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The power of global trade

Market dynamics and economic opportunities in climate change mitigation goods

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Executive summary 04

1. Motivation 07

2. The position of climate change mitigation goods in global trade 08

3. Limited number of key players in the markets for climate change mitigation goods 16

4. Risks to deployment arising from dependencies 32

5. Unlocking welfare through global trade 44

6. The way forward – A practical guide for global trade 52

7. Conclusion 57

8. Glossary 58

9. Appendix 60

10. Endnotes 64

Authors 68

Executive summary

Achieving climate action goals requires more than just investing in clean-energy technologies. It also depends on how quickly and reliably manufacturers can produce, trade and deploy environmentally friendly goods across borders. This paper studies green trade flows with a focus on climate change mitigation (CCM) goods to better understand how trade can help deliver on climate action goals. In our analysis, we describe the current market structure and dynamics using indicators ranging from market share and competitiveness to market concentration and dependencies. Our findings suggest that global trade in CCM goods has the potential to deliver significant welfare gains. However, market concentration among a few key suppliers introduces vulnerabilities. Building on these insights, the study shows how we can use global trade to drive decarbonization without compromising competitiveness and supply chain security.

Key insights and implications

1. Climate change mitigation goods are gaining traction in global trade—opening up new export opportunities worldwide. Environmental protection, recycling and climate change mitigation goods already account for more than 10% of global merchandise trade, amounting to 11.4% or USD 2.8 trillion in 2025. CCM goods have become the sector's primary growth engine, with an average annual growth rate of 8.0% between 2017 and 2025—significantly higher than recycling (3.5%) and environmental protection goods (3.8%). For wider context, they also outpaced the 4.7% growth rate of overall global merchandise trade. This trend indicates that decarbonization is actively shaping international trade patterns, rather than merely being a domestic policy issue. However, growth is not consistent across all product segments or trade routes. Clean mobility is particularly dynamic, while other segments lag behind. The key to thriving in expanding international markets is to foster innovation ecosystems and secure strategic positioning, taking into account market momentum, technological expertise, financing needs and comparative advantage.

2. Global exports of climate change mitigation goods are highly concentrated among a few key suppliers—with China and Germany as the largest exporters. In 2025, China accounted for 26% of global exports in climate change mitigation goods, making it the world's leading exporter. Germany ranks second with around 10%, followed by Japan (7%) and the United States (6%). China and Germany have an even stronger position compared with the overall merchandise export market, where their respective shares amount to just 14% and 7%. Although the countries currently in the lead start from a relatively strong position, their competitiveness depends on continued investment, innovation and business-friendly conditions. Industrial policy may help to achieve these objectives by, for example, making climate change mitigation projects attractive to private investors, reducing bureaucratic barriers and simplifying onerous regulations. Finding the right policy mix for each country will depend on its specific market conditions and available resources.

3. High market concentration can create significant deployment risks, highlighting the need for strategic risk management to bolster supply-side resilience. On the export side, 24% of the 182 product categories in the climate change mitigation domain are highly concentrated, compared with 34% across global merchandise trade as a whole – but those affected are the ones where substitution is hardest. A small pool of suppliers dominates the sector's two largest categories: lithium-ion batteries (accounting for 7% of exports in CCM goods) and photovoltaic cells and LEDs (5%). In addition, trade statistics measure cross-border flows rather than production capacity, and these two figures can differ significantly. For example, China has close to 85% of the global production capacity for battery cells, but only a 59% share of exports of finished batteries. Similarly, it has more than 80% of the production capacity of solar PV, but only a 47% share of exported cells and panels, now that more of the final assembly activities are being relocated to Southeast Asia. If importing countries rely on a small number of suppliers and lack alternative sources of supply, this can lead to dependency. The IEA estimates that each month of interruption in battery supply chain exports from China would lead to EV production losses in other regions of around USD 17 billion. More than half of these losses would be in the European Union, where electric mobility is an important segment of specialization. The relevant policy question is not about concentration but rather about how it relates to scale, essentiality and limited substitutability. Potential responses include supplier diversification, additional production capacity and increased circularity. The relative merits of these options depend on the specific risks and costs of the product in question.

4. International cooperation is crucial for maintaining well-functioning markets, and the potential welfare gains from climate change mitigation goods are particularly high. The literature suggests that global trade has positive effects on welfare. Countries and businesses with a comparative advantage in particular product segments can increase their output and access deployment markets more quickly,

resulting in faster scaling and diffusion of technology. For CCM goods, these effects are particularly important for three reasons. Firstly, most of these goods are capital or intermediate inputs, where the gains from trade tend to be larger. Secondly, most of these goods are small, mass-manufactured units, such as modules, cells, heat pumps and lamps, which have seen their cumulative global output double every few years. Both points suggest that market size has a greater impact on costs than either mature markets or large, site-built plants—as illustrated by the falling prices of solar modules (see "Key insights for Germany" on p. 6). Thirdly, because deploying these technologies fights global climate change, they provide an environmental benefit that standard trade calculations fail to capture. Market frictions can limit these potential benefits. However, a stable, rules-based market environment, free from unnecessary barriers and supported by international cooperation, can generate higher gains from trade. Trade agreements are among the few instruments that allow countries to align their climate action objectives with economic incentives. By linking them to market access, they can sustain coalitions that voluntary agreements cannot. Along the same lines, transparent, proportionate and internationally compatible standards can reduce unnecessary barriers to entry while preserving environmental integrity and trust in environmental protection and climate change mitigation goods.

5. Trade has the potential to both accelerate decarbonization and provide economic gains—provided that policymakers align their measures across different sectors. Clean technology is no longer a niche market. Global investment in clean energy and electrification is set to reach around USD 2.2 trillion by 2026, compared to approximately USD 1.2 trillion invested in oil, gas and coal. While investment in fossil energies has remained relatively stable over the last ten years, investment in clean energy has roughly doubled. The market value of key clean energy technologies has grown by around 20% per year during this period and the IEA expects it to double by 2035—under current and announced policies. While global trade can sustain this transition, it also brings serious risks. Success depends on a commitment to address competitiveness vulnerabilities, supply chain dependencies and technical barriers to market access. Our findings support a four-pillar approach to leveraging global trade opportunities in climate technologies: (i) targeting export markets with end-to-end value-chain solutions; (ii) establishing a coherent framework that combines trade, climate, industrial and financing instruments; (iii) managing concentration and dependency risks through diversification and circularity; and (iv) improving global markets for CCM goods by engaging in international cooperation to ensure reliable, rules-based trade. Under these conditions, global trade creates a win-win scenario that drives economic gains and speeds up decarbonization.



Key insights for Germany

Germany is both the second-largest exporter and the second-largest importer of climate change mitigation goods. Exports rose from USD 93 billion in 2017 to USD 172 billion in 2024, while imports increased from USD 67 billion to USD 130 billion. In both cases, growth exceeded the global average for this domain. Germany's position as a global supplier is therefore dependent on a robust, concurrent expansion of imports.

The strong trade position is based on a narrow competitive advantage. Germany has a high market share in four of the fifteen largest export categories: three road-vehicle categories and low-voltage switchboards, all of which have long been areas of strength for the country in both automotive and industrial equipment manufacturing. Germany has no significant comparative advantage in the largest product categories, including lithium-ion batteries and photovoltaic cells. Clean mobility, which is the fastest growing segment in our study, seems to hold the greatest potential for the country. Germany led global exports in this segment from 2020 to 2023 until China caught up in 2024, achieving a 16% market share compared to Germany's 17%. In 2025, China took the lead with a share of 18%, while Germany's remained at 17%.

The potential for import dependencies is greatest in the categories most relevant for deployment. Overall, Germany's position is comparatively strong: Of the CCM product categories Germany imports, only 41% come from highly concentrated supplier markets, which is the lowest share among the 226 countries in the sample. However, photovoltaic cells and LEDs are mainly sourced from a single supplier, primarily in China, which can result in dependency risks. The situation is different for lithium-ion batteries, which come from a wider set of countries. We should note that diversification is measured at the point of shipment, and that one stage further upstream Chinese manufacturing capacity in battery cells far exceeds Chinese export shares in finished batteries. This creates a significant vulnerability for Germany, as its signature clean mobility products rely on these exact cells.

Structural alignment is highest with European neighbours rather than China. Germany's export profile aligns most closely with that of the Czech Republic—which can indicate direct market competition as well as integration in the same regional value chains. By comparison, Germany shares a relatively low structural alignment with China, the world's leading exporter, where there is limited overlap in their overall export compositions. However, within the clean mobility segment, competition with China is much more intense, in line with the convergence of German and Chinese export shares in the segment.

Implications for German trade policy. While Germany specializes in the downstream production of assembled vehicles and electrical equipment, much of its risk exposure lies in the upstream production of cells and associated components. The four pillars of trade policy apply accordingly. In terms of export opportunities, it is better to defend this position than to broaden it, selling the underlying technologies as complete solutions rather than as isolated products. In terms of industrial policy, demand-side initiatives on their own will only go so far in boosting domestic returns. They are more effective when paired with upstream measures, including funding for research and production capacity for cells, modules and semiconductor equipment, tailored to the specific market conditions. In terms of risk and dependency, the right instrument depends on the availability of alternatives. The decision to build production capacity should be reserved for the narrow intersection of high supplier concentration, high import exposure and low substitutability. In terms of international cooperation, rules-based trade brings measurable economic benefits to Germany: relying entirely on local supply chains would have driven module prices roughly 83% higher in 2020. There are also business opportunities that allow German enterprises to profit from international demand. Ultimately, the key to Germany benefitting from trade lies in strategically balancing these risks and rewards. One way to achieve this balance is through trade and investment agreements negotiated at EU level.

1. Motivation

The global economy is in transition, with climate change mitigation increasingly at its centre. This transition not only affects domestic investment priorities but is also rapidly reshaping international trade patterns. Trillions of dollars have been redirected from fossil-based technologies to clean alternatives, creating a climate-friendly economy that is opportunity-rich but also fiercely competitive. Over the medium term, we can expect fossil-based technologies to lose ground, while clean technologies experience steep growth. Global investments in clean technologies reached around USD 2.1 trillion in 2025, roughly twice the level of investment in fossil-based technologies, highlighting the scale and direction of change. The IEA expects similar figures for 2026, with clean tech investments estimated at around USD 2.2 trillion, compared to approximately USD 1.2 trillion for oil, natural gas and coal.[1] Over the last decade, the market value of key clean energy technologies has grown by around 20% per year on average, reaching nearly USD 1.2 trillion in 2025. In the IEA's Current Policies Scenario (CPS), this figure doubles to around USD 2 trillion by 2035, while the more ambitious Stated Policies Scenario (STEPS) sees it reach almost USD 3 trillion. In all scenarios, electric vehicles account for the largest share of the clean energy technology market, covering around three-quarters of the total market value in 2035.[2]

With all the potential for growth these dynamics offer, the key to securing a competitive market position lies in leveraging global supply chains and accessing cutting-edge technologies—though different countries and sectors are starting from very different positions. Existing production capacities and capacity gaps vary widely along green value chains. International trade plays a central role in addressing these imbalances. It enables the efficient global provision of green goods by allowing countries to specialize and capitalize on their comparative advantages. It also drives innovation, helps to achieve economies of scale and accelerates the spread of clean technologies.

The advantages of well-functioning markets and global economic integration provide a powerful incentive for international cooperation, which is essential to confront the global challenge of climate change. At the same time, increasing global trade in green goods plays a key role in development and financing: It facilitates technology transfer to emerging and developing economies, supports resilient and sustainable growth, and expands access to climate-friendly infrastructure and solutions.

Focusing on CCM goods and their specific segments, this paper offers a descriptive analysis of global trade flows by analysing export and import values, market shares, specialization, concentration and bilateral trade structures. It provides critical insights into how the benefits of the green transition are distributed internationally, where competitive strengths and vulnerabilities lie, and how to leverage identified trade patterns to unlock additional mitigation and development opportunities. These indicators highlight potential channels for technology diffusion and potential supply chain vulnerabilities. Understanding these patterns is essential for mobilizing investment at scale and can provide businesses, policymakers and financial institutions with the insights they need to uncover opportunities for future growth.



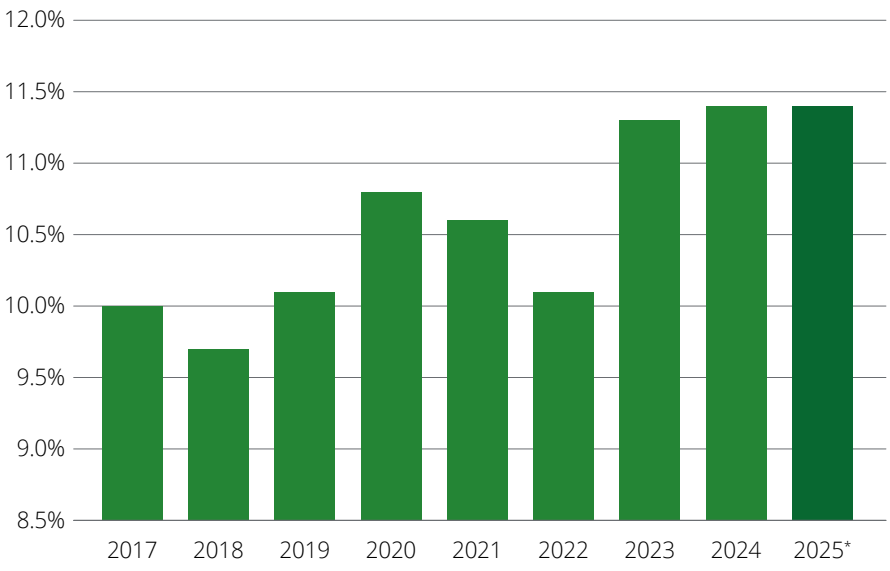
2. The position of climate change mitigation goods in global trade

The transition to a low-carbon economy is fundamentally reshaping international trade and creating a rapidly growing market for climate-friendly products and technologies. This chapter provides an overview of recent developments in climate change mitigation goods—as the most dynamic part of the broader field of green goods.

2.1 Development of trade in green goods

The market share of green goods, based on the classification of goods set out in the OECD's updated Combined List of Environmental Goods (CLEG), is on an upward trend overall (Figure 1). Their share of global trade rose from 10% in 2017 to 11.4% or USD 2.8 trillion in 2025, highlighting their growing importance to the global economy. This trend is even more pronounced in terms of average growth rates: The global value of trade in green goods rose by 6.3% p.a. on average between 2017 and 2025, compared with 4.7% for total merchandise trade.

Fig. 1 – Share of green goods in total merchandise trade
in %



* Projection.
Source: CEPII BACI, HS2017, 2017–2024, and Trade Map (International Trade Centre), HS2022, 2025; authors' calculations (see methodology note on p. 10 for more details).

2.2 Climate change mitigation goods as the growth engine in the green goods sector

The list of green goods comprises 314 harmonized system commodity codes from the 2017 edition (HS2017) that can be grouped, at the highest level, into three overarching domains: climate change mitigation, circular economy and recycling, and environmental protection, collectively referred to as "green goods". Of these 314 commodity codes, 182 are classified as climate change mitigation goods, which we analyse in greater detail in Section 2.3.



Climate change mitigation goods

CCM goods are products designed to reduce greenhouse gas emissions. Following the OECD classification, we divide this domain into three segments: goods used for low-carbon mobility, goods that improve the energy performance of buildings, and goods used to generate, convert, store and distribute renewable energy. See methodology note on p. 10 for more details.

Environmental protection

The remaining OECD categories fall under the umbrella term 'environmental protection', which includes water treatment and wastewater management, air pollution control and noise abatement, as well as environmental monitoring and analysis equipment. These goods are in high demand in industrialized economies. Goods designed primarily to conserve biodiversity or to promote the sustainable use of natural resources, such as certain technologies for water treatment, land management or nature-based solutions, most likely fall into this domain. If they appear on the list at all, this is the most plausible domain for them, since their ecological rationale lies more in ecosystem stewardship than in the direct reduction of greenhouse gases.

Recycling

The Solid Waste Management (SWM) group comprises facilities and goods used for the recovery, sorting and processing of waste materials. This includes industrial composting plants, steel scrap processing equipment and paper recycling machinery. Although this segment has a smaller trade volume than CCM goods, it is particularly relevant for analysing resource efficiency and circular economy policies.

