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Mapping ASEAN's Position in the Global Solar PV Supply Chain

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Mapping ASEAN's Position in the Global Solar PV Supply Chain

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Abstract

Solar photovoltaics (PV) have been the key to the global sustainability agenda which as in recent times come under siege. The economies of ASEAN have long played a critical role in the production and export of solar PVs as the world's second largest exporter since 2013. This paper examines in detail the role of ASEAN economies in the global solar PV supply chains to answer the question of how to continue leveraging the region in driving the sustainability agenda. Using international trade data, our analysis decomposes the solar PV supply chain from raw materials and production goods to the final product. Our analysis finds that ASEAN exports of finished solar PV cells or modules are primarily concentrated on the United States (US) as its largest export destination. However, ASEAN has a limited presence in exporting key inputs and remains highly dependent on imports, particularly from China despite having the local resources to play a larger role. This reliance poses risks amid escalating US–China strategic rivalry. To further develop its solar PV industry, ASEAN needs to diversify both its export markets and import sources.

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1. Introduction

Global commitments to sustainable development and climate change mitigation, such as the UN Sustainable Development Goals (SDGs) and the Paris Agreement, have driven nations worldwide to reduce carbon emissions. ASEAN is no exception. The ten ASEAN member states (AMS) have committed to the Paris Agreement and submitted Nationally Determined Contributions (NDCs) which include targets for greenhouse gas emission reduction.[1][2]

Expanding the adoption of renewable energy is one key avenue to reduced carbon emissions, addressing climate change, and achieving sustainability, as stated in the ASEAN Plan of Action for Energy Cooperation (APAEC) 2021-2025.[3] In the plan, ASEAN collectively aims for 23% of total primary energy supply to be renewables. Individual AMS also have specific goals for renewable energy adoption and implementing supporting policies to encourage uptake.[4]

Solar photovoltaic (PV) power will continue to be one of the most widely adopted renewable energy sources. Globally, solar PV's share of installed capacity increased from 2.37% in 2013 to 15.7% in 2023.[5] The International Renewable Energy Agency (IRENA) estimates, solar PV to have the largest average annual additional power capacity among all renewable energy from 2024 to 2030.[6] Similarly, the International Energy Agency (IEA) estimates solar PVs will account for 80% of the global growth in renewable capacity.[7] The trend also extends to ASEAN, with solar PV power generation estimated to grow tenfold from 2020 to 2050. The share of solar PV power in the region's total power generation will increase from 2% in 2020 to 24% in 2050 and become the second-largest renewable power source in ASEAN.[8]

Solar PV power plays a key role in the energy policies of individual AMS. For example, in its latest NDC submission to the United Nations Framework Convention on Climate Change (UNFCCC) in 2025, Singapore highlights that it will maximise its solar power deployment to meet its climate targets, projecting that solar energy will satisfy around 3% of national electricity demand by 2030.[9] Similarly, in February 2025, the Indonesian government announced that it will increase the share of renewable energy in the energy mix from 12% in 2024 to 35% by 2034, prioritising solar power. Indonesia plans to add 17 gigawatts (GW) of solar power capacity, compared to 16 GW of hydropower, and 5 GW of geothermal power.[10]

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[1] See Begum (2025).
[2] See The National Climate Change Secretariat, Singapore (2025).
[3] See APAEC Drafting Committee et al. (2020).
[4] See Huang and Tan (2024).
[5] See International Renewable Energy Agency (IRENA) (2025).
[6] See IRENA, COP28, COP29, GRA, MoEA and Government of Brazil (2024).
[7] See International Energy Agency (IEA) (2024b).
[8] See IEA (2022a and 2022b).
[9] See The National Climate Change Secretariat, Singapore (2025).
[10] See Spence (2025) and Reuters (2025).

The rising global demand for solar PV power is naturally reflected in the rising trade value of solar PV-related products, notably, solar PV cells and modules. Globally, the import value of solar PV cells or modules grew by 87.7% from 51.2 billion US dollars (USD) in 2013 to 96.1 billion USD in 2023. ASEAN's significance in the global solar PV industry has also grown. ASEAN's total trade value of solar PV cells or modules increased by 265% from 9.39 billion USD to 34.3 billion USD from 2013 to 2023, far outpacing the global growth rate (88.5%). The region has been the world's second-largest solar PV cell or module exporter after China since 2013, and its share of total global exports grew from 12.7% in 2013 to 26.6% in 2023, reflecting its capability to meet the rising global demand for solar PV final products. Concurrently, ASEAN's import share also increased from 5.82% to 9.29% from 2013 to 2023, highlighting the growing local demand in the region.

Leveraging its emerging role as a global export hub of solar PV cells or modules, ASEAN envisions increasing its manufacturing capacities in relevant key inputs along the supply chain. As highlighted in ASEAN's Carbon Neutrality Strategy, "Developing green industries and capturing the full value of regional green value chains to unlock ASEAN manufacturing and export potential" is one of the four key outcomes of the strategy.[11] It was also mentioned in the AMS's renewable energy industrial development strategies. For example, Indonesia expects that with the rising demand for solar modules domestically, there will be a growing incentive for manufacturers of these products to establish production facilities within the country, and this can also grow the market for relevant material manufacturing.[12] The country also secured an 11.5 billion USD investment commitment from a Chinese glass company in 2023 to build an integrated wafer industry.[13] Malaysia regards itself as a major international hub for PV components manufacturing[14] and saw that the export of solar PV panels would be a major driver of the energy sector's GDP growth between 2013 and 2030.[15]

To advance these regional and national ambitions, ASEAN and AMS need to map their positions within the global solar PV supply chain. Here, "position" refers to both ASEAN's collective role and the contributions of AMS. To facilitate this mapping, we will decompose the global solar PV supply chain into three segments: final products, intermediates, and fixed capital. This will allow us to see the strengths within the supply chain at both regional and national scales.

The study will proceed as follows: Section 2 provides a technical background of a solar PV system and introduces key components of the solar PV supply chain. Section 3 explores the dynamics of ASEAN's and individual AMS' roles in the trade of solar PV cells or modules and their key inputs, including intermediates, and fixed capital. Furthermore, we provide a detailed mapping of ASEAN's major import sources and export destinations for each product. Section 4

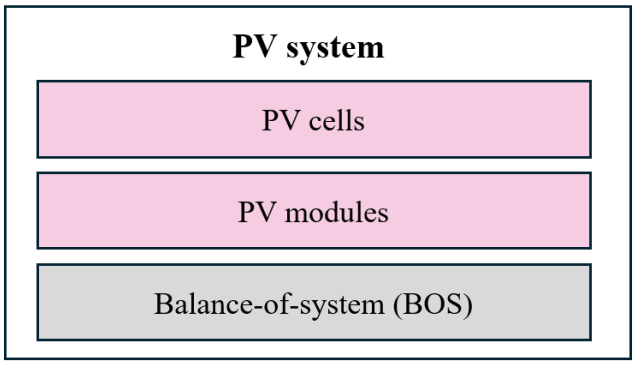
[11] See ASEAN Secretariat (2023).
[12] See Just Energy Transition Partnership Indonesia (JETP) (2023).
[13] See Karyza (2023).
[14] See Ministry of Economy, Malaysia (2023).
[15] See Ministry of Energy, Green Technology and Water (KeTTHA) (2017).

provides policy implications of the mapping, focusing on the risks of relying on a single partner and potential solutions. Section 5 synthesises the research findings and concludes that as an exporter, ASEAN is much stronger in final products – solar PV cells or modules and their parts, compared to key inputs.

2. Technical Background

To explore the global landscape of the solar PV supply chain, it is necessary to understand a solar PV system's basic technical structure. A solar PV system primarily consists of three main parts: solar PV cells, solar PV modules, and the balance of system (BOS) technologies (Figure 1). Solar PV cells generate electricity from solar radiation. Because the electricity generated from a single cell is limited, cells must be assembled into solar PV modules, also known as solar panels, through coating, wiring, and encapsulation processes.[16] Lastly, the modules are connected to and managed by the BOS to ensure the generated electricity can be efficiently delivered to the end-users.[17]

Figure 1. The Overview of a Solar PV System



Source: Authors' recreation based on Kalthaus (2019)

Solar PV cells are the core of a solar PV system.[18] In this study, solar PV cells refer to cells made of crystalline silicon (c-Si) wafers because c-Si is currently the dominant solar PV technology in the global market.[19] The production process of c-Si solar PV cells commences with purifying high-purity quartz sand or silica sand (SiO_2) into metallurgical-grade silicon (MGS, 98-99% purity), which is the primary feedstock for solar-grade silicon (99.9999% purity), also known as polysilicon.[20] Polysilicon is subsequently melted into ingots and sliced into wafers. After

[16] See Kalthaus (2019).
[17] See Shubbak (2019).
[18] See Kalthaus (2019).
[19] See IEA (2022c).
[20] See Braga, Moreira, Zampieri, Bacchin, & Mei (2008); Seigneur et al., (2016); Chigondo, (2018); Osenius-Eite, Mirrlees-Black, & Scott (2023).

obtaining these key intermediates, the next stage is to fabricate wafers into solar PV cells, which are then encapsulated and electrically interconnected into modules.[21]

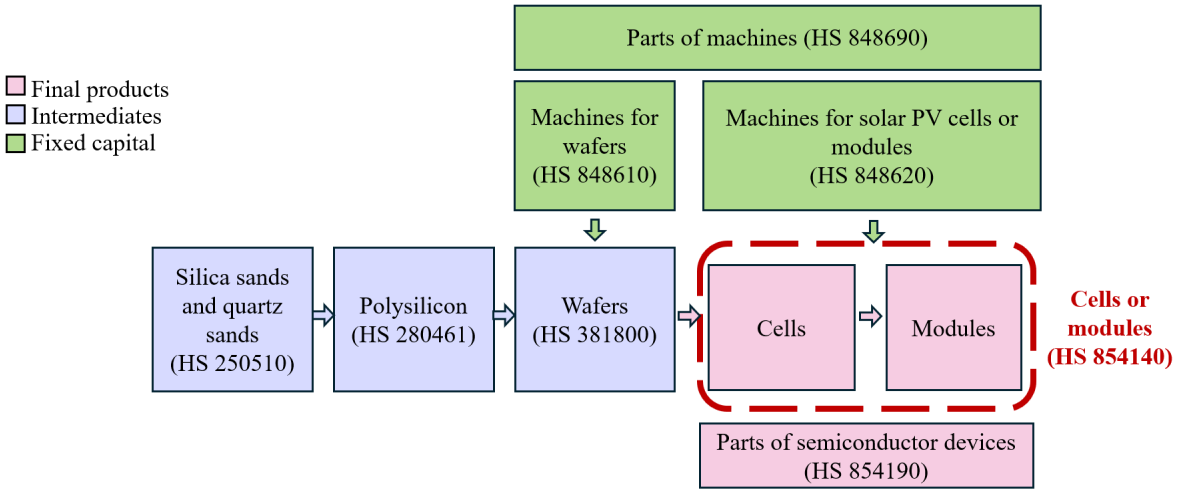
3. Trade in Solar PV Cells or Modules and Key Inputs

Existing studies have identified a wide range of goods and their corresponding 6-digit Harmonised System (HS) codes for analysing the global trade of solar PV-related products.[22] This study selects eight products and categorises them into three groups by their end-use[23]: final products, intermediates, and fixed capital, as presented in Figure 2, with their 6-digit HS (2017 version, hereafter as HS 2017) codes shown in parentheses. Polysilicon (280461), wafers (381800), solar PV cells or modules (854140), and parts of semiconductor devices (854190) are primary components frequently examined in the literature.[24] Further, since silica sands and quartz sands serve as raw materials for polysilicon, we search for their HS 2017 code (250510) in the classification documents from the World Customs Organization.[25] Lastly, to complete the supply chain mapping, we also include fixed capital, namely, machines for wafers (848610), machines for solar PV cells or modules (848620), and parts of machines (848690).[26] Using these 6-digit HS 2017 codes, we source bilateral trade data between 2013 and 2023 from the UN Comtrade database. A detailed list of HS codes and their descriptions is provided in the Appendix.

There are two key limitations of using the 6-digit HS 2017 classification. First, there is a lack of granular data that allows for isolating trade values specifically for manufacturing solar PV-related products. As a result, the reported trade values for solar PV-related products in this study are overestimated and should be interpreted with caution. This is because products classified under the HS 2017 code are often used across multiple industries, and the codes do not differentiate by end use. For example, while MGS can be processed into polysilicon for solar wafers, it can also be used in semiconductors, silicones, silanes, and aluminium alloys.[27] Overestimation also applies to parts of machines "848690" and parts of semiconductor devices "854190". According to HS 2017, "848690" represents parts and accessories of all four types of machines under "8486", only two of which are used in solar PV manufacturing. Likewise, "854190" can be found not only in solar PV cells or modules but in other semiconductor devices under "8541".[28]

[21] See Latunussa, Mancini, Blengini, Ardente, & Pennington (2016); Basore & Feldman (2022).
[22] See World Trade Organization & IRENA (2021); Caravella, Crespi, Cucignatto, & Guarascio (2024); IEA (2024); United Nations Conference on Trade and Development (UNCTAD) (2024).
[23] ACI's classification based on Broad Economic Categories Rev.5. See United Nations (2016)
[24] See Caravella, Crespi, Cucignatto, & Guarascio (2024); IEA (2024); United Nations Conference on Trade and Development (UNCTAD) (2024)
[25] See World Customs Organization (n.d.-a).
[26] See World Trade Organization & IRENA (2021); Caravella, Crespi, Cucignatto, & Guarascio (2024).
[27] See Basore & Feldman (2022).
[28] See World Customs Organization (n.d.-a).

Figure 2. Key Inputs to Manufacture Solar PV Cells or Modules



Source: Authors'creation based on Braga, Moreira, Zampieri, Bacchin, & Mei (2008); Seigneur et al., (2016); Chigondo, (2018); Osenius-Eite, Mirrlees-Black, & Scott (2023); Latunussa, Mancini, Blengini, Ardente, & Pennington (2016); Basore & Feldman (2022); Caravella, Crespi, Cucignatto, & Guarascio (2024); IEA (2024); United Nations Conference on Trade and Development (UNCTAD) (2024); World Customs Organization (n.d.-a); World Trade Organization & IRENA (2021).

The second issue pertains to the identification of solar PV cells and modules. Despite being technically different, these two products share the same HS 2017 code, "854140", which covers "electrical apparatus; photosensitive, including photovoltaic cells, whether or not assembled in modules or made up into panels, light-emitting diodes (LED)." However, following the HS classification amendment in 2022, "854140" was substituted with four new codes, including "854141" (Light-emitting diodes (LED)), "854142" (Photovoltaic cells not assembled in modules or made up into panels), "854143" (Photovoltaic cells assembled in modules or made up into panels), and "854149" (Other). [29] As this study aims to track changes in ASEAN's trade of solar PV products from 2013 to 2023, we use "854140" to ensure consistency across the full time span, as it applies to a longer period than the new codes. For countries that adopted HS 2022, we calculated their post-2022 trade values under "854140" by summing the trade values reported under the four replacement codes.

The remaining subsections of Section 3 are organised as follows. Subsection 3.1 focuses on the trade in final products, specifically solar PV cells or modules and parts of semiconductor devices. 3.2 traces backwards to intermediates, focusing on wafers and the key materials used in the wafers' production process. Besides intermediates, fixed capital, including machines and their parts, is also indispensable during the manufacturing processes, as we shall discuss in 3.3. For each product, we will first outline the major global exporters and importers, and highlight ASEAN's collective

[29] See Joint Research Centre (2023); World Customs Organization (n.d.-c)

position in the global market. Then, we will delve into the individual AMS to identify regional trade leaders as well as their primary trading partners. Finally, subsection 3.4 will provide a summary of ASEAN's role in the global solar PV supply chain.

3.1 Final Products

3.1.1 Solar PV Cells or Modules

Throughout the period from 2013 to 2023, China maintained a strong presence in global solar PV cells or modules exports. China's exports were valued at 15.8 billion USD in 2013, accounting for over 31.3% of the global exports. By 2023, China had further enhanced its position as the top exporter globally, with its export values growing by 202% to 47.6 billion USD, and its market share expanded to 50.0%.

Following China, ASEAN grew its position as the world's second-largest exporter during this period. From 2013 to 2023, exports of solar PV cells or modules by all AMS combined rose from 6.41 billion USD to 25.3 billion USD, and the region's share in global exports increased from 12.7% to 26.6%. Compared with China, ASEAN exhibited a higher growth rate (296%) during the period.

