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Net Zero's trade imperative:

A case study on the global demand for solar technology

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Executive summary

Growth in solar technologies and diversification of supplies in the solar manufacturing value chain is key for supply chain resilience.

The commitment to limit the increase in global temperatures to 2°C and ideally 1.5°C was recently reaffirmed at the United Nations Framework Convention on Climate Change's meeting in Sharm El Sheikh in November 2022. To achieve this, substantial reductions in emissions of greenhouse gases are needed by 2030, and net emissions should fall to zero by 2050. This will require a transformation of the energy sector, with massive implications for supply chains. In this report, using the example of the supply chain for solar panels, we show how global trade will be essential to sustain the transition, with important implications for trading relationships.

The scale of the challenge is illustrated by the International Energy Agency's (IEA's) *Net Zero by 2050* scenario under which power generation from solar photovoltaics (PV) increases from approximately 1,000 terawatt-hours (TWh) in 2021 to almost 7,500 TWh in 2030. To reach this, the rate of installation of solar generation facilities needs to increase from the 2021 volume of 150 GW to nearly 900 GW annually. Using the IEA's top-down projections, combined with data from the World Bank on solar potential, we have estimated in this report the required 2030 solar capacity for economies in the Sustainable Trade Index (STI), and for most this will be a large multiple of current capacity. The STI is produced by the Hinrich Foundation and the IMD World Competitiveness Center and ranks 30 key economies on their capacity to conduct global trade in a sustainable manner.[1]

The large growth in solar installations requires a correspondingly large growth in manufacturing. Most economies do not have domestic solar industries. Only China, Malaysia, and South Korea are currently active in all segments of the solar manufacturing value chain. Other countries have some involvement but are primarily focused on the downstream segments of cells and modules production. A key conclusion of this work, therefore, is that trade growth in solar technologies is indispensable to the global drive toward Net Zero climate goals, and in particular trade between STI economies.

In common with other renewable energy technologies, access to specific raw materials is essential to manufacture solar panels. Silver is a material component of the value of the inputs even though it represents only 0.03% of the weight of a solar panel. Three countries are responsible for producing over half of global production; in contrast, silicon, which contributes 4.4% of the overall weight of the finished product, is a very common mineral. However, only very pure silicon sources can be used, and the conversion into polysilicon is an energy intensive process. Polysilicon production is dominated by China, which has increased its market share from 56% to 83% between 2015 and 2022. The last ten years have seen all parts of the solar supply chain become dominated by China, if the location of manufacturing does not change then exponential growth in solar capacity means exponential growth in imports of solar panels from China. This analysis demonstrates that diversification of supplies will be important to protect the supply chain.

Greater attention must be afforded to the amount of greenhouse gas emitted in producing a solar panel.

Production of solar PV is very energy intensive, and production continues to rely on electricity produced from fossil fuels with approximately 360 kilograms of carbon dioxide equivalent ($kgCO_2e$) emitted for each kilowatt of capacity produced. Approximately 45% of global polysilicon production is located in China's western region of Xinjiang, where coal is the dominant fuel in electricity production. Emissions reduction plans should take account not just the cost of installing solar panels, but also the location and associated greenhouse gas emissions of their production. The evidence suggests that it may take up to five years for the CO_2 saved by installing a solar panel to offset the CO_2 emitted in its production in some locations.

We find that there are potential benefits from applying Border Carbon Adjustments (BCA) even those explicitly covering the solar trade. BCAs are a novel trade policy that countries are showing increasing interest in enacting. BCAs are tariff mechanisms intended to level the playing field for economies that produce at higher costs due to CO_2 emissions policies or carbon taxes. A border carbon adjustment levies an import tariff based on the amount of carbon embedded during the offshore production process. It is likely that the European Union will be the first jurisdiction globally to implement a border carbon adjustment, aiming to do so by 2026.

If BCAs are implemented, this would increase costs to install solar capacity and this may influence the pace of deployment. Recent experience of implementing import tariffs on solar by the US and India suggest that even a relatively modest carbon price of $100 per metric tonne of CO_2e would raise the price of an imported solar panel sufficiently to impact trade and by extension the speed of solar capacity installation. It is possible, however, that solar panels would be exempted from BCAs as an environmental good. But given the complexity of modern supply chains it is possible that such goods are inadvertently covered. There has been a distinct lack of progress in defining 'green' goods in multilateral negotiations. Exemptions are likely to be difficult to implement when there are intermediate goods involved, such as aluminium which is specifically tariffed in the proposed EU scheme and is a significant input in solar panels.

While the evidence from the US and India suggests that a border carbon adjustment will impact trade in the short-term, it may achieve its intended objective of shifting trade to countries with lower energy intensity. The US for example is currently using trade policy in an attempt to re-shore solar manufacturing, with some success. A shift of solar manufacturing from China to the US would likely reduce embedded carbon in panels. The US relies far less on coal and more on fuels with lower emissions factors such as natural gas. The existence of substantial amounts of nuclear in the US's generation mix also substantially reduces its emissions footprint. Other countries that have expanded solar manufacturing recently include Malaysia, Vietnam, and Thailand. All three have a lower reliance on coal than China. Vietnam's hydropower stands out for its low emissions. If solar production were to shift to these countries, this is also likely to reduce carbon emissions.

1. Net zero requires a step up in the pace of solar installation

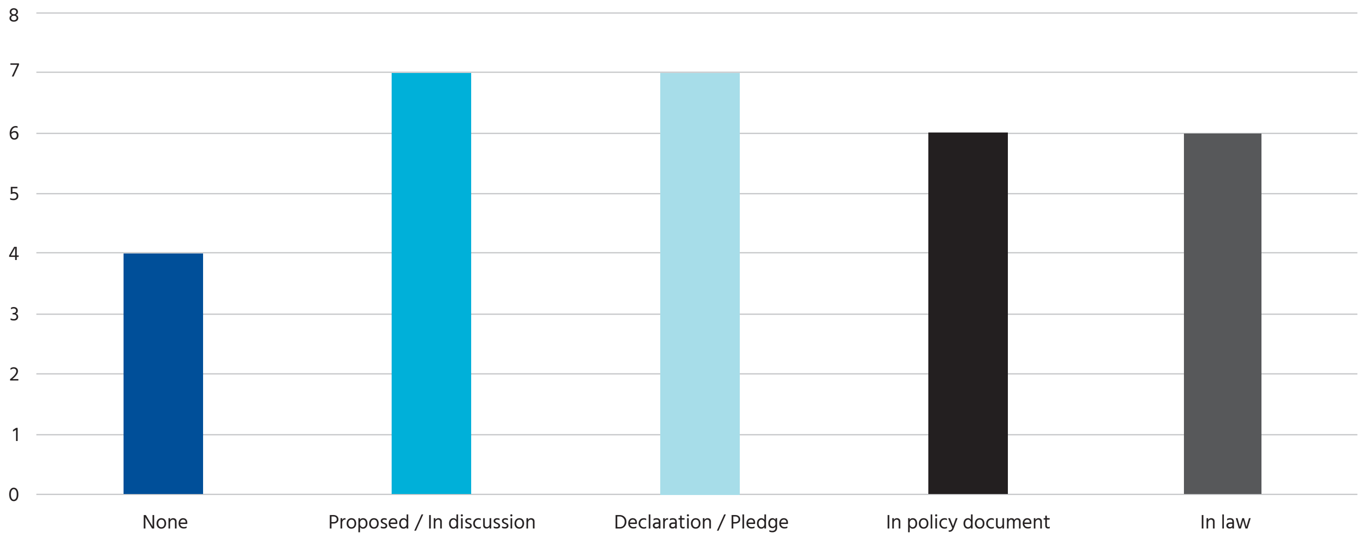
The global ambition to achieve Net Zero by 2050 has become a key symbolic goal. Net Zero refers to an outcome where the volume of greenhouse gases entering the atmosphere is balanced by an equivalent removal. In 2015, 196 countries adopted the Paris Agreement with an overall goal of limiting warming to no more than 1.5°C above pre-industrial levels.[2] The UN considers that the only way to meet this goal is to achieve Net Zero by 2050.[3] Given current levels of emissions this suggests there is a lot of work to do in the short-term with emissions needing to fall by 45% by 2030.

1.1 Net Zero ambitions on STI economies

Figure 1.1 shows that STI economies have varied levels of commitment to Net Zero. The level of commitment should be read as increasing from left to right with a Net Zero commitment with the force of law being the most binding. While Net Zero is widely discussed, very few countries have made it a domestic legal requirement. Where countries have made references to Net Zero the target date in most cases (70%) is 2050. There are five STI economies where references to achieving Net Zero are after 2050.

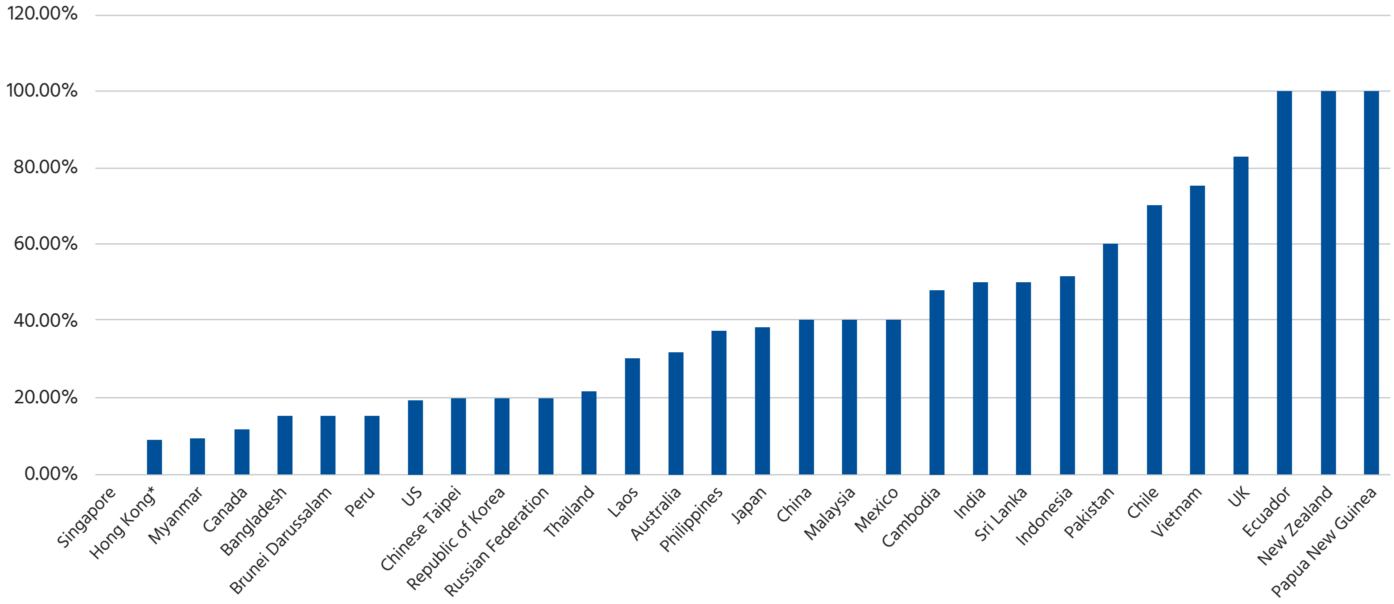
Achieving Net Zero will require substantial change in a range of sectors. One of the more obvious is electricity generation. Its emissions profile will need to fall rapidly towards zero if Net Zero is going to be achieved. The changes required in this sector are clearer than in many others as technology exists today to produce electricity with low carbon emissions – including nuclear, hydro, solar, and wind.

Figure 1.1 – Net Zero commitments



Source: CEPA analysis of REN21 (2022) data, Nikkei Asia, Hong Kong Government

Figure 1.2 – **Renewable electricity generation targets for 2030 by STI economy**[4]



Note: *Mid point of 2035 target range ; **Source:** CEPA analysis of REN21 data (2022), Hong Kong Government

Several STI economies have recognised the importance of this change by setting renewable electricity generation targets. Figure 1.2 shows these targets to 2030. Targets for the renewable shares of electricity generation are incredibly common globally and found in all STI economies, though some STI economies have subnational rather than national targets.[5] There is varied ambition amongst STI economies with regards to increasing the share of renewable electricity generation by 2030. However, ambition does not necessarily mean that the goals are achievable. For example, Papua New Guinea has set a goal of 100% renewable electricity by 2030 but with just 20% of its population supplied with grid electricity this ambition needs to be seen in its proper context.[6]

The solar industry will play a crucial role in achieving Net Zero by 2050.

1.2. What does Net Zero imply for solar?

There are a variety of technologies which can be used to meet each country's renewable electricity targets and Net Zero more broadly. In this report we focus on one of these technologies which holds an almost iconic place in the fight against climate change – the solar panel. Solar capacity is forecast to grow substantially in the coming years and the desire to achieve Net Zero will be a crucial driver of the solar industry. The IEA has established a scenario called 'Net Zero by 2050' and we use their projections in this report focusing on what needs to be achieved by 2030.[7]

Figure 1.3 presents the IEA's projections, and the figures represent a substantial challenge. Solar PV power generation needs to increase from approximately 1,000 TWh globally at present to approximately 7,500 TWh in 2030. Likewise, we estimate that solar capacity needs to grow from the approximately 900 GW installed at present to 5,000 GW in 2030.[8] To achieve this, a step change in the rate of capacity additions is required. In 2021, the world installed approximately 150 GW of solar; by 2030 this needs to be almost six times greater at almost 900 GW installed a year.

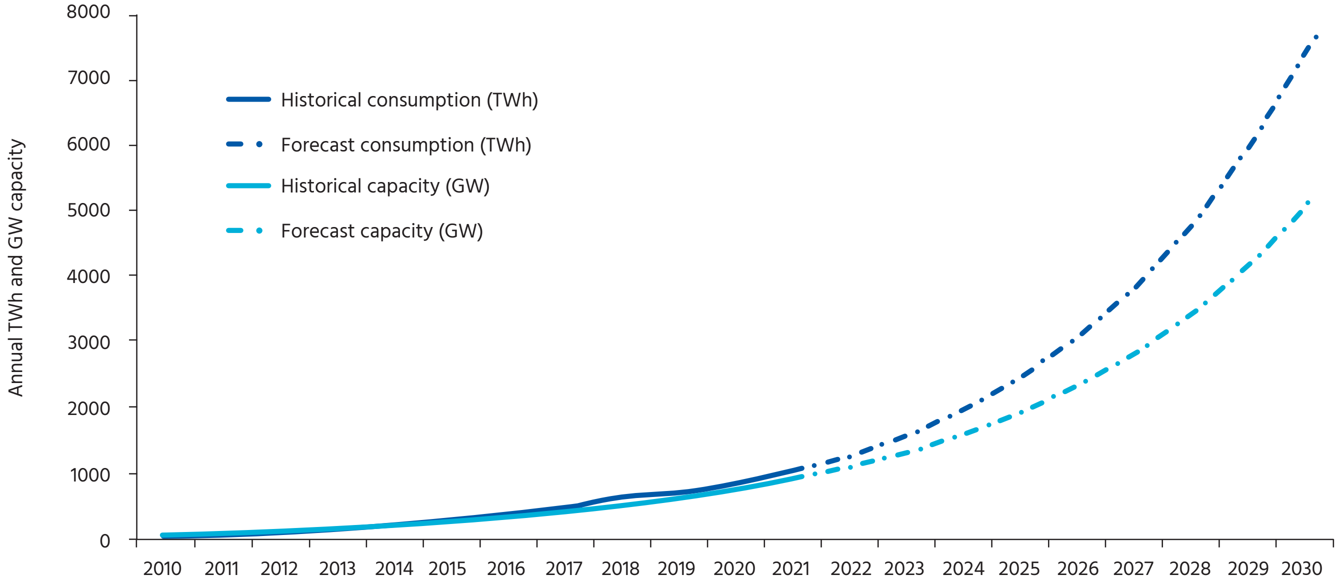
1.3. What can this tell us about individual STI economies?

To understand what the growth in the solar industry might mean for international trade we make projections of solar installations for each STI economy. This is not straightforward, and we are unaware of a publicly available dataset with solar installation projections for all STI economies. In this section we attempt to assign the IEA's global forecast down to the STI economy level. We are not attempting a precise allocation, merely to demonstrate how ambitious the IEA's projection is compared to current installed capacity and rate of installation.

The IEA Net Zero scenario has an exponentially increasing trend for solar capacity installation and we allocate a share of this capacity to each STI economy. As some countries are more suitable for solar than others, we use the World Bank's solar potential index to account for this. In summary, our assignment method is as follows:

- We base our estimate on solar capacity implied by the IEA's Net Zero 2030 projection of 5,042 GW.
- We assign the capacity to all countries included in the World Bank's solar potential dataset, based on an equal weighting of 2022 electric power consumption per capita, population, and practical solar potential.
- Finally, we cut down the list to focus only on STI economies.

Figure 1.3 – Estimates of required solar capacity and generation by 2030



Source: IEA (2021) and CEPA analysis[9]

Infrastructural compatibility and the scale of required installation in each country are key obstacles to overcome.

Projections

Our analysis of the required capacity at an STI country level is set out in Table 1.1. For some countries the projected growth in installations is dramatic. For example, the United States currently has an installed solar capacity of 73 GW. If we project a linear trend of solar installations this would achieve 144 GW by 2030. However, top-down assignment of the IEA's Net Zero projection leads to a requirement of 1,055 GW by 2030, a substantial step change in capacity. This assignment depends on our assumptions, but if an individual country has been assigned too high an amount of capacity this would need to be re-assigned elsewhere for the global projection to be achieved.

Obstacles do exist to amplifying solar's role in Net Zero goals, including infrastructural incompatibility. Older power systems often aren't designed to feed the inflow of power generated from solar panels installed in private homes into community grids. That said, the broad consumption and capacity data we analyse nevertheless illustrates the key message which is the IEA's Net Zero scenario implies a high pace of installations.