Methodology note:
Green goods and climate change mitigation goods: product universe, data sources and limitations

Product universe
This study classifies green goods according to the OECD Combined List of Environmental Goods (CLEG) adapted to the HS2017 nomenclature, yielding a final dataset of 314 distinct commodity codes. At the broadest level, these goods fall into three domains: climate change mitigation, the circular economy and recycling, and environmental protection. CCM goods constitute a subset of 182 commodity codes associated with reducing greenhouse gas emissions. These include goods used for generating renewable energy and related infrastructure, energy-efficient buildings and low-carbon mobility. In Section 2.3, the CCM goods are divided into three segments: Renewable Energy Systems (RES), Energy Efficient Housing (EEH) and Clean Mobility (CMO).

Data sources
We sourced the trade data for the period from 2017 to 2024 from CEPII's BACI database[3] and the data for 2025 from Trade Map, the International Trade Centre's database of trade statistics.[4] Our analysis of the BACI data is based on the OECD's Combined List of Environmental Goods, using the HS2017 classifications. The Trade Map data is based on the current HS2022 classifications, which the OECD uses to identify an equivalent list of green goods. As the 2025 figures rely on a different data source, comparisons between 2024 and 2025 should be treated with caution. Figures and tables covering the period from 2017 to 2025 identify the respective data source in their notes. Trade values are in current USD.

When interpreting these results, it is important to note that gross trade data includes re-exports and international assembly. These metrics therefore capture total cross-border product flows rather than the specific domestic value added from the production of CCM goods.

Excluded areas
In line with the scope of the CLEG framework, this study focuses on goods related to environmental protection and greenhouse gas mitigation rather than the full range of goods associated with environmental and climate policy. Carbon capture and storage (CCS) technologies are not systematically identifiable within the classification. Climate adaptation goods, such as flood-protection infrastructure, drought-resistant agricultural inputs and heat-resilient construction materials, are also outside the analytical scope. As they address vulnerability to the physical impacts of climate change rather than directly reducing greenhouse gas emissions, they require a separate conceptual and empirical framework.

Note on interpretation
The classification identifies product categories associated with environmental or mitigation objectives. However, this does not necessarily mean that every product with an assigned HS code is exclusively designed to protect the environment or reduce emissions by a specific amount, since HS codes may cover multiple applications. The results should therefore be interpreted as evidence of international trade in product categories relevant to climate change mitigation. This analysis does not directly measure lifecycle emissions, domestic value added, actual technology deployment or the emissions reductions resulting from the use of traded products—nor does it consider emissions from the physical transport of the goods.

The product universe is defined at the six-digit HS level, which limits what we can observe. Technologies with largely general-purpose equipment, such as carbon capture and storage or electrolysers for low-emissions hydrogen, have no dedicated codes and are therefore not represented as such. The same applies to upstream activities, including cells, wafers and processed raw materials. In addition, the results cover only the traded goods identifiable by the classification, not the full set of technologies relevant to climate change mitigation.

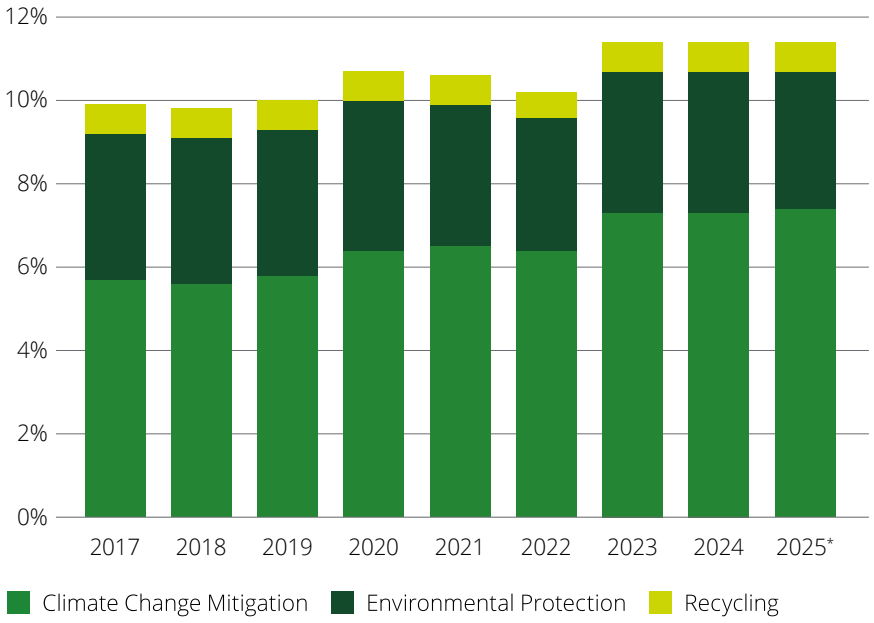
When we examine bilateral trade flows across the full set of 314 commodity codes for green goods starting from 2017, the first year with consistent coverage under the HS2017 nomenclature, we see a difference in the significance of trade between the three broad product categories identified above (Figure 2). CCM goods account for 7.4% of global merchandise trade compared to 11.4% of green goods overall. They therefore represent roughly two-thirds of total green-goods trade, while environmental protection and recycling together account for the remaining one-third.

The aggregate trend in green trade is driven mainly by CCM goods rather than by the other two domains. The share of environmental protection goods and recycling technologies has remained fairly stable during this period, while the trajectory of CCM goods tells a very different story. Not only do CCM goods account for the largest share of green trade by value, but they have also recorded the strongest growth since 2017. The average annual growth rate of CCM goods was 8.0% from 2017 to 2025, more than merchandise trade as a whole (4.7%) and also more than trade in green goods in general (6.3%) and environmental protection and recycling in particular (3.8% and 3.5%).

The drivers behind the rising climate-goods trajectory are straightforward but crucial for our analysis. Firstly, the cost of clean technologies, from photovoltaic to wind power and batteries, has fallen—lithium-ion cell prices, for example, have dropped by 99% since 1991, mainly due to economies of scale and efficiency gains.[5] In conjunction with energy transition initiatives at the national level and the increasing impact of carbon pricing mechanisms, the competitive landscape has shifted in favour of clean capital goods. Demand for CCM goods closely tracks the accelerating deployment of renewable energy capacity worldwide, the rapid scaling of energy-efficient industrial and building technologies, and the increasing integration of low-carbon solutions into global supply chains.

CCM goods also play an important role in policymaking. The central question behind this study is whether and to what extent international trade promotes or restricts the diffusion of mitigation technologies between countries. The best way to respond to this question is to examine those goods with the greatest direct impact on emissions reduction. Renewable energy equipment, high-efficiency industrial machinery and climate change mitigation technologies form the backbone of the global energy transition. Understanding how the production, import and bilateral trade flows of these goods evolve over time is therefore relevant for assessing policy options—for negotiating trade agreements, shaping climate-friendly industrial policy or financing international climate action. The following analysis focuses on climate change mitigation goods precisely because they are so important for economic, political and mitigation policies.

Fig. 2 – Share of different domains of green goods in global trade
in %



* Projection.
Source: CEPII BACI, HS2017, 2017–2024, and Trade Map (International Trade Centre), HS2022, 2025; authors' calculations (see methodology note on p. 10 for more details).



2.3 The three segments of climate change mitigation goods

In the next step, we analyse the domain of CCM goods in more detail. This involves dividing the 182 different CCM goods into three mutually exclusive segments (see also Figure 3), using the OECD's CLEG taxonomy as a guide with only minor adjustments:[6]

- **Renewable Energy Systems (RES):** RES comprises goods used to generate, convert, store and distribute renewable energy. It covers photovoltaic and concentrated solar technologies (including solar cells, modules, wafers, solar glass, mirrors and related manufacturing equipment); wind and hydropower equipment (including turbines, generators, towers, gearboxes and components); solar water heaters; and equipment for geothermal, biomass, biogas and hydrogen applications. It also includes energy-storage devices, electrical converters, transformers, control equipment and other grid-related components.
- **Energy Efficient Housing (EEH):** EEH comprises goods that improve the energy performance of buildings, including thermal and acoustic insulation materials (e.g., glass and mineral wool, cork, plastic insulation and fibre-based panels), insulating glass and solar window films, energy-efficient lighting and fittings, low-carbon or insulating construction materials, heat-exchange units, and smart energy meters and their components. It also includes heat pumps as well as air-conditioning equipment, such as reversible heat pumps, window, wall, ceiling, floor and split-system air conditioners.
- **Clean Mobility (CMO):** CMO comprises goods used for low-carbon mobility, including electric and hybrid vehicles along with related vehicle parts, rail and tramway rolling stock, rail infrastructure, signalling and traffic-control equipment, and bicycles and their components. The segment also includes hydrogen and ammonia as energy carriers, hydrogen-capable combustion engines, gas containers, selected batteries, trailers and semi-trailers as well as certain ancillary appliances and equipment.

By dividing the domain into RES, EEH, and CMO, we show that each segment has a specific technology track and therefore a specific profile in terms of suppliers, diffusion speeds and supply bottlenecks, rather than the general properties of goods classified under "climate change mitigation". It is important to understand the different types of goods as well as their product-specific characteristics and bottlenecks before moving on to the detailed analysis of concentration, dependencies and competition in later subsections.

Fig. 3 – Composition of the global trade value of CCM goods by product category
in USD, 2024



Source: CEPII BACI (HS2017), 2017–2024; authors' calculations (see methodology note on p. 10 for more details).

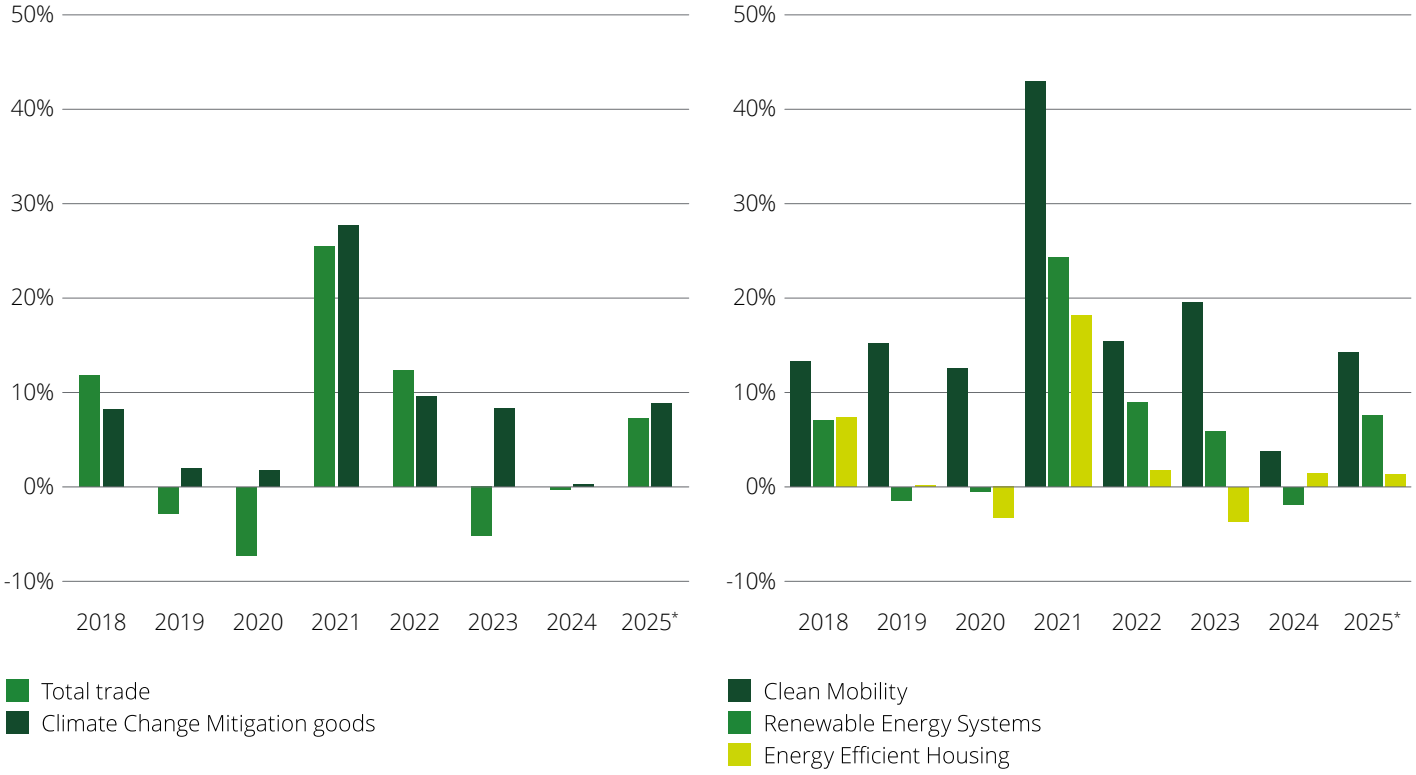
The top 15 product categories account for approximately 61% of the total global export value of CCM goods (see Appendix A), and the six largest categories account for around 39%. This suggests that the CCM goods portfolio is concentrated in a relatively small number of key product groups, even though there is a total of 182 HS product categories in this classification.

Growth rates differ widely across the different groups of CCM goods (Figure 4). Average growth rates from 2018 to 2025 are highest in CMO (16.7%), lowest in EEH (2.7%) and range in between for RES (6.0%).

These growth patterns reflect the different characteristics of each group of goods. Key drivers include falling costs for solar photovoltaic and wind power, national energy transition initiatives and the growing impact of carbon pricing. Together, these forces alter the relative competitiveness of clean versus fossil-based technologies.

Annual growth rates offer further insight into the different dynamics at play across the three segments. Clean Mobility was the main driver of growth, recording the highest rates in every year. This includes a spike of 43.0% in 2021 as well as above-average annual growth of approximately 15.4% in 2022 and 19.5% in 2023. Trade in Energy Efficient Housing generally follows the same pattern as Clean Mobility, with a less pronounced spike in 2021. Unlike Clean Mobility, however, the trade value in the Energy Efficient Housing segment declined in 2020 and 2023. The annual growth rate of Renewable Energy Systems generally falls between the other two segments. It peaked at 24.3% in 2021 and was lower in other years. In two years, 2019 and 2024, trade values actually fell year-on-year, before recovering in 2025.

Fig. 4 – Growth in total merchandise trade and trade in CCM goods
Change in the trade value (USD) compared to the previous year, in %



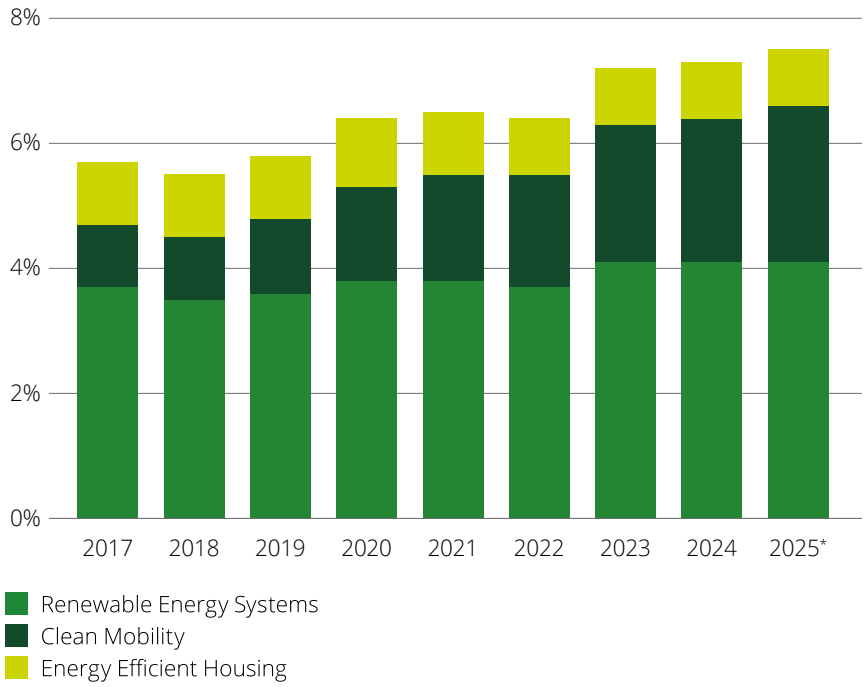
* Projection.
Source: CEPII BACI, HS2017, 2017–2024, and Trade Map (International Trade Centre), HS2022, 2025; authors' calculations (see methodology note on p. 10 for more details).

As a result, there has been a shift in the relative share of the three segments, leading to corresponding changes in their share of the total merchandise trade. Between 2017 and 2025, Renewable Energy Systems remained the largest segment within CCM goods, although its share declined from around 64% to 55% of the overall trade value in this domain. Clean Mobility was the second-largest segment, expanding its share from about 18% to 33% over the same period. Energy Efficient Housing remained the smallest segment, with its share falling by around six percentage points to 12% in 2025. The shift in segment shares points to a significant realignment in CCM goods.