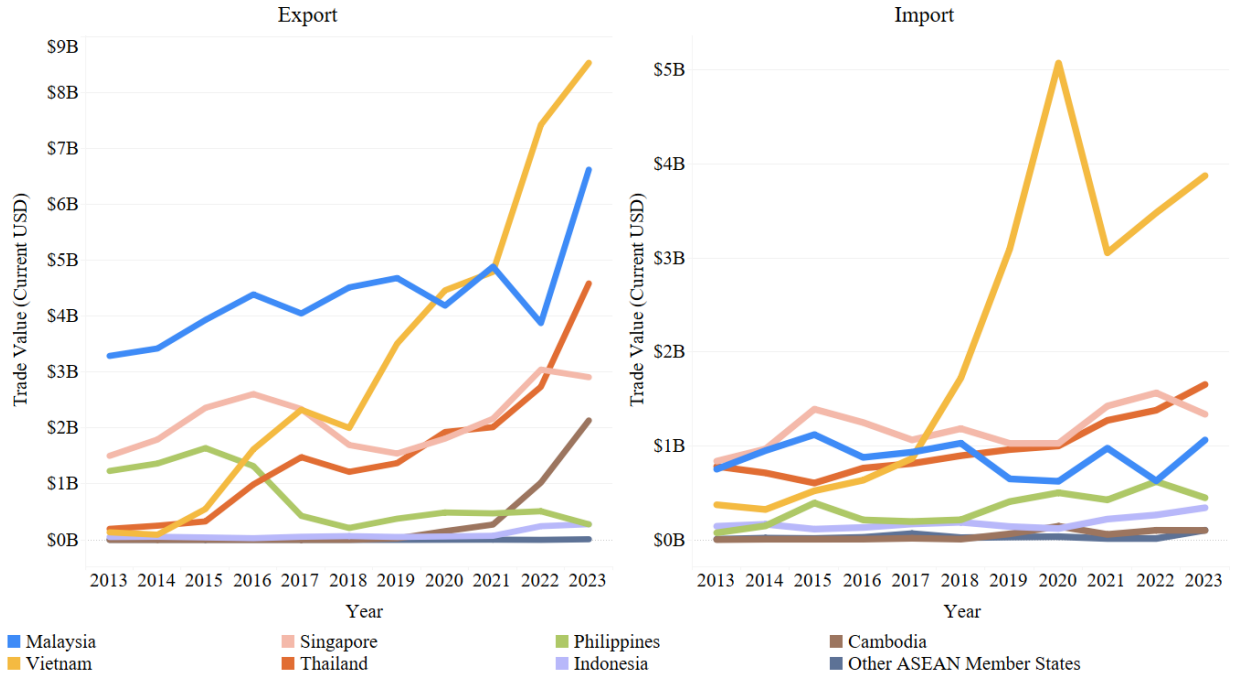
In terms of imports, China, once the top importer in 2013, reduced its import value by 31.2% by 2023. Its corresponding global import share shrank from 17.6% in 2013 to 6.44% in 2023. Similarly, Japan, which was positioned second globally behind China in 2013, saw a significant 64.4% drop in its import value by 2023. In contrast, the US, ranking third globally in 2013, replaced China as the largest importer worldwide in 2016. From 2020 to 2023, the country further enhanced its leading position globally by expanding its import value by 111%. By 2023, the US reached a global share of 22.9%.

Overall, ASEAN's collective import share grew from 5.82% in 2013 to 9.29% in 2023. Although the regional market seemed rather limited compared with the US, ASEAN's total import value experienced a robust 199% expansion within a span of 10 years, while other traditionally major importers, like China and Japan, reduced their demand for imported solar PV cells or modules. Additionally, ASEAN climbed from the seventh to the second-largest importer globally, surpassing China.

To further examine the evolution of AMS' export performance, Figure 3 illustrates the changes across the 2013-2023 period. As the left panel of Figure 3 reveals, in earlier years, Malaysia was the largest ASEAN exporter, whose exports gradually climbed from 3.29 billion USD in 2013 to 4.68 billion USD in 2019. However, its exports contracted in 2020 and again in 2022. Vietnam, initially a minor player, saw a staggering growth rate of 6,205% within the 2013-2023 period. Its exports surged from a mere 0.135 billion USD in 2013 to 8.53 billion USD in 2023. Its rapid expansion persisted almost every year, except for slight declines in 2014 and 2018. On a global scale, Vietnam and Malaysia became the second and third largest global exporters in 2023, with

8.96% and 6.95% of the global share, underscoring ASEAN's enhanced presence in the international market.

Figure 3. Trade Value of Solar PV Cells or Modules by ASEAN Member State, 2013-2023



Note: Other ASEAN Member States include Brunei, Laos, and Myanmar. However, Laos did not report trade data in 2022. This applies to all figures in Section 3.

Source: ACI's calculations based on the UN Comtrade

Besides Vietnam and Malaysia, Singapore and Thailand also played key roles in ASEAN's exports of solar PV cells or modules. Singapore was the second-largest exporter among all AMS in 2013, exporting 1.50 billion USD, while Thailand exported 0.197 billion USD. By 2023, Singapore's exports increased by 93.6%, while Thailand's surged by 2,229%. Notably, between 2022 and 2023, Thailand's exports grew by 67.5%. By 2023, Thailand and Singapore became the world's fourth (4.81%) and sixth (3.05%) largest exporters of solar PV cells or modules' export value.

Cambodia's take-off from 2018 to 2021 was also noteworthy. During this time, Cambodia's export value grew from 0.24 million to 2.13 billion USD. In particular, its exports grew by a whopping 10436% between 2018 and 2019 and maintained positive and strong annual growth rates for the subsequent years. By 2023, Cambodia became the 10th largest exporter globally (2.24%).

In contrast to the expanding exports of the aforementioned AMS, the Philippines' exports experienced a prolonged decline, shrinking from a peak of 1.64 billion USD in 2015 to merely

0.212 billion USD in 2018. From 2019 to 2023, the Philippines' exports recorded a 26.7% drop, making it the only AMS that exhibited a negative growth rate.

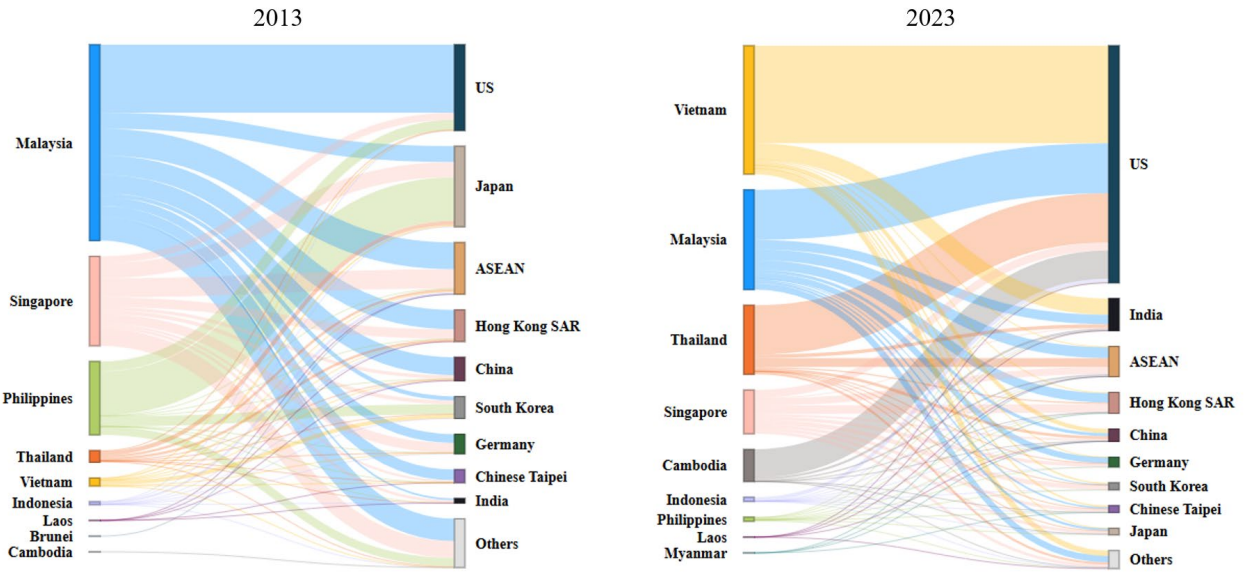
On the import side, Vietnam was the only AMS with a significant import share of solar PV cells or modules worldwide. As shown in the right panel of Figure 3, Vietnam's imports grew exponentially from 2014 to 2020. Its import value skyrocketed from 0.324 billion USD to 5.07 billion USD, marking an average annual growth rate of 60.3% during the period. In 2020, the country became the third-largest importer globally (8.66%), following the US (17.9%) and China (12.4%). Vietnam's import value plummeted to 3.05 billion USD in 2021, but it reversed the decline and continued to grow since 2022. The country's import value reached 3.88 billion USD in 2023, representing 4.03% of the global share.

The growth of Vietnam's imports of solar PV cells or modules reflects its heightened domestic demand for solar PV installation, driven by two generous feed-in tariffs (FiT) schemes that encouraged renewable energy adoption. Vietnam introduced its first FiT scheme in 2017, followed by a second round in 2019, under which solar PV electricity generation projects that entered commercial operation by December 31, 2020, were eligible to sell electricity at an above-market rate fixed for over the next 20 years.[30] Despite domestic installation slowing down as the FiT incentive phased out in 2021, Vietnam remained ASEAN's top importer, indicating the untapped potential of domestic market expansion.

To further examine the bilateral trade of solar PV cells or modules between each AMS and its trading partners, Sankey charts are employed to illustrate the composition of export markets and import destinations. Each chart consists of two panels, depicting trade flows in 2013 and 2023, with exporters displayed on the left and importers on the right. For instance, Figure 4, which visualises the export flows from AMS to the rest of the world, AMS exporters are located on the left-hand side, while their corresponding export destinations are on the right-hand side.

[30] See Do et al. (2021).

Figure 4. ASEAN Member States' Exports of Solar PV Cells or Modules, Share by Exporter and Destination, 2013 vs 2023



Source: ACI's calculations based on the UN Comtrade

In 2013, the US and Japan were the two largest export markets of ASEAN's solar PV cells or modules, accounting for 22.5% and 21.1% of ASEAN's total exports, respectively. Exports to the US were mainly from Malaysia, while those entering Japan were primarily from the Philippines. Intra-ASEAN trade represented 13.6% of the region's total exports this year. Among these regional flows, 88.6% were contributed by Malaysia and Singapore. Within the region, Malaysia's largest export destination was Singapore in 2013, while for Singapore, Thailand was its top AMS export market. Despite being the world's top importer of solar PV cells or modules at that time, China only represented 6.15% of ASEAN's total exports.

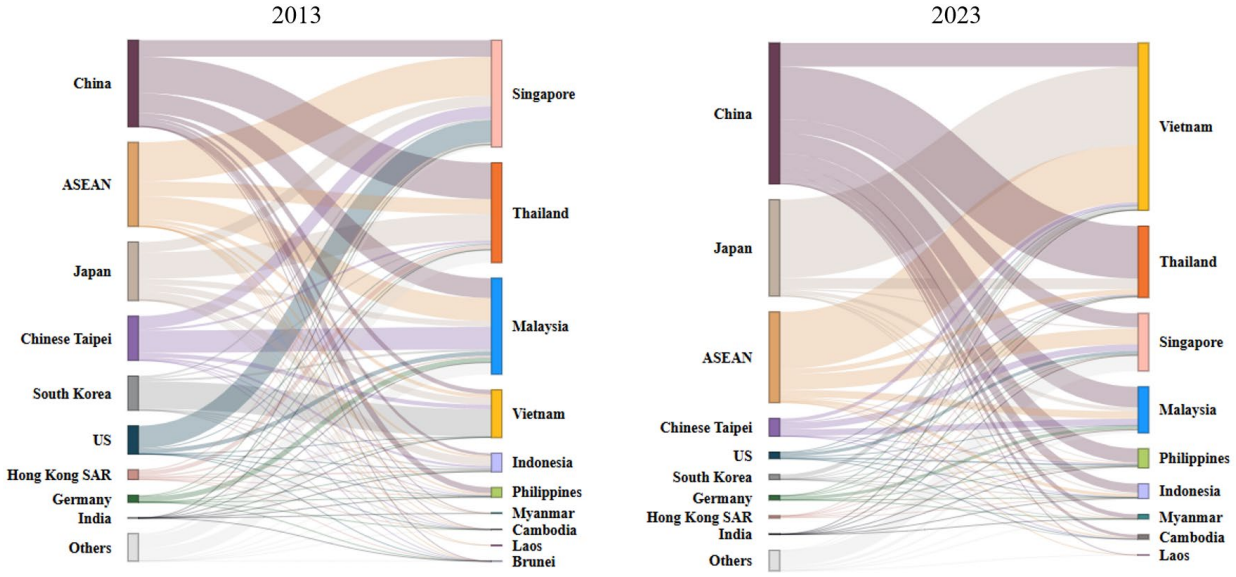
By 2023, the landscape changed significantly. ASEAN's exports to the US grew by 993%, driving the US's share among all destinations up to 62.1%. At the AMS level, the US remained the largest export market for Malaysia. Furthermore, the US became the top buyer for other leading AMS exporters, occupying 87.2% of Cambodia's exports, 75.9% of Vietnam's, and 71.4% of Thailand's. Vietnam's export growth to the US was particularly remarkable. From 2013 to 2023, Vietnam's exports to the US skyrocketed by 5,115 times, while its exports to all other countries combined only increased by 14.3 times.

Following the US, the second-largest export destination of ASEAN in 2023 was India. India's share among all export destinations rose from 1.20% in 2013 to 8.43% in 2023. In particular, India was the second largest market for Cambodia and Vietnam, and the third largest for Malaysia and Thailand.

Conversely, Japan's share diminished, accompanied by a noticeable contraction in exports from the Philippines, which used to be its largest trade partner in ASEAN in 2013. The share of intra-ASEAN trade also decreased to 7.92%.

Regarding imports, as Figure 5 shows, ASEAN's top three import sources in both 2013 and 2023 were China, intra-ASEAN trade, and Japan. In 2013, these three sources collectively supplied 60.2% of the solar PV cells or modules imported by ASEAN, and this share rose to 85.1% by 2023. Among the three sources, the most noticeable expansion came from China, whose share rose by 13.8 percentage points, from 22.7% in 2013 to 36.6% in 2023. In the meantime, imports from Japan increased by 9.64 percentage points, and intra-ASEAN by a mere 1.44 percentage points.

Figure 5. ASEAN Member States' Imports of Solar PV Cells or Modules, Share by Importer and Source, 2013 vs 2023



Source: ACI's calculations based on UN Comtrade

Despite this overall trend, AMS had varying degrees of reliance on imports of solar PV cells or modules from China. Among the top four ASEAN importers, Thailand exhibited the highest dependence throughout the period, with China's share in Thailand's imports nearly doubling from 36.4% in 2013 to 73.5% in 2023.

Meanwhile, Vietnam has diversified away from sourcing mostly from South Korea. In 2013, solar PV cells or modules from South Korea dominated Vietnam's imports with a 57.7% share. When Vietnam's total imports of solar PV cells or modules peaked in 2020, 66.6% of these products were sourced from China. But since 2021, China's share decreased to 14.2% in 2023. Instead, Japan (46.8%) and Intra-ASEAN trade (34.1%) emerged as Vietnam's two primary import sources. Furthermore, Thailand and Malaysia supplied the bulk of Vietnam's intra-ASEAN

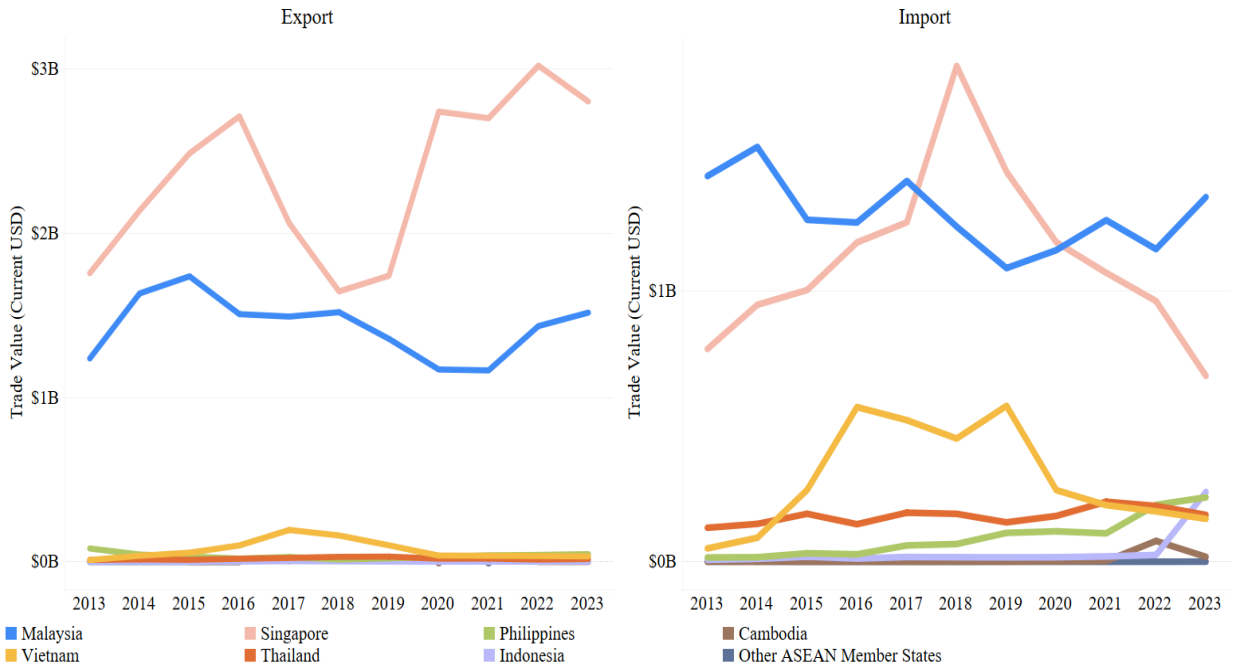
imports, supplying 18.4% and 23.7% of Vietnam's total imports of solar PV cells or modules in 2023.