It is also instructive to note the scale of required installation in each country and the extent to which they are present in segments of the manufacturing supply chain, indicated in the last five columns of Table 1.1. Most STI economies are in the position of having to import solar panels with no domestic manufacturing capacity at any stage. For countries that do have some domestic manufacturing capacity, this does not often cover all stages. Indeed, as discussed in the next section when it comes to the solar supply chain only China has substantial manufacturing capacity at all stages.

Table 1.1 shows five stages of solar panel manufacturing: Polysilicon (P), Ingots (I), Wafers (W), Cells (C) and Modules (M). These stages are described in detail in Section 2 of this report.

Table 1.1 – Solar capacity (current and forecasts) and current position in solar supply chain

STI economy	2020 solar capacity (GW)	2030 solar capacity implied by top-down assignment (GW)	Current position in solar supply chain[10]				
Australia	17.3	67.5	P	I	W	C	M
Bangladesh	0.3	11.4	P	I	W	C	M
Brunei Darussalam	0.0	1.0	P	I	W	C	M
Ecuador	0.0	4.6	P	I	W	C	M
Cambodia	0.3	1.0	P	I	W	C	M
Canada	3.3	125.6	P[11]	I	W	C	M
Chile	3.2	22.2	P	I	W	C	M
China	253.4	1,210.1	P	I	W	C	M
Taiwan	5.8	*	P	I	W	C	M
India	39.0	268.0	P	I	W	C	M
Indonesia	0.2	46.7	P	I	W	C	M
Japan	69.8	194.3	P	I	W	C	M
Laos	0.0	0.0	P	I	W	C	M
Malaysia	1.5	31.3	P	I	W	C	M
Mexico	5.1	76.4	P	I	W	C	M
Myanmar	0.1	2.7	P	I	W	C	M
New Zealand	0.1	9.2	P	I	W	C	M
Pakistan	0.9	25.5	P	I	W	C	M
Papua New Guinea	0.0[12]	0.0	P	I	W	C	M
Peru	0.3	12.0	P	I	W	C	M
Philippines	1.1	16.6	P	I	W	C	M
South Korea	14.6	117.9	P	I	W	C	M
Russia	1.4	182.4	P	I	W	C	M
Singapore	0.3	10.1	P	I	W	C	M
Sri Lanka	0.4	2.8	P	I	W	C	M
Thailand	3.0	40.8	P	I	W	C	M
United Kingdom	13.5	50.8	P	I	W	C	M
US	73.8	1,055.9	P	I	W	C	M
Vietnam	16.7	27.6	P	I	W	C	M

** World Bank solar potential dataset does not include Taiwan.*

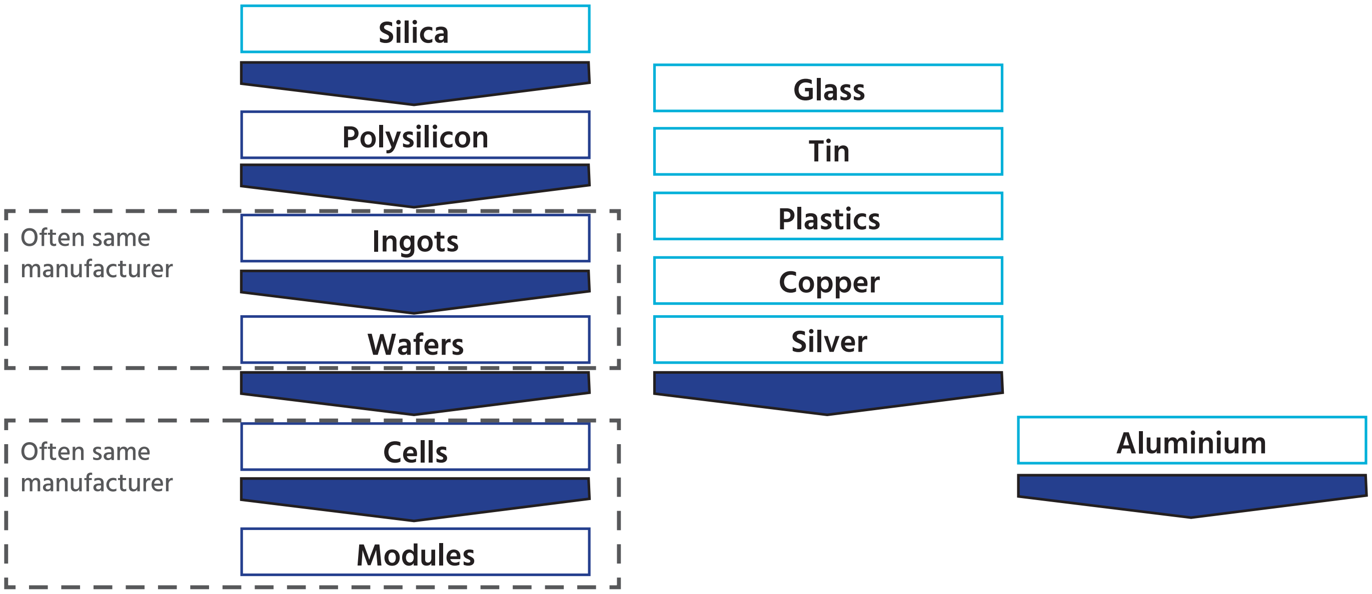
Source: CEPA analysis of IRENA and World Bank data.

2. Evolution of the solar supply chain

The previous section discussed the overall ambition for solar demonstrating the exponentially growing demands on the solar supply chain under the IEA's Net Zero scenario. There are two important questions to consider. Firstly, where will this manufacturing capacity be built (covered in this section)? Secondly, what is the carbon impact from this growth in manufacturing capacity (covered in Section 3)?

We start our assessment by examining the industry as it is today. This section provides a brief overview of the global solar supply chain with a specific focus on STI economies and at a very high level covers the solar production process. In terms of market share, China dominates each stage of the production process and the growth of solar over the last ten years has been a story of China's expanding manufacturing capacity. Trade has also followed this story. China generally produces all intermediate solar goods (such as polysilicon and wafers) domestically and even raw materials such as silicon, meaning there is limited international trade in these segments relative to the value produced. In turn, China exports solar cells and modules.

Figure 2.1 – **Solar manufacturing process**



Source: IEA (2022)

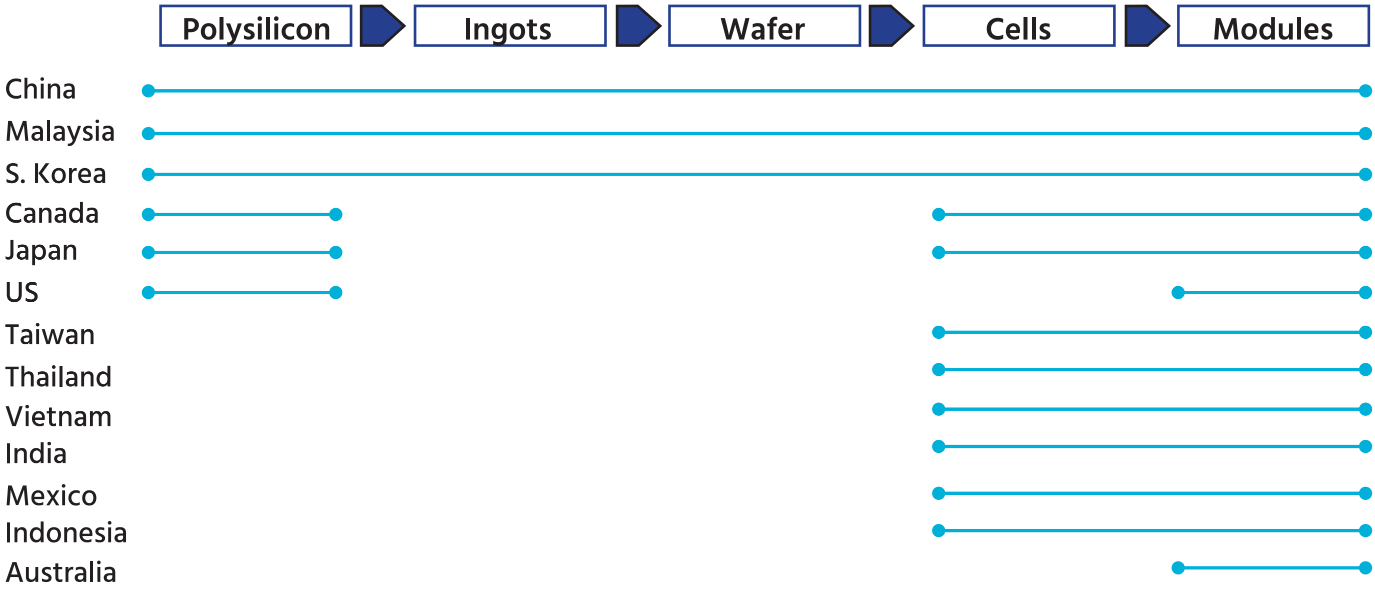
2.1. The solar production process

The solar manufacturing process has several steps as shown in Figure 2.1, along with the key raw resources for manufacturing solar panels. The starting point of the solar production process is the use of metallurgical-grade silica (MGS) to create polysilicon. Polysilicon production plants require large capital investments and the production process itself requires large amounts of energy.[13] Polysilicon in turn is melted to grow monocrystalline silicon ingots which are then sliced into thin silicon wafers. Solar cells are then created by incorporating the required electronic interconnections and sandwiching the wafers between plastic and glass sheets. The final step in the process is the assembly of the module which involves attaching the cell to an aluminium frame.

2.2. Contribution of STI economies to solar manufacturing

There are thirteen STI economies with some level of solar manufacturing capacity. Their participation in each segment of the solar manufacturing process is set out in Figure 2.2. The contribution of different STI economies to each segment and how it has evolved is discussed in the following subsections, including the flow of goods and intermediate products across borders. Although there is some diversity in supply, China is dominant throughout the process and the successful rollout of solar globally has depended almost entirely on growth in Chinese manufacturing capacity. As manufacturing capacity at all stages has been concentrated in China, trade has matched this. Polysilicon is manufactured in China and a series of steps internal to China leads to a solar module being produced. This is then exported from China.

Figure 2.2 – **STI economy participation in the solar manufacturing process**



Source: CEPA analysis of IEA data

Note: Canada shown here as producing polysilicon. However, this is production of feedstock for thin film cadmium telluride PV not polysilicon for silicon based solar. This is included as it occupies a similar place in the supply chain.

The Uyghur Forced Labour Prevention Act constrains the United States from importing polysilicon from China.

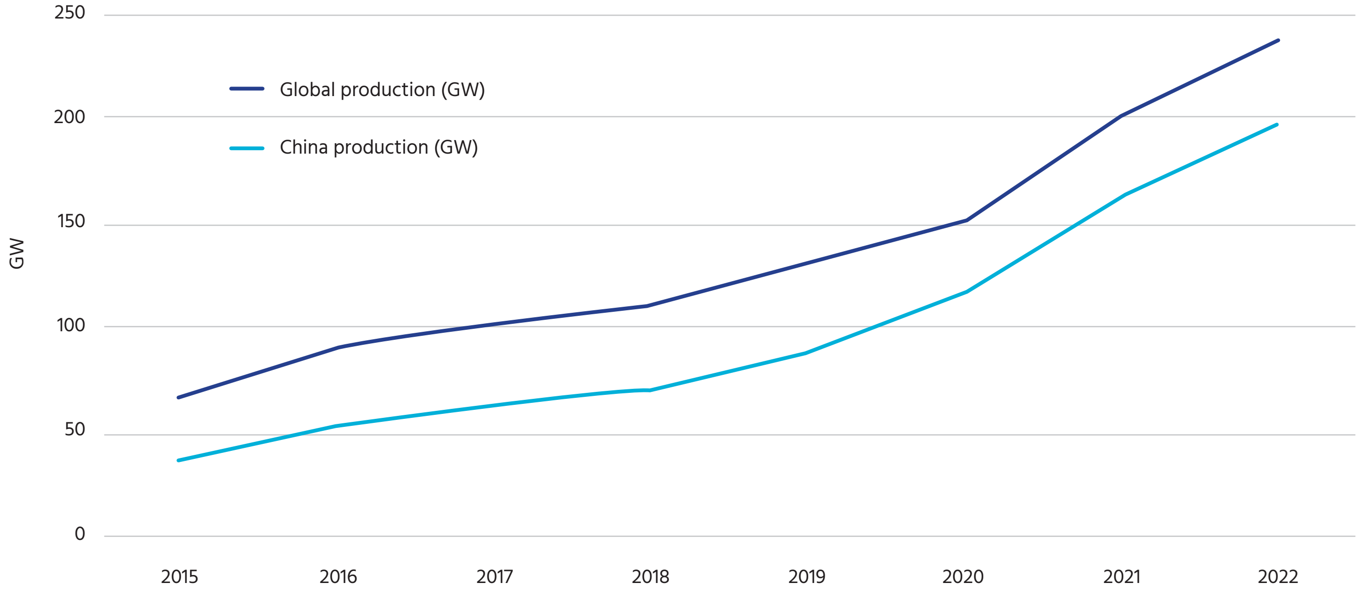
Polysilicon

Polysilicon production is dominated by China as shown in Figure 2.3. Between 2015 and 2022 the proportion of global production attributable to China grew from 56% to 83%. In this period total Chinese production of polysilicon grew by approximately 23 GW each year and market share increased consistently.[14] The other STI economies with polysilicon manufacturers include the United States, South Korea, Malaysia, and Japan. Germany, a non-STI economy, is also involved in polysilicon production.

Before 2017, most Chinese polysilicon manufacturing was located in the eastern province of Jiangsu. Since then, Chinese companies have continued with their efforts to reduce costs by locating in regions with cheaper land, electricity, and labour.[15] This has meant movement into Xinjiang which now hosts 54% of Chinese polysilicon manufacturing. Coal dominates electricity generation in Xinjiang supplying 77% of power in 2019.[16] This is a higher proportion of coal-fuelled power than the Chinese national average of approximately 59% in 2019.[17]

In terms of trade, the consequences of such large proportions of polysilicon being manufactured in Xinjiang have increased since the US passed the Uyghur Forced Labour Prevention Act (UFLPA) in 2021.[18] This establishes a presumption that imports manufactured wholly or partly in Xinjiang were produced using forced labour. This prohibits their import into the US under the Tariff Act of 1930. Importers need to convince the Commissioner of US Customers and Border Protection that there is clear and convincing evidence that the goods have not been produced using forced labour.

Figure 2.3 – **Global production of polysilicon**



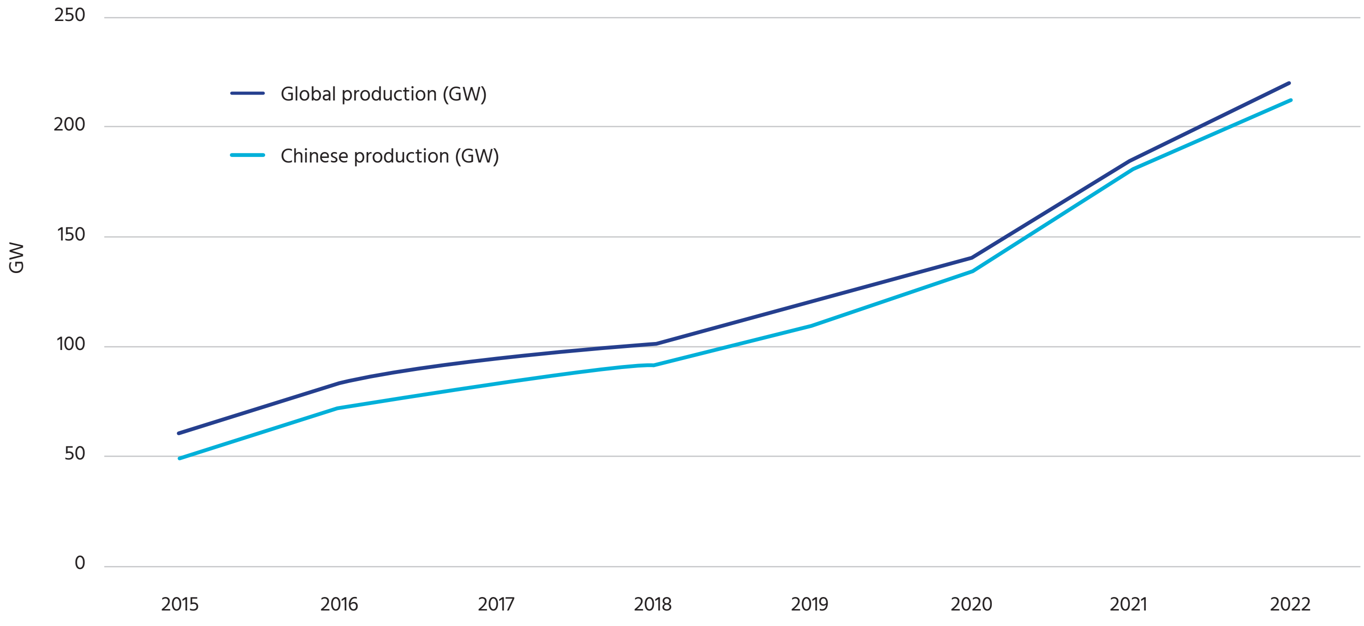
Source: IEA (2022)

Ingots and wafers

The production of ingots and wafers is even more concentrated than polysilicon. China produces approximately 95% of global solar ingots and wafers. Due to this concentration, virtually all buyers of solar-grade polysilicon are in China. The figure below shows global and Chinese production of solar wafers since 2015. Chinese production of solar wafers was approximately 80% of the global total in 2015 increasing to approximately 95% by 2021. As shown in Figure 2.4, there are small amounts of ingot and wafer production outside China. For example, Malaysia now has a small amount of ingot and wafer manufacturing as LONGi (a Chinese company) has set up a plant.[19] However, this has a maximum production of 0.5 GW/year, which is on a small scale compared to operations inside China.