These fluctuations within the CCM goods domain have an impact on the share of the three segments in global merchandise trade (Figure 5). In 2025, the share of Energy Efficient Housing in the total value of global trade in merchandise remains at 2017 level. Although the share of Renewable Energy Systems has increased to 4.1%, this 0.4 percentage point increase is significantly smaller than that of the Clean Mobility segment, which increased its share of global merchandise trade from 1.0% to 2.5%. In other words, growth patterns in CCM goods not only reflect an increase in overall trade value but also a shift towards mobility-related products.

Growth in the Clean Mobility segment is concentrated in a small number of vehicle categories. In 2024, battery-electric vehicles accounted for 8% of global exports of CCM goods, non-plug-in hybrid vehicles for 8%, and plug-in hybrid vehicles for 4%. Together, these three categories made up 20% of total trade in CCM goods in 2024, suggesting that growth in Clean Mobility tracks the increase of trade in electric and hybrid vehicles.

Fig. 5 – Share of CCM goods segments in global trade
in %



* Projection.
Source: CEPII BACI, HS2017, 2017–2024, and Trade Map (International Trade Centre), HS2022, 2025; authors' calculations (see methodology note on p. 10 for more details).

3. Limited number of key players in the markets for climate change mitigation goods



Our analysis has established that CCM goods are the fastest growing domain within green trade. In this chapter, we analyse who is supplying these markets and where demand is highest on the international market by looking at export and import positions, the bilateral structure of trade flows and the intensity of competition among the leading exporters.

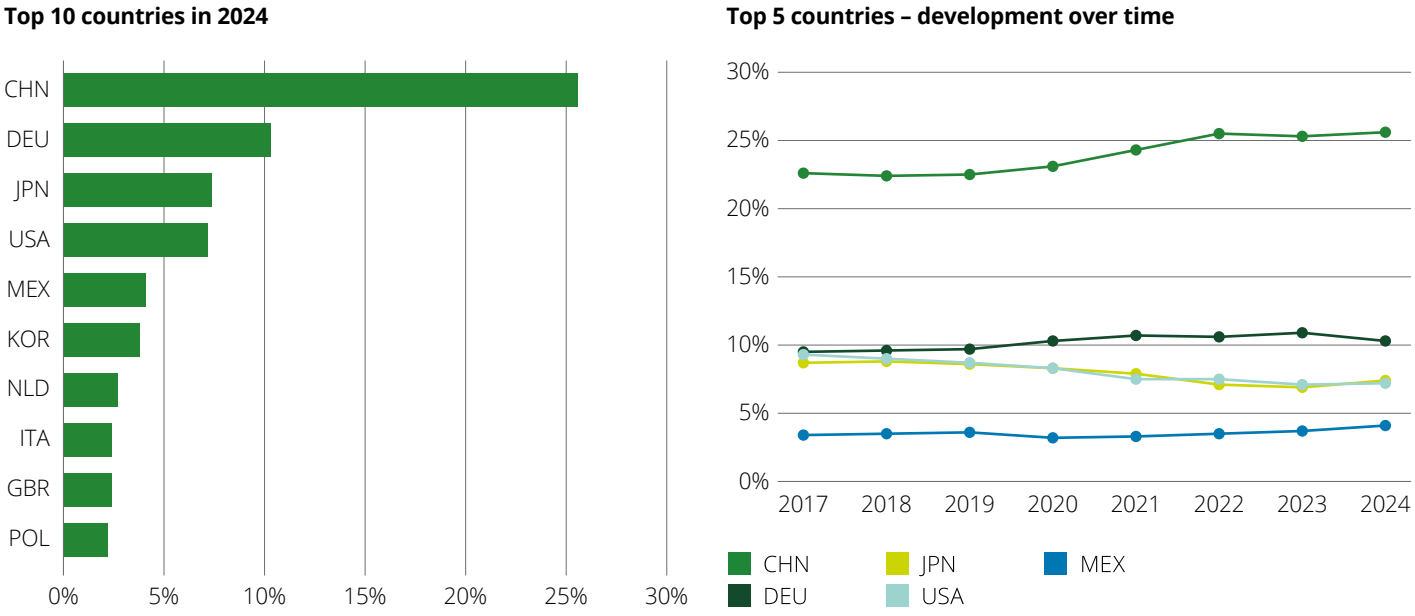
3.1 The position of individual countries in the trade in climate change mitigation goods

A small number of countries, notably China, Germany, Japan and the United States, account for a significant share of global exports of CCM goods. This concentration of export value reflects differences in economies of scale, technological capabilities and their position within international supply chains. China is the largest exporter of CCM goods, and its lead has actually grown over time to approximately 26% of global exports in 2024 (Figure 6). Germany ranks second overall with around 10% of global exports; its share rose between 2017 and 2023, declining only slightly in 2024. Japan and the United States follow with approximately 7% each. Mexico ranks fifth with around 4% and has shown a slight upward trend over time.

Based on International Trade Centre data, projections for 2025 suggest there will be no change at the top of the rankings. China, Germany and Japan appear to be maintaining a relatively stable share of global exports, at about 26%, 10% and 7% respectively, while the US has likely lost ground (6%).

To some extent, this pattern reflects the overall shares in global trade. However, China's leadership position in CCM goods is much more pronounced than its lead in merchandise trade as a whole, where the country accounted for only 15% of global exports overall in 2024 (and 14% in 2025).[7] The same is true for Germany, which ranks second for CCM goods, while accounting for just 7% of exports in both 2024 and 2025, taking into account all goods traded on global markets.

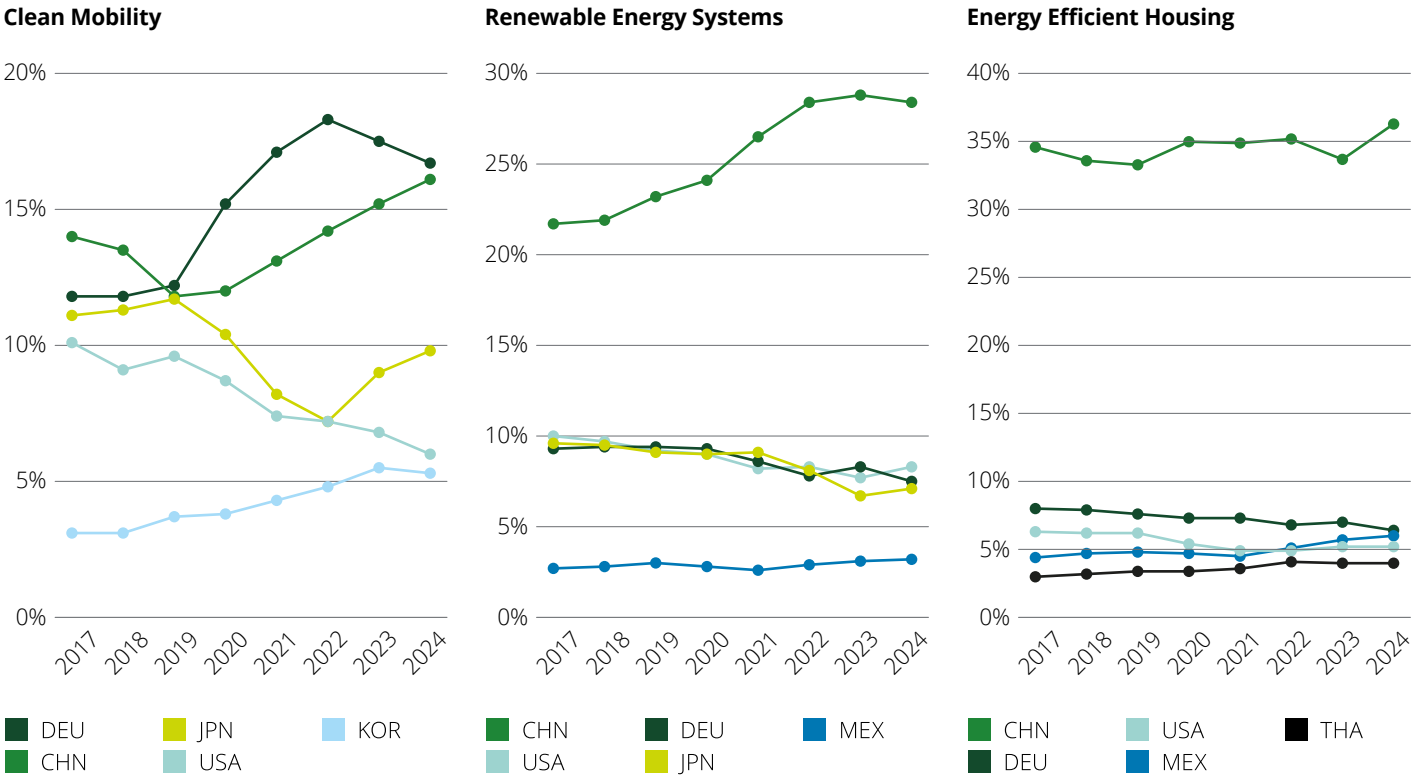
Fig. 6 – Main exporting countries of CCM goods
Export by country as percentage of total exports of CCM goods



Source: CEPII BACI, HS2017, 2017–2024; authors' calculations (see methodology note on p. 10 for more details).

As the largest exporter of CCM goods overall, China also leads exports in two of the three key segments: with a share of around 28% of the trade value in Renewable Energy Systems and approximately 36% in Energy Efficient Housing (Figure 7). In both segments, the export shares of the countries that follow are relatively similar. Competition is more intense in the Clean Mobility segment. Germany was the leading exporter from 2020 to 2023 until China caught up in 2024, and now the two countries account for around 17% and 16% of global exports, respectively. Japan ranks third with approximately 10%. Based on data from the International Trade Centre, projections indicate that China will overtake Germany in this segment of CCM goods in 2025, reaching a share of 18% of the global export value (Germany: 17%).

Fig. 7 – Top 5 exporting countries by segment of CCM goods
Export by country as percentage of total exports by segment of CCM goods

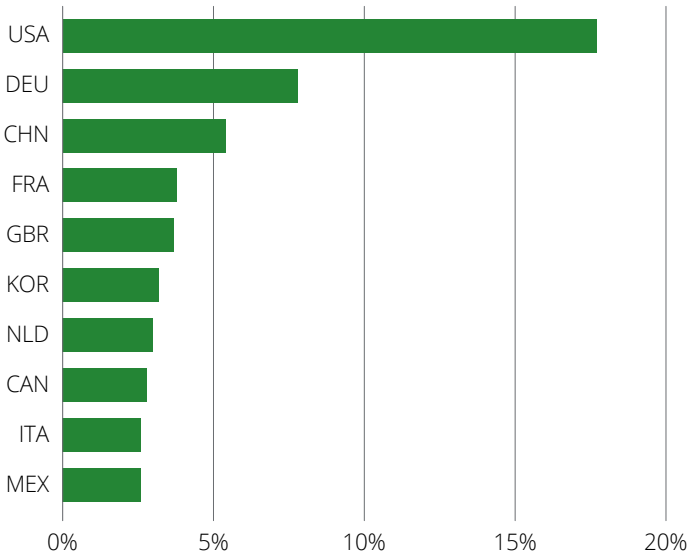


Source: CEPII BACI, HS2017, 2017–2024; authors' calculations (see methodology note on p. 10 for more details).

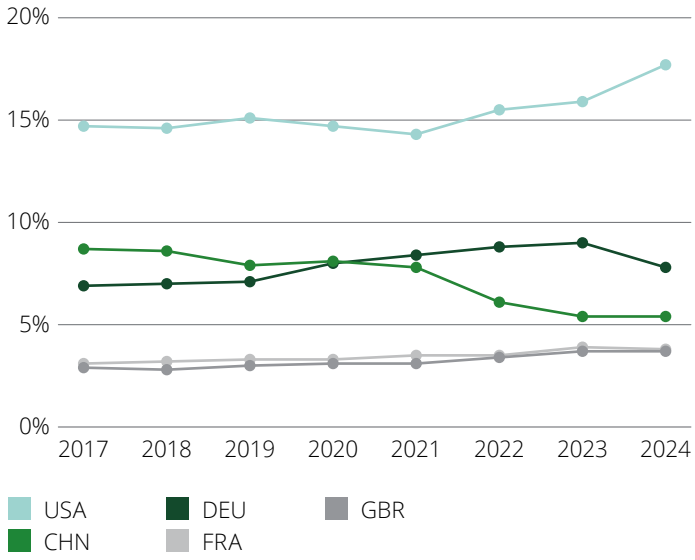
The United States was the largest importer of CCM goods between 2017 and 2024, accounting for approximately 18% of global imports in 2024 (Figure 8). It also led imports in Renewable Energy Systems, Energy Efficient Housing and Clean Mobility, with shares of around 18% in each segment (Figure 9). Germany ranked second among the leading importers in all three segments, accounting for approximately 9% of imports in Renewable Energy Systems, around 6% in Energy Efficient Housing and 7% in Clean Mobility. Germany also became the second-largest importer of CCM goods overall, surpassing China, whose relative share of imports declined to about 5% between 2017 and 2024, while Germany's share stood at 8% in 2024. France and the United Kingdom follow with nearly identical shares of 3.8% and 3.7%, respectively. Based on International Trade Centre data, estimates suggest that the situation will remain largely unchanged in 2025. However, the projected share of imports from the US fell to about 15%, while no change is expected in the shares of the other countries.

Fig. 8 – Main importing countries of CCM goods
Import by country as percentage of total imports of CCM goods

Top 10 countries in 2024



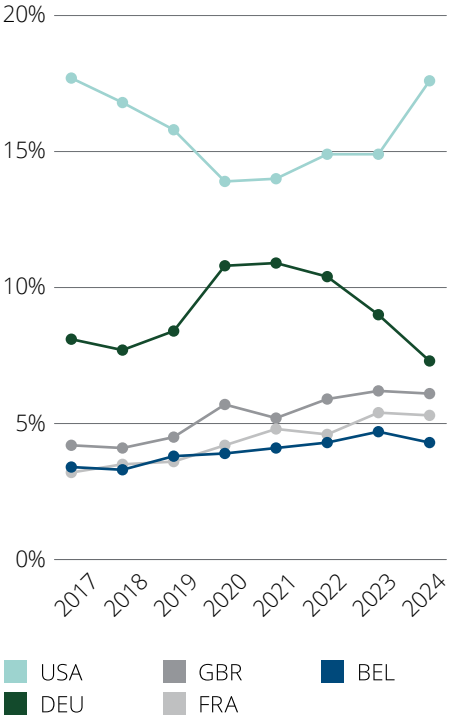
Top 5 countries – development over time



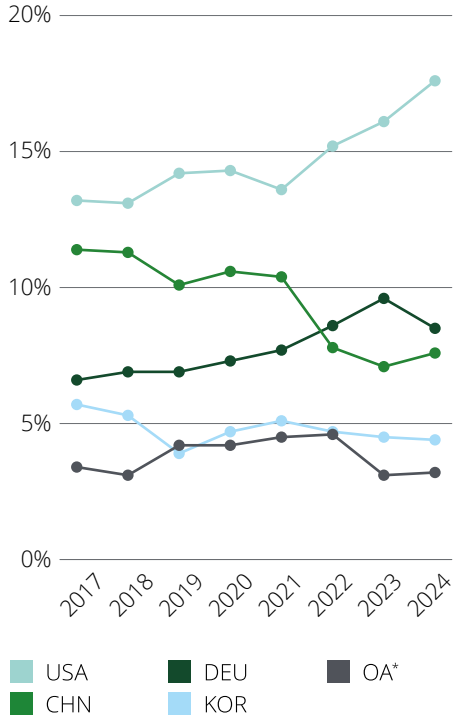
Source: CEPII BACI, HS2017, 2017–2024; authors' calculations (see methodology note on p. 10 for more details).