3.1.2 Parts of Semiconductor Devices

Globally, ASEAN was collectively the largest exporter of parts of semiconductor devices throughout the 2013–2023 period, with the region's export share rising from 37.6% to 50.7%. This was predominantly driven by Singapore and Malaysia, which together accounted for an average of 96.4% of ASEAN's total exports during the decade. In 2013, Singapore led globally with a 21.3% export share, followed by China and Hong Kong SAR (both 16.6%) and Malaysia (15.0%). By 2023, Singapore further strengthened its lead to 32.1%. Malaysia also demonstrated some progress, ascending to be the world's second-largest exporter with a share of 17.4%, overtaking China (14.0%). Apart from the two leaders, the other AMS played an insignificant role in exporting parts of cells or modules, as seen in Figure 6.

On the import side, China remained the top global importer in most years throughout the period, although its share of global imports fell from 49.5% in 2013 to 34.9% in 2023. Following China, ASEAN collectively ranked as the second largest importer with a share of 24.5% in 2013. By 2023, ASEAN's collective share rose to 35.4%, overtaking China.

Figure 6. Trade Value of Parts of Semiconductor Devices by ASEAN Member State, 2013-2023



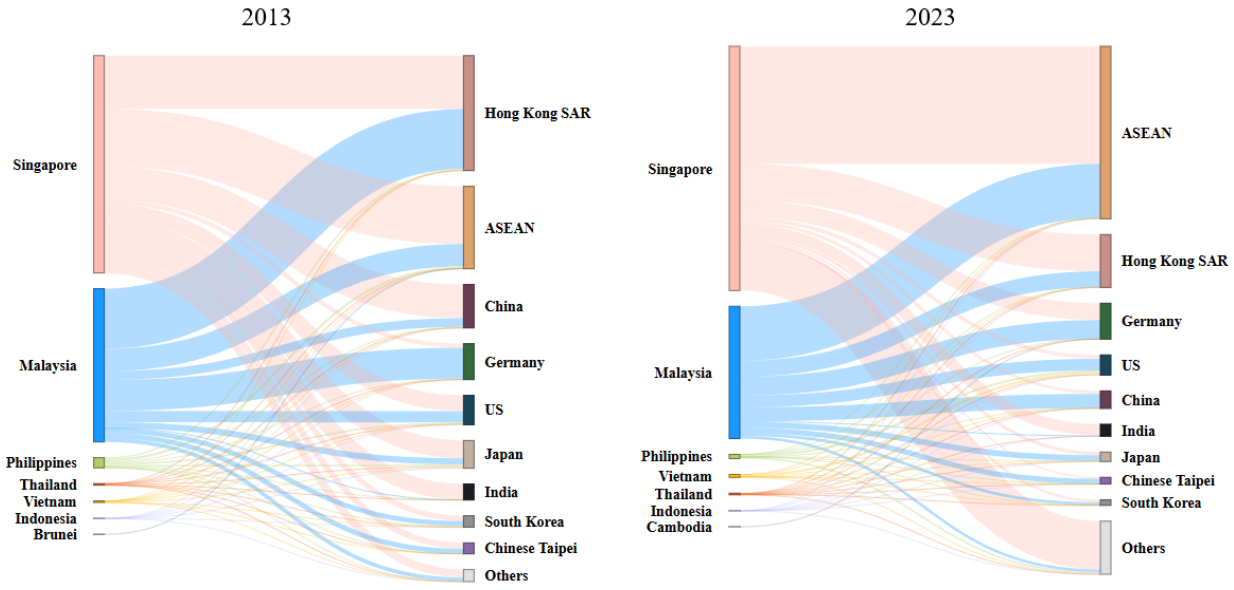
Source: ACI's calculations based on UN Comtrade

Similar to the patterns observed from exports, ASEAN's largest importers were Malaysia and Singapore, each accounting for 14.5% and 8.00% in 2013, respectively. During 2018-2020, Malaysia was overtaken by Singapore, whose imports spiked by 46.1% from 2017 to 2018. However, Singapore's imports consistently declined from 2019. By 2023, Malaysia ranked the second-largest single-country importer in the world with a share of 16.6%, followed by Hong Kong SAR (9.02%) and Singapore (8.44%).

Outside of Singapore and Malaysia, import demand by other AMS also increased. The Philippines' imports grew 1398% from 2013 to 2023, outpacing Vietnam (221%). It is also worth noting that Indonesia's expansion accelerated from 2020 onwards. Notably, the uptick between 2022 and 2023 recorded a staggering annual growth rate of 927%. By 2023, Indonesia became the third-largest importer in ASEAN and ranked sixth worldwide with a global share of 3.17%.

Regarding the export destinations of ASEAN's parts of semiconductor devices, we can see from Figure 7 that in 2013, Hong Kong SAR was the largest export destination, receiving 29.9% of ASEAN's total exports in this category. This was followed by intra-ASEAN trade (21.4%), China (11.3%), and Germany (9.36%). By 2023, intra-ASEAN trade became the primary export destination, with the share more than doubling to 44.7%. Both Hong Kong SAR's and China's importance declined, Hong Kong SAR remained important as ASEAN's second largest export destination, representing 13.7% of the region's total exports. Germany maintained a share (9.30%) comparable to its 2013 level, but its ranking rose to third place.

Figure 7. ASEAN Member States' Exports of Parts of Semiconductor Devices, Share by Exporter and Destination, 2013 vs 2023



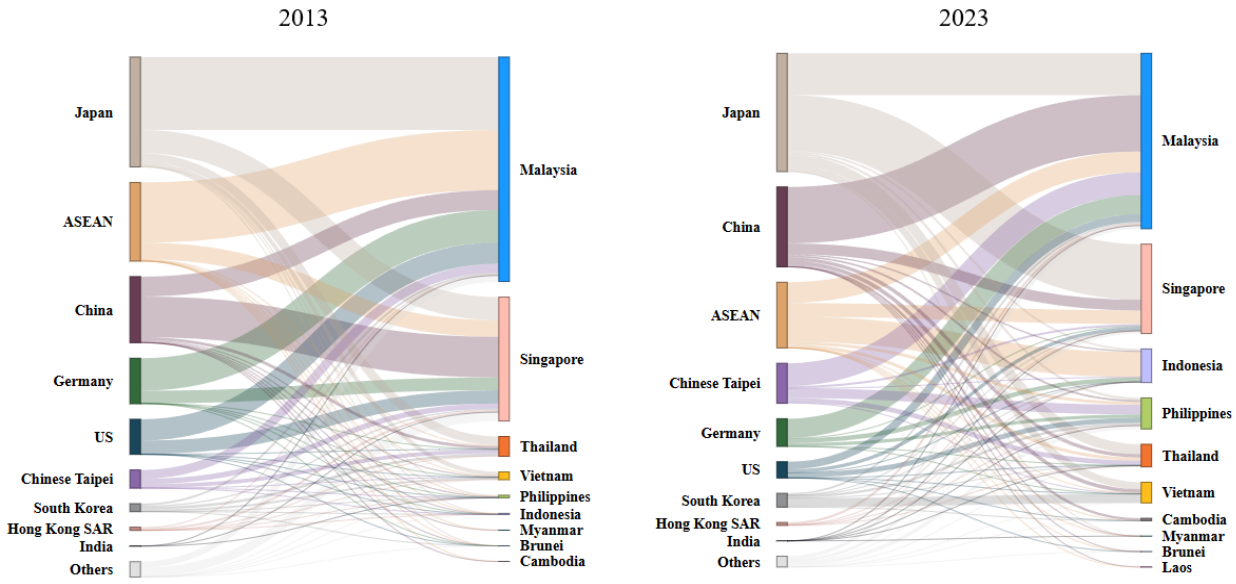
Source: ACI's calculations based on UN Comtrade

In 2013, Hong Kong SAR served as the principal market for both Singapore and Malaysia, accounting for 24.5% of Singapore's exports and 39.3% of Malaysia's. Singapore's second-largest export destination was China, which accounted for 15.4% of its exports. Malaysia's second-most important market was Germany, receiving 20.2% of its exports. The sizeable intra-ASEAN trade in 2013 was largely driven by Singapore. Thailand was Singapore's largest destination within the bloc, constituting 35.8% of Singapore's total intra-ASEAN exports of semiconductor devices in that year.

By 2023, Singapore directed 39.3% of its total exports towards Malaysia, contributing to the rise of intra-ASEAN trade. Following Malaysia, the Netherlands (under the "Others" group) emerged as the second largest destination for Singapore, absorbing 19.1% of the country's exports. For Malaysia, Singapore replaced Hong Kong SAR as its largest export market, accounting for 38.6% of Malaysia's exports. Germany remained Malaysia's second-largest export destination, albeit with a share that declined to 14.2%.

The primary source of ASEAN's imports of parts of semiconductor devices remained Japan in both 2013 and 2023 (Figure 8). In 2013, Japan contributed 28.9% of ASEAN's total imports, followed by intra-ASEAN trade (20.7%), China (17.4%), and Germany (12.0%). By 2023, Japan and China further strengthened their presence to 31.5% and 21.3%, respectively. In contrast, the share of intra-ASEAN trade declined slightly to 17.5% and Germany to 7.38%. Additionally, the rise of Chinese Taipei was particularly noticeable, and its share in total imports more than doubled from 4.79% in 2013 to 10.7% in 2023.

Figure 8. ASEAN Member States' Imports of Parts of Semiconductor Devices, Share by Importer and Source, 2013 vs 2023



Source: ACI's calculations based on UN Comtrade

At the AMS level, in 2013, Malaysia's top three import sources of parts of semiconductor devices were Japan (32.5%), intra-ASEAN trade (26.8%), and Germany (14.5%). In particular, Malaysia imported 365 million USD from Singapore in 2013, which constituted 25.6% of Malaysia's total imports and 95.5% of its intra-ASEAN imports in the year. For Singapore, China was its largest import partner in 2013 (32.8%), and Japan ranked second (18.7%).

The right panel of Figure 8 illustrates the composition of ASEAN's import partners in 2023. China emerged as Malaysia's most important import source, accounting for 32.2% of Malaysia's total imports – a share nearly four times higher than in 2013 (8.84%). Meanwhile, Japan's share in Malaysia's imports declined to 23.8%, although it remained the second-largest source. In 2023, Chinese Taipei overtook Germany as Malaysia's third-largest import source, occupying a share of 13.0%. In Singapore, China and Japan remained its primary import sources. But Japan expanded its presence, whose share rose to 62.3% in 2023, while China's share dropped to 12.0%.

Indonesia, ASEAN's third-largest importer in 2023, sourced 171 million USD from the Philippines. In contrast, trade between the two dominating regional exporters appeared less prominent. In 2023, Malaysia only imported 120 million USD of such products from Singapore, making up 8.86% of its total imports. As for Singapore, although Malaysia's share in its total imports rose from 2.94% in 2013 to 11.5% in 2023, the import value remained modest at 78.8 million USD in 2023. The relative significance of Indonesia–Philippines trade signals a broadening of the intra-ASEAN trade network that extends beyond the traditionally dominant Malaysia-Singapore pair.

3.2 Intermediates

In subsection 3.1, we highlighted that in the solar PV supply chain, ASEAN has a strong presence in the exports of final products. Subsection 3.2 will trace back along the supply chain to examine ASEAN and AMS' position in the key intermediates to manufacture the final products. In the following subsections, 3.2.1 focuses on wafers; 3.2.2 explores the polysilicon; and 3.2.3 addresses silica sands.

3.2.1 Wafers

China and Japan were the top global wafer exporters from 2013 to 2023, with their collective share increasing from 46.3% to 56.5%. Chinese Taipei was the third-largest exporter before 2017. ASEAN replaced Chinese Taipei to rank third from 2017 to 2023. Collectively, the bloc exported 2.03 billion USD of wafers in 2023, a 104% growth from 2013, boosting its global share from 9.84% in 2013 to 10.5% in 2023.

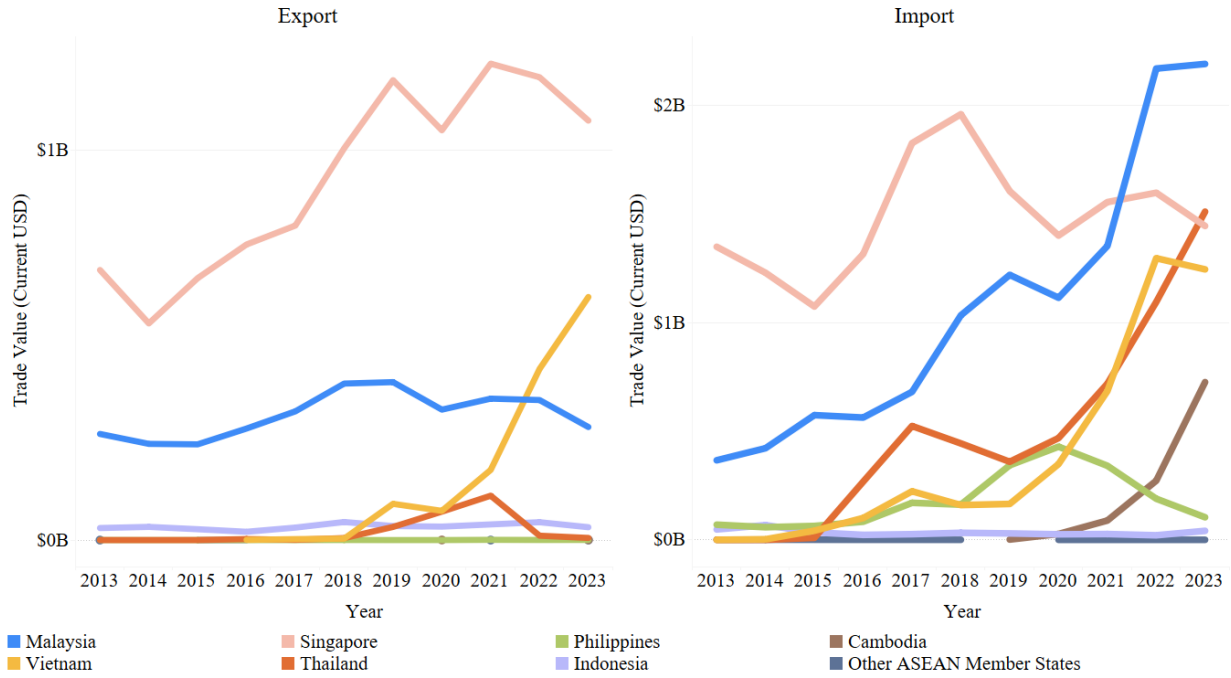
On the import side, Chinese Taipei was the world's largest wafer importer from 2013 to 2016, but it was overtaken by ASEAN since 2017. Since then, Chinese Taipei has ranked second, with its global share dropping from 20.7% in 2017 to 14.7% in 2023. ASEAN's wafer import value grew by 296% from 2013 to 2023 and reached 7.26 billion USD in 2023, outpacing the global rate (94.9%), contributing to its rising global share from 16.4% in 2013 to 33.3% in 2023. China's

global share increased from 10.4% in 2013 to 12.1% in 2023, ranking global third between 2020 and 2023.

The breakdown of wafer exports within ASEAN is shown in Figure 9 (left). Singapore, Vietnam, and Malaysia were the regional top three exporters in 2023. Among them, Singapore's wafer export value was well ahead of other AMS'. Its wafer exports increased by 55.3% from 2013 to 2023, reaching 1.08 billion USD. Yet, its global share slightly dropped from 6.84% to 5.56%. Malaysia was the second largest exporter before 2022. Its exports grew from 272 million USD in 2013 to the peak of 405 million USD in 2019 but declined between 2019 and 2023, with its global share dropping from 2.88% in 2019 to 1.50% in 2023. Vietnam demonstrated the most remarkable growth among the top three exporters throughout the period, with its global share rising from under 0.1% in 2016, when it first reported export data, to 3.22% (valued at 623 million USD) in 2023 and climbing up to the regional second. Vietnam first took off in 2017, with the wafer export value increasing by 332% from 2016. It then grew by a staggering 2401% from 2018 to 2019. After a dip in 2020, it then continued to grow by more than 140% annually in 2021 and 2022.

The right panel of Figure 9 charts the import values of the AMS. Singapore was the largest importer in ASEAN from 2013 to 2021, but it was replaced by Malaysia in 2022. Malaysia's wafer imports surged by 498% over the decade to reach 2.19 billion USD in 2023, pushing up its global share from 3.27% in 2013 to 10.0% in 2023.