The concentration of ingot and wafer manufacturing within China is also high at a firm level. In 2020, ten Chinese manufacturers produced 98% of global solar wafers with three companies producing 71%.[20] Half of the global capacity is concentrated in just eight plants.

Figure 2.4 – **Global production of solar wafers**



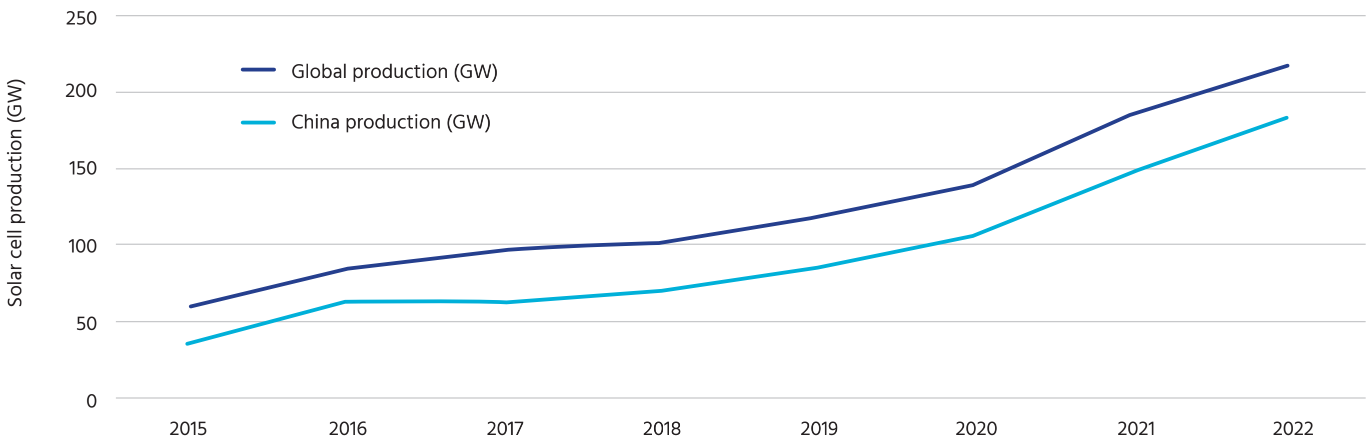
Source: IEA (2022)

Cells and modules

The production of cells and the assembly is far more diversified than ingots and wafers. China's market share in production is approximately 84% in cells and 71% in modules.

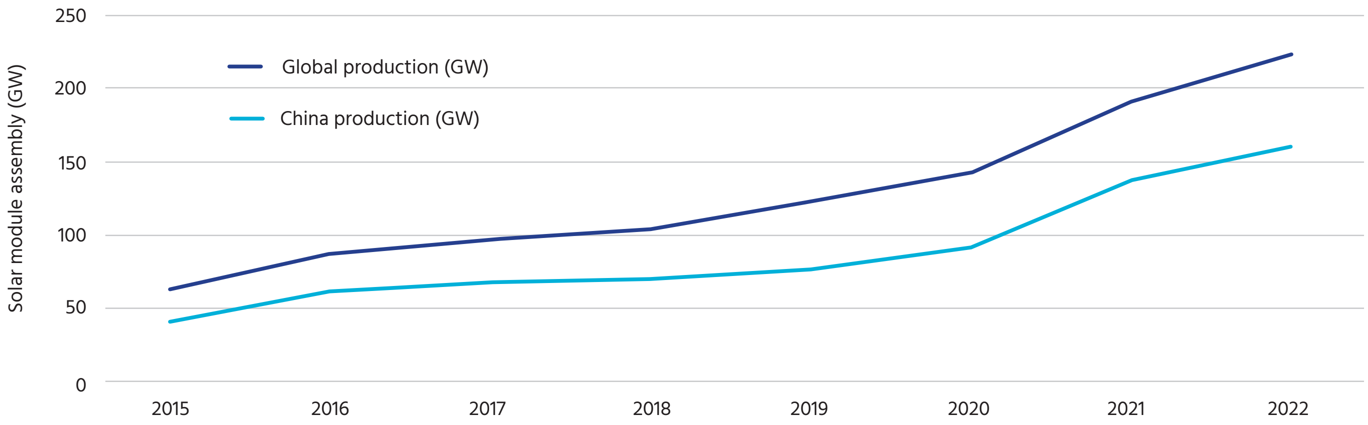
Figure 2.5 and Figure 2.6 show the production of solar cells and modules in China and globally. The Chinese market share for cells has grown from approximately 61% in 2015 to 84% in 2022 while for modules this was 63% to 71% respectively. Most of the remaining solar cell and module manufacturing is in Taiwan, Thailand, South Korea, Malaysia, and Vietnam. There is also a small amount of solar cell and module manufacturing in India as highlighted in our discussion of import tariffs in Section 5.

Figure 2.5 – **Global production of solar cells**



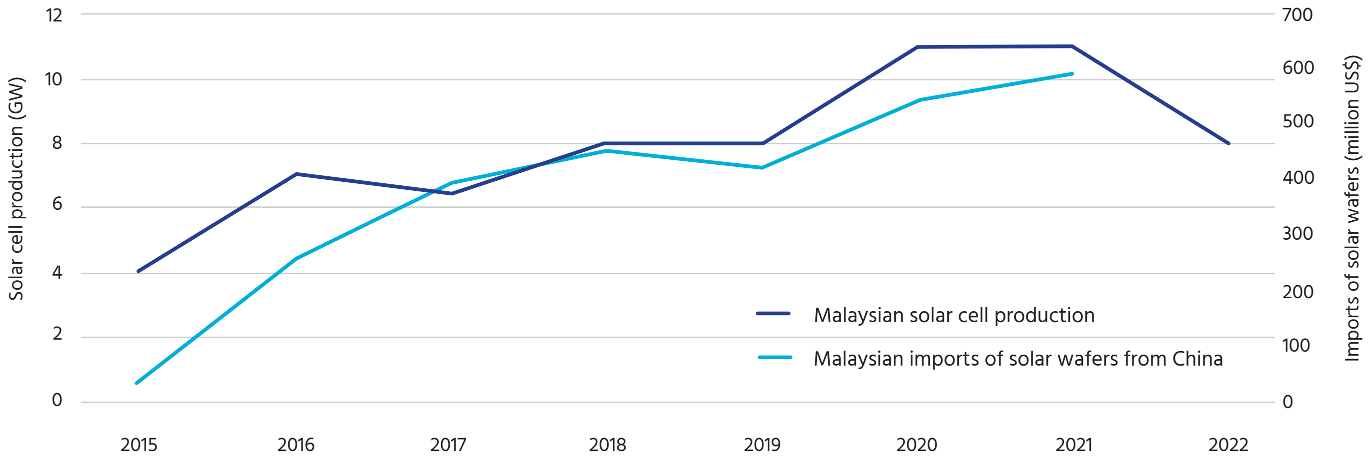
Source: IEA (2022)

Figure 2.6 – **Global production of solar modules**



Source: IEA (2022)

Figure 2.7 – **Malaysian production of solar cells and imports of solar wafers from China**



Source: IEA (2022) and CEPA analysis of UN Comtrade data

Despite apparent global diversification in the manufacturing of solar cells and modules, the dependence on China remains because of their dominance in ingot and wafer manufacturing. Countries that produce solar cells at volume are effectively required to import wafers from China. This can be seen in the trade data as demonstrated for Malaysia in Figure 2.7 As Malaysia's solar cell production has grown the value of wafers imported from China has also grown. Solar cells imported from Malaysia are very likely to include Chinese components. While we have not assessed other countries, this is almost certainly the case elsewhere. This demonstrates the high degree of dependency on trade with China for intermediate manufactured inputs in the solar supply chain.

China's dominance in the production of solar cells and modules leaves countries highly dependent on trade with China.

Raw materials

Table 2.1 shows the raw resource requirements for a 1MW solar module.[21] Several of these elements are incredibly common while others are relatively rare. Figure 2.1 above shows the stage at which these raw materials are required. These need to be extracted from the ground and made available to the manufacturing process often crossing borders in the process. To demonstrate the importance of trade associated with manufacturing solar panels we briefly touch on two of these elements, one incredibly common (silicon) and one far rarer (silver).

One of the key inputs into solar panels is silicon, more specifically metallurgical grade silicon (MGS). Silicon is the second most abundant mineral in the earth's crust.[22] It occurs naturally in the form of quartz but there are limitations on the type of quartz that can be used as high levels of purity are required. Some elements are easy to remove from silica (such as aluminium and calcium) while others (such as iron, phosphorous, titanium and boron) are difficult to remove and impact solar performance. This leads to selectivity in the quartz that can be used and despite abundance of silicon limits the locations it can be extracted from.

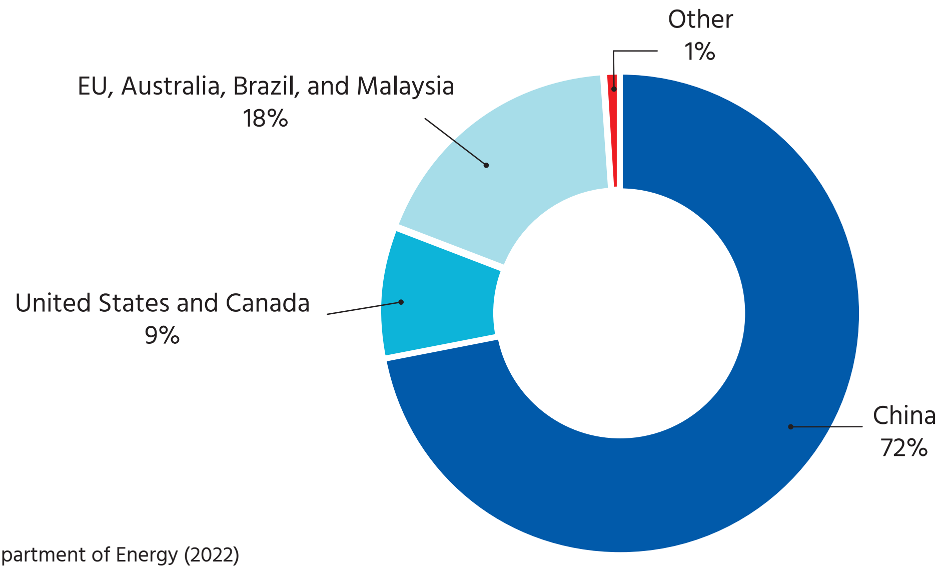
Table 2.1 – Raw resource requirements (kg per MW solar)[23]

Material	kg	% of finished product
Silicon	2,993	4.36%
Aluminium	11,085	16.48%
Copper	525	0.78%
Silver	17	0.03%
Tin	68	0.10%
Plastics	7,565	11.24%
Glass	45,089	67.02%

Source: CEPA analysis of IEA data

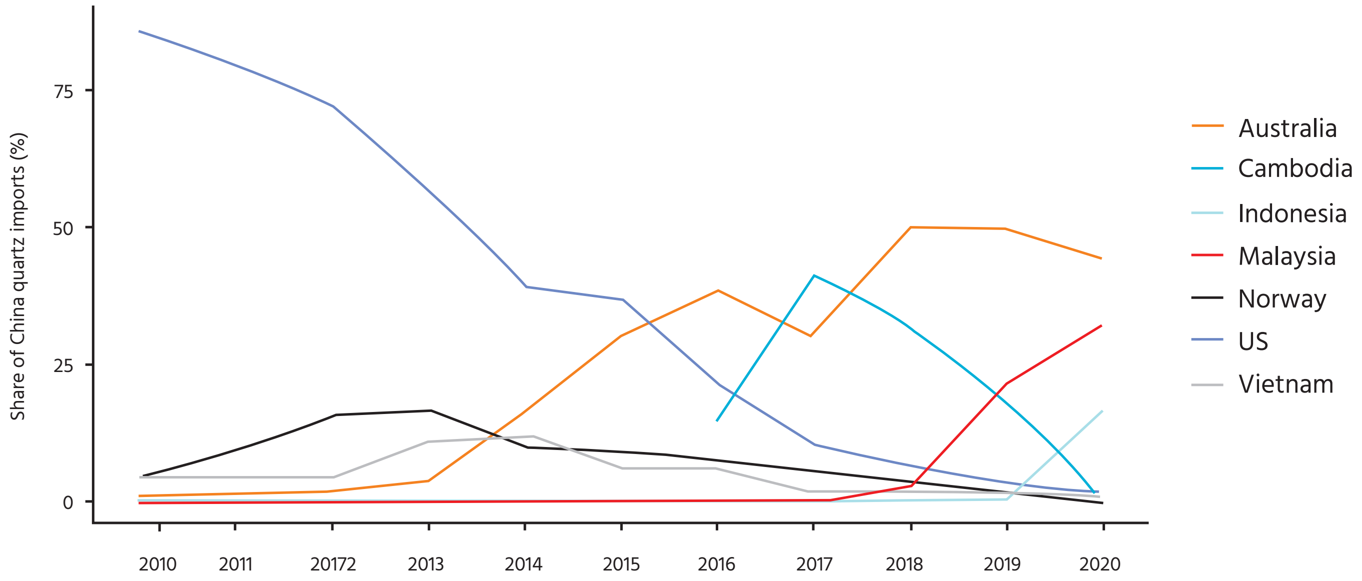
Figure 2.8 shows the production of MGS by country. Production is dominated by China, meaning polysilicon manufacturing can be partially met by domestic supplies of MGS. There are 14 other countries that can produce MGS, but these do not present significant competition to China. China does however import quartz to create MGS. The United States is world's largest producer of high-quality quartz. However, trade has allowed production of MGS to shift to China. In 2010 over 75% of China's quartz imports were from the United States, but this has rapidly declined over the last 10 years falling to 2% in 2020. China has diversified the countries it depends on for quartz imports.

Figure 2.8 – Global production share of MGS (2020)



Source: US Department of Energy (2022)

Figure 2.9 – Trends in the share of China's quartz imports by trade partner

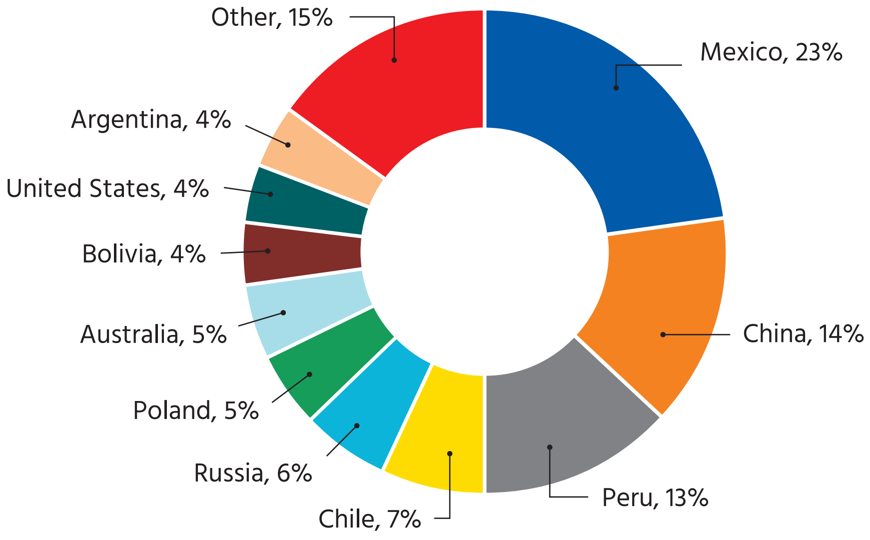


Source: CEPA analysis of UN Comtrade data

Silver is also a key input in the solar panel supply chain. Despite only making up 0.03% of the total weight of a finished panel, the relative rarity of silver means that it can make up a sizeable proportion of value. The number of countries that mine silver is concentrated, the top three producers of silver account for half of the total silver produced in 2021. Mexico produced roughly 5,600 metric tonnes of silver 2021, followed by China and Peru which produced 3,400 and 3,000 metric tonnes, respectively.[24]

Of the countries that produce silver, only China currently manufactures solar panels cells. Broadening the global trade in silver is imperative to diversify global PV supply chains and amplify solar's role in global decarbonization. Solar cell manufacturers are concentrated in Southeast Asia while most of the silver produced each year originates in Latin America. Increased trade between large silver suppliers such as Mexico and Peru, and growing solar cell manufactures such as Malaysia, Thailand, and Vietnam, would reduce risks associated with relying on China for both silver and wafers.

Figure 2.10 – **Silver production by country**



Source: The Silver Institute (2020)

2.3. Key issues in solar production to 2030

Section 1 showed that for the IEA's Net Zero projection to be achieved solar capacity needs to grow exponentially. Key observations on likely developments include:

- The solar supply chain needs to expand to meet demand and constraints are most likely to emerge in the polysilicon segment.
- Other countries in SE Asia are increasing their presence in the solar supply chain, although China is likely to remain dominant.
- While raw material constraints aren't as serious as they are for battery manufacturing, there is a risk that they could inhibit growth.