Fig. 9 – Top 5 importing countries by segment of CCM goods
Import by country as percentage of total imports by segment of CCM goods

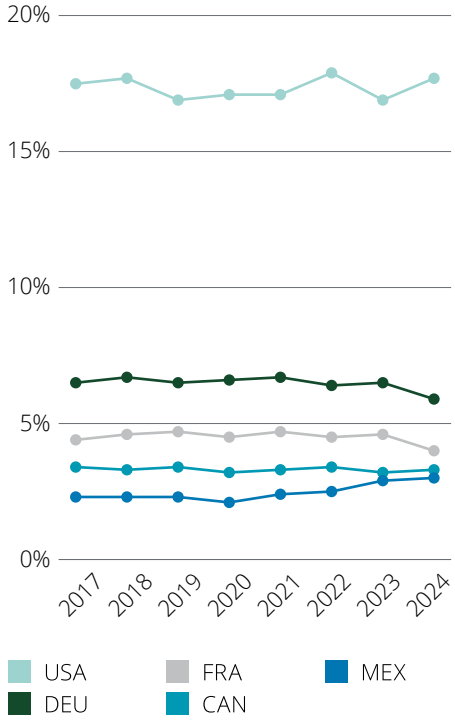
Clean Mobility



Renewable Energy Systems



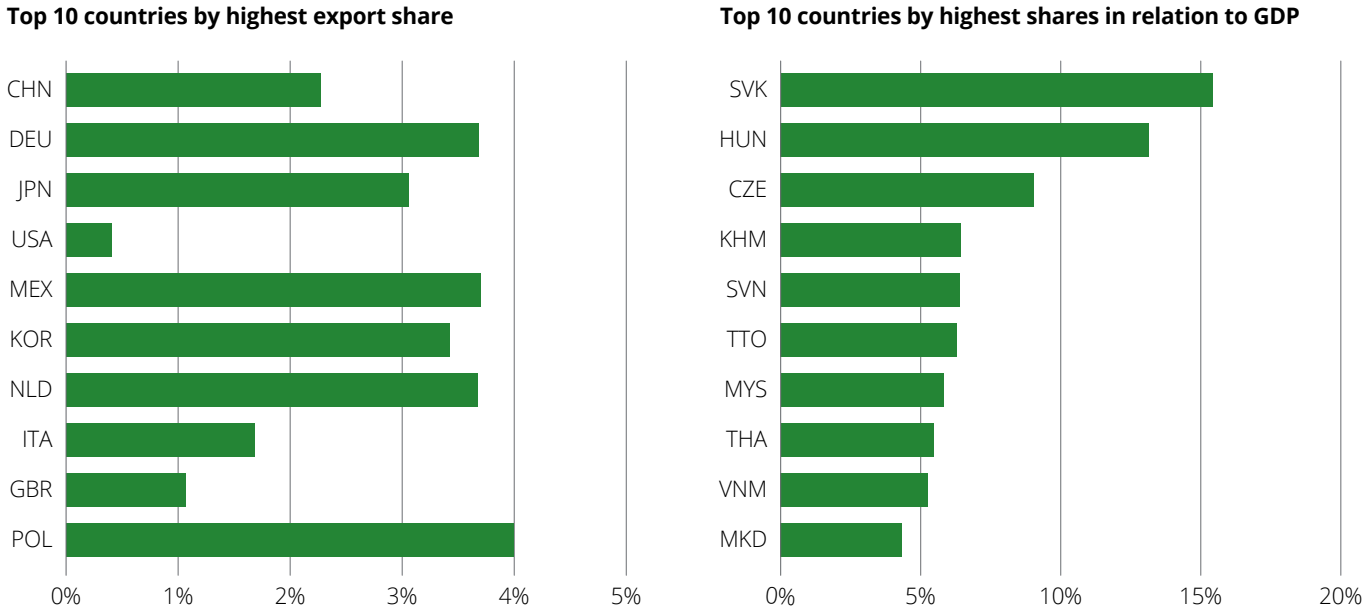
Energy Efficient Housing



*OA is Other Asia, esp. Taiwan.
Source: CEPII BACI, HS2017, 2017–2024; authors' calculations (see methodology note on p. 10 for more details).

Two aspects are worth noting when interpreting these figures. Firstly, export shares tend to reflect cross-border trade rather than domestic production. This may understate the position of China and other countries with large domestic markets. Such countries absorb a significant proportion of their own production, so their share of global manufacturing is likely to exceed their share of global exports. Secondly, there is considerable variation in the importance of CCM goods relative to a country's GDP. Smaller countries tend to be more open to trade. It is therefore hardly surprising that trade in CCM goods accounts for a comparatively large share of economic output in many smaller countries, while the relative weight is often lower in the largest exporting and importing economies. In smaller countries in particular—for example, Slovakia, Hungary and the Czech Republic—exports of CCM goods make up a large share of GDP (Figure 10). Among the major exporters and importers of CCM goods, this trade tends to be less significant in terms of its share of economic output, though it can still be substantial, accounting for more than 3% of GDP in six of the ten countries (Figure 10).

Fig. 10 – Importance of exports of CCM goods relative to economic output
Export of CCM goods in relation to GDP (2024) in %



Note: The left panel lists the 10 countries with highest shares in exports of CCM goods; the right panel displays the 10 countries with the highest share of exports in CCM goods relative to GDP.
Source: CEPII BACI, HS2017, 2017–2024; authors' calculations (see methodology note on p. 10 for more details).

3.2 Bilateral trade in climate change mitigation goods

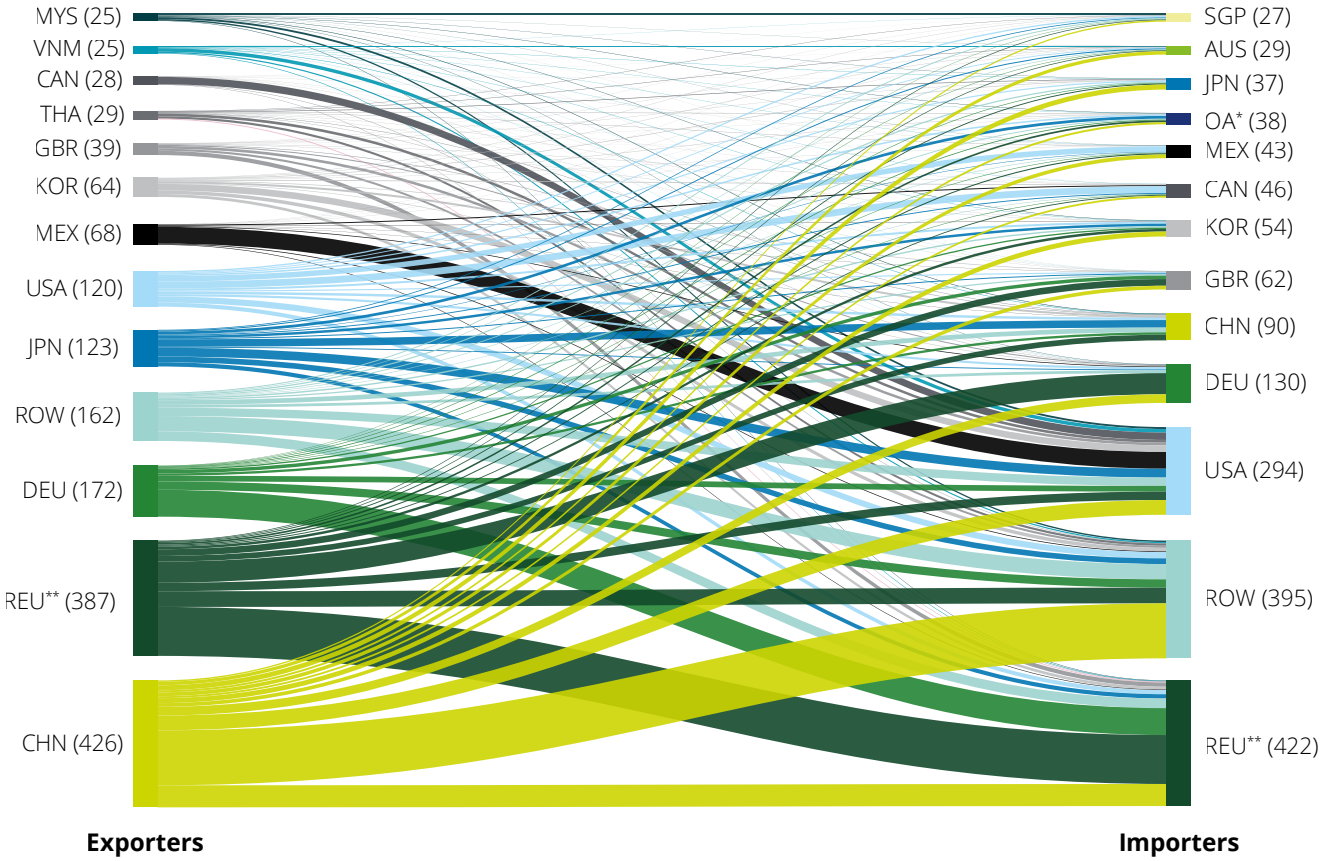
Bilateral trade flows provide insight into which countries trade with one another. The chapter outlines the underlying structure, for example, which countries trade with which partners and how trade relations are grouped into typical trade routes. This approach matters for two reasons:

- **CCM goods are embedded in international value chains.** A significant share of trade reflects not only final demand, but also intermediate production, component specialization and cross-border assembly operations. As a result, a lack of suppliers is not the only source of deployment risk; disruptions in the upstream value chain can also pose a risk.
- **Trade networks lead to uneven exposure.** When trade relations are concentrated in certain bilateral links, shocks do not spread symmetrically. Some partner routes become choke points, potentially delaying deployment, impacting costs and slowing down the process of mobilizing alternative suppliers.

Bilateral trade structure connects competitiveness to resilience. Two exporters may occupy a similar overall position on global markets, yet their risk exposure differs depending on whether alternative bilateral routes exist and how quickly they can reconfigure supply chains. In the event of a demand shock, the exporting country must find new buyers for its products—in fact, the composition of its customer base will influence the probability of such events in the first instance. The reverse argument also applies to importing countries. This suggests that the finance sector and policymakers must go beyond global rankings when assessing risks and take the architecture of trade relations into account as well.

Bilateral trade flows of CCM goods show that the majority of trade takes place between industrialized countries (Figure 11). It is also important to note that a substantial volume of trade occurs within the EU. Equally evident is the central role that China plays as a supplier CCM goods, particularly for many smaller countries as well as developing and emerging economies.

Fig. 11 – Bilateral trade in CCM goods
Trade value in billions USD, 2024



* OA is Other Asia, esp. Taiwan, ** REU is EU excluding Germany.
Source: CEPII BACI, HS2017, 2017–2024; authors' calculations (see methodology note on p. 10 for more details).

The following findings are notable with regard to the development of bilateral trade flows since 2017 for key participants in the trade of CCM goods:

- China is the world's largest net exporter of CCM goods, substantially expanding its trade surplus since 2017. Gross exports increased from USD 221 billion to USD 426 billion in 2024, with imports largely stable at around USD 90 billion. Chinese exports to smaller markets, grouped under rest of the world (ROW), and to European countries saw relatively strong growth. In contrast, exports to the US declined in relative terms, mirroring the broader pattern of China's overall goods trade.

- The United States is the largest net importer. While exports of CCM goods increased from USD 91 billion in 2017 to USD 120 billion in 2024, imports rose even more from USD 144 billion to USD 294 billion. Similar to its exports to the US, China's share of US imports has declined significantly. Other Asian countries such as South Korea, Thailand and Vietnam have become increasingly important as suppliers of CCM goods, as have all the other countries grouped under ROW.

- European economies are key players in global trade in CCM goods, largely because of intra-European trade, though their trade balances vary considerably. The EU member states (excluding Germany) and the UK recorded exports of CCM goods worth approximately USD 426 billion, compared with imports totalling USD 484 billion, resulting in a moderate trade deficit. While the UK was already a net importer of CCM goods in 2017, the other EU countries (excluding Germany) have collectively shifted from being net exporters to net importers. Germany has strengthened its standing as a net exporter since 2017. Its exports rose from USD 93 billion to USD 172 billion, while imports increased from USD 67 billion to USD 130 billion.

The analysis of bilateral trade flows shows that the largest players in international markets have starkly different trade balances. While China and Germany are net exporters, the United States, the rest of the EU and the UK are net importers. Over time, the structural balances of these major players have shifted. China has consolidated its position as the leading global net exporter. Germany has also strengthened its standing as net supplier of CCM goods in international markets. Conversely, the United States remains the largest net importer, marked by a deepening trade deficit. For other major trading nations such as Japan, South Korea and Mexico, the value of CCM exports consistently outpaces imports. This implies that many smaller developing and emerging economies operate as net importers, with a substantial portion of their demand met directly by China.



Spotlight on Germany

Germany plays a dual role in the global market for CCM goods, acting as both a major exporter and importer. It is the second-largest exporter accounting for around 10% of global exports and has seen its share rise between 2017 and 2024. It is also the second-largest importer after the US, having overtaken China. Exports rose from USD 93 billion in 2017 to USD 172 billion in 2024, while imports increased from USD 67 billion to USD 130 billion, amounting to roughly 9% and 10% growth per year and exceeding the global average of 8% for this domain. The simultaneous increase in exports and imports may stem from rising domestic demand and perhaps also greater integration in international value chains, for example in the case of battery imports, which are used as an intermediate product for electric vehicles.

The export dynamics in the different segments are more nuanced than the big picture. In the fastest-growing segment, Clean Mobility, Germany was the leading global exporter between 2020 and 2023. China caught up in 2024, achieving a comparable share of 16% of global exports (see Figure 7), and surpassed Germany in 2025. Germany ranks third in Renewable Energy Systems with 8%, behind China (28%) and the US (8%). In Energy Efficient Housing, Germany ranked second with a 6% share, behind China (36%) in 2024. Germany ranks second for imports in all segments, accounting for approximately 9% of global imports in Renewable Energy Systems, 6% in Energy Efficient Housing and 7% in Clean Mobility.

Germany's dual role in export and import markets indicates a strong export position, but one that rests on a robust, concurrent expansion of imports. This may reflect its integration in international production networks. Germany remains a major exporter, although its position is being challenged, particularly in the fastest-growing segment, Clean Mobility.

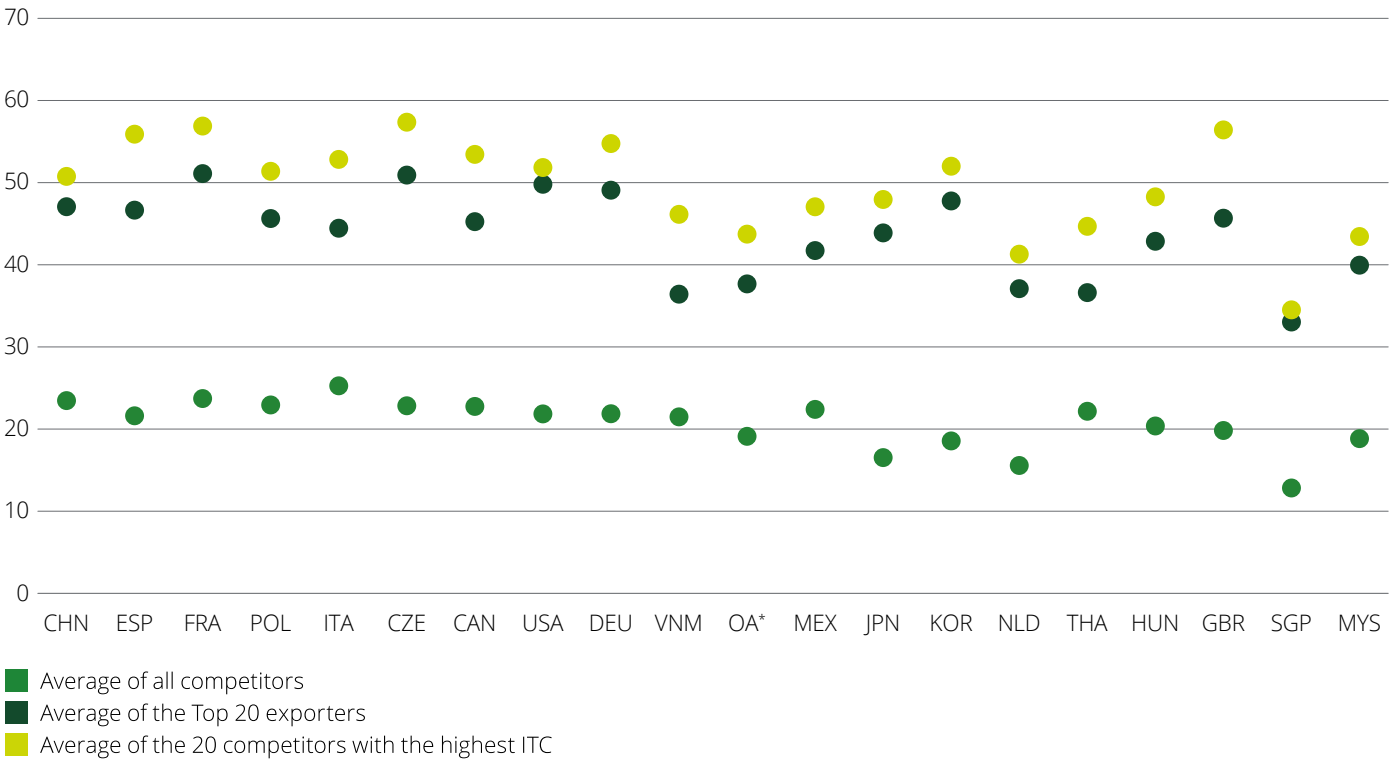


3.3 Intensity of competition

A country's position in global markets is not only determined by its market share, but also by the structure of its export portfolio. Strengths in selected product groups can create opportunities for growth, yet a narrower product focus can also leave a country more exposed to competitive pressure. Market shares and how they evolve are informative, but competitiveness is ultimately specific to individual products and segments. In this section, we look at how competitive intensity among the main exporters of CCM goods has changed, combining two indicators: the Index of Trade Competition (ITC), which captures similarities in export structures, and the Revealed Comparative Advantage (RCA) indicator, which identifies a country's areas of relative specialization. Taken together, they give a fuller picture of each country's competitive position.