Figure 9. Trade Value of Wafers by ASEAN Member State, 2013-2023

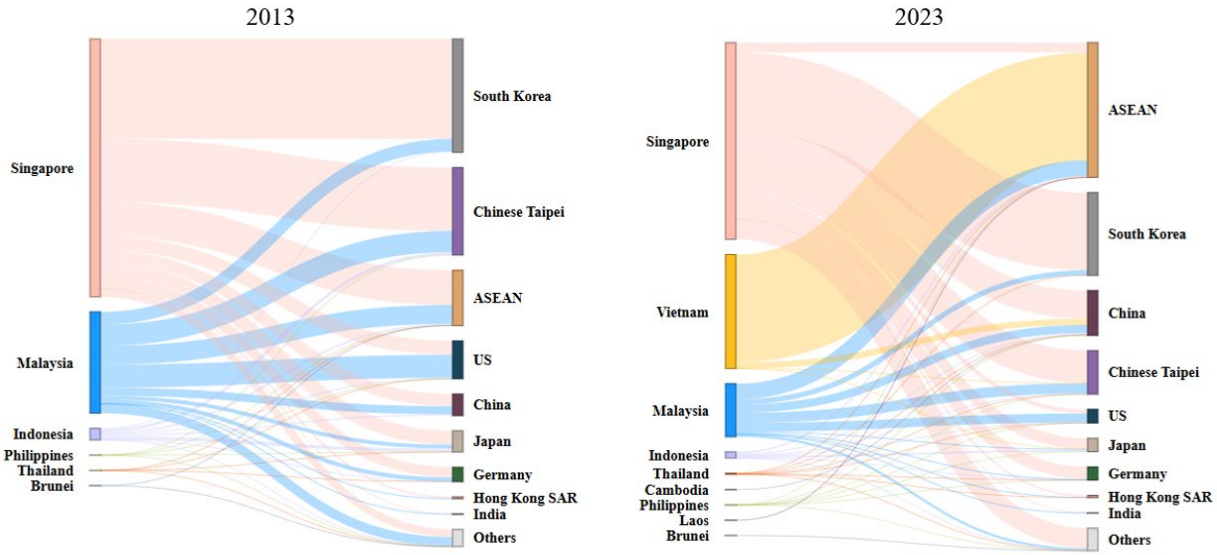


Source: ACI's calculations based on the UN Comtrade

Vietnam and Thailand were the other two drivers of ASEAN's wafer import growth. They recorded the world's largest and second-largest growth in wafer imports from 2013 to 2023. Vietnam's imports surged from 46,831 USD in 2013 to 1.25 billion USD in 2023, with global share growing from 0% to 5.71%. Thailand's imports grew from 263 thousand USD to 1.51 billion USD from 2013 to 2023, and the global share increased from 0.002% to 6.93%, becoming ASEAN's second-largest importer in 2023. Cambodia's wafer import growth was also remarkable since its take-off in 2019. Notably, imports surged by 1,985% from 2019 to 2020 and maintained a high average annual growth rate of 201% from 2021 to 2023. In 2023, it accounted for 3.33% of the global imports.

ASEAN's top three export destinations changed from 2013 to 2023, as depicted in Figure 10. South Korea was ASEAN's largest wafer export destination in 2013, receiving 30.6% of ASEAN's wafer exports, but its share declined to 22.3% in 2023, becoming the second-largest market. In contrast, the share of intra-ASEAN exports grew significantly from 14.9% to 36.3% from 2013 to 2023, becoming ASEAN's largest market in 2023. Intra-ASEAN export growth was largely driven by Vietnam's exports to Malaysia. In 2023, Vietnam sent 85.2% of its wafer exports to Malaysia, representing 72.0% of all intra-ASEAN exports in the year.

Figure 10. ASEAN Member States' Exports of Wafers, Share by Exporter and Destination, 2013 vs 2023



Source: ACI's calculations based on UN Comtrade

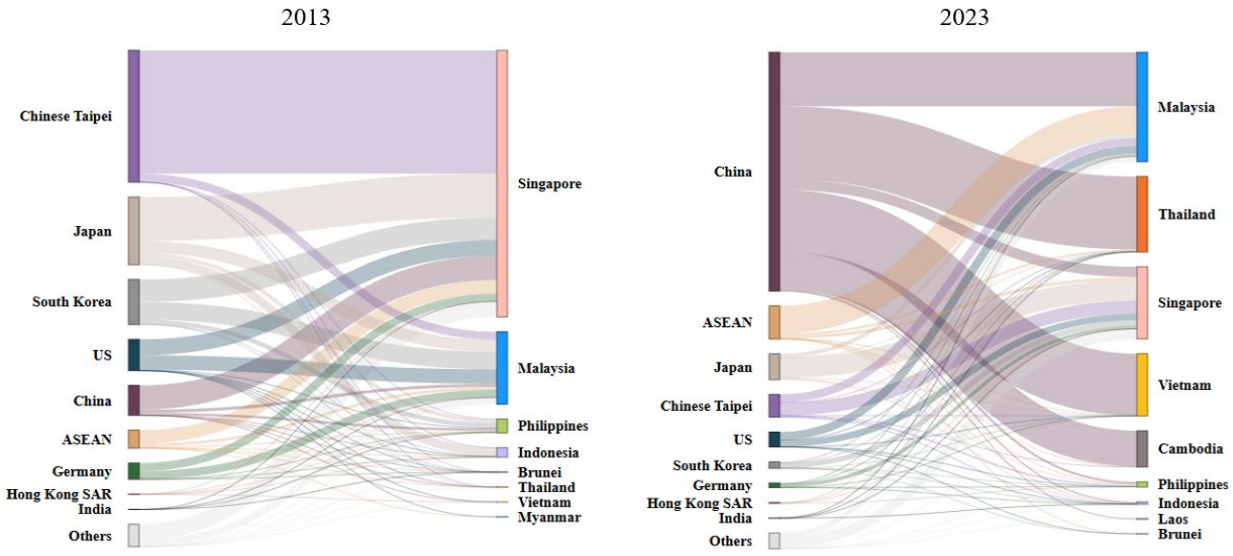
China also occupied a larger share of ASEAN's wafer exports, from 5.81% to 12.1%, over the period. The rise of China was largely driven by the growing exports from Singapore and Malaysia to China. From 2013 to 2023, Singapore's wafer exports to China grew by 369% to reach 153 million USD, boosting China's share in its exports from 4.73% to 14.3%. Malaysia's wafer exports

to China also increased sharply by 107% over the period, reaching 44 million USD in 2023. China's share in Malaysia's wafer exports also grew from 7.95% to 15.5%.

The trade flows between AMS importers and their suppliers are presented in Figure 11. In 2013, the top three suppliers were Chinese Taipei, Japan, and South Korea. This changed significantly in 2023. By 2023, China ascended to become ASEAN's largest wafer supplier, replacing Chinese Taipei (Figure 11, right). Its share in ASEAN's wafer imports surged dramatically from 8.24% in 2013 to 65.8% in 2023. In 2023, China was the largest import source for all AMS, except for Laos and Singapore. In particular, China accounted for 49.4% of Malaysia's wafer imports, 96.3% of Thailand's, and 99.9% of Vietnam's, which were ASEAN's major wafer importers.

In addition, intra-ASEAN imports rose sharply by 632% from 151 million USD in 2013 to 4.78 billion USD in 2023. Its share in ASEAN's imports also increased from 4.15% in 2013 to 9.15%, making it the second-largest source of AMS' wafer imports. Japan was ASEAN's third-largest wafer supplier, accounting for 7.13% of its imports, in 2023.

Figure 11. ASEAN Member States' Imports of Wafers, Share by Importer and Source, 2013 vs 2023



Source: ACI's calculations based on UN Comtrade

3.2.2 Polysilicon

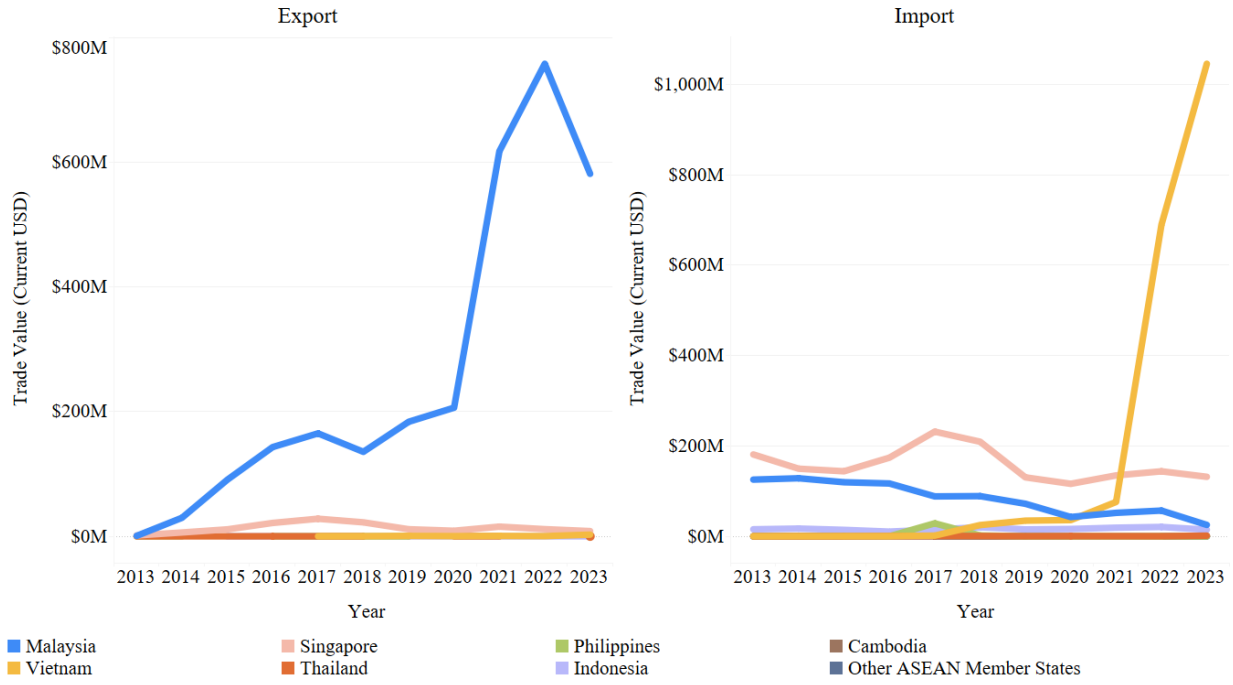
Globally, Germany and the US were the global top polysilicon exporters in most years from 2013 to 2023. On average, the two countries collectively accounted for 55.0% of the global polysilicon exports during the period. While Germany's global share rose from 28.3% in 2013 to 34.6% in 2023, the US's share remained stable at around 27.4%. Japan and South Korea variously held the third place from 2013 to 2020, but were overtaken by ASEAN since 2021. ASEAN's

polysilicon exports increased sharply from 2.09 million USD in 2013 to 593 million USD in 2023, with global share surging from 0.0423% in 2013 to 14.0% in 2023.

As for imports, China was the largest polysilicon importer from 2013 to 2023, with a rising share from 31.7% to the peak of 49.7% in 2021, but decreased to 38.0% in 2023. Japan and Chinese Taipei were among the top three largest importers until 2022, when ASEAN rose to be the second-largest importer, accounting for 15.7% of the global imports in 2022 and further up to 25.9% in 2023.

ASEAN's growth in polysilicon exports was predominantly driven by Malaysia (Figure 12, left). Malaysia's polysilicon exports soared by 4,146% in 2014 and 206% in 2015, before dropping to an average annual growth rate of 20.6% between 2016 and 2020. In 2021, the growth rate surged again to 199%, making Malaysia the world's third-largest single-country polysilicon exporter, before a 23.3% drop from 2022 to 2023.

Figure 12. Trade Value of Polysilicon by ASEAN Member State, 2013-2023



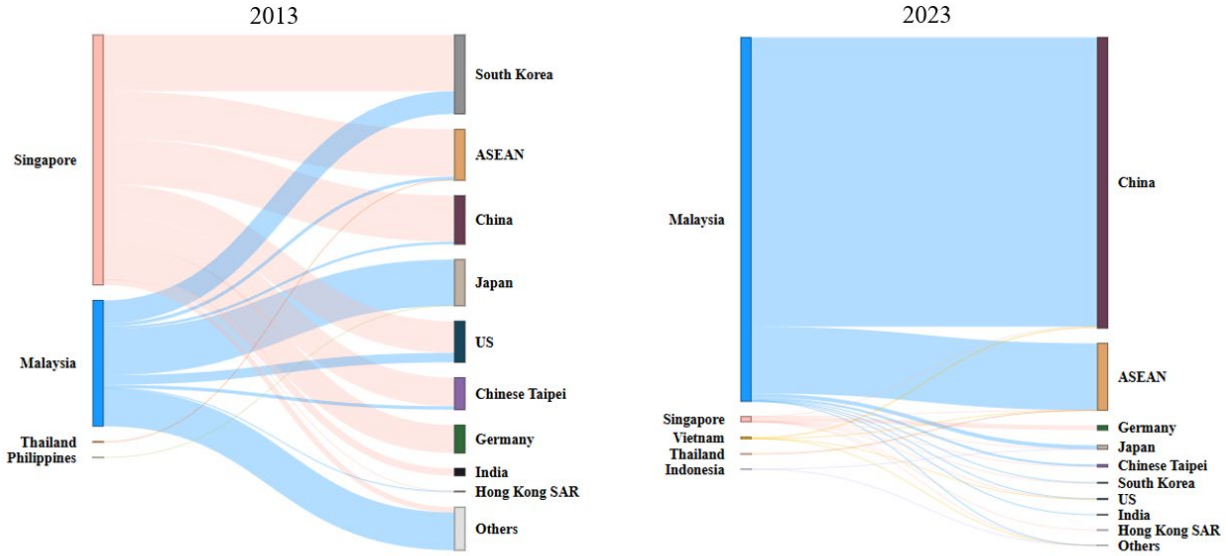
Source: ACI's calculations based on UN Comtrade

ASEAN's polysilicon imports increased by 278% to 1.22 billion USD from 2013 to 2023, with an average annual growth rate of 25.7% over the period, far ahead of the global average (2.78%), boosting its global share from 6.44% in 2013 to 25.9% in 2023. Vietnam was the primary driver of the growth (Figure 12, right). Its polysilicon imports rose from 217 thousand USD to 1.05 billion USD from 2013 to 2023, making its global share jump from 0.00434% to 22.2%, and it became the world's second-largest single country importer in 2023. Vietnam's imports first took off in 2018 and further accelerated its growth momentum in 2022, when it surpassed the traditional

regional leader, Singapore, to be ASEAN's largest and the world's third-largest single country polysilicon importer. In contrast, Singapore's global share dropped from 3.62% in 2013 to 2.80% in 2023.

ASEAN's polysilicon export markets shifted significantly between 2013 and 2023, as shown in Figure 13. In 2013, ASEAN's polysilicon exports were distributed to diverse destinations, mainly covering South Korea (21.0%), ASEAN (13.5%), China (12.9%), Japan (12.3%), and the US (10.9%). However, by 2023, the exports were overwhelmingly concentrated in China, which occupied 78.4% of the region's total polysilicon exports. This largely stemmed from the export patterns of Malaysia, ASEAN's leading polysilicon exporter, which directed 79.5% of its exports to China in 2023. Intra-ASEAN exports were relatively limited compared to those to China. Only 18.3% of Malaysia's exports that year went to the ASEAN region, especially to Vietnam, which accounted for 99.8% of Malaysia's intra-ASEAN exports.

Figure 13. ASEAN Member States' Exports of Polysilicon, Share by Exporter and Destination, 2013 vs 2023

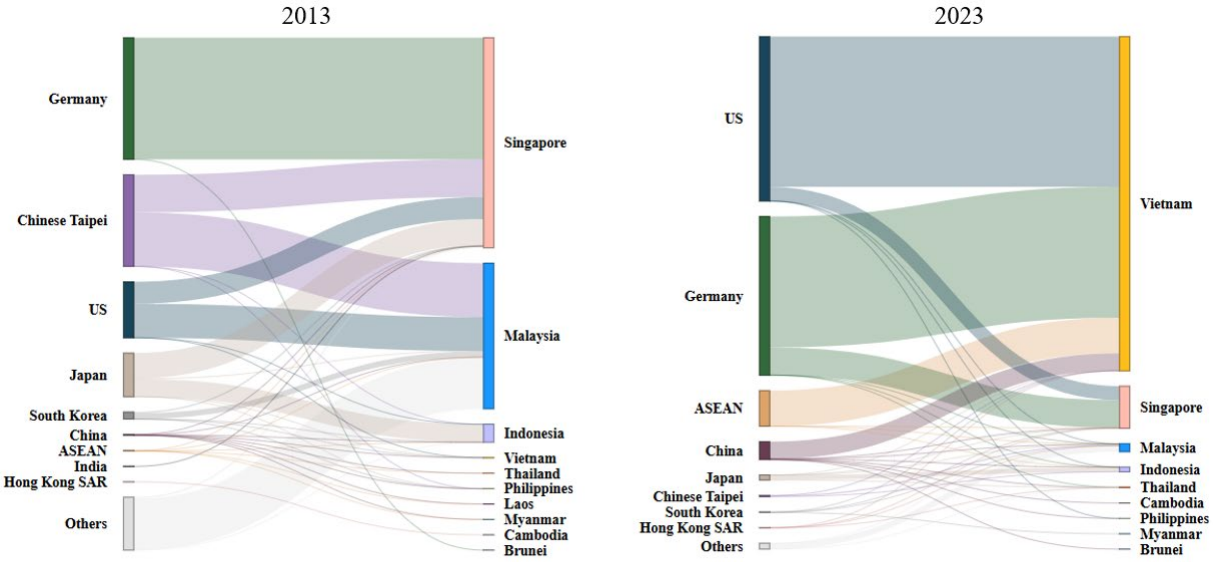


Source: ACI's calculations based on UN Comtrade

Changes in ASEAN's polysilicon suppliers are illustrated in Figure 14. In 2013, ASEAN's major polysilicon suppliers were Germany (32.5%), Chinese Taipei (24.5%), and the US (15.0%). Singapore and Malaysia, two leading regional importers in 2013, showed different supplier compositions. For Singapore, 57.9% of its polysilicon imports in 2013 were from Germany, 17.9% from Chinese Taipei, and 12.1% from Japan. For Malaysia, Chinese Taipei (37.0%), Italy (35.3%, under the category of "Others" in Figure 14, left), and the US (23.3%) were its top three import sources.