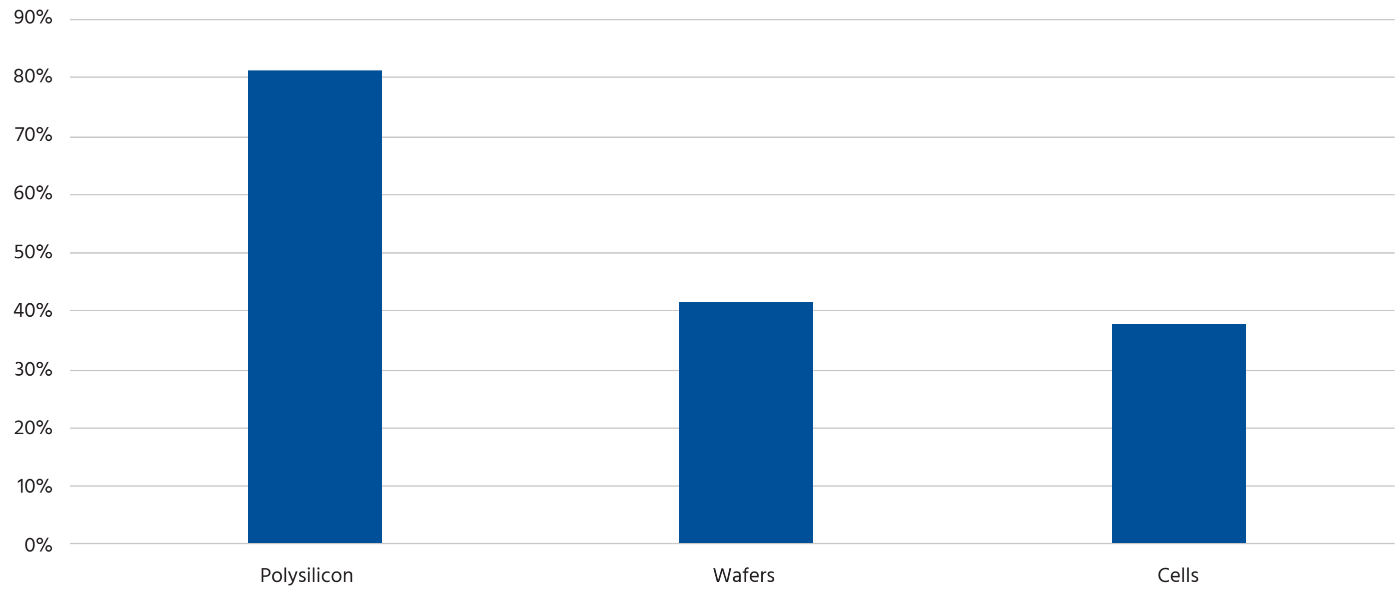
Addressing supply constraints, increasing competition, and future demand for raw materials are key issues that warrant greater attention.

Segments approaching supply constraints

The fast growth in demand for panels means a substantial increase in the pace of manufacturing is required to meet demand. It is possible that manufacturing capacity may act as a constraint on capacity growth.

The IEA finds that there is currently substantial spare capacity in parts of the solar supply chain. Polysilicon manufacturing capacity is currently acting as a constraint with a maximum production of 290 GW equivalents per year. This is compared to more than 500 GW equivalents per year for wafers and cells. Polysilicon prices have increased recently which has been attributed to the demand/supply imbalance caused by significant expansion in ingot/wafer manufacturing.[25] Meeting the IEA's Net Zero scenario will require expanding polysilicon manufacturing capacity more urgently.

Figure 2.11 – **Estimate of utilisation of manufacturing capacity (2022)**



Source: IEA (2022)

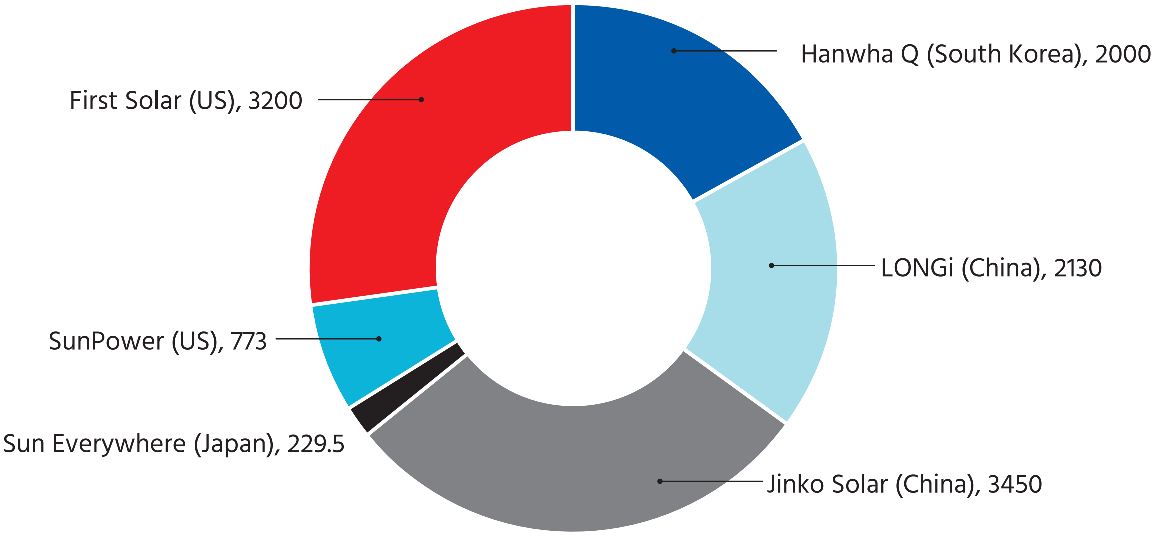
Our hypothesis above was that new plant location may drive market share changes. Given spare capacity this suggests that it is polysilicon that is most vulnerable to change. Nonetheless, this is not what has been born out in recent history. Substantial change in solar market share in other segments currently seems more likely. There is limited construction of new polysilicon manufacturing facilities outside China, and it does not look like there will be substantial new capacity outside China in the near future. Polysilicon production requires large capital investments, skilled labour, and low electricity costs. This limits the geographical locations and by extension countries that can successfully compete in this segment.[26]

Diversification of sources of supply

Despite underutilization, there is early evidence of deconsolidation of other parts of the intermediate supply chain, primarily solar cells. China currently holds a predominant position, but this may have begun to change. As discussed below in Section 4.1, this appears to have been partially driven by the imposition of tariffs on China by the United States. The import profile of solar cells and modules to the United States has changed substantially in recent years. This may have contributed to solar cell manufacturing pivoting to Southeast Asian countries including Thailand, Malaysia, and Vietnam. However, this movement remains limited and import profiles have not generally changed elsewhere. Overall Chinese market share in cells continues to be maintained.

The evidence from Thailand, Malaysia, and Vietnam shows that other countries can rapidly increase solar cell manufacturing capacity if the right conditions exist.

Figure 2.12 – **Malaysian solar cell manufacturing capacity by manufacturer (2019)**[27]



Source: CEPA analysis of IEA (2019)

These countries have increased manufacturing capacity for export, showing the importance of being able to respond to changing global trade conditions. However, these 'right conditions' still rely on Chinese companies to some extent. Figure 2.12 shows solar cell manufacturing capacity in Malaysia by company. Both LONGi and Jinko Solar are Chinese companies. The other companies are from South Korea, Japan, and the US. Furthermore, as highlighted above, the solar wafers that are going into these cells are almost exclusively manufactured in China.

The segment that has seen most change in recent years is solar modules. As demonstrated in Section 5 below the United States has implemented tariffs to re-shore manufacturing of solar panels. India has also taken action to protect their domestic solar industry from Chinese competition. The implementation of tariffs by the United States appears to have been successful in starting the process of re-shoring module assembly albeit with negative impacts on solar capacity growth. This is not the case for intermediate goods such as solar cells, which remain entirely imported. This means that the dependence on trade from China to meet solar growth remains.

Future raw material requirements

There are seven key raw materials that go into manufacturing a solar panel.[28] The raw material constraints facing solar are not considered to be as severe as for batteries where many commentators have highlighted the potential for substantial shortages of lithium.[29] Nonetheless, the exponential growth scenario will draw in a substantial amount of raw material into the solar industry.

Constraints on the supply of most of these materials aren't yet apparent. However, silver, despite only contributing to 0.03% of a finished panel in weight, may be an exception.

If mitigating strategies are not put in place, access to silver presents a material risk to the uptake in solar photovoltaic panels (solar PV) following the IEA's exponential forecast scenario. Analysis by the IEA[30] found that in 2020, each additional solar PV cell required 0.03% of silver by weight. A PV panel with 1 MW of capacity weighs approximately 67,000 kg meaning each MW of solar requires 17 kg of silver. We use this as a baseline scenario. A report by the Silver Institute analysing the role of silver in the solar PV industry found that the amount of silver used per cell had decreased significantly from 2010 and would continue to decease in the future by around 20%.[31] Using this assumption as an upside scenario for silver needed per MW of PV capacity, results in a scenario where around 13.5 kg of silver is needed for each additional MW of capacity.

The additional capacity in GW each year required to meet IEA's 2030 target is presented in Table 2.2. Using the baseline and upside scenarios outlined above, the amount of silver demanded each year is also calculated.

Efficiency gains in the use of silver as an input into PV cells has kept demand for silver relatively flat over the past 10 years, even as solar capacity has grown significantly.

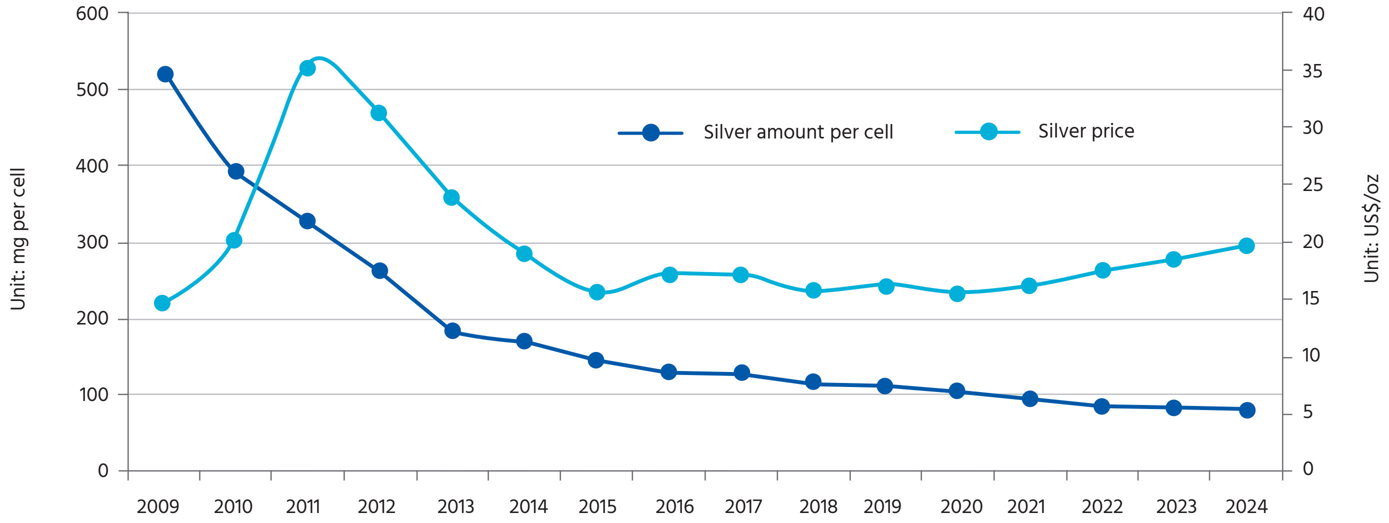
Table 2.2 – **Additional capacity required to meet IEA's NZE target**

Year	Additional capacity (GW)	Silver demand – Baseline (kg, 000s)	Silver demand – upside (kg, 000s)
2022	185	3,148	2,500
2023	225	3,826	3,038
2024	274	4,653	3,695
2025	333	5,662	4,496
2026	406	6,894	5,475
2027	494	8,399	6,670
2028	602	10,239	8,131
2029	735	12,489	9,917
2030	869	15,240	12,103

Source: CEPA analysis of IEA (2020) and Silver Institute (2020)

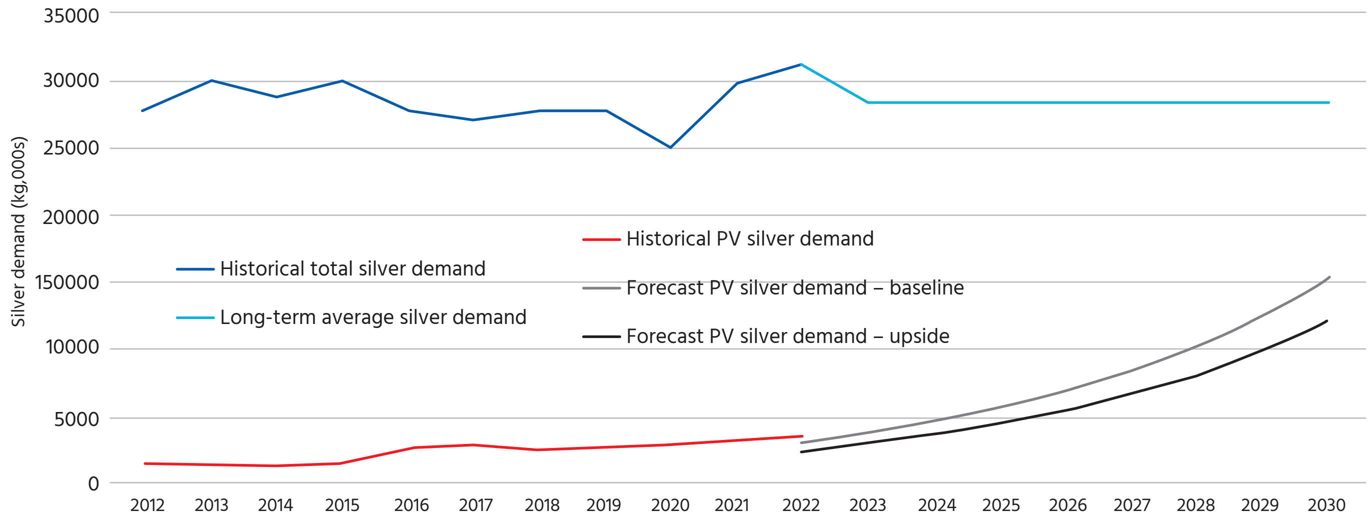
However, efficiency gains are slowing, and the construction of solar capacity is forecast to accelerate. If silver is used in the same way during construction of PV cells as it is today, and additional efficiencies over the next 8 years are limited to be no greater than 20%, the amount of silver demanded to produce PV cells will grow quickly and represent a significant proportion of total silver demanded by 2030, assuming demand in other industries remains constant.

Figure 2.13 – **Silver price and silver usage per solar cell**



Source: CRU

Figure 2.14 – **Historical and forecast demand for silver**



Source: CRU

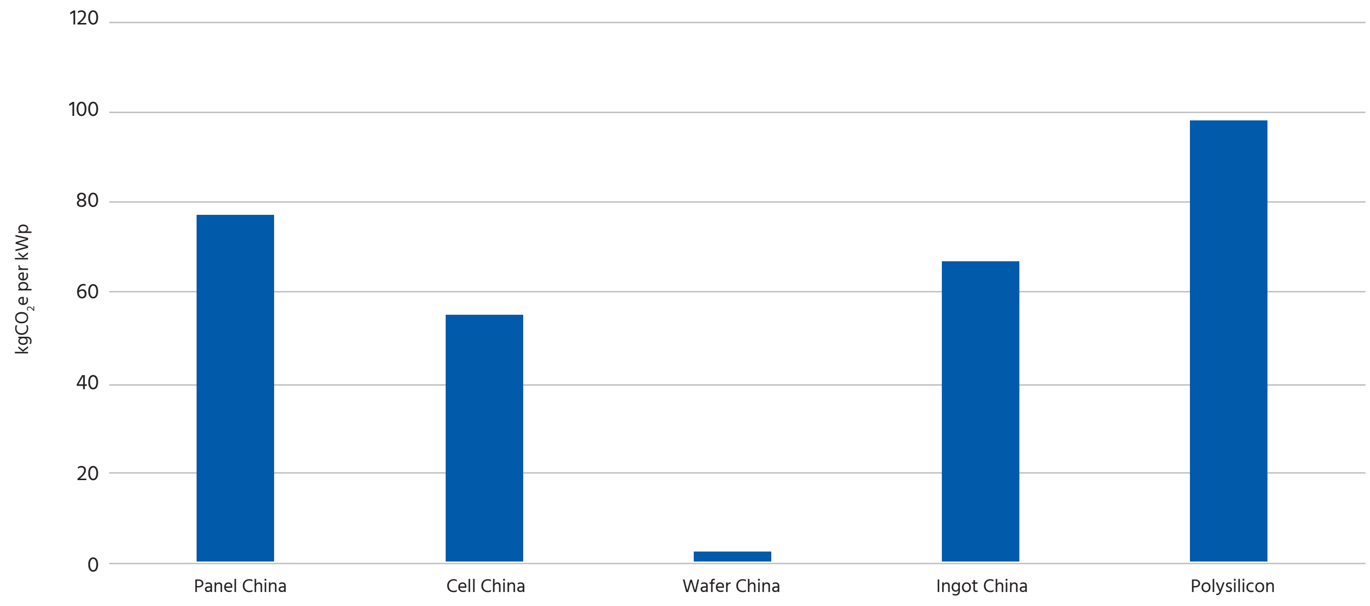
3. Managing carbon in the solar supply chain

3.1 Contribution of carbon in solar manufacturing value segments

Each stage of the solar PV production process involves emissions of CO_2. Manufacturing of solar requires large amounts of electricity and most of this electricity is currently produced by carbon emitting generation. Estimates for the amount of carbon embedded in a solar panel vary widely and we rely on a report by Elementa Consulting which provides embedded carbon estimates for a range of manufacturers.[33] These range from 242 $kgCO_2e$ per kWp to 1,520 $kgCO_2e$ per kWp with the study selecting 360 $kgCO_2e$ per kWp for their analysis.[34] For this report we are electing to use a range of 300 to 600 $kgCO_2e$ per kWp.

Figure 3.1 provides estimates for the contribution of embedded carbon at each stage of the production process. These are based on the proportion of greenhouse emission for each stage of production for a panel imported into the EU from China as estimated by the IEA.[35] We then apply our estimate of 300 $kgCO_2e$ per kWp of finished solar to these proportions to recover the estimates.

Figure 3.1 – Contribution to embedded carbon by stage of production



Source: CEPA analysis of IEA data

Without actively decarbonising the solar supply chain, efforts to go green may end up futile.