As a first step, we look at the Index of Trade Competition (ITC) to determine whether major exporters offer a similar range of products to the global market in terms of value. The more similar their export value composition, the more intense the competition will be between two countries. Major exporters that typically have a high share of global exports usually also have a broad export portfolio, meaning they trade in the vast majority of goods in the CCM domain. For the 20 most important exporting countries, our analysis focuses on three groups of competitors. First, we calculate the average ITC across all countries to represent potential competitors. Second, we calculate the average based on the 20 highest ITC values, representing a country's strongest competitors. Third, we calculate the average ITC for the remaining major exporters in the group. It turns out that the average ITC for the other major exporters is only slightly below that of the 20 countries with the strongest competition. However, the gap is significantly larger relative to the overall average, which indicates lower overall competitive pressure (Figure 12).

Fig. 12 – Competition for the main exporters of CCM goods
Index of trade competition, 2024



* Other Asia, esp. Taiwan.
Source: CEPII BACI, HS2017, 2017–2024; authors' calculations (see methodology note on p. 10 for more details).

Even though major exporting countries often face direct competitive pressure from their peers rather than fringe suppliers, our findings also indicate that smaller Asian economies such as Vietnam and Thailand are under competitive pressure from other emerging economies (Appendix B). One reason for this may be changes in the mix of export goods due to industrialization and specialization or their integration in international value chains. Trade and production networks also typically have a regional structure, which is also evident in the competition between major export countries (Appendix C). The Index of Trade Competition suggests that European countries face significant competitive pressure, particularly from other major European exporting countries, as well as from China, South Korea, Japan and American competitors. Competition among major exporting countries in Asia does not seem to be as intense, suggesting different regional patterns of specialization.

In a second step, we analyse the Revealed Comparative Advantage to provide a more complete picture. The index measures the proportion of a country's exports that exceed the global average (see methodology note on p. 26). To make a fair comparison, the number of goods should be similar. Otherwise, countries with a large number of goods would be at a disadvantage, as countries only trading a limited number of product categories naturally have a high export share in those categories. Revealed Comparative Advantage highlights the goods in which a country may have a competitive edge in international trade.



Methodology note:
Competition in international trade

Index of Trade Competition (ITC)
The Index of Trade Competition (ITC) measures the extent to which two countries compete by exporting similar products; that is, how far their export flows overlap on the global market. It combines the similarity of the two countries' export structures with the value of their exports: the higher the index, the greater the overlap and the more likely the two countries are to be in direct competition.[8]

$$\sum_{n} \frac{EX^{n}_{A\,t} + EX^{n}_{B\,t}}{\sum_{n} EX^{n}_{A\,t} + \sum_{n} EX^{n}_{B\,t}} \left(1 - \frac{\left|a^{n}_{A\,t} - a^{n}_{B\,t}\right|}{a^{n}_{A\,t} + a^{n}_{B\,t}}\right)$$

$EX^{n}_{A\,t}$ Value of exports in category n of country A in year t

$EX^{n}_{B\,t}$ Value of exports in category n of country B in year t

$a^{n}_{A\,t}$ Share of the product category n in the exports of country A in year t, in terms of value

$a^{n}_{B\,t}$ Share of the product category n in the exports of country B in year t, in terms of value

While similar export shares may point to competitive overlap, they may also indicate that both countries are integrated into the same international value chains. The index also does not directly measure technological or price-based competition. Moreover, a decline in similarity could result from a country either losing market share to a competitor or gaining it at the competitor's expense. In both cases, the index would register lower competitive pressure, albeit for very different reasons.

Revealed Comparative Advantage (RCA)
International trade data reveal the comparative advantages of individual countries in the production of goods. From this data, we can calculate the Revealed Comparative Advantage using this standard formula:

$$RCA_{Ant} = a^{n}_{A\,t} \Big/ a^{n}_{t} > 1$$

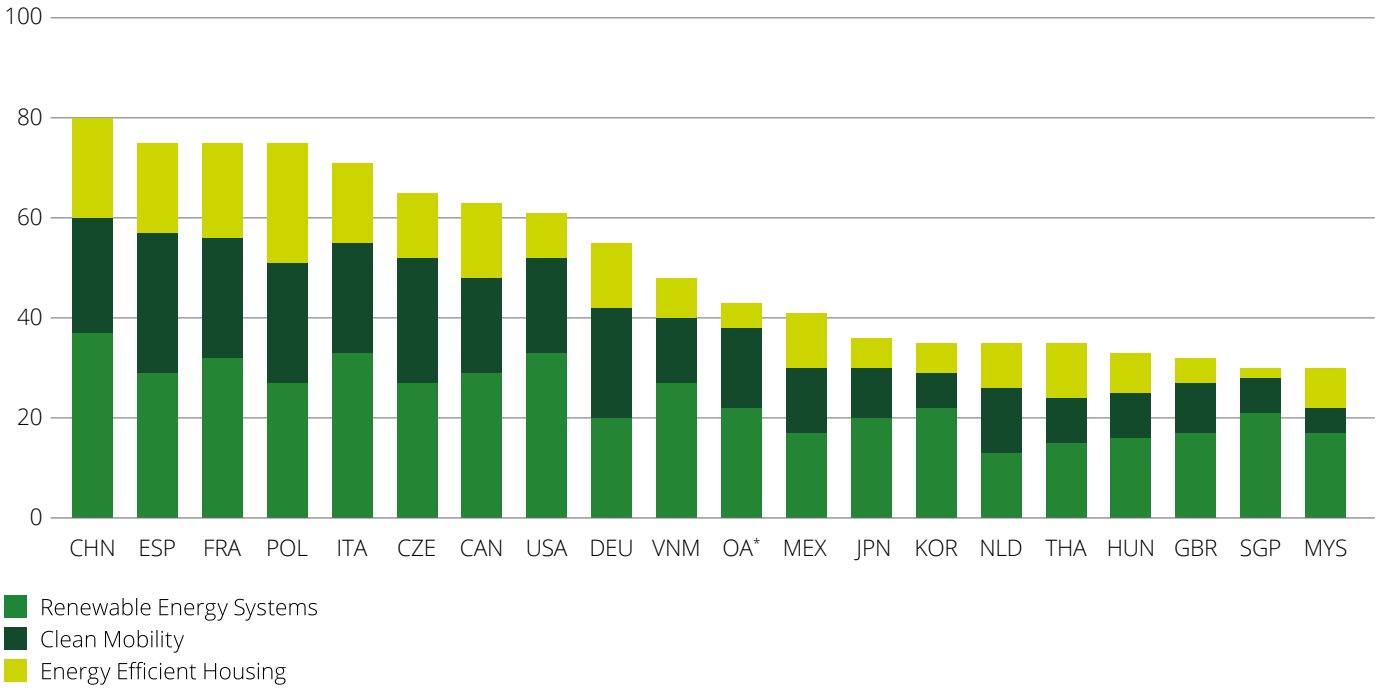
$a^{n}_{A\,t}$ Share of the product category n in the exports of country A in year t, in terms of value

a^{n}_{t} Share of the product category n in global exports in year t, in terms of value

A country has a Revealed Comparative Advantage in a particular product if the share of that product in the country's total exports exceeds the share of that product in global exports; in other words, the product accounts for a larger share of the country's exports than the international average. However, any interpretation of the index must acknowledge its asymmetry and potential small country bias.[9]

The largest exporters of CCM goods, measured by value, show a comparative advantage for a substantial number of goods (Figure 13). Of the 79 product categories in Renewable Energy Systems, they report an RCA for an average of 24 categories; for Energy Efficient Housing, the figure is 11 out of 40, and for Clean Mobility, 16 out of 63 categories. China is leading with an RCA in 80 product categories of CCM goods, whereas Singapore and Malaysia show an advantage in only 30 of the 182 product categories.

Fig. 13 – Revealed Comparative Advantage in CCM goods of main exporters
Number of product categories with RCA index > 1 by segment, 2024



Source: CEPII BACI, HS2017, 2017–2024; authors' calculations (see methodology note on p. 10 for more details).

The success of major exporting countries likely depends on their comparative advantage in those CCM goods with the highest export value. Therefore, the top 15 countries that export CCM goods are related to the top 15 CCM goods with the largest global markets. To analyse the product categories where major exporters perform particularly well, we use RCA indices with values higher than 1 to determine the extent of their comparative advantages (see the left-hand graphic in Figure 14). Seven of the major exporting countries have an RCA in two product groups, electric cars (HS 870380) and switchboards (e.g., those used for industrial automation and electrical system engineering, HS 853710). For the product groups hybrid cars (HS 870340), piston engines (including hybrid and hydrogen engines, HS 840734), iron and steel structures (e.g., those used in wind turbines, HS 730890) and regulating or controlling instruments and apparatus (HS 903289), six of the countries under consideration each report a higher share of export value than the global average.

As a group, the major exporters therefore have significant comparative advantages in hybrid cars, but those for semiconductor machinery (HS 848620 and HS 848690) are even greater, reflecting the Netherlands' specialization in the semiconductor value chain.

Fig. 14 – Aggregate Revealed Comparative Advantage for main exporters of major CCM goods
Sum of RCA index > 1, 2024



* Other Asia, esp. Taiwan.
Note: For each product category with an RCA greater than one, the RCA value itself is added to the bar total. Bar height therefore reflects both the breadth (number of categories with RCA>1) and the intensity (magnitude of RCA in each) of a country's specialization.
Source: CEPII BACI, HS2017, 2017–2024; authors' calculations (see methodology note on p. 10 for more details).

Conversely, not all major exporters have a comparative advantage in all the goods traded in the largest global markets (see the right-hand graphic in Figure 14). China and the Czech Republic have a comparative advantage (i.e., an RCA value greater than one) in a relatively large number of the fifteen largest product categories, but with comparatively low RCA values in each. By contrast, Mexico, Japan and the Netherlands have a comparative advantage in fewer categories, but with much higher values, resulting in the highest aggregate scores among major exporters despite the narrower focus. For the Netherlands, this aggregate score stems almost entirely from a single, highly specialized category, namely semiconductor machinery. Vietnamese exports, on the other hand, are almost entirely focused on photosensitive electrical apparatus. The RCA findings show that having a broad range of products and being highly specialized are two different aspects of competitiveness.



Spotlight on Germany

Germany's second place in global exports of CCM goods is based on a comparatively narrow specialization profile and a distinctive competitive environment.

Who competes with Germany. Czech Republic records the highest ITC index (Figure 15), indicating a comparatively high degree of overlap between the two countries' export structures. This observation can be interpreted in two ways. First, the two countries export similar product categories to global markets. Second, Czech production is closely integrated into German value chains, particularly in the automotive sector. The next highest ITC values are for Spain, Belgium and France. The United States show a rather stable index around 60–65. South Korea's ITC has been increasing over time, reaching values similar to the US in 2024. When focusing on Clean Mobility, however, also China appears as a major competitor, with an index rising since 2017 and reaching a value of 65 in 2024, in line with the convergence of German and Chinese export shares in this segment (Section 3.1).

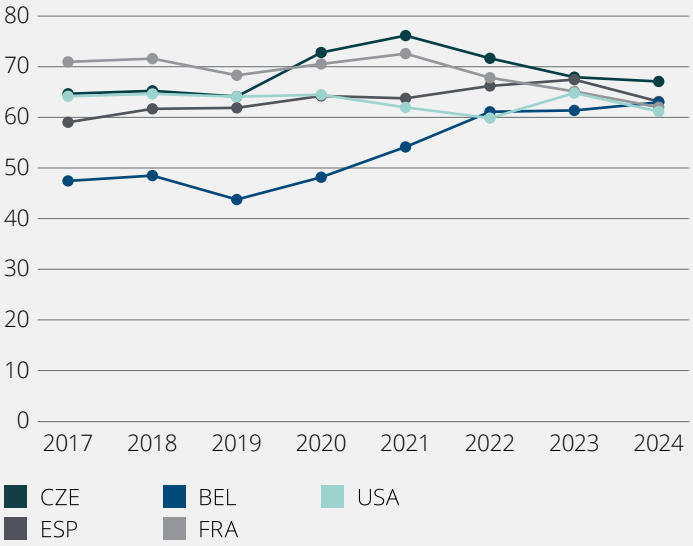
Why portfolios differ. China's exports are particularly prominent in component categories such as lithium-ion batteries (HS 850760, listed under "electric accumulators" in the HS nomenclature), whereas Germany's exports are more strongly concentrated in assembled vehicle categories such as electric cars (HS 870380). South Korea's overlap with Germany is spread across a broader set of products rather than being driven by a single category, even if both countries have an export focus on electric cars.

Where Germany is specialized. Germany has a comparative advantage in four of the 15 largest CCM goods categories: electric cars (HS 870380), hybrid passenger cars (HS 870340), reciprocating piston engines, covering hybrid and hydrogen engines (HS 840734)[10] and switchboards (HS 853710). Three of the four are road-vehicle categories, the fourth is industrial electrical equipment. Together they reflect Germany's longstanding strengths in automotive and industrial equipment manufacturing. Germany has no RCA in the large categories that dominate the segment by value, including lithium-ion batteries (HS 850760), photovoltaic cells and LEDs (HS 854140) and semiconductor manufacturing equipment (HS 848620). Across the full set of 182 categories, Germany has an RCA in 55 categories, ranking it 9th among the top 20 exporters (Figure 13).