In 2023, ASEAN's top three import sources shifted to the US (42.2%), Germany (40.7%), and ASEAN (9.16%). This change was mainly driven by the rise of Vietnam as the top importer in the region. Vietnam imported 44.9% of its polysilicon from the US, 39.2% from Germany, and 10.7% from Malaysia in 2023. Singapore, the region's second-largest polysilicon importer, imported mostly from Germany (65.9%) and the US (33.6%).

Figure 14. ASEAN Member States' Imports of Polysilicon, Share by Importer and Source, 2013 vs 2023



Source: ACI's calculations based on UN Comtrade

3.2.3 Silica Sands and Quartz Sands

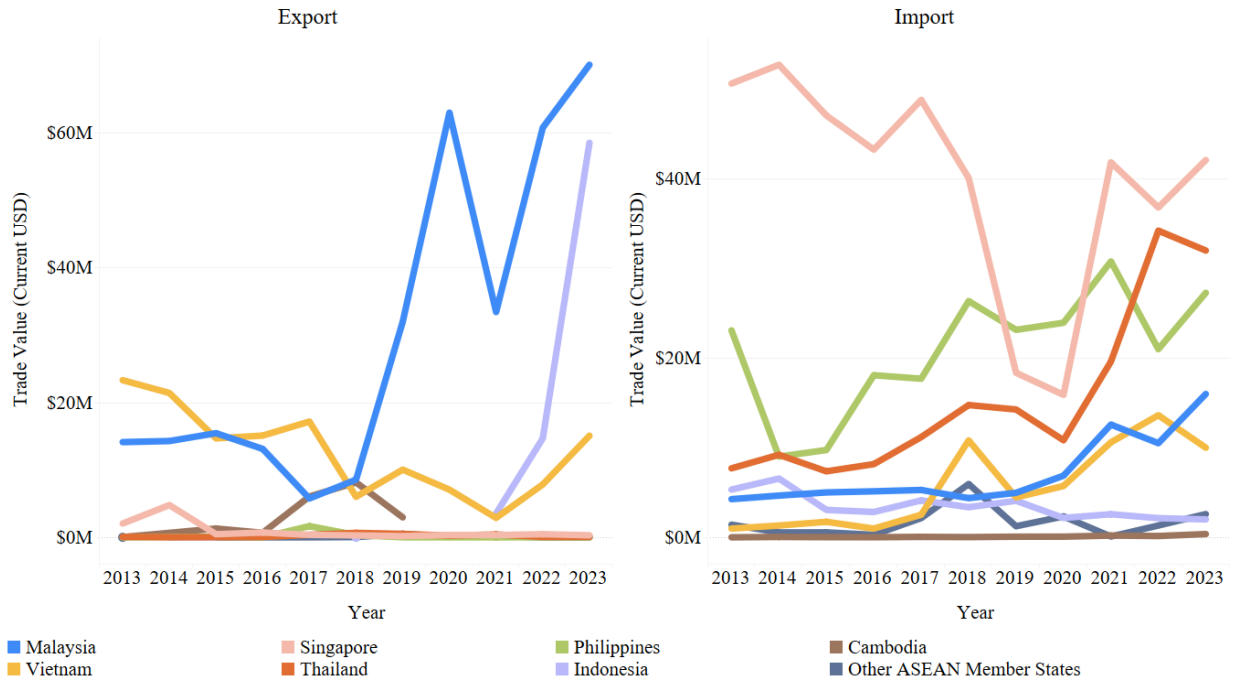
Globally, the US remained the world's largest silica sands and quartz sands (hereafter silica sands) exporter from 2013 to 2023, whose global share averaged 41.8% throughout the period. Belgium ranked second from 2013 to 2022. Yet, its global share kept declining from 2020 onwards, dropping from 10.4% in 2020 to 5.45% in 2023. ASEAN's market share grew from 4.61% in 2013 to 9.52% becoming the second largest exporter.

In terms of global imports, Canada was the world's largest silica sands importer from 2013 to 2022, averaging 15.7% of global imports. China's global share rose from 4.50% in 2013 to 18.6% in 2023, overtaking Canada. ASEAN's share was stable at around 6.72%, and accounted for 7.40% of the global imports in 2023, making it the third largest importer.

Figure 15 examines the evolution of AMS' silica sand export performance. Malaysia was a primary contributor to ASEAN's expanding silica sands exports. Its silica sand exports increased by 396% from 2013 to 2023, and the global share increased from 1.64% to 4.63%. The most notable surge being between 2017 and 2020, during which Malaysia's silica sand exports surged by 993%.

Indonesia was the second-largest silica sands exporter in the bloc in 2023. Its silica sands exports surged only after 2020 (Figure 15, left), reaching 58.6 million USD in 2023. Indonesia accounting for 40.6% of the regional exports and 3.87% of global exports in 2023. Vietnam used to be the region's largest exporter in 2013, but its global share has declined from 2.71% to 1.00% from 2013 to 2023.

Figure 15. Trade Value of Silica Sands and Quartz Sands by ASEAN Member State, 2013-2023



Source: ACI's calculations based on UN Comtrade

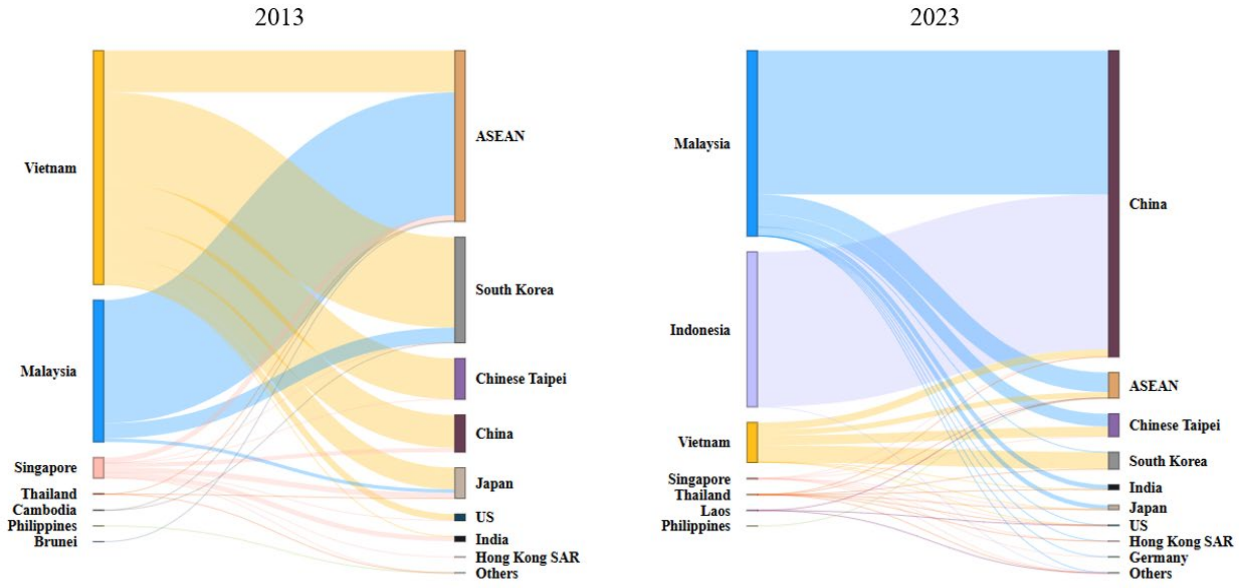
Within ASEAN, leading importers of silica sands were Singapore, the Philippines, and Thailand (Figure 15, right). Singapore remained the region's largest importer for most years between 2013 and 2023, barring some contractions occurring from 2018 to 2020. Its imports rebounded to 41.8 million USD in 2021, yet still fell short of 2013 levels. In parallel, Singapore's global share also declined from 4.11% in 2013 to 2.35% in 2023.

The Philippines was the region's largest or second-largest silica sands importer between 2013 and 2021, but dropped to regional third in 2022 and 2023 (Figure 15, right). Its silica sand imports increased by 242% from 2014 to 2021, reaching 30.7 million USD in 2021, boosting its global share from 0.653% to 2.00%. Its imports shrank by 31.8% to 21.0 million USD in 2022, allowing Thailand to overtake it. Although the value recovered to 27.2 million USD in 2023, the Philippines remained ranked behind Thailand. Thailand's silica sands imports experienced a strong growth of 316% from 7.69 million USD in 2013 to 32.0 million USD in 2023. This boosted its global share from 0.624% to 1.79%.

ASEAN's silica sands export destinations were more diverse in 2013 compared to 2023, as plotted in Figure 16. In 2013, intra-ASEAN, South Korea, and Chinese Taipei accounted for 43.1%, 26.6% and 10.3% of ASEAN's silica sands exports, respectively. By 2023, the exports heavily concentrated in China, whose share rose from 9.35% in 2013 to 80.3%. Meanwhile, the share of intra-ASEAN exports declined to 6.72% in 2023, but remained the second-largest export market. Chinese Taipei and South Korea were ASEAN's third and fourth destinations in 2023, accounting for a similar share of ASEAN's silica sand exports, 5.96% and 4.46%, respectively.

The dependence on China's market was notable in Malaysia and Indonesia, the bloc's largest exporters. China's share in Malaysia's exports saw its most significant rise between 2018 and 2023, surging from 7.69% to 77.5%. As for Indonesia, China was its only export destination since its exports took off in 2021.

Figure 16. ASEAN Member States' Exports of Silica Sands and Quartz Sands, Share by Exporter and Destination, 2013 vs 2023



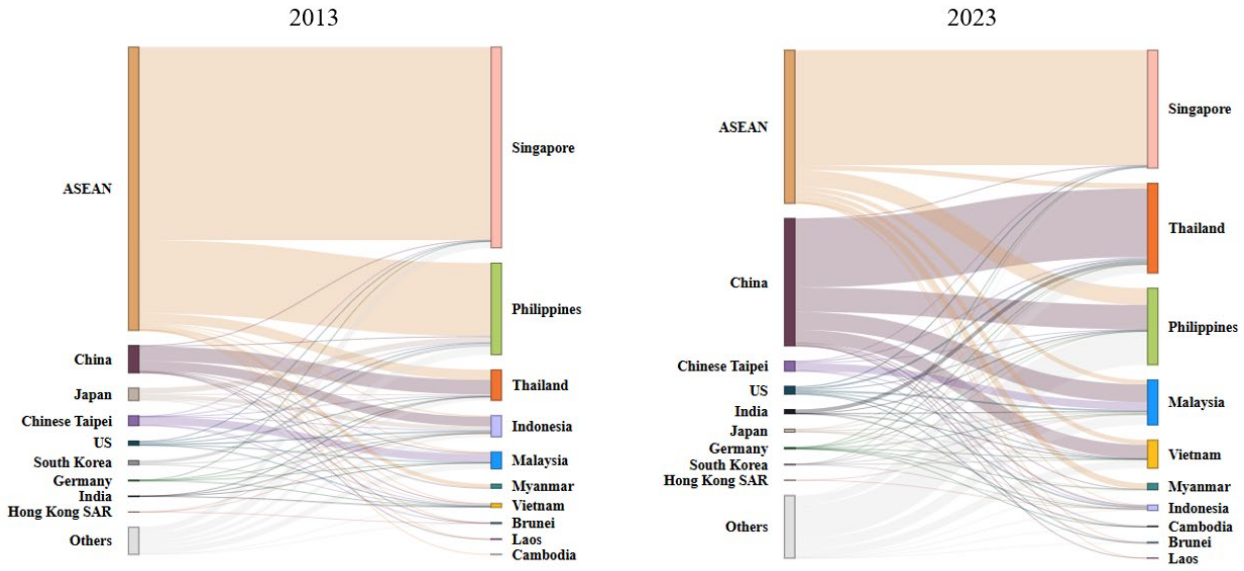
Source: ACI's calculations based on UN Comtrade

In terms of import partners, ASEAN and China were major suppliers of ASEAN's silica sands imports in 2013 and 2023 (Figure 17). Although intra-ASEAN imports remained the largest silica sands source for ASEAN, their share shrank from 76.5% to 41.3% from 2013 to 2023 (Figure 17), with their value decreasing by 23.5%. Singapore, the region's largest importer, was the only major importer that still sourced most of its silica sands within ASEAN, 97.5% in 2023, slightly up from 96.1% in 2013. Malaysia was Singapore's major import source, accounting for 97.4% of its total silica sands import in 2023.

In contrast, ASEAN's silica sands import value from China grew by 564% from 2013 to 2023, boosting China's share from 7.33% to 34.3%. This was especially apparent in Thailand and the

Philippines. China's share in Thailand's silica sands imports increased from 47.8% in 2013 to 76.3% in 2023, and the share in the Philippines rose from 0.636% to 31.8%. It is also noteworthy that the Philippines' largest import source was Australia in 2023, which was covered under the "Others" in Figure 17, right panel. Australia occupied 43.4% of its imports in 2023.

Figure 17. ASEAN Member States' Imports of Silica Sands and Quartz Sands, Share by Importer and Source, 2013 vs 2023



Source: ACI's calculations based on UN Comtrade

3.3 Fixed Capital

ASEAN's growing role as the world's top importer of wafers underscores its reliance on external manufacturing inputs. To comprehensively assess ASEAN's capacity to vertically integrate the solar PV supply chain, it is essential to understand the trade of production machinery for both wafers and solar PV cells or modules. Specifically, the imports of machines signal the region's efforts to localise upstream production (e.g., wafer fabrication), while the exports reflect ASEAN's potential as a high-end manufacturing technology provider.

3.3.1 Machines for Solar PV Cells or Modules

Globally, the exports of machines for solar PV cells or modules increased steadily by 243% from 21.6 billion USD in 2013 to 74.1 billion USD in 2023. The top three global exporters of these machines were Japan (28.2%), the US (28.1%), and the Netherlands (25.3%) in 2013. By 2023, the Netherlands (26.8%) became the largest exporter, followed by ASEAN, whose share rose from 4.57% in 2013 to 21.7%, which was dominated by Singapore. Japan ranked third, with 21.0%.

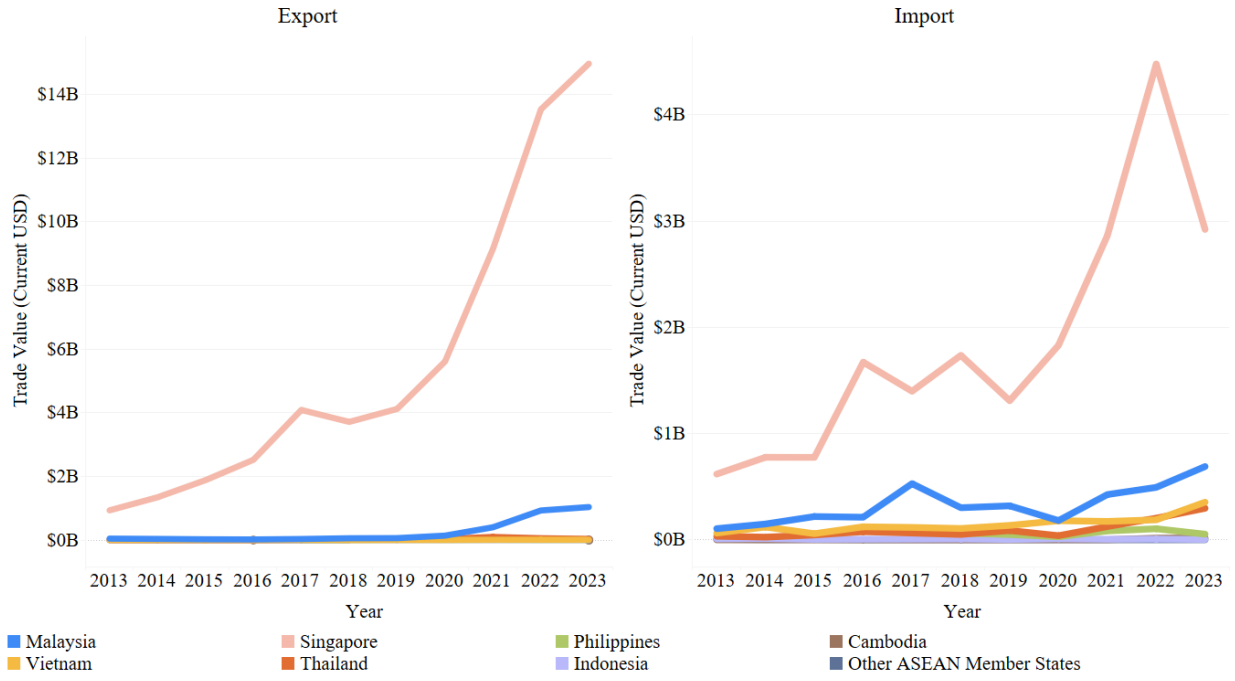
In 2013, the top three global importers were Chinese Taipei (40.0%), South Korea (17.5%), and the US (13.8%). In 2023, China is now the top importer, with a global share of 34.9%. Chinese

Taipei dropped to the second, with its share decreasing to 21.4% in 2023. South Korea became the third-largest importer, with a global import share of 15.9%. ASEAN's collective share in global imports increased from 3.83% in 2013 to 5.52% in 2023, making it the fifth largest importer.

Within ASEAN, Singapore's exports were far ahead of those of other AMS (Figure 18, left). Its global share increased sharply from 4.33% in 2013 to 20.2% in 2023. Malaysia ranked second in the region throughout the period. By absolute trade value, it grew by 2172% from 45.6 million USD in 2013 to 1.04 billion USD in 2023, but its global share only increased moderately from 0.212% to 1.40%, way below Singapore.