It may feel oxymoronic to consider the amount of carbon embedded in a panel. After all, solar panels are a product so intrinsically tied to the 'green' movement. Nonetheless, most of the energy that goes into producing a panel currently comes from coal. This can be demonstrated for polysilicon. Figure 3.1 shows that a substantial proportion of the total embedded carbon contained in a panel occurs at the polysilicon stage. The production of polysilicon as with all else solar is dominated by China and as highlighted above the majority of Chinese polysilicon manufacturing capacity is in Xinjiang. The IEA estimates that 66.5 kWh of electricity is required to produce each kilogram of polysilicon. Given Xinjiang's electricity generation mix, this means the equivalent of 51.2 kWh will be generated by coal to make a panel. The production of polysilicon is a significant activity relative to Xinjiang's overall generation and we estimate that 4.9% of the region's annual generation is currently used for polysilicon.[36] Given the emissions factor of coal, we estimate that 280 kg of CO_2 will be released for each MW equivalent of polysilicon produced.[37]

A solar panel will offset its embedded carbon emissions over time. However, the amount of time required will vary considerably. The first element is the capacity factor of the panel, which represents how well utilised the panel is. This will depend on temperature, how sunny a location is and the direction the panel is facing. The second is the type of generation that is avoided by installing the panel. If a country's electricity system is heavily dependent on coal, then it is simple to conclude that the installation of the panel will directly offset carbon. This ensures that the embedded carbon is paid back. But if solar is used to offset nuclear, then the embedded carbon will never be paid back. As such, general estimates of the amount of time required to completely offset the embedded carbon will be situationally dependent. Regardless of this, the time required will be measured in years and two to five years may be typical.[38]

Net Zero requires a rapid decarbonisation of all parts of the economy, this includes the solar supply chain. The manufacturing of solar panels is carbon intensive, and the embedded carbon takes years to offset. This points to potential advantages in reducing the amount of carbon embedded in a panel in the first place.

3.2. Future carbon emissions

The carbon emissions associated with expansion of solar supply can be reduced to two high-level scenarios. The first is that Chinese market share is maintained, which means that the Chinese energy mix will predominantly determine the amount of embedded carbon in each panel. Alternatively, other economies gain market share and increasingly determine the energy mix going into panel production.

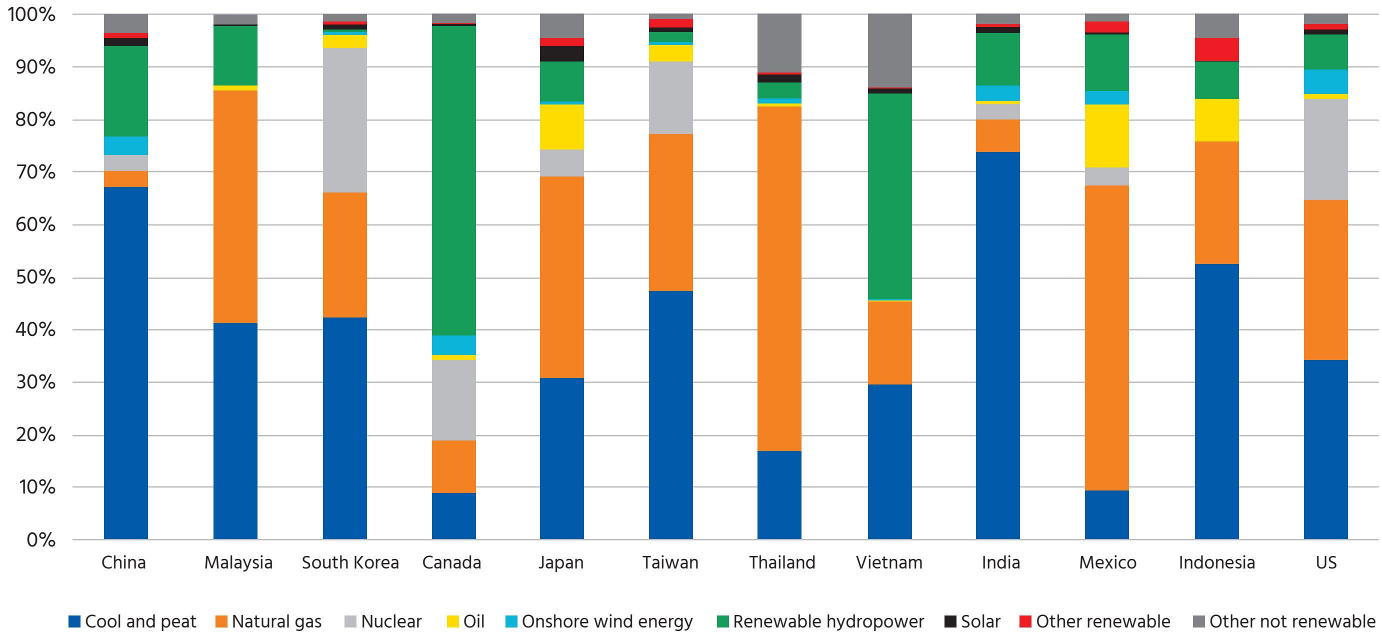
Given the dominance of China in all segments of the supply chain we can take this as the default position with movements in country of manufacturing compared against this baseline. For illustrative purposes, we consider three scenarios which include re-shoring of solar to the US, and expansion of solar production in Malaysia, Vietnam, Thailand, and India.

Figure 3.2 shows the national generation mix for select STI economies. We can surmise the following:

- A shift of solar production from China to the US would likely reduce embedded carbon in the panels. The US relies far less on coal and far more on fuels with lower emissions factors such as natural gas. The profile below also points to the importance of nuclear power, contributing 19% of total generation in 2020. The existence of nuclear in US's generation mix substantially reduces the country's emissions profile.
- A shift of solar production from China to Malaysia, Vietnam, and Thailand would also likely have the impact of reducing embedded carbon. Reliance on coal is far lower in each of the three countries. Vietnam stands out as having a particularly low emissions factor due to the large amount of hydropower.
- A shift of solar production from China to India would likely increase the amount of embedded carbon in each panel. India relies even more heavily on coal than China.

This illustrative analysis shows that even if national generation mixes remained static to 2030, then decisions by manufacturers on where to locate will drive the amount of carbon embedded in a solar panel.

Figure 3.2 – Generation profiles for select STI economies (2020)



Source: CEPA analysis of IRENA data

The reduction of carbon emissions by relocation is ineffective, and successful reduction must be evaluated from a global perspective.

3.3. Border carbon adjustments (BCAs)

The STI report and our discussion in Section 1 demonstrates varied commitment to environmental factors including efforts to decarbonize. Any locational contest for the solar supply chain will take this into account. The price of energy is a crucial factor in decisions regarding where to locate manufacturing. If the price of energy is kept low with coal, then this is where manufacturers will prefer to locate as demonstrated by recent history. Manufacturers are likely to seek alternative locations from jurisdictions that drive carbon prices higher.

Carbon pricing is an indication of this varied commitment. The STI 2022 report uses carbon pricing as one of its indicators. It shows that there are nine economies with carbon pricing and one which has announced carbon pricing but is not yet implemented. The remaining 20 economies do not have carbon pricing, nor have they announced that they will implement such policies.

Decarbonization must be seen as a global effort. If an individual country unilaterally reduces its carbon emissions simply for carbon emitting activities to re-locate then nothing has been achieved. It is total emissions that count not the location they are emitted. This means that the location of manufacturers and decarbonisation ambitions increasingly become a cross-border agenda.

We can envisage a range of policies that would seek to influence trading partners, such as making payments to exporters to reduce emissions. Commitments to climate finance are one form of this redistribution. Governments may also directly pay foreign authorities to curb emissions, such as the abortive agreement for Norway to pay up to $1 billion to Indonesia to conserve peatlands and rainforests.

Trade policy can also be used as a lever to influence other countries' decarbonization efforts and manufacturers' location decisions. In this report we propose one such policy which are commonly referred to as border carbon adjustments or BCAs. A BCA makes it possible for firms to face the same cost of carbon regardless of where they are located. In theory, from the point of view of a purchaser within a jurisdiction, the carbon cost of an imported good will be assessed equivalently to its domestically produced counterpart.

What is a border carbon adjustment?

Border carbon adjustments (BCAs) apply a carbon price to emissions embodied in traded goods. This could potentially be based on the domestic carbon price which would level the playing field between imports and exports. This is particularly the case for emissions-intensive and trade-exposed industries. Currently there are no national jurisdictions which levy BCAs. However, it is now likely that the EU will implement such a scheme with the current operational date being aimed for 2026.[39]

The general aims of BCAs will differ by jurisdiction and some potential objectives include:[40]

- Reducing the risk of carbon leakage: This occurs when carbon policies and costs cause companies or investors to move production to jurisdictions with lower carbon costs. The result is that emissions are not reduced but simply emitted from a different location. We would also highlight another potential objective, which is to influence the locational decisions of firms and investors even if these goods are purely imported and will never be produced domestically.

- Maintaining the competitiveness of domestic industries: Domestic companies may incur carbon costs while foreign businesses might not. A BCA could help ensure imported goods face the same carbon costs as domestically produced goods.
- Support greater domestic climate ambition: By levelling the playing field between imported and domestic goods BCAs may allow increased ambition in domestic policies.
- Driving international climate action: BCAs can influence other countries to implement strong domestic climate policies, in particular if these policies mean their exports avoid the BCA.

What does current policy look like?

The EU is most advanced in considering BCAs and the features of their scheme can provide some insights into how the potential objectives of BCA's will be achieved in practice. A substantial step in the process of implementing a BCA for the EU was included as part of the EU's 'European Green Deal' policies announced in 2019. The policy committed the European Commission (EC) to proposing a carbon border adjustment mechanism (CBAM). The EC also stated that they will design the CBAM to comply with WTO rules and other international obligations.

In July 2021, the EC provided further details on the key features of the scheme:[41]

- The CBAM will initially only cover five industrial sectors: iron and steel, cement, fertilisers, aluminium, and electricity generation. These sectors were selected because of the risk of carbon leakage, magnitude of carbon emissions, and administrative feasibility.[42]
- The CBAM should be seen in the context of the EU emissions trading system (ETS), this currently requires some sectors to acquire emissions allowances. The EC provides free allowances to sectors at risk of carbon leakages. The EC is planning to start phasing out free allowances from 2026 and the CBAM will only apply to the proportion of emissions that do not receive free allowances under the EU ETS.
- The price overseas manufacturers would pay for CBAM certificates would be directly linked to the EU ETS price.
- There will be a transition period scheduled to occur from January 2023 to December 2025. During this time importers would be required to calculate and report carbon emissions but not yet make payments.
- Only direct emissions (i.e. scope 1 emissions) released during the production process would be covered by the CBAM. Indirect emissions (i.e. scope 2 and scope 3) would not be covered, which includes emissions generated from electricity used for manufacturing.

There has been further progress on the scheme since July 2021 and in December 2022 political agreement was reached between the European Parliament and the European Council on the CBAM. This was announced as a substantial step forward in successfully implementing the CBAM. The implementation of the transitional phase was delayed slightly and is now scheduled to start on 1 October 2023. There will now also be a review of the transitional phase prior to importers being required to make payments.[43]

Other than those in the EU, other countries are still very much at the preliminary stage of considering BCAs. In 2021, the Canadian government consulted on a potential BCA but only with the high-level aim of identifying questions that would be examined further.[44] Details on practical operation have not yet been considered. It has also been reported that Japan's government has also been considering the introduction of a border carbon tax and are consulting with experts.[45] Again, no practical details are yet available. It is possible that the introduction of the EU scheme and if it is seen as successful will accelerate progress elsewhere. However, if the time required for the EU to implement their scheme is anything to go by, BCAs in Canada and Japan are a long way off.

What might this look like for solar?

Solar panels have embedded carbon as the production process is not carbon-neutral. This means in theory a BCA could be applied to solar. This could be applied to final goods (i.e., complete solar modules) or intermediate inputs into solar panels. For example, one of the sectors that will be covered by the proposed EU scheme is aluminium, a crucial input into solar.

The carbon price that importers would need to pay if a BCA were applied to solar is uncertain. In the proposed EU scheme this will be based on the prevailing ETS price, which is currently approximately €87/metric tonne (US$93 as of late December 2022).[46] To demonstrate the potential impact, we illustrate with an indicative carbon price of US$100/tonne, which is close to the currently prevailing ETS price. This produces a carbon price of between $30 and $60 per kWp of solar. To put this into perspective, the price of an imported panel into the US in 2021 was $337/kWp, which would mean the carbon price would be between 8.9% and 17.9% of the value of the panel.[47]

4. What should policymakers consider?

Policymakers must carefully weigh the benefits of implementing BCAs and their short and long term effects.

There is a high likelihood that at least some jurisdictions will implement BCAs prior to 2030. This is a period where there needs to be a substantial transition to renewable electricity sources including the installation of large amounts of solar if Net Zero is to be achieved. This will include increased trade in solar panels and solar panel inputs. A broad-based BCA would cover all imports including solar panels and selective BCAs may impact inputs regardless. In this section we consider whether it is useful and appropriate to implement a BCA covering solar panels or whether they should be avoided. Furthermore, we consider whether selective BCAs could avoid solar panels or 'green' goods entirely.

To answer these two questions in this section we:

- Examine the case studies of US and India, both of which have recent experience of implementing import tariffs on solar goods albeit not driven by carbon. These provide a good basis to consider whether a BCA might influence the choice of trade partners and what the consequences might be for the domestic solar industry and capacity additions. We find that import tariffs can be effective in changing trade patterns at least in the short-term but there may be negative consequences for solar capacity growth.
- Consider the current state of multilateral negotiations on exempting 'green' goods from tariffs. If these types of goods can be identified and agreement between countries achieved, then it is less likely that solar goods will be covered by future BCAs. We find that multilateral negotiations on these issues appear stalled. This raises the risk that BCAs may cover solar or solar goods.

4.1. Import duties matter

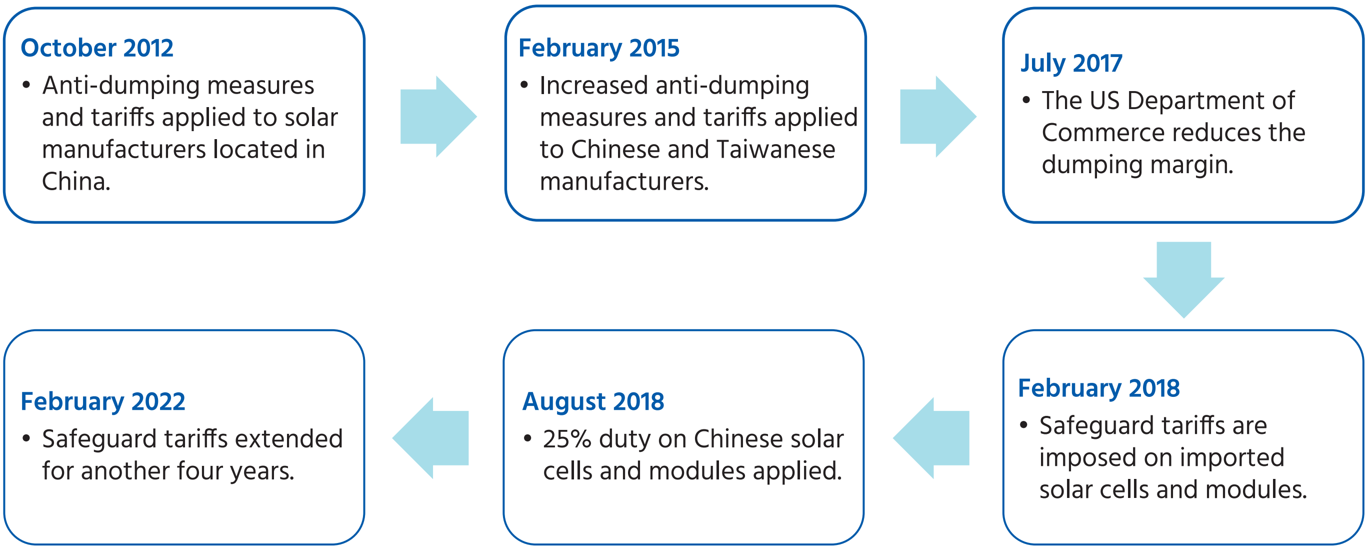
Our examination of the recent US and Indian experiences with import duties on solar panels demonstrates that similarly sized tariffs to a potential BCA can reduce solar installation in the short-term.

United States

Since 2012, the US has implemented a series of tariffs and anti-dumping measures against overseas solar panel manufacturers, in particular Chinese and Taiwanese manufacturers. The timeline in Figure 4.1 shows these measures.

Anti-dumping measures and countervailing tariffs were implemented to protect US domestic manufacturing of solar cells and modules. We have relied on UN Comtrade data[48] and US data on domestic manufacturing to consider the tariff's impact on trade, whether domestic manufacturers successfully increased output given the increased cost of imports, and to examine the trends in solar capacity installed to consider whether installations were impacted either by lack of inputs or raised costs.

Figure 4.1 – Timeline of US anti-dumping measures and tariffs[49]



October 2012
- Anti-dumping measures and tariffs applied to solar manufacturers located in China.

February 2015
- Increased anti-dumping measures and tariffs applied to Chinese and Taiwanese manufacturers.

July 2017
- The US Department of Commerce reduces the dumping margin.

February 2018
- Safeguard tariffs are imposed on imported solar cells and modules.

August 2018
- 25% duty on Chinese solar cells and modules applied.