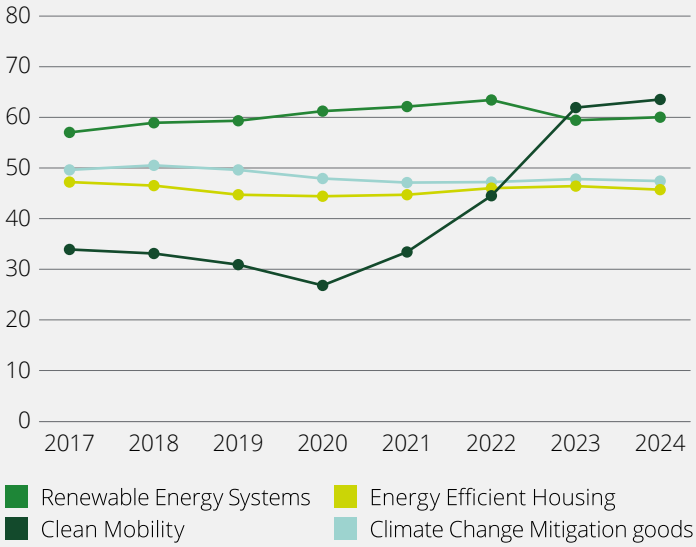


Fig. 15 – Trade competition in CCM goods for Germany

ITC index for the respective Germany – competitor country pair for CCM competitor country pair for CCM



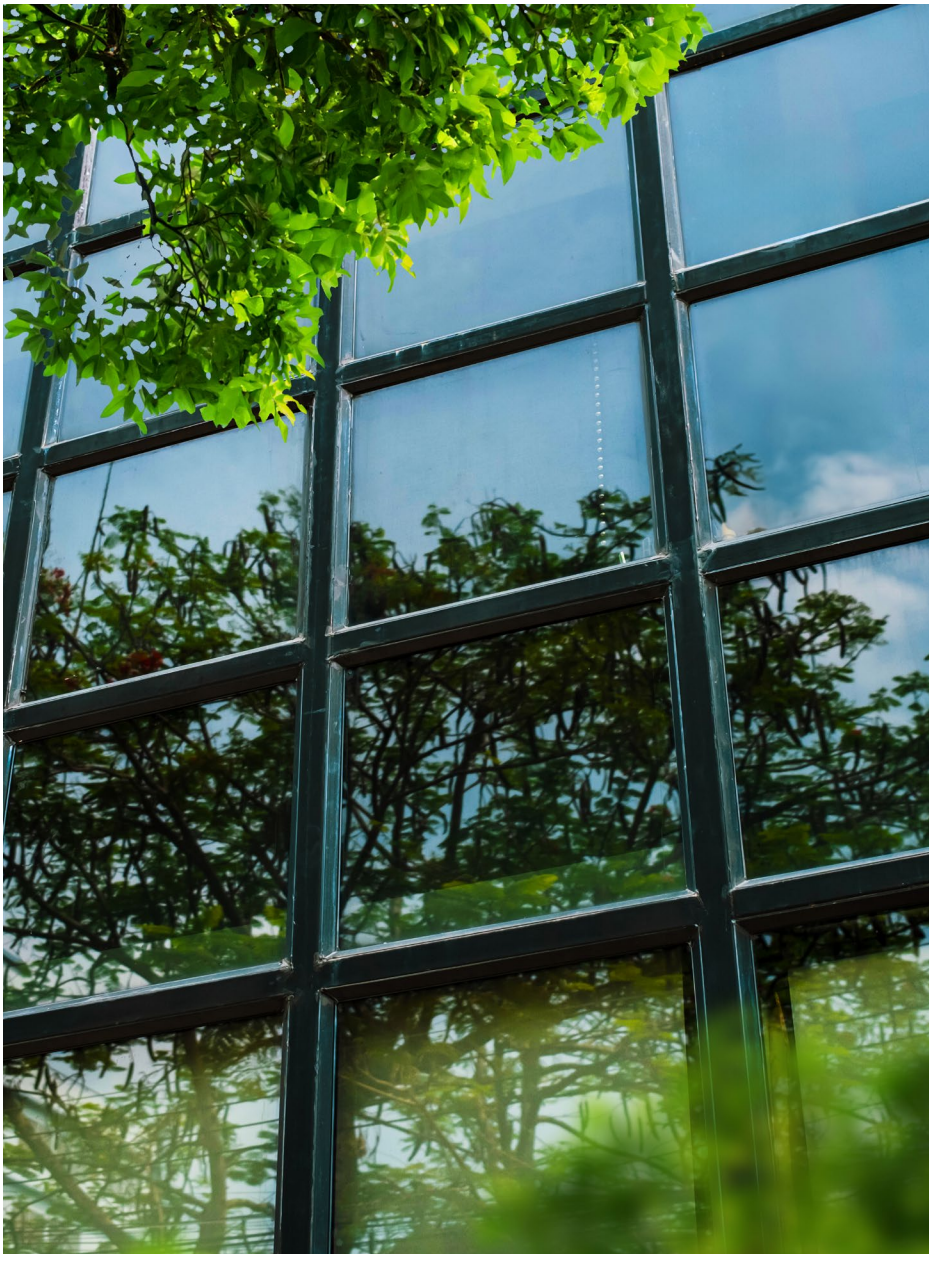
ITC index for the Germany-China pair for CCM goods and its three segments



Note: Germany's current main competitors represent the countries with the highest ITC in 2024.
Source: CEPII BACI, HS2017, 2017–2024; authors' calculations (see methodology note on p. 10 for more details).



4. Risks to deployment arising from dependencies



4.1 Concentration of global exports and imports of climate change mitigation goods

The deployment of mitigation technology depends not only on the availability of products but also on the structure of the markets in which they are traded. Concentration in trade can create bottlenecks, particularly when a country sources a product from only a few supplier countries (import concentration) and global exports of that product are dominated by a small number of countries (export concentration), leaving few alternative suppliers.

Firstly, we examine how the global export and import value of each CCM product group is distributed across countries of origin and destination, which gives a measure of global concentration at product level. To identify product categories with the highest concentration, we calculate the Herfindahl-Hirschman Index (HHI) for global exports and imports, using an HHI value above 2,000 as a screening threshold for high concentration.

Methodology note:
Market concentration

The Herfindahl-Hirschman Index (HHI) is a widely used measure of market concentration, applied here to countries rather than firms. For global exports, it is calculated by squaring each country's market share of the total export value of a product group and summing the results. For global imports, we apply the same method to the shares of destination countries:

$$\sum_{c} (a_{ct})^2$$

a – Share of country c in the value of global exports or imports
c – country
t – year

The export HHI measures how global exports of a product category are distributed across exporting countries, while the import HHI measures how global imports are distributed across destination countries.

The literature reports HHI on two different scales, depending on how market shares are presented. The HHI ranges from 0 to 10,000 or from 0 to 1. For example, a HHI of 0.33 corresponds to approximately 3,300, and a value of 0.40 corresponds to approximately 4,000. Higher values indicate greater concentration.

There is no universally accepted threshold for classifying a market as highly concentrated. Our analysis uses an HHI above 2,000 as a screening **threshold** for highly concentrated markets, in line with the European Commission's practice in competition policy.[11]

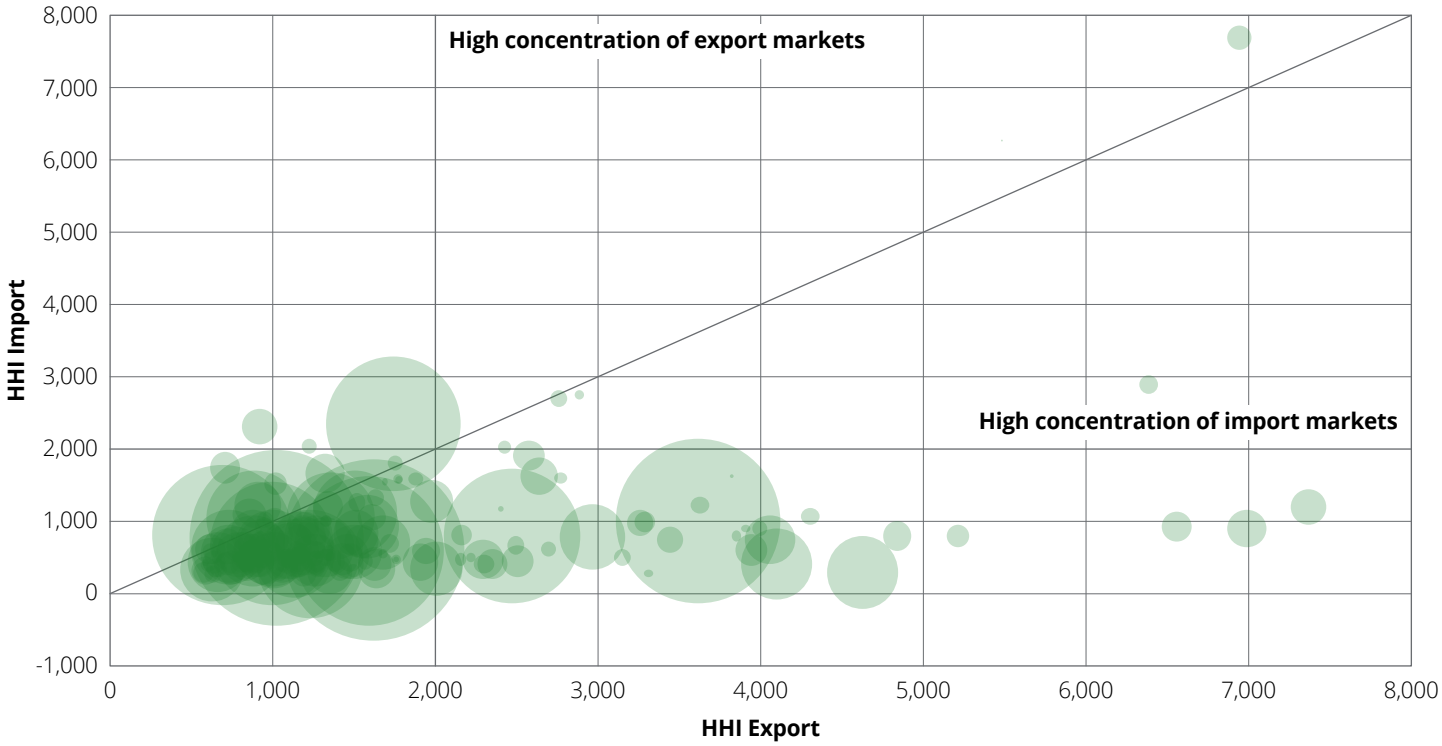
Although the HHI offers an indication of the level of concentration, it should not be interpreted as a universally valid indicator of strategic import dependence, supply disruption risk or market power. Other factors also influence these risks, whether it is substitutability, switching costs, spare capacity, barriers to entry or lead times for mobilizing alternative supply. A high export HHI reflects a concentrated supplier base, but it does not show whether individual suppliers can raise prices, restrict supply or prevent market entry. Similarly, a high import HHI shows that imports are concentrated in a small number of destination countries, but it says nothing about the vulnerability of any particular importing country. A resilience assessment should therefore distinguish between trade concentration, manufacturing capacity, upstream component production and access to critical inputs. This could help to identify cases in which seemingly diversified trade routes still depend on a highly concentrated production base. This limitation does not affect the relative comparisons in this chapter, which apply the same measure consistently across all categories, but it does affect how we interpret concentration in absolute terms, particularly for solar and battery products.

Comparing export and import concentration across CCM product categories, two findings stand out (Figure 16):

First, the majority of the 182 CCM product categories exhibit low concentration. For exports, 76% of the product categories—accounting for 79% of the global export value—fall below the HHI threshold. For imports, the HHI of 95% of product categories—also accounting for 95% of the global import value—does not reach the threshold for high concentration. Concentration is therefore relevant but confined to a subset of products: Most categories are not highly concentrated on either side of the market, while a limited number show high concentration, particularly on the export side. The findings for CCM goods resemble merchandise trade in general, where 34% of product categories are highly concentrated on the export side and 11% on the import side. Concentration may matter more for CCM goods, however, when a product is essential to deploying renewable energy, energy efficiency or clean mobility technologies and cannot easily or quickly be substituted. In such cases, market concentration poses risks not only to the economy but also to climate change mitigation.

Second, the higher concentration among global suppliers than import destinations suggests an asymmetric risk structure, where global supply is concentrated in fewer countries than global demand. This could give suppliers more leverage, increase exposure to disruptions in certain product markets and make it harder to absorb disruptions where alternative sources are limited. However, additional information is needed with regard to the availability, cost and scalability of alternative suppliers to determine actual import dependency.

Fig. 16 – Global export and import concentration for CCM goods by product category
Herfindahl-Hirschman-Index (HHI), bubble size indicates the trade value in USD (2024)



Note: Each bubble represents one HS2017 six-digit product category. The size of the bubble corresponds to the size of the market. The 45-degree line represents equal export and import concentration. An HHI value greater than 2000 indicates high concentration.
Source: CEPII BACI, HS2017, 2017–2024; authors' calculations (see methodology note on p. 10 for more details).

An assessment of concentration on a product-by-product basis reveals that relevant risks arise in specific product categories rather than across the entire portfolio of CCM goods. The categories with the highest HHI values for global exports include vacuum flasks and vacuum vessels, LED light sources and lamps, railway and tramway goods wagons, portable electric lamps and selected cooking appliances (Table 1).[12] While these examples are indeed relevant to the deployment of climate technology, they may be difficult to classify as strategically critical mitigation technologies. A more informative approach is to look at products with significant market shares: The two largest product categories with a high concentration of exports are lithium-ion batteries (HS 850760, 7% of CCM goods trade) and photovoltaic cells and LEDs (HS 854140, 5%). Together, they account for roughly half of the export value in categories with a high concentration of exports and 12% of the total export value of CCM goods (Table 1, Panel B). The remainder is spread across numerous much smaller categories. Some HS codes cover products with multiple applications, but whether concentration matters typically depends on a particular product's role in a specific technology or value chain. The concentration patterns revealed by the HHI are therefore useful as a screening tool, but the index alone does not establish how critical each product actually is.

Tab. 1 – CCM goods with high concentration on the export side (in 2024)
Panel A: Categories with highest HHI values

HS code	Description	HHI of global exports per category	Share in total trade value of CCM goods
961700	Vacuum flasks and other vacuum vessels, complete with cases; parts thereof other than glass inners	7365	0.3
853950	Lamps; light-emitting diode (LED) light sources, light-emitting diode (LED) lamps	6987	0.4
860691	Railway or tramway goods vans and wagons; covered and closed, not self-propelled	6943	0.1
851310	Lamps; portable, electric, designed to function by their own source of energy (excluding lighting equipment of heading no. 8512)	6556	0.2
732119	Cooking appliances and plate warmers; for solid fuel and fuels other than gas or liquid, of iron or steel	6387	0.1

Panel B: Highly concentrated export categories (HHI> 2000) with the largest trade value

HS code	Description	HHI of global exports per category	Share in total trade value of CCM goods
850760	Electric accumulators, including separators therefore, whether or not rectangular (including square); lithium-ion	3618	6.9
854140	Electrical apparatus: photosensitive, including photovoltaic cells, whether or not assembled in modules or made up into panels, light-emitting diodes (LED)	2473	4.7
841510	Air conditioning machines, comprising a motor-driven fan and elements for changing the temperature and humidity, including those machines in which the humidity cannot be separately regulated; of a kind designed to be fixed to a window, wall, ceiling or floor, self-contained or "split-system"	4628	1.3
940540	Luminaires and light fittings; electric, photovoltaic, designed for use solely with light-emitting diode (LED) light sources	4101	1.3
940510	Chandeliers and electric ceiling or wall light fittings; (excluding those used for lighting public open spaces or thoroughfares), for use other than with light-emitting diode (LED) light sources	2970	1.1

The concentration of trade flows describes the dynamics of international markets rather than the overall capacity of domestic production. To gain a fuller picture of possible dependencies and risks of supply disruptions, it is important to consider not only export concentration indicators, but also the distribution of actual production and production capacity across countries and along the value chain. The two diverge significantly for both of the largest CCM product categories with high export concentration: China accounts for more than 80% of global manufacturing capacity across all stages of the solar PV chain, including polysilicon, ingots, wafers, cells and modules, as well as close to 85% of global battery cell production capacity.[13] However, its export shares are much lower, at 47% for photovoltaic cells and panels, and 59% for lithium-ion batteries, in 2024.[14] So, while we can clearly see the concentration on the export side, this still understates the uneven distribution of production across countries.

One factor contributing to this gap is domestic absorption in a large home market; another is the international division of labour. For solar photovoltaics and batteries, the exporting country may differ from the location of upstream manufacturing capacity, particularly where manufacturers have moved final assembly to third countries. Chinese investment has enabled Vietnam, Malaysia and Thailand to become significant exporters of photovoltaic products in their own right,[15] and all three countries rank among the twenty largest exporters of CCM goods (Figure 12 in Section 3.3). In trade data, this registers as a broader supplier base, which lowers the HHI of global exports, but it does not, on its own, broaden the base of upstream production. The vast majority of ingot and wafer capacity is still in China, and Chinese manufacturers largely operate the plants in the third countries through subsidiaries.[16] This same mechanism is likely a factor in the competition patterns for Vietnam and Thailand that we discuss in Section 3.3, where the position of these countries is determined more by specialization in the destination country than by independent technological expertise.