Singapore and Malaysia remained major regional importers (Figure 18, right). Singapore's global share increased from 2.84% to 3.72% during the period, and Malaysia's share increased slightly from 0.483% to 0.887%.

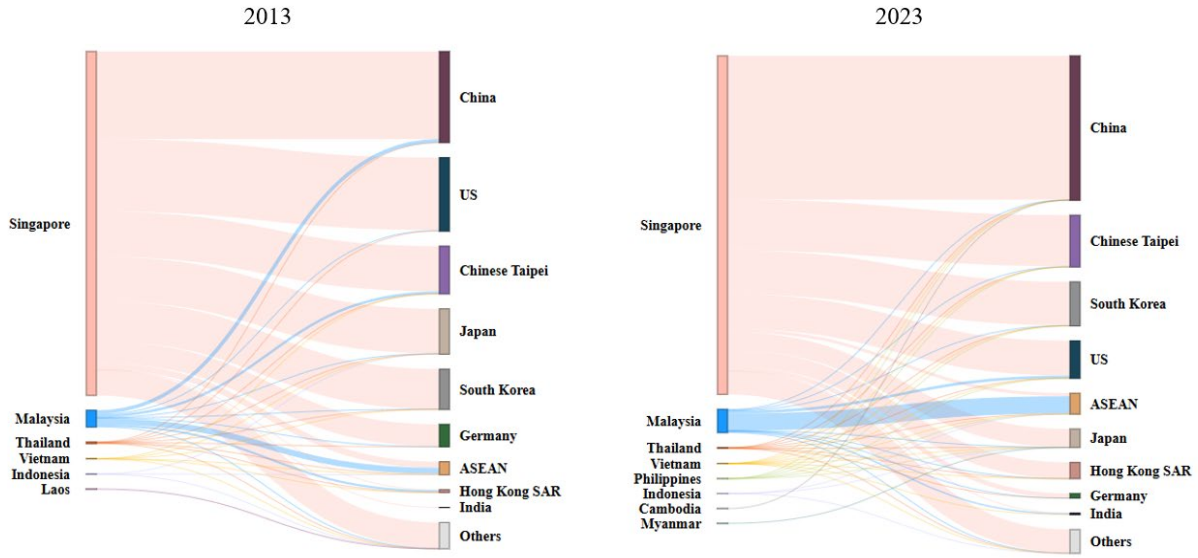
Figure 18. Trade Value of Machines for Solar PV Cells or Modules by ASEAN Member State, 2013-2023



Source: ACI's calculations based on UN Comtrade

ASEAN's major export destinations in 2013 were China (25.1%), the US (20.3%), and Chinese Taipei (13.2%), as shown in Figure 19, left. By 2023, ASEAN's top three export markets changed to China (39.8%), Chinese Taipei (14.3%), and South Korea (12.1%). As the region's largest exporter, Singapore's exports in 2013 were mainly to China (25.5%), the US (21.1%), and Chinese Taipei (13.1%). The export patterns shifted slightly toward greater reliance on East Asia in 2023, as shown Figure 19, right, with China's share rising to 42.5%, followed by Chinese Taipei (15.1%) and South Korea (12.9%). Meanwhile, the US's share halved to 10.3%.

Figure 19. ASEAN Member States' Exports of Machines for Solar PV Cells or Modules, Share by Exporter and Destination, 2013 vs 2023



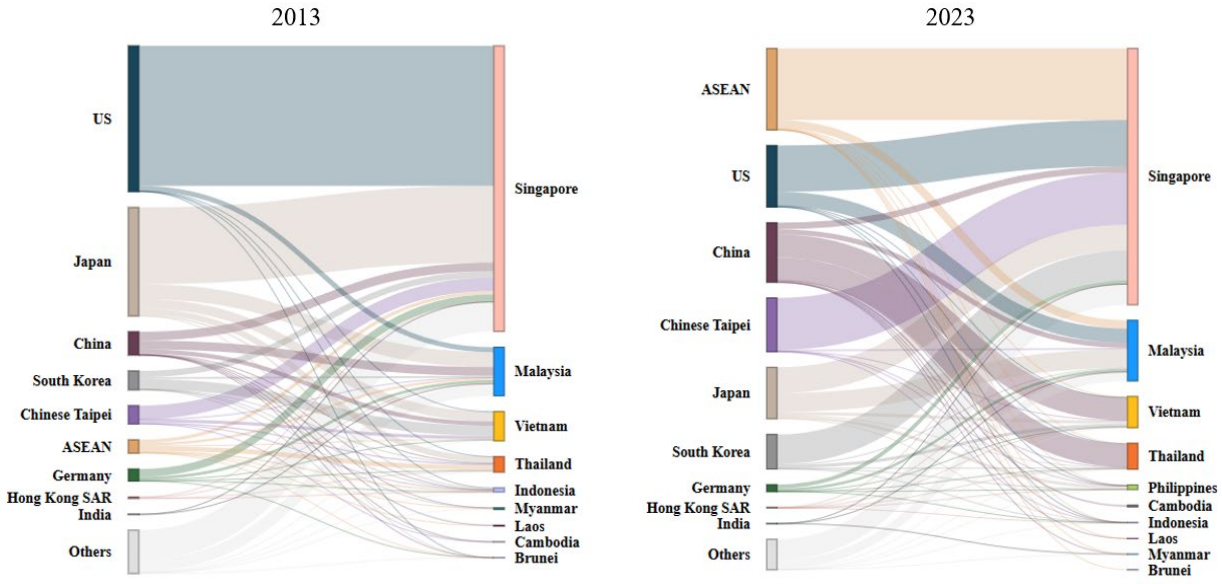
Source: ACI's calculations based on UN Comtrade

For Malaysia, in 2013, its exports of machines for solar PV cells or modules were primarily intra-regional (Figure 19, left), with trade with other AMS accounting for 35.1% of total exports. This was followed by exports to China (21.5%) and Chinese Taipei (14.8%). By 2023, Malaysia reinforced its involvement in the regional solar PV supply chain, with the share of intra-ASEAN trade increasing to 73.3% (Figure 19, right), primarily directed to Singapore. Concurrently, the US emerged as Malaysia's second-largest export destination, covering 11.3% of its exports, which was a substantial growth from 4.83% in 2013. China's share declined to just 2.23%, indicating reduced export dependence on China's market.

The shifting dynamics of ASEAN's imports of machines for solar PV cells or modules can be observed in Figure 20. In 2013, ASEAN's top three import sources were the US (37.8%), Japan (28.2%), and China (6.04%). By 2023, the top three import suppliers changed to ASEAN (21.4%), the US (16.2%), and China (15.7%). The growing imports from intra-ASEAN sources were dominated by the Singapore's imports from Malaysia. China's rising share was mainly driven by the increased imports from Vietnam and Thailand.

In Singapore, Malaysia accounted for a growing share in Singapore's imports of machines for solar PV cells or modules, with the share rising from 0.942% in 2013 to 27.6% in 2023. It ascended to be Singapore's largest import source in 2023 and dominated Singapore's imports from the ASEAN. Chinese Taipei's share also increased from 4.73% in 2013 to 20.3% in 2023, and it climbed up to be the second-largest import supplier. In contrast, the US was its largest import source in 2013, accounting for 49.0% of its imports. The share fell to 18.05% in 2023, making it the third-largest source. Similarly, Japan's share declined and dropped out of the top three sources.

Figure 20. ASEAN Member States' Imports of Machines for Solar PV Cells or Modules, Share by Importer and Source, 2013 vs 2023



Source: ACI's calculations based on UN Comtrade

However, Malaysia's import partners were distinct from Singapore's imports. Unlike Singapore, where the US's share diminished, Malaysia saw growing importance of imports from the US, whose share grew from 10.4% in 2013 to 23.5% in 2023, being its second largest import source. Japan remained Malaysia's top supplier in both 2013 and 2023, its share slightly increasing from 30.4% to 30.9%, despite fluctuations during the period.

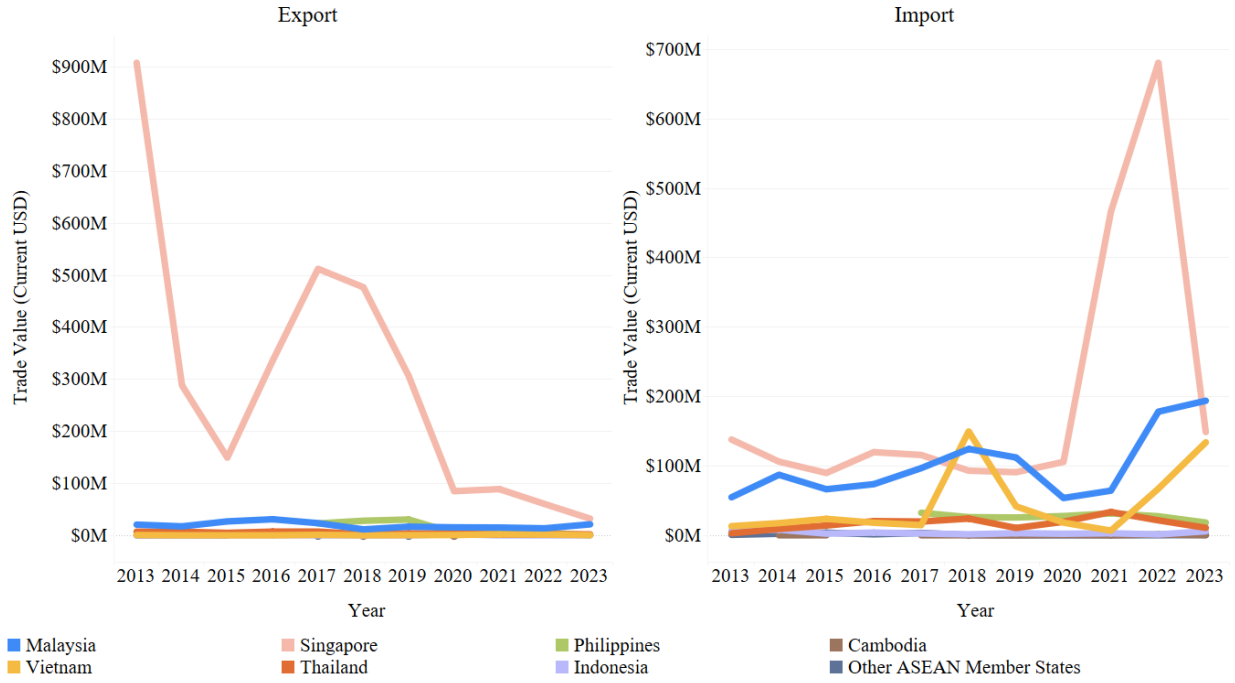
3.3.2 Machines for Wafers

Globally, exports of machines for wafers grew significantly by 51.2%, from 2.17 billion USD in 2013 to 3.28 billion USD in 2023. ASEAN was the largest exporter in 2013, accounting for 43.1% of the global exports, but its share plummeted drastically to only 1.70% in 2023. In contrast, Japan doubled its global share from 26.3% in 2013 to 48.0% in 2023, ascending to the world's largest exporter. Within the same period, Germany, whose share rose from 9.27% to 25.8%, ranked second. China's share rose sharply from only 1.27% in 2013 to 10.2% in 2023, becoming the third largest exporter of machines for wafers.

From 2013 to 2023, global imports of machines for wafers tripled from 1.43 billion USD to 4.45 billion USD. China and Chinese Taipei remained listed among the top two importers globally. China's import value surged from 369 million USD in 2013 to 1.76 billion USD in 2023, increasing its market share from 25.8% to 39.6%. Chinese Taipei also experienced strong growth, with imports rising from 470 million USD to 1.12 billion USD, though its market share declined from 32.8% to 25.1%. ASEAN retained the third place in both 2013 and 2023, though its share decreased from 15.1% to 11.5%.

As illustrated in Figure 21 (left), ASEAN's sharp decline in exports of machines for wafers was largely driven by Singapore's contraction. Singapore's exports of wafer manufacturing machines totalled 909 million USD in 2013, occupying 41.8% of the global market and ranking first worldwide. However, exports declined sharply between 2013 and 2015, with a brief rebound from 2015 to 2017, before resuming a downward trend through to 2023. By 2023, Singapore's exports fell to 32.0 million USD, reducing its global share to just 0.976%. Malaysia was the second largest exporter in the regional exports of such machines in 2013 and 2023, but its global share (less than 1%) was far below Singapore's.

Figure 21. Trade Value of Machines for Wafers by ASEAN Member State, 2013-2023



Source: ACI's calculations based on UN Comtrade

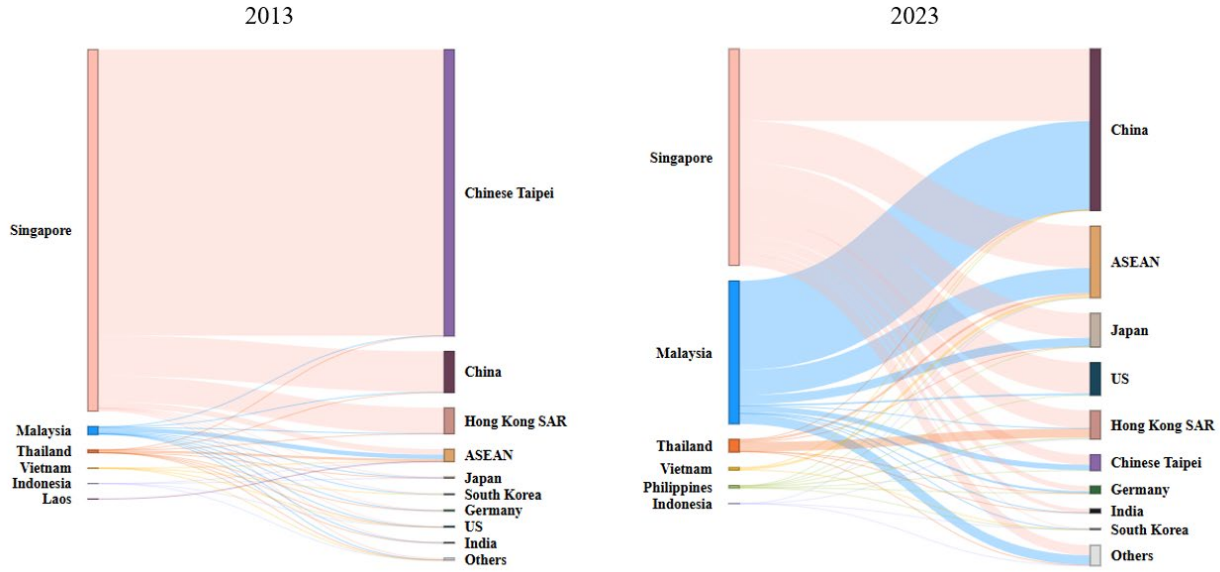
Similar to the export patterns, Singapore also contributed significantly to the region's total import demand. Singapore's imports of machines for wafers presented an upward trend from 2013 to 2022, as shown in Figure 22, right. Especially, there was a jump of 341% in 2021, reaching 681 million USD in 2022, and further grew by 46% in 2022, reinforcing its position as the region's largest and global third-largest single-country importer. Yet, Singapore's imports experienced a sharp contraction of 78.1% in 2023, and the global share shrank to only 3.35%. It dropped to the region's second-largest importer, surpassed by Malaysia.

Malaysia's imports started from 54.8 million USD in 2013 and grew by 254% to reach 194 million USD in 2023, securing 4.36% of the global share. Following Malaysia, Vietnam was ASEAN's third-largest importer in 2023. Its import value recorded a 916% increase from 13.2 million USD in 2013 to 134 million USD in 2023. In 2018, there was a one-year surge when

Vietnam recorded the highest import value among all AMS (150 million USD), although this expansion was not sustained. Vietnam's global share was 3.01% in 2023.

In 2013, ASEAN's export partnerships almost solely followed Singapore's because of the country's dominant position in supplying machines for wafers. Back then, Singapore's exports were highly concentrated in Chinese Taipei, which accounted for 79.1% of its total exports, as shown in Figure 22. Singapore's second and third largest export destinations were China and Hong Kong SAR, representing 11.2% and 7.11% of its total exports. Singapore's sales to intra-ASEAN buyers only made up 1.54% of its exports, most of which were contributed by exports to Malaysia.