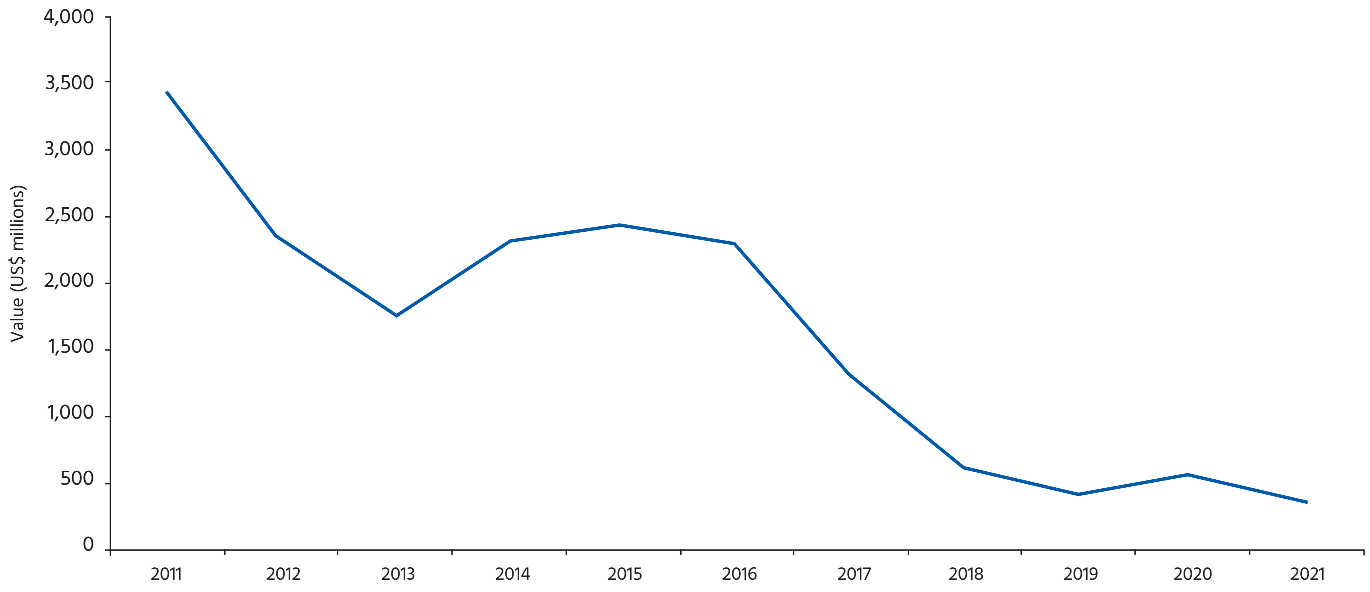
February 2022
- Safeguard tariffs extended for another four years.

Figure 4.2 shows the value of solar cells and modules imported to the US from China between 2011 and 2021. There appears to have been a substantial impact from the 2012 tariffs with the value of imports almost halving. The period between 2013 and 2016 shows some recovery before the increased tariffs in 2015, which also have a significant impact. From 2016 onwards the value of cells and modules imported from China entered terminal decline and show no sign of recovering.

At the start of this period China held the largest share of the US import market for solar cells and modules. As we move towards the present the mix of importing countries changes. Figure 4.3 shows the overall import values of cells and modules into the US. We observe that the 2012 tariffs had less of an impact on overall imports, suggesting that other countries substituted for Chinese production. Nonetheless, the broad-based tariff measures in 2018 did have a short-term impact taking several years to recover.

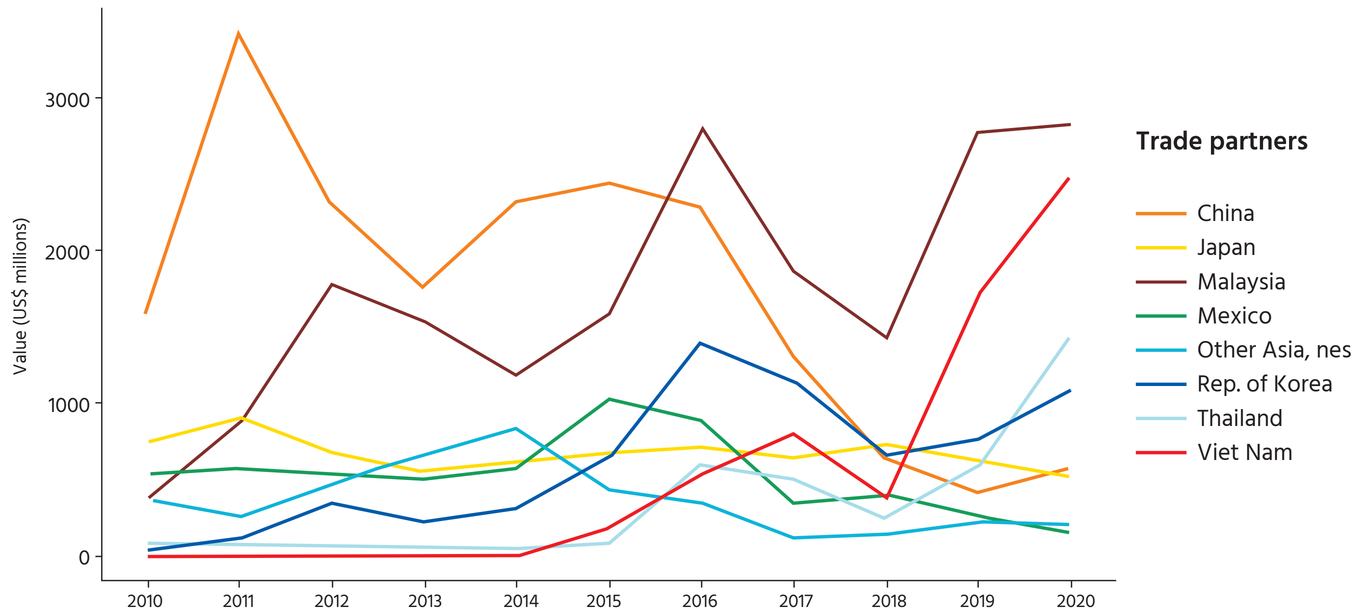
As Figure 4.3 suggests, the solar supply chain exhibited flexibility. Where Chinese and Taiwanese manufacturers were impacted by tariff measures in 2012 and 2015, other countries responded by increasing exports. Figure 4.4 shows the percentage of total imports into the US of solar cells and modules by country. The key beneficiary countries from tariffs targeting China and Taiwan were Thailand, Malaysia, and Vietnam. The combined market share of these three countries started at 13% in 2011 and increased to approximately 60% in 2018 staying stable since then.

Figure 4.2 – US solar cell and module imports from China



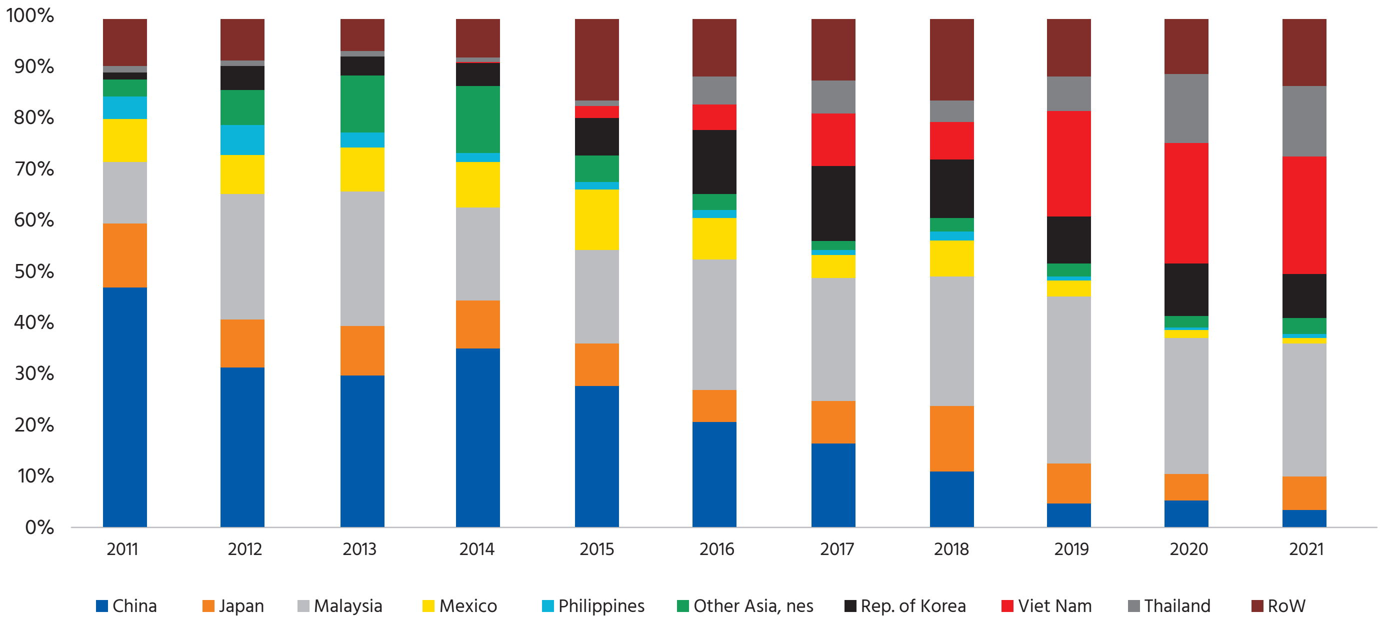
Source: CEPA analysis of UN Comtrade data

Figure 4.3 – US solar cell and module imports by trade partner[50]



Source: CEPA analysis of UN Comtrade data

Figure 4.4 – Share of US imports of solar cells and modules[51]



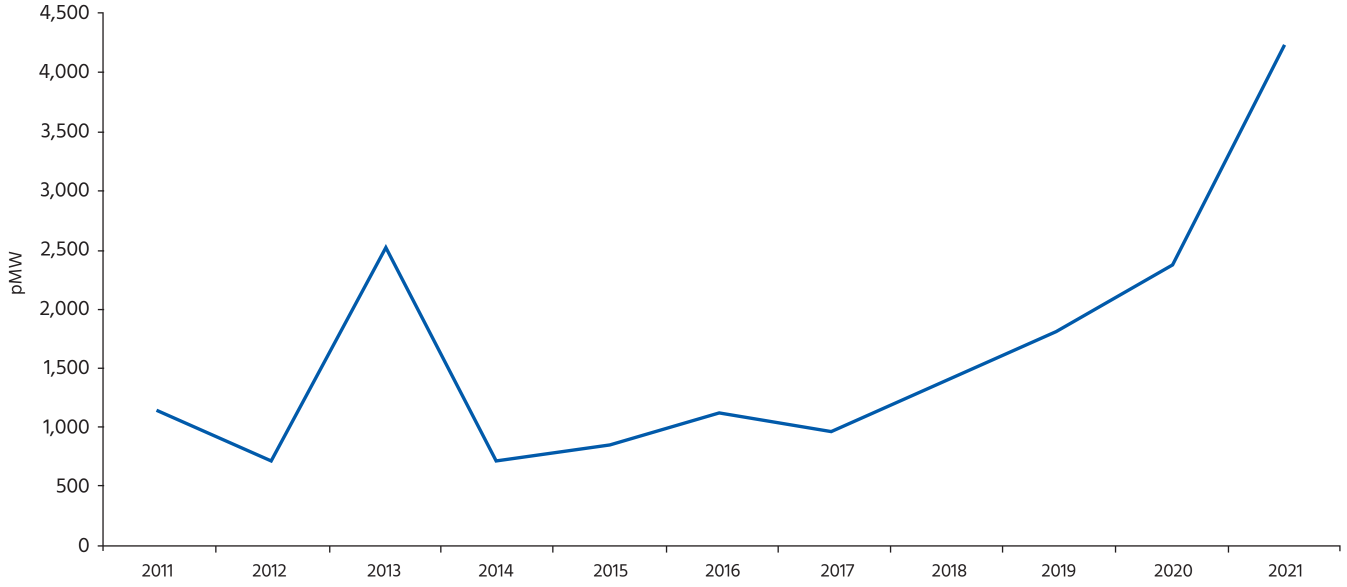
Source: CEPA analysis of UN Comtrade data

One of the stated aims of the various tariff measures is to protect local manufacturing. Figure 4.5 shows local manufacturing of solar cells and modules.[52] The data exhibits a substantial jump in 2013. It can be hypothesised that this was caused by the initial tariff measures applied to Chinese manufacturers. However, this impact was temporary with US solar manufacturing stagnating between 2014 until 2018, as China retaliated with duties on US producers. The 2018 measures appear to have been widely successful with solar cell and module manufacturing growing substantially. In 2021, US local manufacturing of solar modules was approximately 4 GW, which is the highest it has been in the last decade.

For an economy as large as the US, the key context is local solar capacity additions. In 2021, the majority (72%) of domestically manufactured panels was used locally. Figure 4.6 shows the annual capacity additions of solar between 2011 and 2020. In 2020, approximately 14GW of solar was installed in the US. Between 2014 and 2016, there was a growing trend in capacity additions. However, this trend is interrupted between 2016 and 2019. This is likely because of the impacts of tariffs over this period. The growing trend resumes in 2020.

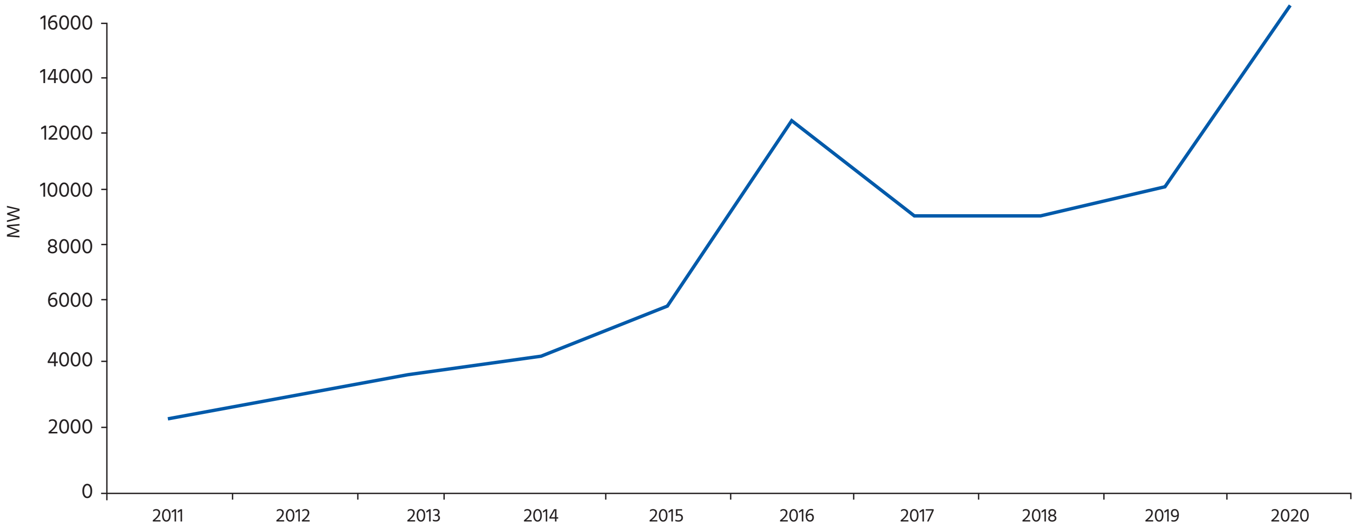
The profile of imports and domestic manufacturing of solar modules in the US indicates a diversification in supply. This includes increasing domestic production as well as replacing dependence on China with a mix of Thailand, Malaysia, and Vietnam. It is worth highlighting that despite these measures there are currently no US-based ingot, wafer, or cell manufacturers. The increase in manufacturing capacity is entirely for the last stage in the manufacturing process, namely module assembly. We highlighted in Section 2 that China dominates the global supply of polysilicon and wafer production. This suggests that dependence on China in the supply chain has simply moved one level upstream.

Figure 4.5 – **US domestic solar module manufacturing capacity**[53]



Source: CEPA analysis of US EIA data

Figure 4.6 – **US solar capacity additions**



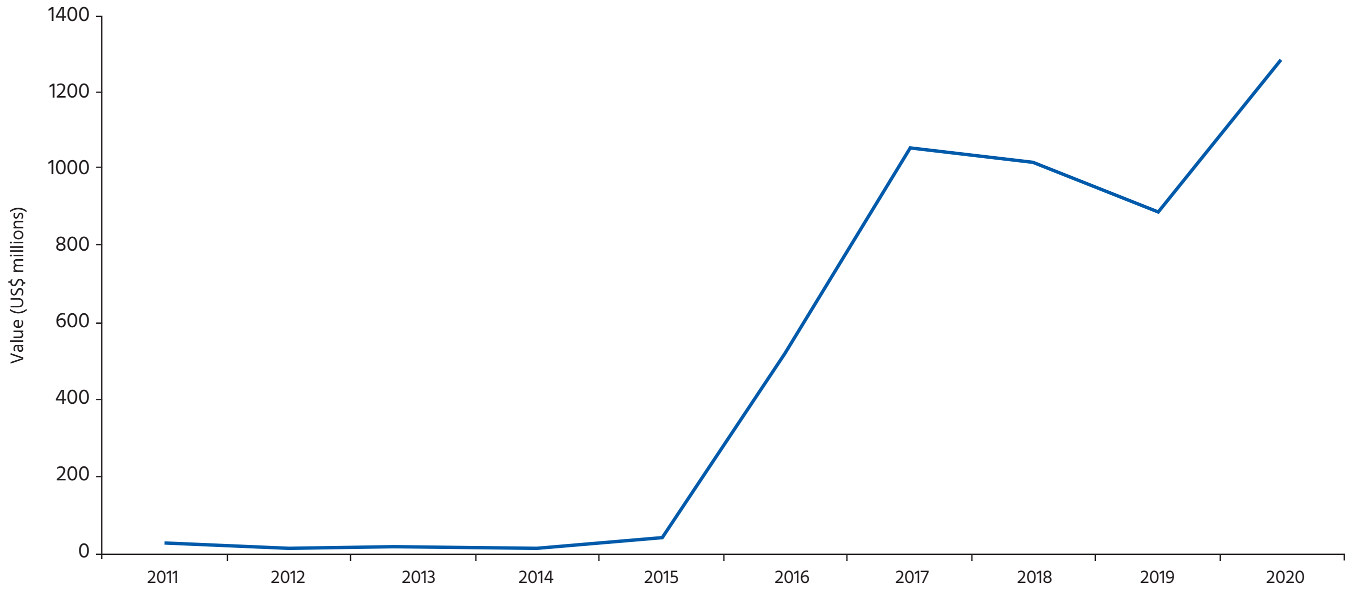
Source: CEPA analysis of IRENA data

While the US has imposed a slew of tariffs against China, the overall dependence on China to fulfil the US's ambitions for solar roll-out has not decreased materially.