4.2 Import concentration at the country level

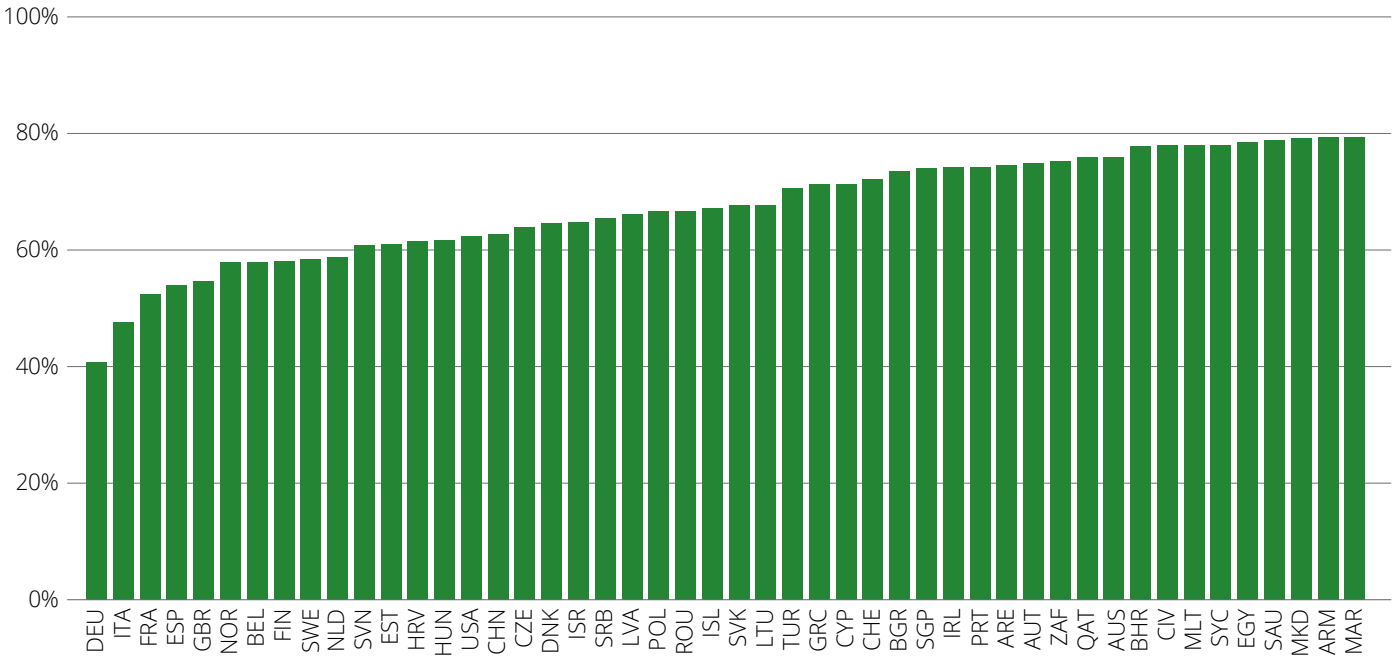
The importance of supplier concentration becomes clearer when viewed from the perspective of importing countries. Whereas the global import HHI shows how trade in a product category is distributed across destination countries, country-level import concentration measures the degree to which individual countries rely on a small number of supplier countries for that category.

Figure 17 shows that for 59 out of 226 countries in our sample, imports are highly concentrated (HHI>2,000) in every CCM product category they import. For a further 63 countries, the share of highly concentrated product categories is between 95% and just under 100%. Germany and Italy are the only countries that source fewer than half of their CCM product categories from highly concentrated supplier markets. Overall, just 48 countries import less than 80% of these product categories from highly concentrated supplier markets. Even China, the largest supplier of many CCM goods, shows high import concentration in 63% of the product categories it imports.

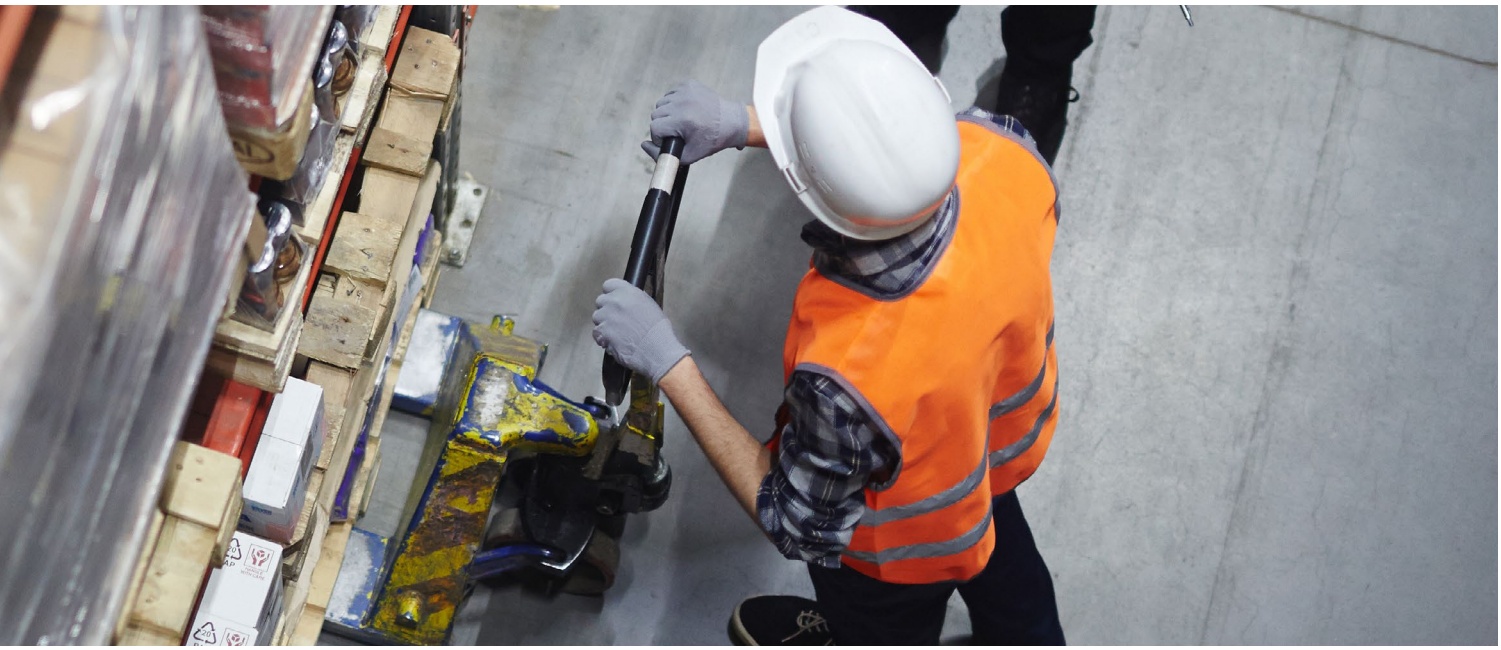


Fig. 17 – Import concentration of CCM goods by country

Share of CCM goods with an HHI > 2000 in the number of all CCM goods imported by a country in %, 2024



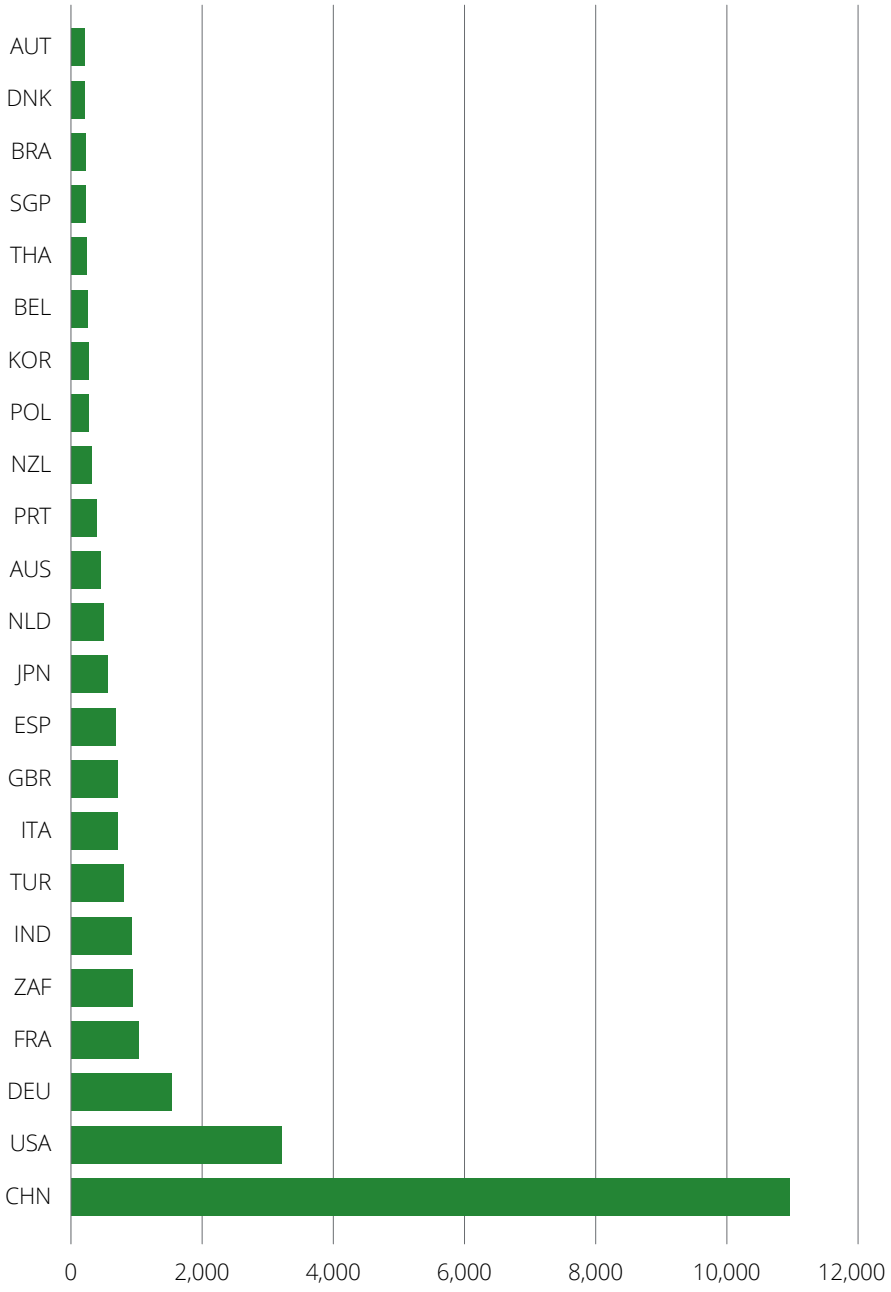
Note: For the 178 countries not displayed in the figure, the share of product categories with highly concentrated imports is higher than 80%.
Source: CEPII BACI, HS2017, 2017–2024; authors' calculations (see methodology note on p. 10 for more details).



China's example shows that a country can become a major global supplier while relying on a limited number of foreign suppliers for many of its own imports. To gain a fuller picture, however, we must also consider the role that individual countries play as suppliers of concentrated imports (Figure 18). China is the main supplier of CCM goods in the largest number of country-product combinations where imports of other countries are highly concentrated. The United States, Germany and France rank a distant second, third and fourth, followed by other major emerging economies, including South Africa, India and Türkiye. These key suppliers tend to face high import concentration in a smaller share of product categories than other countries, suggesting that a strong supplier position may help a country maintain comparatively diversified imports. However, it does not generally protect against import concentration altogether: Even a country whose imports are diversified overall may remain exposed to supply risks in individual product categories where it relies on only a few suppliers.

The above analysis shows that import concentration in CCM goods is widespread at the country level. The question is whether that matters. Concentration can be a problem when a concentrated input is essential to deployment and cannot quickly be replaced. Conversely, even a less concentrated market can create dependency risks if a product is difficult to substitute for technological reasons, is strategically important or is essential to a critical value chain. The key insight is that critical dependencies arise where concentration intersects with high import exposure, limited substitutability and economic or strategic importance. It is this intersection that makes certain products disproportionately important for continuity, timing and cost of deploying mitigation technologies.

Fig. 18 – Main suppliers for highly concentrated imports of CCM goods
Number of country-product combinations with highly concentrated imports (HHI > 2000) in which each country is the main supplier, 2024



Source: CEPII BACI, HS2017, 2017–2024; authors' calculations (see methodology note on p. 10 for more details).

4.3 From concentration to import dependence

Market concentration is a necessary but insufficient condition for identifying import dependencies. This is not simply a case of "imports largely coming from one country"; dependencies arise where concentrated sourcing coincides with substantial import exposure and limited or costly alternatives. Shifting from market concentration to import dependency requires additional criteria related to supplier diversity, import exposure, net imports and the main supplier's global position. The literature uses different combinations of these criteria to identify product categories that warrant further assessment (see box "Import dependencies").

Import dependencies

There is no single, universally accepted method of identifying import dependencies. Existing approaches typically consider factors such as the number of supplier countries, supplier concentration, the main supplier's share of a country's overall imports, the global market position of that supplier and the net import position of the importing country. The ultimate goal is to determine the extent to which a country's imports are influenced by a single supplier country and the alternative options available in the event of a disruption. For EU Member States, the distinction between intra-EU and extra-EU trade may also be relevant.

Literature applies, among others, the following criteria:

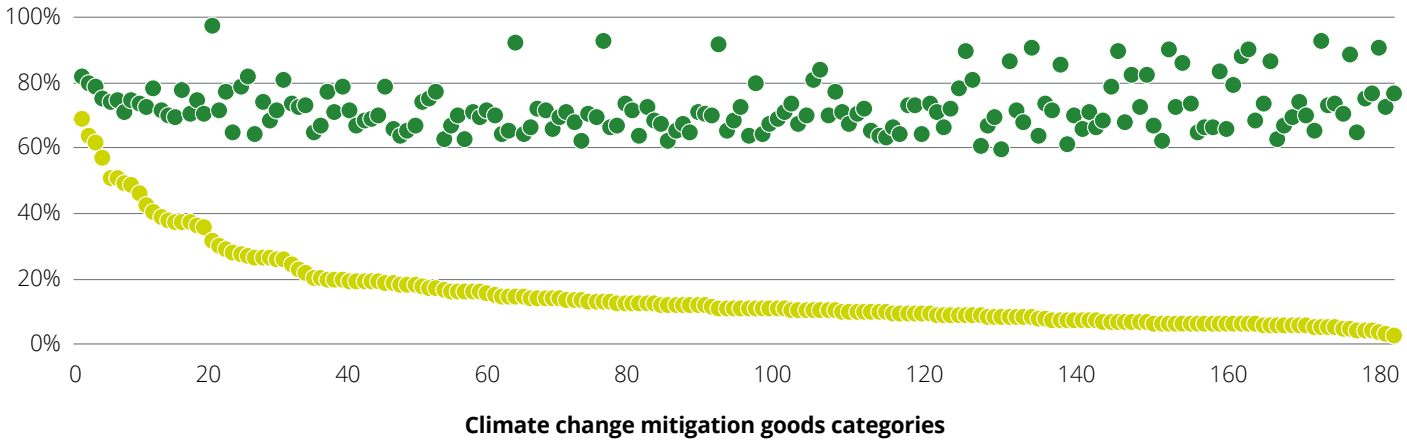
- **Market share:**[17] The share of imports supplied by one country or a group of countries exceeds a defined threshold, such as 50% or 80%, depending on the import value and the product category.
- **Market share plus:**[18] The importing country is a net importer, the main supplier accounts for more than 50% of its imports and that supplier has a global market share above 30%.
- **Market concentration:**[19] Imports originate from no more than three supplier countries or the normalized HHI exceeds 0.33, in combination with a net import position.
- **Market concentration plus:**[20] The normalized HHI exceeds 0.40 and additional conditions are met, such as extra-EU imports exceeding 50% of total imports or imports exceeding exports.

Concentration is not the same as dependency. Critical vulnerabilities arise where concentrated sourcing intersects with high import exposure and limited substitutability.



Fig. 19 – Import dependence and scope for alternative suppliers of CCM goods

Average of the highest import share by supplying country for highly concentrated import categories at the country level and average export market share of the main supplier, in %, 2024



Note: Imported categories of CCM goods with HHI > 2,000 at the country level, 2024
Source: CEPII BACI, HS2017, 2017–2024; authors' calculations (see methodology note on p. 10 for more details).

Digging deeper into the question of market concentration and possible dependencies, we switch from the country view to the product view but continue to restrict our analyses to highly concentrated imports at the country level (Figure 19). Our findings show that in every category of CCM goods, there is at least one country that sources 100% of its imports from a single supplier country. As one would expect with highly concentrated imports, the average share originating from the most important supplier country—averaged across all importing countries—is also high for each product category, generally over 60%. There is, however, at least one country in each product category where the main supplier accounts for a significantly smaller share of imports. This suggests that there is potential for diversification, as other supplier countries are available to diversify imports.

This argument is supported by the fact that, for the majority of product categories, the average global market share of the respective county-specific main suppliers lies below the 30% threshold.

From exposure to consequence. To continue the analysis beyond market structure, we take a closer look at the costs of disruption. Estimates based on external models give an indication of the scale involved. According to the IEA's estimates, every month of disruption to exports from the Chinese battery supply chain would reduce output at electric vehicle factories in the rest of the world by around USD 17 billion, with more than half of these losses in the European Union. A comparable interruption to exports in the solar supply chain would reduce monthly output at solar PV module factories outside China by around USD 1 billion, with over 40% of the affected output in Southeast Asia and India.[21] The same report finds that every key supply chain has at least one stage where suppliers outside China could not meet even a quarter of the rest of the world's demand.

These are model-based counterfactual scenarios rather than observed outcomes and cover a narrower range of technologies than the 182 categories in our analysis. However, they show why the interplay of market concentration, import dependence and limited substitutability is so important as a screening criterion. Concentration alone does not determine the cost of disruption: Costs are highest when an input is essential, cannot be replaced quickly and is sourced from a highly concentrated market.