Figure 22. ASEAN Member States' Exports of Machines for Wafers, Share by Exporter and Destination, 2013 vs 2023



Source: ACI's calculations based on UN Comtrade

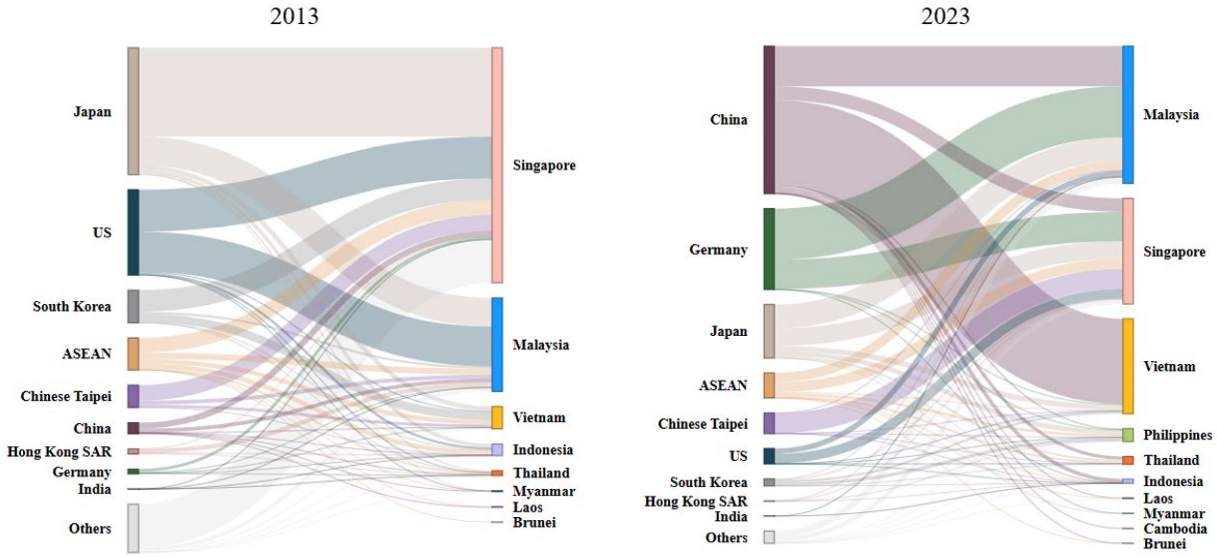
By 2023, ASEAN's wafer machine exports shifted away from regional concentration towards a more globally diversified export structure. China became ASEAN's largest wafer machine export market, occupying 42.9% of its exports, followed by ASEAN itself and Japan, occupying 19.0% and 8.93% of its wafer machine exports, respectively. However, Chinese Taipei and Hong Kong SAR dropped out of the top three destinations. For Singapore, the region's largest exporter, China rose to become its largest export destination (33.3%), followed by ASEAN (19.4%), predominantly by exports to Malaysia, which accounted for 96.1% of its intra-ASEAN exports. The US was the third-largest market, with a share of 14.3%.

Malaysia also experienced a realignment in its export markets (Figure 22). China climbed up to be its largest export market in 2023, occupying 62.4% of its exports. ASEAN's share of its exports declined sharply from 54.1% in 2013 to just 17.5% in 2023, though it remained its second-

largest market. Singapore was Malaysia's major market within ASEAN, accounting for 71.3% of its total exports to ASEAN.

Figure 23 highlights the shifts in ASEAN's import partners of machines for wafers between 2013 and 2023. At the ASEAN level, Japan (34.4%), the US (23.1%), and South Korea (8.85%) were the top three import sources in 2013. However, at the AMS level, the two major importers, Singapore and Malaysia, exhibited different partner profiles. In 2013, Singapore sourced most of its imports from Japan (37.8%), the US (17.8%), and the Netherlands (14.7%, under the category of "Others" in Figure 23, left). In Malaysia's case, the country's top two import sources were the US (42.8%) and Japan (30.6%), while none of the other suppliers secured a share higher than 7% of Malaysia's total imports in 2013.

Figure 23. ASEAN Member States' Imports of Machines for Wafers, Share by Importer and Source, 2013 vs 2023



Source: ACI's calculations based on UN Comtrade

ASEAN's major import source of machines for wafers changed by 2023. Notably, China, which only supplied 3.00% of ASEAN's total imports in 2013, emerged as the largest import source of ASEAN, with a share of 40.7% in 2023. Germany became ASEAN's second-largest import source, accounting for 22.3% of the region's total imports, largely up from only 1.28% in 2013. Japan's share declined to 14.8% as the third-largest import source.

Malaysia, as the largest ASEAN importer in 2023, sourced 37.1% of its imports from Germany, which contributed to Germany's growing role as one of the key machine suppliers for the region. The second and third largest import sources of Malaysia were China (29.3%) and Japan (17.3%).

In Singapore, the second-largest ASEAN importer in 2023, Germany also served as its largest import source, with 27.9% of its wafer machine imports originating from there, followed by Chinese Taipei (19.0%) and Japan (16.7%).

As for Vietnam, South Korea used to occupy 36.6% of its total imports, followed by Japan (19.4%) and Malaysia (15.6%) in 2013. At that time, China only contributed 0.878% of Vietnam's imports. By 2023, while China became its top import source (90.0%) with a growth rate of 103934% in import value from 2013 to 2023, South Korea's presence shrank to 2.27%.

3.3.3 Parts of Machines

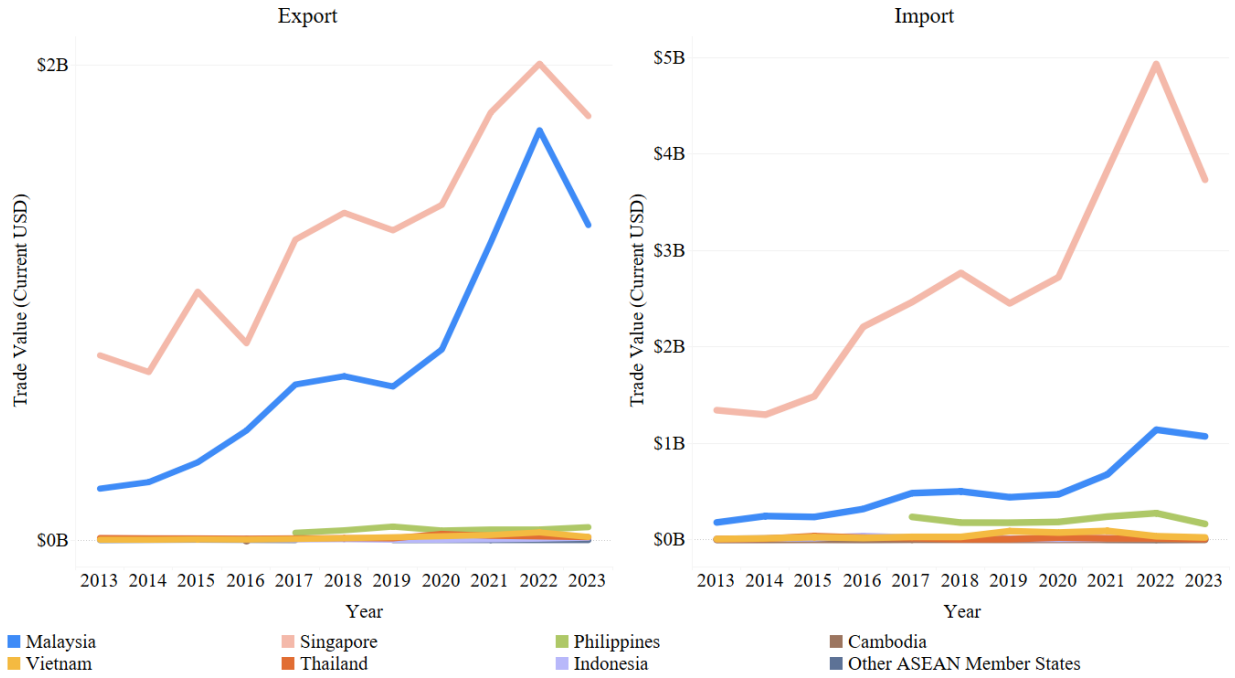
The global leaders in exporting parts of machines were Japan, the US, and the Netherlands from 2013 to 2023, though their shares and positions changed. Japan's share decreased from 26.4% to 17.4%, the US's share dropped slightly from 23.7% to 22.4%, while the Netherlands's share increased from 12.2% to 14.8%. ASEAN remained the fourth largest exporter, with a rising share from 9.00% to 10.6%, and the value increased by 218% from 2013 to reach 3.2 billion in 2023.

In terms of global imports, the US (17.8%), Chinese Taipei (16.8%), and the Netherlands (11.9%) were among the global top three importers in 2013. ASEAN occupied 11.8% of the global imports and ranked fourth. In 2023, the Netherlands climbed up to be the largest importer, covering 18.3% of the global imports in the year. Chinese Taipei maintained its second position with its share slightly rising to 18.1%. ASEAN improved to the global third with a share of 14.1%, with its value increasing by 224% over the period.

Within the ASEAN, Singapore and Malaysia were the regional top two exporters of parts of machines from 2013 to 2023 (Figure 24, left panel), and they were far ahead of other AMS. In 2013, Singapore and Malaysia accounted for 6.96% and 1.94% of the global exports, respectively. The global share of other AMS was negligible. Singapore's exports of parts of machines presented an upward trend from 2013 to 2023, with the value increasing significantly by 130% from 2013 to 2023, despite some fluctuations. As for Malaysia, its export value increased significantly by 512% from 2013 to 2023 (Figure 24, left panel), with an average annual growth rate of 22.4%. This boosted Malaysia's global share from 1.94% in 2013 to a peak of 5.19% in 2022, though it dropped slightly to 4.39% in 2023.

ASEAN's imports of parts of machines were also led by Singapore and Malaysia over the decade (Figure 24, right panel). Singapore's import value increased by 267% from 1.34 billion USD in 2013 to the peak of 4.93 billion USD in 2022, but dropped by 24.3% to 3.73 billion USD in 2023. Its global share increased from 10.2% in 2013 to the peak of 13.6% in 2016 but dropped to 10.5% in 2023. Malaysia's import value increased more sharply by 496% during 2013-2023 and reached 1.07 billion USD in 2023, boosting its global share from 1.37% in 2013 to 3.01% in 2023.

Figure 24. Trade Value of Parts of Machines by ASEAN Member State, 2013-2023

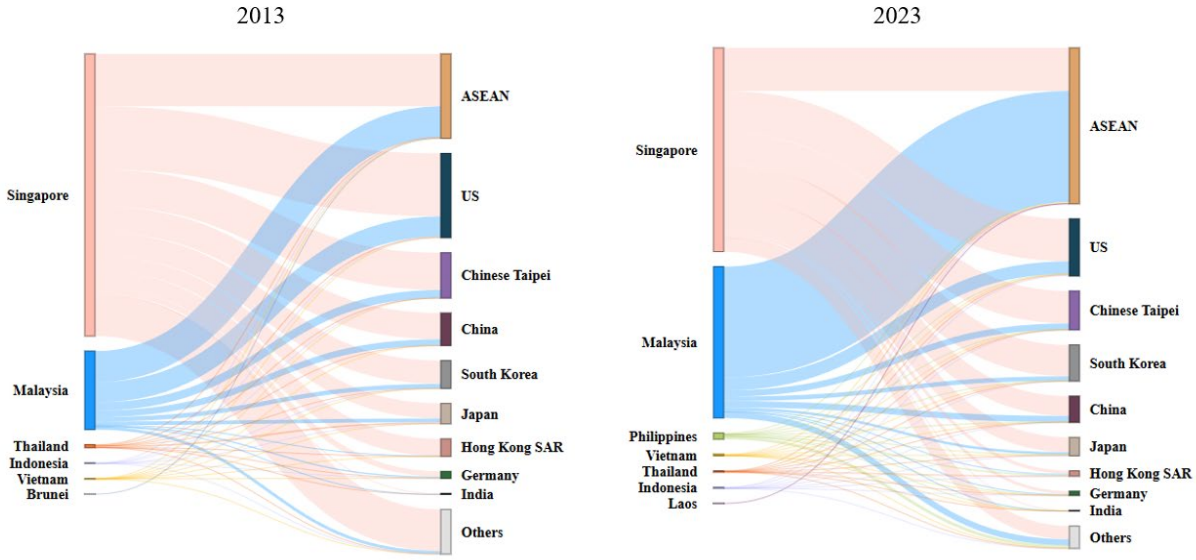


Source: ACI's calculations based on UN Comtrade

ASEAN's major export destinations for parts of machines are depicted in Figure 25. Intra-ASEAN (23.1%), the US (23.1%), and Chinese Taipei (12.4%) were among ASEAN's top three export destinations in 2013. The exports further concentrated within the ASEAN in 2023, with the intra-ASEAN exports' share increasing to 42.7% in 2023 while the share of the US and Chinese Taipei shrank to 15.6% and 10.6%, respectively.

The intra-ASEAN exports in both 2013 and 2023 were mainly driven by bilateral trade between Malaysia and Singapore, especially for Malaysia, whose exports to Singapore increased from 29.1% of its total exports in 2013 to 70.6% in 2023. Meanwhile, the share of other major export markets of Malaysia in 2013 dropped in 2023. The share of the US, its second largest destination in 2013, dropped from 25.7% to 8.28% and the share of Chinese Taipei decreased from 10.4% to 4.22%. In contrast, though Singapore exports to Malaysia rose from 6.50% of its total exports in 2013 to 16.8% in 2023, it still had a diverse export portfolio. The US, Chinese Taipei, and South Korea accounted for 20.8%, 15.9%, and 15.4% of its exports, respectively, in 2023.

Figure 25. ASEAN Member States' Exports of Parts of Machines, Share by Exporter and Destination, 2013 vs 2023

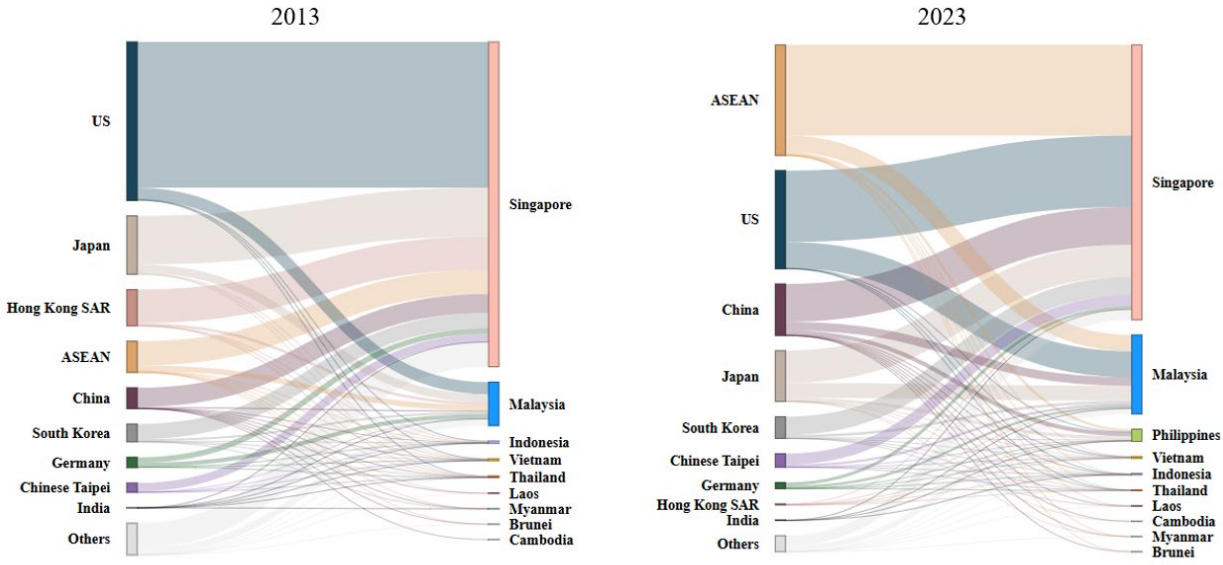


Source: ACI's calculations based on UN Comtrade

ASEAN's major import sources for parts of machines are plotted in Figure 26. The US (42.3%), Japan (15.6%), and Hong Kong SAR (9.68%) were among the top three sources in 2013. The US was the largest import source of both Singapore and Malaysia in 2013. It occupied 44.9% of Singapore's imports and 27.7% of Malaysia's. Japan was the second-largest import source for Singapore and Malaysia, covering 15.0% and 18.9% respectively. Meanwhile, imports from Hong Kong SAR were mostly directed to Singapore.

In 2023, intra-ASEAN trade accounted for 29.9% of the region's total imports of parts of machines, surpassing the US (26.5%) to be the largest source. The intra-ASEAN imports in 2023 were mainly between Singapore and Malaysia. Malaysia was Singapore's top supplier of parts of machine, providing 31.4% of its imports. Meanwhile, Malaysia imported 18.1% from Singapore. China's share also doubled from 5.56% in 2013 to 13.9% in 2023, emerging as ASEAN's third-largest import source. In contrast, the share of the US in ASEAN's imports of parts of machines dropped to 26.5% in 2023.

Figure 26. ASEAN Member States' Imports of Parts of Machines, Share by Importer and Source, 2013 vs 2023



Source: ACI's calculations based on UN Comtrade

3.4 Summary of ASEAN's Role in Solar PV Trade

Building on the preceding analysis of ASEAN and AMS trade performance by solar PV product, Figure 27 summarises their global export and import shares in 2023. As indicated by the blue dots in the "ASEAN" column, ASEAN has established itself as a global leader in exporting final products, including solar PV cells or modules and parts of semiconductor devices. In contrast, its presence in exporting key inputs, including intermediates and fixed capital, was not as strong (except for the machines for solar PV cells or modules). Instead, ASEAN was a large importer of key inputs, particularly wafers and polysilicon. At the AMS level, Malaysia, Singapore, and Vietnam contributed the most to ASEAN's solar PV trade. Singapore and Malaysia established noticeable shares across almost all products but demonstrated different strengths and weaknesses. In contrast, other AMS play a negligible role in the supply chain.