It is interesting to consider whether the trade data supports this hypothesis.[54] Figure 4.7 shows the total value of wafer exports from China to Vietnam, Thailand, and Malaysia combined. The total value of wafer imports from China to these countries in 2020 was 52 times the value in 2011. This suggests that the dependence on China to fulfil the US's ambitions for solar roll-out has not actually decreased materially.

The safeguard tariff measures also have an interesting interplay with domestic manufacturing. There are no US-based cell manufacturers. This is despite the tariff measures applying to both cells and modules. However, the safeguard measures have always included a duty-free exemption of a certain capacity of cells. This now stands 5 GW a year. With domestic manufacturing at approximately 4 GW, this duty-free allowance is close to being exceeded.

Figure 4.7 – **China exports of solar wafers to Vietnam, Thailand, and Malaysia**



Source: CEPA analysis of UN Comtrade

India

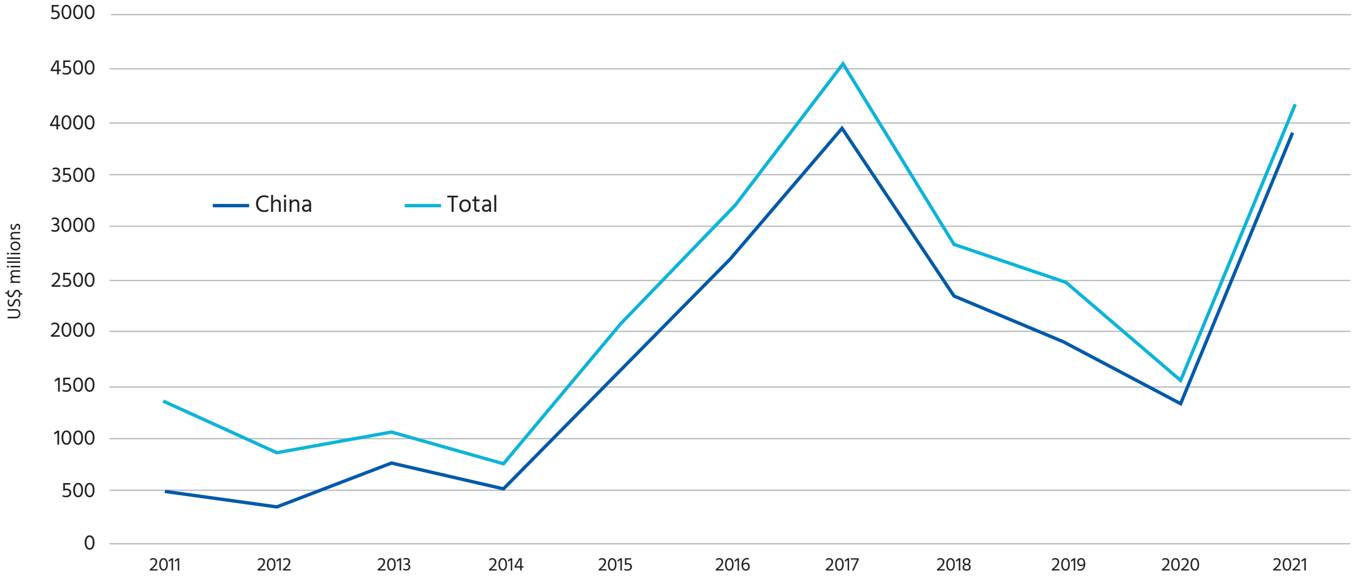
In 2018 India implemented anti-dumping tariffs against solar cells and modules imported from China, Malaysia, and Taiwan. This was in response to a petition by five Indian cell and module manufacturers. The 2018 tariffs started at 25% and were reduced to 15% in a 2019.[55]

As with the US we consider three main impacts from these measures: imports, domestic manufacturing, and solar capacity additions.

Figure 4.8 shows total imports of solar cells and modules for India.[56] Chinese imports are shown separately but as demonstrated by the figure they represent the vast majority. The 2018 tariffs appear to have had a substantial impact with imports from China approximately halving from the 2017 peak. Nonetheless, if the aim of the tariffs was to prevent solar module and cell imports then the impacts of the tariffs were only temporary with imports rebounding in 2021. Furthermore, it is possible that general supply chain disruption caused by Covid in 2020 may be contributing to the overall fall in trade.

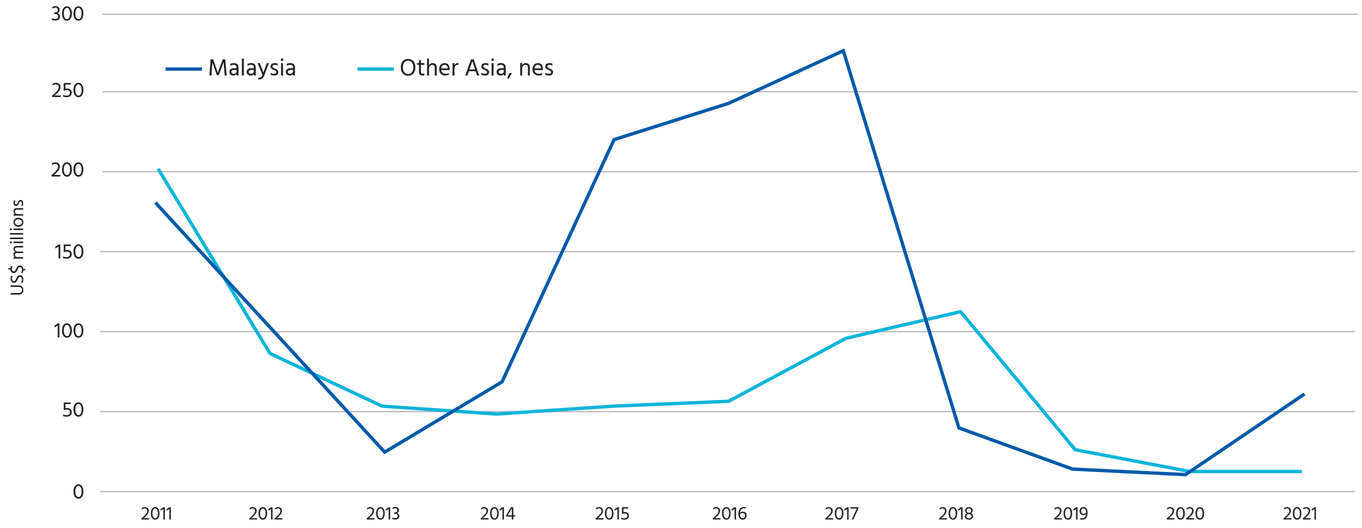
Figure 4.9 shows the impact on imports from the two other affected countries, Malaysia and Taiwan.[57] The tariffs seem to have had an outsized impact on imports compared to China. Imports from Taiwan fell to a negligible amount and never recovered. The same can be said for Malaysian imports and it is currently unclear whether the slight increase in 2021 will be sustained going forward. We have not been able to precisely explain the exact reason for the outsized impact on these two countries relative to China. Overall, Malaysia gains global market share over this period while Taiwan retreats, so this is not necessarily the explanation.

Figure 4.8 – **India imports of solar cells and modules (value) – from China**



Source: CEPA analysis of UN Comtrade

Figure 4.9 – India imports of solar cells and modules (value) – from Malaysia and Taiwan



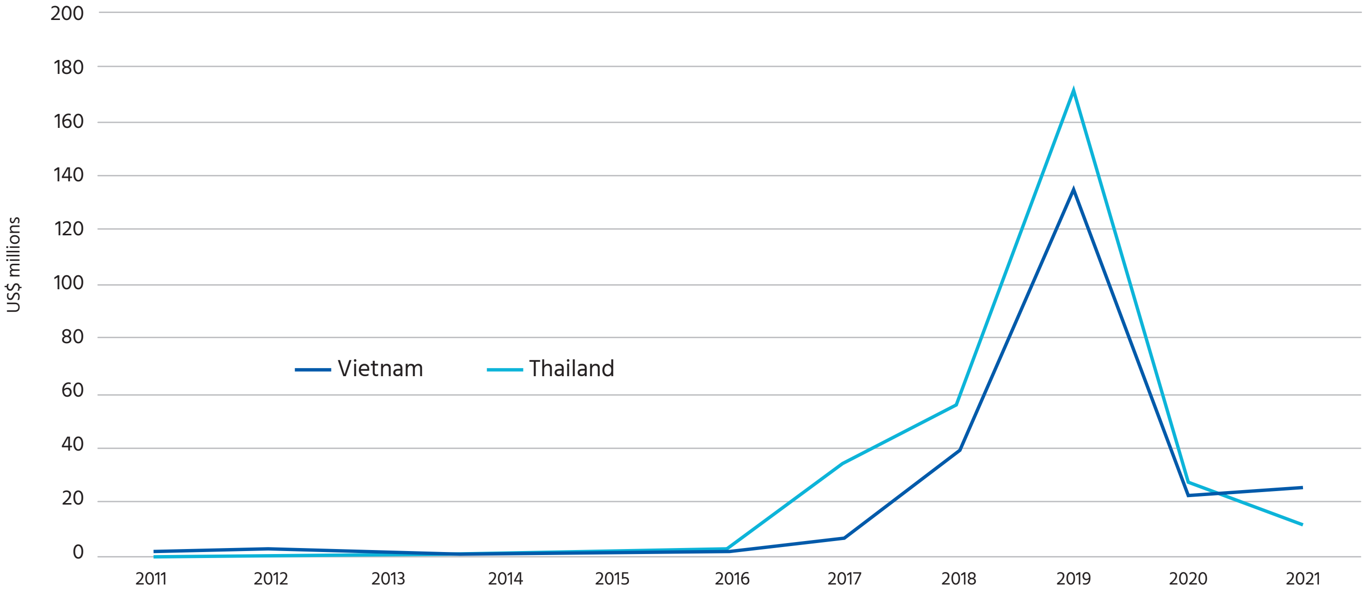
Source: CEPA analysis of UN Comtrade

We find evidence of substitution to other countries not covered by the tariffs. As highlighted in Section 3 both Vietnam and Thailand have substantial cell and module manufacturing industries aimed at export. Figure 4.10 shows solar imports from Vietnam and Thailand. There appears to be a substantial spike in imports from these two countries in response to the tariffs. However, this is short-lived and Vietnam and Thailand manufacturers/exporters do not appear to have capitalised on the tariffs. Furthermore, while the increase in 2019 looks substantial in the context of Vietnam and Thailand, the total value was just 12.5% of total Chinese imports.

We are unaware of a publicly available dataset that provides quality time series data on Indian solar manufacturing output. It is therefore more difficult to measure the impact of tariffs on domestic manufacturing overtime. Unlike the US, India has both cell and module manufacturers. However, like the US there are no wafer or polysilicon manufacturers. It is estimated that in 2022 India had cell manufacturing capacity of 4.2GW/year and module manufacturing capacity of 18GW/year.[58] However, production falls far short of capacity and utilisation is approximately 50%. Module manufacturing capacity has increased from 5.8 GW/year in 2016. However, given the data it is difficult to attribute this to tariffs.

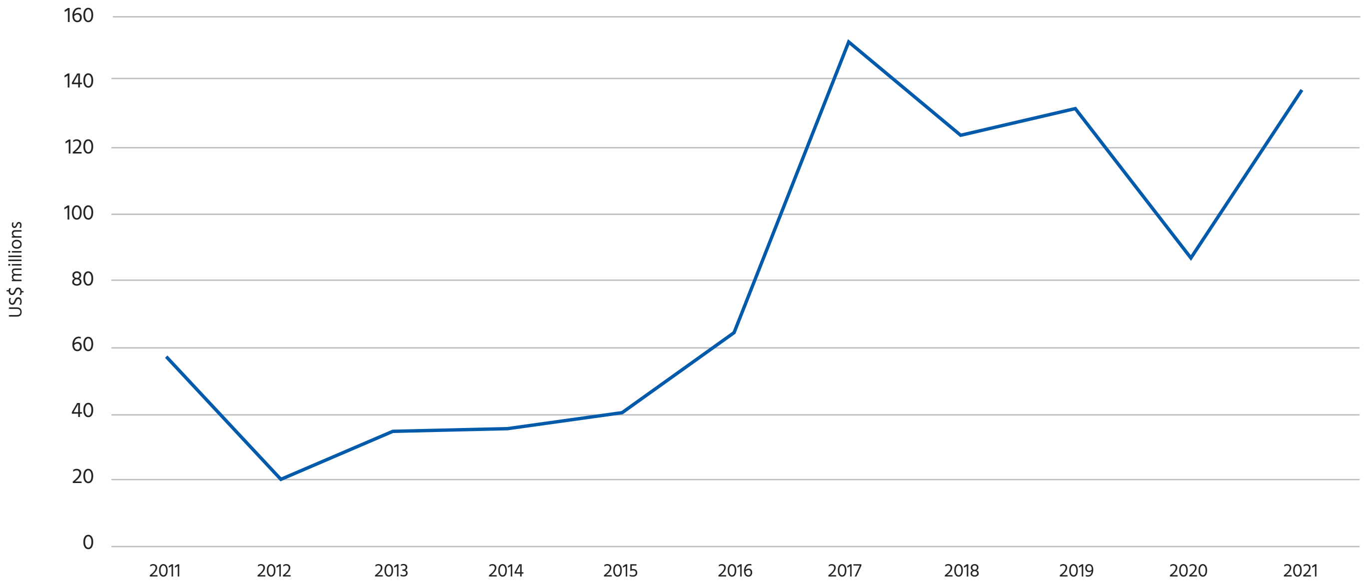
One potential alternative way of considering the impact of tariffs on Indian solar cell manufacturers is to examine the import values for solar wafers. This is because there are no wafer manufacturers in India and China dominates supply, meaning that if cell output increased then wafer imports also need to have increased. Figure 4.11 shows Indian imports of solar wafers from China. There appears to have been no visible positive impact from the 2018 tariffs. Indeed, the positive trend up until that point reversed.

Figure 4.10 – India imports of solar cells and modules (value) – from Vietnam and Thailand



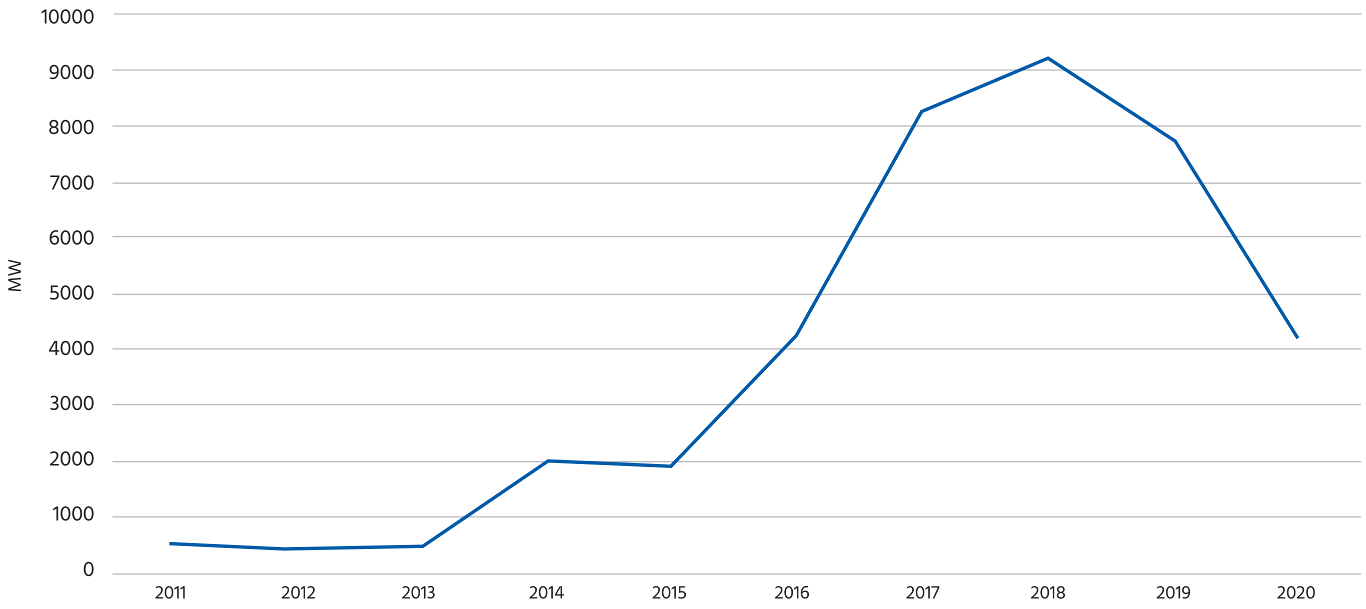
Source: CEPA analysis of UN Comtrade

Figure 4.11 – Indian imports of solar wafers – from China



Source: CEPA analysis of UN Comtrade

Figure 4.12 – Solar capacity installations – India (MW)



Source: CEPA analysis of IRENA data

There has been a drastic fall in solar capacity additions since 2018 which coincides with the implementation of tariffs. Figure 4.12 shows total solar capacity additions a year in India. Solar capacity additions peaked in 2018 at approximately 9 GW/year. Given the drastic fall in Chinese solar imports following 2018 and a lack of evidence of domestic manufacturing stepping in to fill the gap, this is not surprising. We do not yet have capacity additions data for 2021. Given the recovery in Chinese imports we should expect capacity additions to also accelerate in 2021.

