due to the presence of feed-in tariffs in Germany, Spain, and Italy and renewable portfolio standards in the United States and Japan. Similarly, after China introduced its national feed-in tariff for solar PV modules, installations of solar modules started to slowly increase in China but remained at first limited to the western provinces (Ye, Rodrigues and Lin, 2017[40]). Installed capacity subsequently grew at a more rapid pace, going from 10 990 MW in 2013 to 34 550 MW in 2016 following the government's decision to update the feed-in tariff to encourage solar panel investments in the eastern and central provinces of China. Lack of grid infrastructure, notably of long-distance transmission lines caused significant waste of solar PV electricity, however, forcing the Chinese Government to impose a quota (*ibid*).

Figure A C.1. Annual solar and wind generation capacity installed in MW, by jurisdiction

Left: Solar PV modules
Right: Wind turbines)



Note: For wind, the data only show the annual installed wind power capacity added each year for those five countries among the top 10 that appear every year in the ranking.
Source: IEA (2023[11]) and REN21 Global Renewables Status Report from 2009 to 2022.

Installed wind power capacity in China also closely followed the central government's feed-in tariff scheme. It surged sharply precisely after the government adopted the feed-in tariff for wind power in 2009, increasing from 6.3 GW in 2008 to 13.8 GW in 2009 and 30.8 GW in 2015; annual capacity additions declined between 2016 and 2018 concomitantly with two rounds of reduction of the feed-in tariff (Xia, Lu and Song, 2020[41]).[42]

[42] Note that during the period 2009-15, the price guaranteed through the feed-in tariff for wind power producers remained unchanged (Xia, Lu and Song, 2020[41]), thus underpinning the continuous growth in annual wind power capacity between 2009 and 2015 – albeit with a slight decline in 2013.

As further evidence of the influence exercised by demand-pull support measures, installation capacity has at times experienced boom and bust cycles due to changes in these government schemes. The rate of wind turbine installations in the United States has proved highly sensitive to the successive lapse and re-introduction of production and investment tax credits. More recently, following the Chinese Government's announcement in 2018 that it would gradually reduce the tariff of its national feed-in premium for, among others, solar PV modules, before phasing it out, China's National Energy Administration stopped approving temporarily feed-in premia for new solar energy projects in 2018 and 2019. This caused a steep decline in the installation of solar modules in the country during these two years (REN21, 2022[42]). Since then, however, the annual installed capacity of solar modules has grown exponentially as project developers sought to benefit from the final years of the solar power feed-in premium, which was definitively phased out in 2022.[43]

[43] The feed-in premium for solar power has been replaced with an auction scheme, which follows a 'grid parity' model. Under this scheme, solar power developers successfully bidding for a price inferior or equal to the prevailing coal tariff will enter into a contract guaranteeing the purchase of the electricity they generate at a fixed, negotiated price for at least 20 years. See https://chineseclimatepolicy.oxfordenergy.org/book-content/domestic-policies/renewable-power (accessed on 4September 2024).