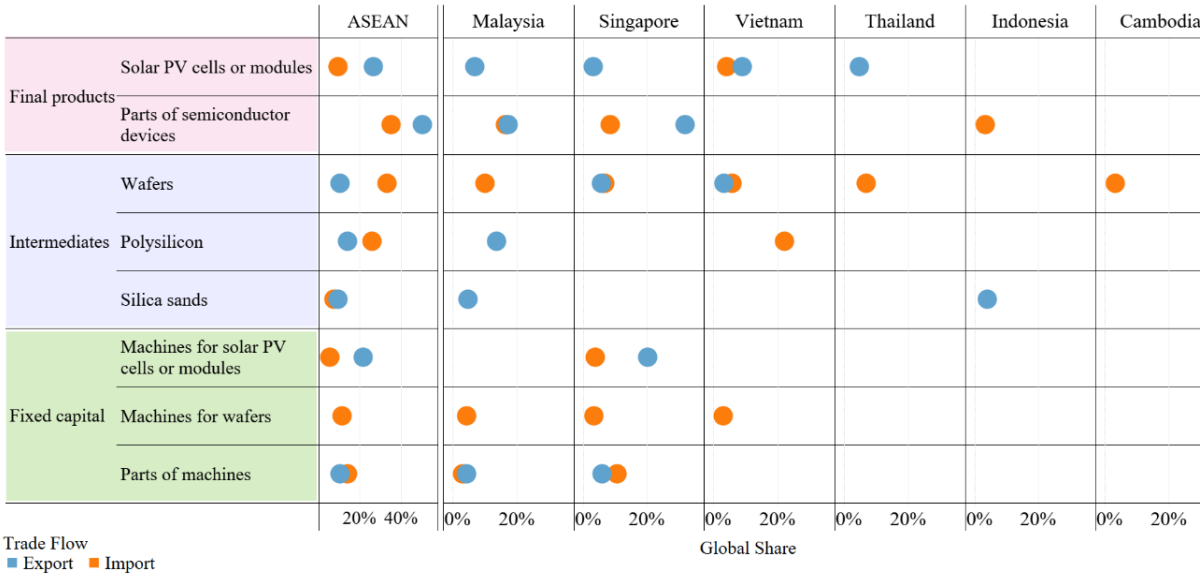
Malaysia has been a critical trading hub for solar PV-related products. Notably, it exported the most silica sands and polysilicon among AMS, and was the largest wafer importer in the region in 2023.

Singapore served as a key player in high-end manufacturing, as evidenced by its significant contribution to the exports of machines for cells or modules. It was also the largest ASEAN exporter of wafers, which corresponded to its substantial imports of machines for wafers.

Vietnam stood out in terms of both the exports and imports of solar PV cells or modules. This reflects Vietnam's growing importance as a supplier of final products and demonstrates substantial domestic demand incentivised by the policies boosting solar PV installations. It was also an

important regional player in wafer exports. Consequently, it was a large importer of polysilicon, an important input for wafer manufacturing.

Figure 27. ASEAN's and AMS' Global Share by Product and Trade Flow, 2023

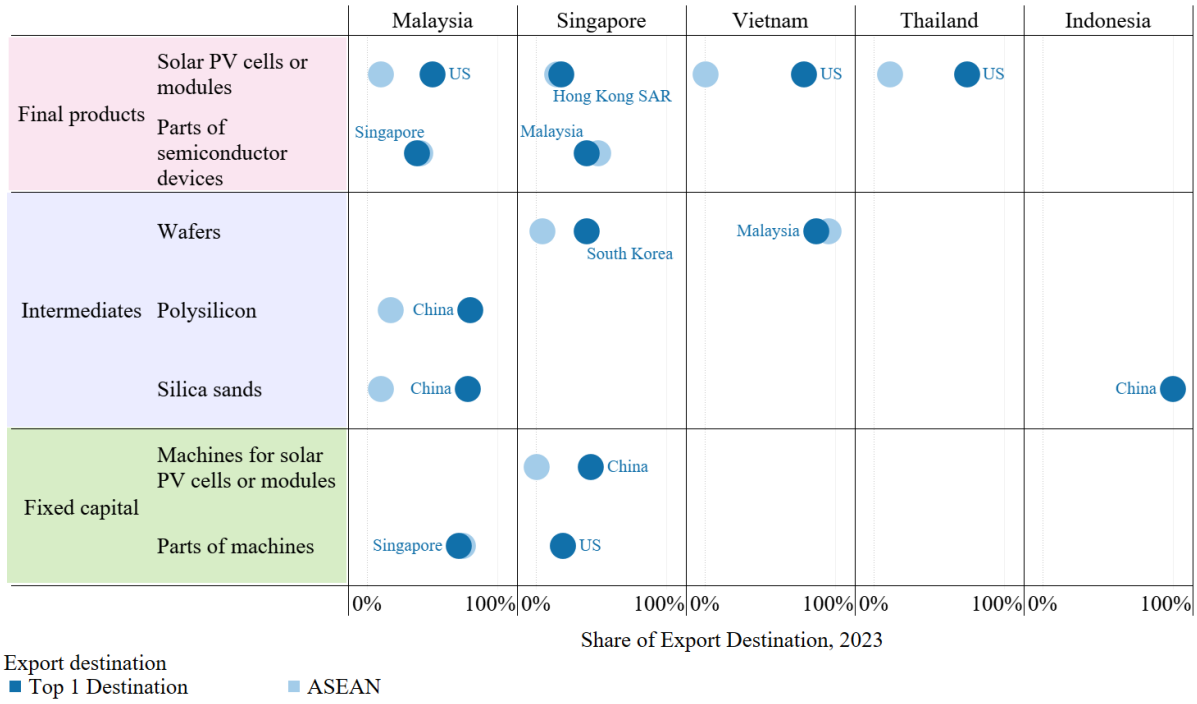


Note: The global share of "ASEAN" means the collective share of the ten AMS. Only the data points representing global shares greater than 3% are shown in the figure.

Source: ACI's calculations based on UN Comtrade

In terms of trade partners, ASEAN's major export markets for solar PV products were primarily extra-regional. This can be seen in Figure 28, which compares the share of top 1 destination and intra-ASEAN trade at AMS level. Notably, the region showed strong and growing reliance on the US as its largest export market for solar PV cells or modules (Figure 28 and Figure 4). In contrast, intra-ASEAN exports were comparatively limited—especially for key inputs. In 2023, for most AMS, the primary export destination for key input products was a non-ASEAN country. Exceptions include Malaysia's and Singapore's exports of parts of semiconductor devices, Vietnam's exports of wafers, and Malaysia's exports of parts of machines, where intra-ASEAN trade played a larger role than extra-regional exports.

Figure 28. The Share of the Top One Export Destination and ASEAN in Selected AMS' Exports of Solar PV Products

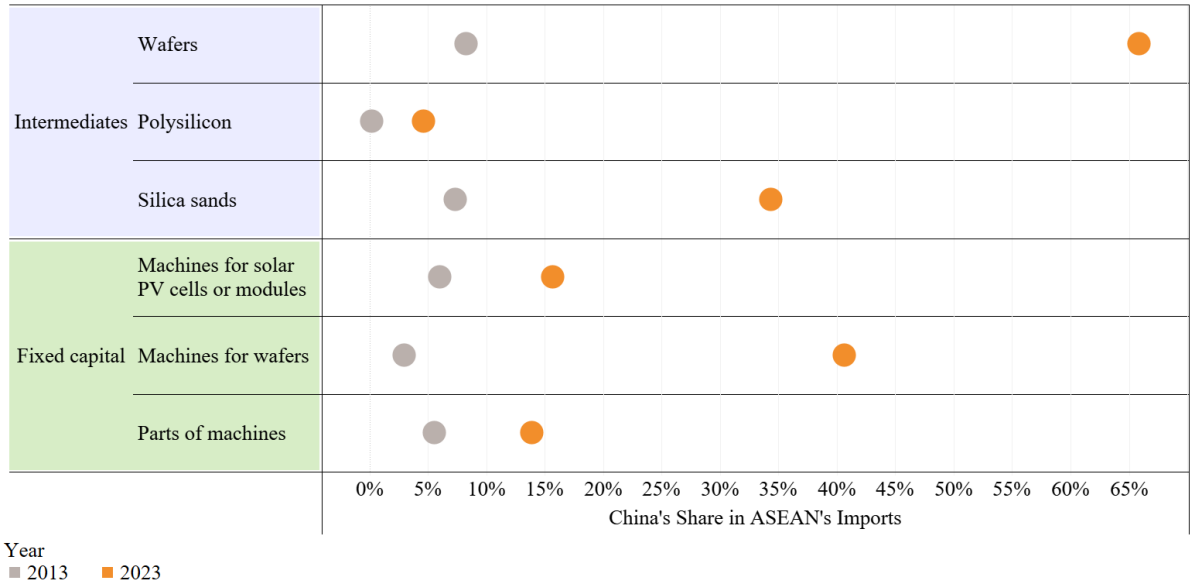


Note: For each product and AMS, partners will only be presented on the chart if the AMS's share in the product's global exports is larger than 3%.

Source: Authors' calculations based on UN Comtrade

Meanwhile, China was an increasingly important import source of ASEAN's key inputs from 2013 to 2023. As shown in Figure 29, China accounted for a rising share in ASEAN's imports of all key inputs to manufacture the final products, especially in the imports of wafers, where ASEAN imported the most among the four intermediates.

Figure 29. China's Share in ASEAN's Imports of Solar PV Key Inputs, 2013 VS 2023



Source: ACI's calculations based on UN Comtrade

4. Policy Implications

The mapping in the trade section highlights that ASEAN has a strong and growing reliance on Chinese key inputs and the US as the biggest destination market for its final products—solar PV cells or modules. Such reliance exposes ASEAN to the risk of losing its market in the US due to its close supply chain relations with China. The latest example is that in April 2025, the US announced anti-dumping duties of up to 271% and countervailing duties of up to 3404% on solar PV cells or modules from Cambodia, Malaysia, Thailand, and Vietnam. These four countries are among ASEAN's most US-reliant exporters, and the duties were imposed on the grounds that their solar PV producers received subsidies from both their own governments and the Chinese government.[31] At the time of writing, the order of such duties is pending the issuance by the US International Trade Commission; if implemented, it will soon push up the price of the solar cells or modules from the four countries and make them uncompetitive in the US market, and thereby lose their market share in the US.

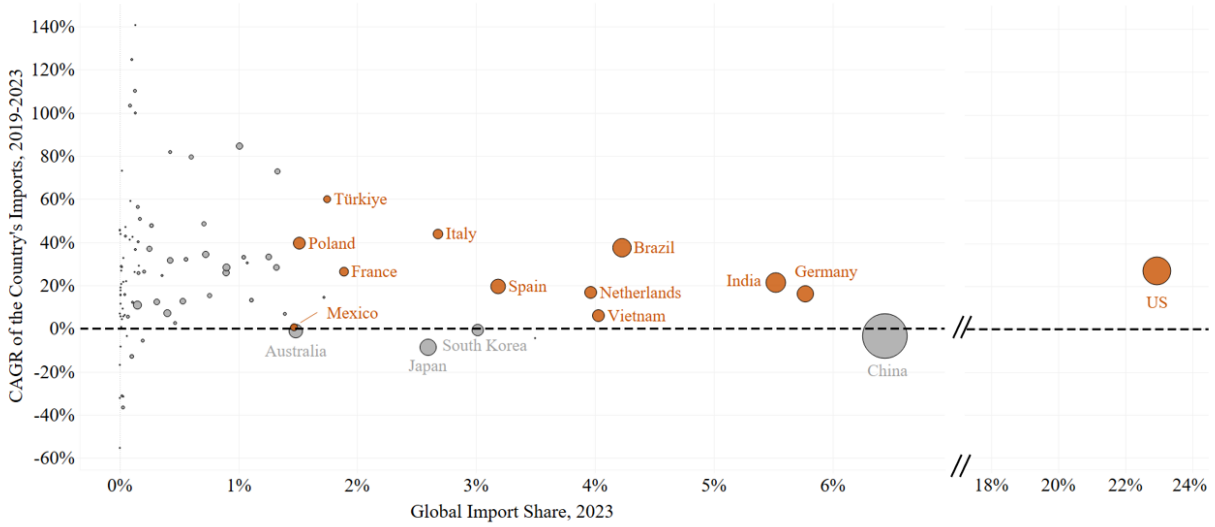
To address such risk and sustain the growth of ASEAN's solar PV cell or module exports, we propose two directions for policy action. First, ASEAN and AMS need to explore what potential alternative export markets could offset potential market losses in the US. One way to do this is to identify markets with large and growing solar PV import demand. We assessed market potential based on three criteria (as shown in Figure 30):

[31] See US International Trade Administration (2025a), US International Trade Administration (2025b) and US International Trade Commission (2025).

1) Markets that ranked among the top 20 global importers of solar PV cells or modules in 2023;
2) Markets with positive compound annual growth rates (CAGR) in imports from 2019–2023;
3) Markets that were also among the global top 20 countries in newly installed solar PV capacity from 2019 to 2023.

We identified 11 promising markets for solar PV cells or modules based on the three criteria, as shown in the dark orange dots in Figure 30. In Europe, these include France, Germany, Italy, the Netherlands, Poland, and Spain. In Asia, India, Turkey, and Vietnam stood out. In Latin America, Mexico and Brazil could be promising. Except for India, ASEAN's second-largest export destination behind the US, most others remain underexplored. Even for India, its share in ASEAN's export composition was well below that of the US. For most of the ten remaining promising markets, their share in individual AMS exports of solar PV cells or modules was below 1% in 2023. This underscores the need to explore the potential opportunities and challenges for ASEAN companies' market entry and expansion.

Figure 30. Potential Export Destinations for ASEAN's Solar PV Cells or Modules



Note: Bubble sizes indicate the country's newly installed solar PV capacity (GW) from 2019 to 2023. CAGR stands for Compound Annual Growth Rate.

Source: Authors' calculations based on UN Comtrade and IRENA

Secondly, ASEAN should diversify its import sources for key inputs**,** with a particular focus on boosting intra-ASEAN trade as a way to reduce reliance on China. This not only aligns with ASEAN's green economy vision, but it is also practically feasible. Several AMS already produce the products that other AMS in the region import (as shown in Figure 27) — yet much of this trade still occurs outside the bloc (Figure 28). In other words, ASEAN has the capacity for greater self-reliance, but the intra-regional trade flows have not kept pace. For instance, countries like Malaysia

and Thailand, which are major wafer importers, could source more wafers from Singapore and Vietnam. Vietnam and Singapore, as key regional importers of polysilicon, could turn more to Malaysia, while Malaysia could reduce external dependence by importing more solar machinery from Singapore. Strengthening these regional trade linkages would enhance supply chain resilience and reduce exposure to external shocks.

5. Conclusion

Expanding the adoption of renewable energy is critical to supporting global sustainability efforts. Solar PV has been one of the prevalent renewable energy sources both in the world and in ASEAN. To capitalise on the opportunities during the expansion of renewables, ASEAN needs to understand the global landscape of the solar PV supply chain and its position in it. This paper used trade data to assess ASEAN and individual AMS' positions on the global solar PV supply chain.

ASEAN collectively ranked as the second-largest global exporter of solar PV cells or modules in 2023. However, its presence in exporting key inputs was rather limited, compared to its performance in final product exports. It was a larger importer of key inputs in the world. The region was the world's largest importer of wafers and the second-largest importer of polysilicon in 2023. Within the region, Singapore, Malaysia, and Vietnam were key players in most products, while the remaining AMS were only present in several products with negligible shares in the global trade. As for trade partners, ASEAN presented a strong reliance on the US as its final product's destination market, while intra-ASEAN trade remained limited across most solar PV products. The strong reliance on the US as its largest export market for final products and on China for key inputs, especially wafers, exposed the region to risks from trade tensions between the two great powers, particularly losing its largest export market. In response to the risk, AMS should diversify their export destinations by exploring promising solar PV markets. They should also diversify their import sources by strengthening intra-ASEAN trade, given the region having the local resources to manufacture more key inputs. Both will make their solar PV supply chain more resilient when exposed to geoeconomic and political risks during the great power rivalry between the US and China.

Appendix

Section	Product	HS Code	HS Code Version	Detailed Descriptions
3.1 Final products	Solar PV cells or modules	854140	2017	Photosensitive semiconductor devices, including photovoltaic cells whether or not assembled in modules or made up into panels;
		854141	2022	Light-emitting diodes (LED)
		854142	2022	Photovoltaic cells not assembled in modules or made up into panels
		854143	2022	Photovoltaic cells assembled in modules or made up into panels
		854149	2022	Other
	Parts of semiconductor devices	854190	2017	Parts
3.2 Intermediates	Wafers	381800	2017	Chemical elements doped for use in electronics, in the form of discs, wafers or similar forms; chemical compounds doped for use in electronics.
	Polysilicon	280461	2017	Containing by weight not less than 99.99 % of silicon
	Silica sands and quartz sands	250510	2017	Silica sands and quartz sands
3.3 Fixed capital	Machines for wafers	848610	2017	Machines and apparatus for the manufacture of boules or wafers
	Machines for solar PV cells or modules	848620	2017	Machines and apparatus for the manufacture of semiconductor devices or of electronic integrated circuits
	Parts of machines	848690	2017	Parts and accessories

Source: The product names and HS codes are authors' creation based on Caravella, Crespi, Cucignatto, & Guarascio (2024); IEA (2022c, 2024a); Osenius-Eite, Mirrlees-Black, & Scott (2023); United Nations Conference on Trade and Development (UNCTAD) (2024); World Trade Organization & IRENA (2021), and World Customs Organization (n.d.-a) and (n.d.-b). The detailed descriptions of the HS codes are from World Customs Organization (n.d.-a) and (n.d.-b).

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