4.2. Multilateral negotiations have stalled

The likelihood of BCAs covering solar and other 'green' goods would be lower if there was wide agreement that green goods should be exempt from tariffs. Multilateral agreements could potentially forestall such actions and create confidence in the supply chain going forward.

Recent history

There is a history of attempting to tie together trade with environmental issues and the broader decarbonization agenda at the multilateral level. We start this brief history in 2012 with the endorsement by APEC leaders of the APEC List of Environmental Goods.[59] The APEC leaders committed "to reduc[ing] our applied tariff rates to five percent or less on these environmental goods by 2015". There were 54 environmental goods included in the list including solar cells and modules but not polysilicon or wafers.

In July 2014, attempting to build on the success of APEC, 46 WTO members launched negotiations to reduce tariffs on environmental goods. The Environmental Goods Agreement (EGA) went through 18 rounds of negotiations.[60] Each round focused on a different category of goods, with round 4 relevant to solar for its focus on renewable energy and energy efficiency. Unlike the APEC voluntary commitment, this negotiation was under the auspices of the WTO specifically aimed at creating an 'open plurilateral agreement'.[61] Such agreements mean that signatory countries will extend tariff cuts to all WTO members not just those that sign up to the agreement. In this case, to prevent freeriding, the agreement would only come into effect if it covered 80% of the global trade in the goods covered by the agreement.

In December 2016 after round 18 the talks collapsed, and negotiations remain suspended.[62] Several reasons were raised for why the negotiations were unsuccessful:[63]

- Negotiators could not reach an agreement on what constituted an environmental good and how broadly this definition should be construed.
- There were debates around 'dual use goods', which had ambiguous effects on the environment.
- The talks were limited by the structure of the discussions. Negotiations were structured around HS codes (HS-6 at the time)[64], which cover categories of goods and not individual products.
- There was criticism that the negotiation was too narrowly focused on tariffs for goods and did not include discussion of environmental services and non-tariff barriers.
- The dynamic between China and the United States may have complicated discussions.

Stakeholders also pointed to the issue of bicycles which may have been one of the core reasons the negotiations collapsed.[65] If bicycles were included in the final EGA goods list this may have impacted bicycle manufacturers in the EU. There is a long history of EU trade action against China over the issue of bicycles. This started in 1993 with the imposition of a 30.06% anti-dumping duty on Chinese bicycle imports. This increased to 48.5% in 2019 which will last until at least 2024. This means EU bicycle manufacturers have benefitted from nearly 30 years of high tariffs. In the negotiations it appears that China held firm on including bicycles in the list of environmental goods. This in turn meant the negotiations could not be concluded.

Expected future developments

There have been calls to restart the EGA negotiations.[66] There are also other active discussions under the WTO covering similar ground such as the Trade and Environmental Sustainability Structured Discussions (TESSD).[67] This includes discussions around "trade in environmental goods and services". Whether such a forum can overcome the issues that sunk the EGA negotiations remains to be seen. We observe that there may be more headwinds now than in 2014.

One such headwind comes from solar panels themselves. Solar panels are clearly an environmental good and should be covered by any EGA agreement. If solar panels are not included in future negotiations, it will be difficult to make the case that the negotiations are about environmental goods at all. However, as described above, both USA and India have recently substantially raised tariffs on solar panel imports. It seems like any future EGA negotiation would be informed by this recent past and may make it difficult to proceed. Solar panels may become the new bicycles.

Countries will benefit by returning to the table and restarting multilateral negotiations.

Issues with defining environmental goods have also not been overcome. Furthermore, the TESSD discussions also include services complicating the issue further. A substantial amount of effort in the initial EGA negotiations went into attempting to define environmental goods. The APEC agreement covered 54 product categories and tended to represent those products exported by developed countries i.e., downstream in the supply chain.[68] However, as our discussion in Section 3 shows the supply chain for solar requires several inputs. This is likely to be the case for any complex 'environmental' good. If there were disruption of wafer exports from China as these weren't covered by an agreement, then solar cell manufacturers would find themselves in difficulty even if solar cells were included. This suggests if the overall aim is to support decarbonization then a narrow negotiation focused on downstream products in a supply chain is likely to be insufficient. It might even be the case that due to the complexity of modern supply chains attempting to define environmental goods is a red herring.

On the other hand, we identify three potential benefits from restarting negotiations. Firstly, reducing costs, even if only in one segment of the supply chain, could reduce overall costs and increase the pace of solar capacity installation. Secondly, if such an agreement makes it less likely that countries will disrupt trade via tariff measures then this may be beneficial in terms of supporting solar roll-out. Thirdly, even if the negotiations are unsuccessful, they may raise the prominence of the importance of sustainable trade in renewable generation technologies such as solar. This may make it more likely countries consider methodologies to avoid impacts from measures such as BCAs.

Indeed, there may already be progress on the bilateral front. A potential model is the recently agreed Singapore-Australia Green Economy Agreement (GEA).[69] The GEA hopes to facilitate trade and investment between the two countries. This includes aims to remove non-tariff barriers to trade in environmental goods and services and accelerate the uptake of green technology to remove carbon emissions. It is worth highlighting that both Singapore and Australia were party to the APEC List of Environmental Goods agreement as well as participating in the EGA negotiations. Given this participation, implementation of the GEA will start in a familiar place for both countries – an attempt to develop a list of environmental goods and services that could be given preferential trade treatment.[70]

4.3. Conclusions

The two sub-sections immediately above focus some of the key risks associated with BCAs when it comes to solar supply chains.

If the objective is to expand solar capacity rapidly over the next ten years, then additional import restrictions is a crucial risk that should be considered. The discussion above on US and Indian import tariffs demonstrates that these measures can negatively impact solar capacity installation at least in the short-term. BCAs are one such potential restriction and are likely to have the same initial impact as regular tariffs. We estimated that a $100/metric tonne BCA would lead to a tariff of between 8.9% and 17.9% of the value of a panel. In comparison, the US safeguarding tariffs are currently set at 15%. This suggests that an appropriately estimated BCA would impact solar trade.

While there has yet to be global consensus on the next step moving forward, countries can consider revisiting their carbon pricing policy.

This assumes that the objective of the policy is to implement a BCA which covers solar. However, it is just as likely that BCAs inadvertently cover parts of the solar supply chain. Our brief history on environmental goods negotiations demonstrates the difficulties in defining environmental goods. This raises the probability that 'green' goods such as solar panels or their intermediate inputs are covered by future BCAs. Indeed, the complexity of modern supply chains means that for any 'green' good may be inadvertently covered by a BCA. This in turn may inadvertently reduce solar roll-out at a time when it is most needed.

These two risks weaken the case for BCAs. These risks need to be set off against the potential benefits. The discussion on import tariffs not only shows potential negative impacts to capacity growth but shows that supply chains in solar are flexible and that these negative impacts are rather short-term. Furthermore, if the objective is to change trade patterns, then the US tariffs show success. This means that if the technical issues with implementing BCAs can be overcome there is evidence that they can influence trade patterns.

The question is then to influence these trade patterns to what end? Section 3.2 demonstrated a series of scenarios that could be imagined as to where capacity growth in solar will occur in the next ten years. Influencing where solar manufacturing grows could be a potential goal for policymakers. This includes shifting parts of the supply chain to countries that have grids with lower emissions factors. Aiming to reduce the amount of embedded carbon in a solar panel explicitly recognising the system wide transformation that is required for Net Zero. There are potentially other benefits from moving away from a supply chain dominated by China. The IEA has made clear the risks associated with the current concentration in the solar supply chain.[71] As solar manufacturing in China is currently dominated by coal a BCA could potentially support diversification in supply.

Implementing a BCA that accords with WTO rules is likely to require that domestic carbon pricing is in place first. National treatment is one of the key principles of the WTO agreements, which says that imported and locally produced goods should be treated equally. Only 9 STI economies currently have carbon pricing, which means that this prerequisite has not yet been widely met. This points to the importance of moving forward with carbon pricing as it can be used to support broader policy action.

Appendix 1: Timeline of US tariffs

In the last ten years the USA has implemented a series of tariff measures against overseas solar panel manufacturers. The initial countries targeted by these measures were China and Taiwan, but the list of countries now impacted is much wider. The US has used two broad legal powers to apply tariffs targeted at solar cells and modules.[72] The timeline below shows the actions taken by the United States:

- October 2012: Following a petition by Solar World Industries and an investigation by the US Department of Commerce the US applies anti-dumping and countervailing tariff measures against solar manufacturers located in China. The dumping margin is set at between 18.32% and 24.48% for a set of named Chinese manufacturers.[73] The dumping margin for all other Chinese manufacturers is set at 249.96%.

- February 2015: Following a further petition by Solar World Industries the US applies anti-dumping and countervailing tariff measures against Chinese and Taiwanese manufacturers of solar cells and modules. For named Chinese manufacturers the anti-dumping duty rate increases to 52.13% while this is set at 165.04% for others. For Taiwanese manufacturers the anti-dumping duty rate for named manufacturers is set between 11.45% and 27.55% while for all others this is set at 19.5%.

- July 2017: A review of these measures by the US Department of Commerce reduces the dumping margin for named Chinese manufacturers to 9.61% and named Taiwanese manufacturers to between 3.65% and 4.2%.

- February 2018: Safeguard tariffs are imposed by US government on imported solar cells and modules. This follows a case before the US International Trade Commission where two US solar manufacturers (Suniva and SolarWorld) were petitioning for relief. The tariffs cover a range of countries including all countries with substantial solar cell and module manufacturing industries.[74] The tariff level was initially set at 30% declining by 5% per year for 4 years. A duty-free import exemption of 2.5 GW for solar cells a year applies.

- August 2018: Separate to the safeguard tariffs the US imposes an additional 25% duty on Chinese solar cells and modules.[75]

- February 2022: The safeguard tariffs are extended for another four years. The tariffs will be maintained at approximately 15% with the quota quantity for duty-free imports of solar cells increased to 5 GW a year.

Appendix 2:
Units and measures

Acronym	Measure
°C	Degrees Celsius
kW	Kilowatt – A unit for measuring power and represents capacity
MW	One thousand kilowatts
GW	One thousand megawatts
TW	One thousand gigawatts
kWh, MWh, GWh, TWh	Kilowatt hour – A unit for measuring energy. The amount of energy if one kilowatt is sustained for one hour
kg	Kilogram
$kgCO_2e$	Kilograms carbon dioxide equivalents

Endnotes

1. Sustainable Trade Index Economies, Hinrich Foundation:https://www.hinrichfoundation.com/research/wp/sustainable/sustainable-trade-index-2022/
2. 194 countries have ratified.
3. UN, Net Zero.
4. We applied some transformations to create these estimates. Some countries have explicit 2030 targets while some do not. Where a target was for a year prior to 2030 this is maintained to 2030. Where a target was for a year after 2030 linear interpolation to 2030 was applied. Where only subnational targets were available these were converted to national targets using each sub-national jurisdiction’s proportion of total generation.
5. Singapore is recorded as 0% in the figure below as it does not have a domestic renewable electricity generation target instead aiming to get 35% renewable electricity via imports by 2035.
6. IFC (2018), Papua New Guinea set to expand renewable energy in Port Moresby.
7. IEA (2021), Net Zero by 2050.
8. We have converted the IEA’s estimate of total required generation to total required capacity assuming solar utilization trends are maintained. In other words, we assume that solar efficiency improvements continue as they have done.
9. We have interpolated the values between 2021 and 2030.
10. P = Polysilicon, I = Ingots, W = Wafers, C = Cells, M = Modules.
11. Cadmium Telluride not polysilicon.
12. Rounded to 1 decimal place.
13. US Department of Energy (2022), Solar Photovoltaics – Supply Chain Deep Dive Assessment.
14. Polysilicon production can be measured in metric tonnes but it has been converted in GW final product equivalents for ease of comparison with the other production steps. In general we have attempted to do this for all solar inputs.
15. US Department of Energy (2022), Solar Photovoltaics – Supply Chain Deep Dive Assessment.
16. CEPA analysis of IEA data.
17. CEPA analysis of IRENA data.
18. U.S. Customs and Border Protection (2021), Uyghur Forced Labor Prevention Act.
19. IEA (2019), National Survey Report of PV Power Applications in Malaysia.
20. US Department of Energy (2022), Solar Photovoltaics – Supply Chain Deep Dive Assessment.
21. IEA (2020), Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems.
22. US Department of Energy (2022), Solar Photovoltaics – Supply Chain Deep Dive Assessment.
23. This table focuses on crystalline silicon based solar panels which make up approximately 95% of the global market. Alternative designs such as cadmium

telluride panels are also manufactured but only hold a small portion of global market share.

24. The Silver Institute (2020)
25. US Department of Energy (2022), Solar Photovoltaics – Supply Chain Deep Dive Assessment.
26. US Department of Energy (2022), Solar Photovoltaics – Supply Chain Deep Dive Assessment.
27. IEA (2019), National Survey Report of PV Power Applications in Malaysia.
28. Silicon based solar.
29. For example: World Economic Forum (2022), The world needs 2 billion electric vehicles to get to Net Zero. But is there enough lithium to make all the batteries?
30. IEA (2020), Life Cycle Inventories and Life Cycle Assessments of Photovoltaic systems.
31. The Silver Institute (2020), Market trend report – Silver's important role in solar power.
32. Given available data, 2022 is a forecast.
33. Elementa Consulting (2022), Whole life carbon of photovoltaic installations: Technical report.
34. This is the amount of carbon embedded measured in terms of the peak rating of the solar panel – kWp. This is the maximum amount the solar panel can output in ideal conditions.
35. IEA (2022), Environmental life cycle assessment of electricity from PV systems (2022 update).
36. We have estimated this using IEA data.
37. A MW equivalent of polysilicon is the amount of polysilicon required in a finished solar module. The IEA estimates this to be 2,800 KG of polysilicon per MW of finished solar.
38. There are a wide range of estimates for how long it takes to payback the carbon embedded in a solar panel. The Elementa Consulting study shows seven years but this is for an entire PV installation (including supporting wiring, inverters etc.). For modules Elementa Consulting quotes other studies which range from 0.68 years to 6 years. IEA (2021) provides an estimate of 1.2 years.
39. European Commission (2021), Carbon Border Adjustment Mechanism.
40. Government of Canada (2021), Exploring Border Carbon Adjustments for Canada.
41. European Commission (2021), Carbon Border Adjustment Mechanism.
42. European Parliament (2022), EU Carbon Border Adjustment Mechanism: Implications for climate and competitiveness.
43. European Commission (2022), European Green Deal: Agreement reached on the Carbon Border Adjustment Mechanism (CBAM).
44. Government of Canada (2021), Exploring Border Carbon Adjustments for Canada.
45. Nikkei (2021), Ministry of Economy, Trade and Industry considers introduction of border carbon tax.
46. As of 2nd December 2022.
47. Source: U.S. Energy Information Administration data
48. We use UN Comtrade data for HS code 854140, which includes solar cells and modules but also potentially other items. Our comparison against aggregate US import values for solar panels as reported by the U.S. Energy Information

Administration shows that HS code 854140 tracks these values closely.

49. A more detailed timeline is available as an annex.
50. UN Comtrade reports Taiwan under Other Asia, nes.
51. UN Comtrade reports Taiwan under Other Asia, nes.
52. There are currently no cell manufacturers in the US, but data in earlier periods may have included cells.
53. No value provided for 2018 instead value linearly interpolated.
54. We use HS code 3818 to represent solar wafers. This is likely to be imperfect but likely to capture trends well.
55. Government of India (2018), Notification: No. 01/2018-Customs (SG).
56. We have again used HS code 854140. Unlike for the US we have not identified a second source of data to confirm how accurate this measure is, but think it very likely that trends if not absolute value can be determined.
57. Reported as Other Asia, NES in UN Comtrade data.
58. JMK Research Associates (2022), Photovoltaic Manufacturing Outlook in India.
59. The APEC countries overlap with the STI economies. APEC countries: Australia; Brunei Darussalam; Canada; Chile; People's Republic of China; Hong Kong, China; Indonesia; Japan; Republic of Korea; Malaysia; Mexico; New Zealand; Papua New Guinea; Peru; the Philippines; the Russian Federation; Singapore; Chinese Taipei; Thailand; the United States of America; Vietnam.
60. Government of Canada (2014), WTO Environmental Goods Agreement.
61. WTO (2017), Plurilateral trade agreements: An escape route for the WTO?
62. Australian Government, Environmental Goods Agreement.
63. CSIS (2021), Environmental Goods Agreement: A New Frontier or an Old Stalemate.
64. A harmonized system (HS) code is a standardized method for classifying traded products.
65. CSIS (2021), Environmental Goods Agreement: A New Frontier or an Old Stalemate.
66. IISD (2022), Trade and Sustainability Discussions at WTO Approaching Next Milestone.
67. WTO (2020), New initiatives launched to intensify WTO work on trade and the environment.
68. CSIS (2021), Environmental Goods Agreement: A New Frontier or an Old Stalemate.
69. Australian Government (2022), Singapore-Australia Green Economy Agreement: Propelling Our Sustainable Future.
70. KWM (2022), Green is the new black! Australia and Singapore Trailblaze with 'first-of-its-kind' green economy agreement.
71. IEA (2022), The world needs more diverse solar panel supply chains to ensure a secure transition to Net Zero emissions.
72. Section 201, Trade Act 1974 ('safeguarding') and section 337 ('anti-dumping and countervailing tariffs'), Tariff Act 1930, see here. These align with the trade protection measures described in the WTO agreements.
73. Our understanding is the named manufacturers covered almost all manufacturing capacity.
74. All countries are covered except those that are 'GSP-eligible'. However, Thailand and Philippines are included despite being GSP-eligible.
75. PV Magazine (2018), United States confirms additional 25% tariffs on Chinese cells, modules.

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