Spotlight on Germany

Germany's import structure is less concentrated than that of other countries in the sample (Figure 17), and yet it imports 41% of its CCM product categories predominantly from a small number of countries, which may vary by category. This is the lowest share in the sample; Germany and Italy are the only two economies that source fewer than half of the categories they import predominantly from a small number of countries. For 178 of the countries we looked at, the share exceeds 80%.

Germany's risk exposure to concentrated imports is substantial in absolute terms but low relative to the other countries in the sample. Germany is also the leading exporter for 1,538 country-product combinations when it comes to highly concentrated imports of other countries. Only China and the US are even more significant, with 10,964 and 3,210 country product pairs respectively. This underlines Germany's role as a key supplier in selected markets; however, that alone does not suggest technological leadership or domestic production capacity. Export positions may also reflect integration into international value chains and regional trade networks.

The findings for Germany bring together three key insights from this chapter. Firstly, Germany's imports are highly concentrated in a substantial share of its product categories, though not the majority. Secondly, this exposure is the result of a supplier structure that may be more concentrated than that of global demand. Thirdly, the risk is product-specific rather than uniform across the entire domain of CCM goods.

As a rule, the fact that a large share of imports originate from a single country is not itself sufficient to establish a dependency. We can assume that imports into Germany from other EU countries carry lower geo-economic risks, which suggests that import dependence is not necessarily relevant in this respect. Our approach therefore draws on a combination of the following criteria: a) imports come from three or fewer countries, b) imports are highly concentrated (HHI > 0.33), c) imports exceed exports in the respective product category (net imports), d) more than half of the import value comes from outside the EU (extra-EU imports > 0.5 * imports), e) imports from non-EU countries exceed exports for the respective product category, f) imports from the main supplier country account for over 50% of the total import value, and g) the world market share of the main supplier country for Germany exceeds 30%. Based on data from 2022 to 2024, no product group in Germany's import portfolio meets all seven criteria at once, but there are several products that meet up to five (Table 2). China is the main supplier for many of these products, with the United States a distant second. To assess whether these dependencies are critical, however, we must take additional criteria into account, such as technology, sector, position in the value chain and the ownership structure of the companies.

Tab. 2 – Germany's goods with the highest import-dependency scores

HS2017	Description	Main supplier country	Score (Max=7)
870370	Plugin diesel electric hybrid vehicles (compression ignition + electric)	USA	5
851310	Portable electric lamps with self contained power source, excl. 8512 lighting	CHN	5
850162	AC generators (alternators) >75kVA ≤375kVA	USA	5
961700	Vacuum flasks and vessels: parts (excl. glass inners)	CHN	5
940520	Electric floor, table, desk or bedside lamps	CHN	5
853950	LED lamps	CHN	5
700992	Framed glass mirrors, excl. vehicle rear view mirrors	CHN	5
732119	Iron or steel cooking appliances and plate warmers for solid/other non-gas/liquid fuels	CHN	5
871491	Cycle frames and forks and parts	CHN	5
732111	Iron or steel gas (or gas + other fuel) cooking appliances and plate warmers	CHN	5
940530	Lighting sets: of a kind used for Christmas trees	CHN	5
854140	Photosensitive electrical apparatus: photovoltaic cells/modules and LEDs	CHN	5
840681	Steam and other vapour turbines >40MW, non marine	USA	4
841013	Hydraulic turbines and water wheels >10000kW	SVN	4
860390	Self propelled railway/tramway coaches, vans and trucks, non external electric, excl. 8604	POL	4
850220	Electric generating sets with spark ignition piston engines	CHN	4
940540	Other electric lamps and light fittings, n.e.c. (9405)	CHN	4
850610	Primary manganese dioxide cells and batteries	CHN	4
860120	Battery powered rail locomotives	NOR	4

5. Unlocking welfare through global trade

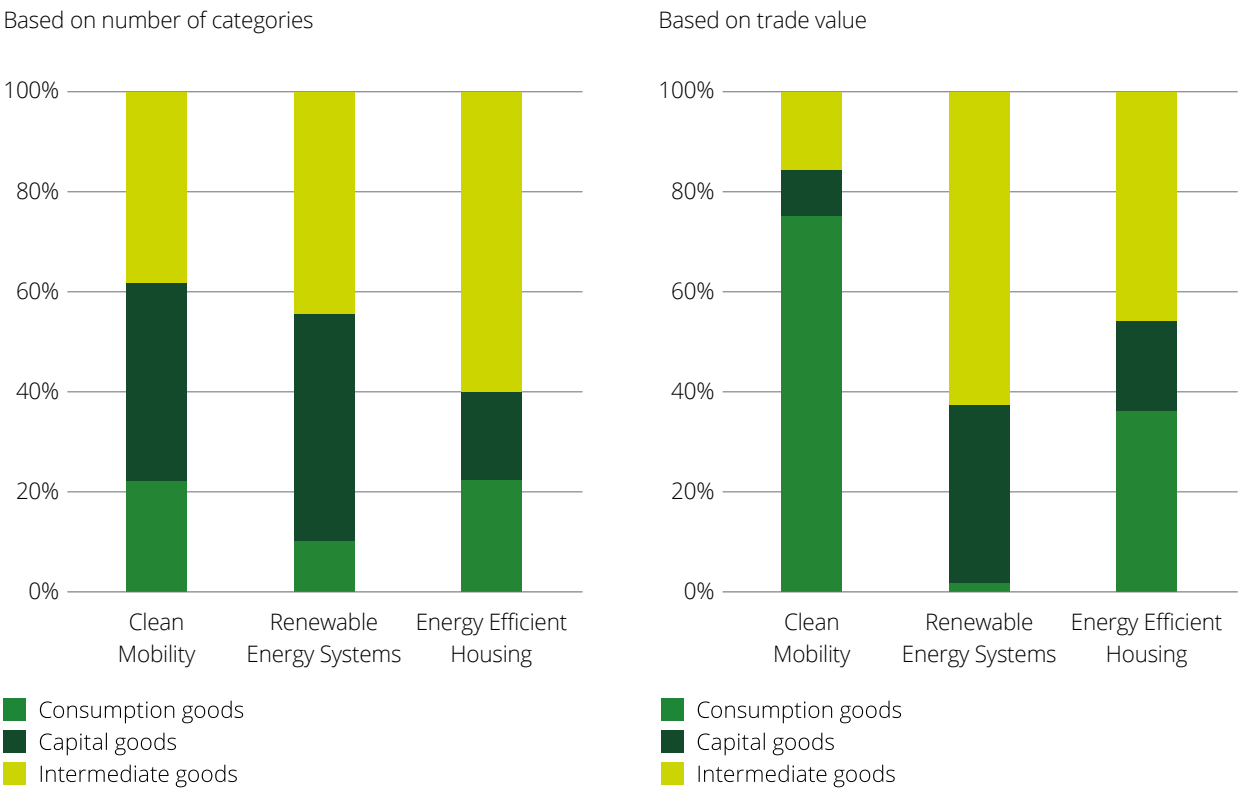
We know that trade affects many different economic outcomes, such as growth and prices, but it can also affect the pace, cost and reliability of global climate action. While international trade can promote the diffusion and scaling of mitigation technologies, supplier concentration, market barriers and insufficient policy coordination can limit these benefits. This chapter examines the economic gains from trade in CCM goods and the role of international cooperation in ensuring that these gains lead to widespread, efficient decarbonization. We draw on the literature and combine three types of evidence: descriptive calculations based on international trade data; findings from the empirical literature on trade, innovation and growth; and model-based or counterfactual estimates from external studies.

5.1 Gains from trade in climate change mitigation goods

Trade in CCM goods can have a positive impact on the economy. In the short term, rising net exports contribute positively to GDP growth, for example, when growing foreign demand causes exports to expand faster than imports. Whether trade causes higher growth, rather than merely accompanying it, is a more difficult question to answer. Recent research based on within-country regressions, synthetic control studies of specific reform phases and country case studies concludes that trade reforms have a positive average effect on growth, although there are significant differences between individual countries.[22] Accounting for 7.4% of global trade in 2025, CCM goods already make up a significant proportion of world merchandise trade.[23] The IEA expects trade in clean energy technologies to increase, although the extent of the increase will depend on the specific scenario.[24] Simulations using the WTO's Global Trade Model forecast that liberalizing trade in energy-related environmental goods (EREGs) and environmentally preferable products (EPPs) would boost trade and slightly raise GDP in all regions, while global CO2 emissions would fall by around 0.6%.[25] Unlike trade's contribution to growth, which depends on net exports, the welfare gains from trade are measured by comparison with a hypothetical situation in which a country does not trade at all (autarky).[26] These economic gains stem from three main sources. First, trade lowers marginal costs and prices and gives consumers a wider choice of products.[27] Second, competitive pressure shifts market share towards more productive businesses and creates incentives to innovate.[28] Third, access to a larger market encourages investment, innovation and technological improvements as well as their diffusion.[29]

Three features of CCM goods amplify the welfare gains from trade. The first feature relates to the role of technology transfer and international value chains. International trade ensures the dissemination of technology, particularly the technology embedded in capital and intermediate goods.[30] Looking at CCM goods, we note that 83% of product categories can be classified as capital or intermediate goods accounting for 71% of the trade value, although the proportions vary across the three segments (Figure 20). This strengthens the case for technology dissemination via trade.

Fig. 20 – Breakdown of CCM goods by major economic categories
Shares in %, 2024



Source: CEPII BACI, HS2017, 2017–2024; (see methodology note on p. 10 for more details); Broad economic categories are assigned using a product-level classification database according to Brockhaus, C., Hinz, J., & Iodice, I. (2026). PLAID: Product-Level AI-Derived Indicators Database for International Trade. Kiel Working Paper; authors' calculations; the breakdown is probabilistic and should be taken as an indication of the composition rather than an exact split.

A large share of goods in the Energy Efficient Housing segment are intermediate goods, whereas nearly half of the goods in Renewable Energy Systems are capital goods. The composition of the export value changes the picture, particularly for Clean Mobility. Here, electric vehicles—which are classified as consumer goods[31]—dominate the segment. Consumer goods also account for a higher share of trade value than they do of the number of product categories in Energy Efficient Housing. For Renewable Energy Systems, by contrast, intermediate goods appear to be more important than one might initially assume based on their share of the product groups. Intermediate goods account for about 63% of the segment's trade value, compared with around 44% of its product categories.

In terms of value, consumer goods make up about three-quarters of trade in the Clean Mobility segment and about 36% of trade in Energy Efficient Housing.

Trade in intermediate CCM goods is consistent with the way production is set up within international value chains. Production coordinated across borders through a division of labour increases gains from trade,[32] particularly where domestic and foreign inputs are complementary. Firm-level studies indicate that roughly half of the productivity gains from imports stem from imperfect substitutability between imported and domestic inputs.[33] This affects the level of gains: Quantitative trade models that take intermediate inputs and sectoral differences into account result in larger welfare gains than single-sector benchmarks.[34] As CCM goods consist mainly of intermediate and capital goods, they show great promise with regard to welfare gains. The evidence supports this on the basis of the model structure rather than through a direct comparison between product groups, so the inference is plausible rather than measured. Finally, the literature also explicitly shows that 'clean' patents receive about 43% more citations on average than comparable 'dirty' patents. This suggests that they are more generally applicable and more radically novel, with a spillover intensity comparable to that of the IT sector.[35]

The second feature concerns the geographic scale of the experience that drives down costs. Solar modules, wind turbines, batteries and electrolysers have followed robust experience curves over several decades, with unit costs falling in line with cumulative global rather than national output, a decline that energy system models have systematically underestimated.[36] Experience curves are not unique to clean technologies. They were first documented in aircraft manufacturing in the 1930s and have since been measured in semiconductors, chemicals and shipbuilding.[37] What distinguishes CCM goods from others is their unit size and their position on the experience curve.

- Energy technologies comprising small, mass-produced units show faster cost reductions per doubling of cumulative capacity than large, site-built plants. This advantage persists even when factoring in the economies of scale associated with unit size. Granular technologies also grow more quickly from 1% to 50% of market share.[38] This has direct implications for a study of trade, as the product universe in our analysis naturally covers much of the granular end of the mitigation technology spectrum: Modules, cells, batteries, heat pumps and lamps are traded as goods across borders and recorded in trade statistics, while nuclear plants, large hydroelectric and carbon capture facilities are classified as projects and are not included in these statistics. Within the product group, the argument remains nuanced. It applies most strongly to modular goods that are cheap to ship—cells, modules, power electronics—where a single factory can meet global demand. It applies less to goods where transport and installation costs are high relative to their unit value, such as wind turbine towers or insulation materials, where the learning process has a larger local component.[39]
- Cumulative production volumes in these technologies continue to double at a rate that the established manufacturing industry left behind decades ago. It took the world 68 years to install the first terawatt of solar capacity, and two years to add the second. The cost of lithium-ion cells fell by roughly 12% a year between 1995 and 2018, while production grew by around 30% a year.[40] When the cumulative output is growing this rapidly, access to a larger market pushes costs further down the experience curve, and the lower cost level then applies to all subsequent installations. For mature products, an additional national market shifts a technology only marginally along the experience curve, so the gains from market size are limited to the familiar static effects. The argument therefore applies specifically to the current phase of these technologies and is not a permanent feature.

The cost reductions are generally attributed to 'learning by doing', although it is difficult to distinguish between the causes.[41] Where experts have tracked it, we see a different story: For both solar modules and lithium-ion cells, research and development made the biggest contribution, while larger factories and bulk purchasing accounted for most of the rest. Practical experience on the production line contributed less than either of these.[42]

This does not weaken the case for an integrated global market; it merely alters the way it is achieved. Research spending, factory scale and bulk purchasing only pay off once a certain sales volume is reached, and this volume is determined more by the global than the domestic market. The history of solar shows the resulting division of labour: inventions largely in the United States, demand-side policies in Japan and Germany, specialized production equipment in Germany, manufacturing scale-up in China—capabilities that have been reinforced, rather than levelled out, by globalization.[43] China's contribution was driven primarily by manufacturing scale-up and access to internationally sourced production equipment, rather than by domestic R&D intensity; its manufacturers spent some 1 to 2% of revenue on research and development, compared with about 5% for their leading US competitors.[44] They acquired technology mainly by buying production equipment on the international market and recruiting experienced engineers, but not through research of their own.[45] No single country supplied all of these inputs, and it took all of them to drive down costs.[46]

The same evidence points to one qualification: The consolidation that accompanied the shift in manufacturing led to a decline in the number of companies filing patents in this segment, with the number of Japanese and German photovoltaic patent applications falling by more than 90% within five years.[47] As the bulk of the cost reduction is attributed to research and development, this is likely to have an impact on the next round of cost reductions rather than on those already achieved. The benefits for buyers are beyond question; what is questionable, however, is the variety of sources that produced them.

Because the relevant benchmark is the world market rather than the domestic one, trade does not merely relocate production at a certain cost but shapes the cost trend itself. A counterfactual analysis for the photovoltaic segment estimates that globalized module supply chains saved installers in the United States, Germany and China a total of USD 67 billion between 2008 and 2020, and that module prices in 2020 would have been 107%, 83% and 54% higher, respectively, had they been sourced purely from domestic supply chains.[48]

These figures represent hypothetical orders of magnitude rather than actual savings achieved through a specific policy measure. They reflect the identification problems inherent in the learning model: If part of the decline in costs is attributable to research or exogenous technical change rather than cumulative output, domestic supply chains would have been more cost-effective than the aggregate figures suggest. In practice, trade restrictions tend to shift production to third countries rather than bringing it back home, so actual outcomes fall between the two hypothetical scenarios of fully global and fully national markets. In any case, fragmentation is the costliest approach precisely in the product categories identified in Chapter 4 as the most concentrated.

Forward-looking estimates point in the same direction but put the cost of fragmentation at a lower figure, while distinguishing between two objectives that are often conflated. According to estimates, the cost of optimizing the supply chain for Europe—increasing self-sufficiency from 10 to 90%—would amount to 6.3% of cumulative industry costs by 2030. However, the cost of creating jobs through the same approach is estimated at 32.2%. If Europe were to phase out Chinese photovoltaic imports, this would raise industry costs and worldwide emissions by an estimated 5%.[49] A structural analysis of tariffs on crystalline silicon solar products confirms these hypothetical scenarios and finds substantial welfare reductions.[50]

The third feature concerns the positive climate externality. As emissions reductions are a global public good, a reduction in the costs of deploying mitigation technologies is worth more than conventional measures of consumer and producer surplus capture. Welfare analyses that fail to take this into account underestimate both the gains from trade and the cost of trade barriers. Two qualifications ensure that this argument remains proportionate. Trade policy is a second-best instrument here: carbon pricing is the best instrument, and supplementing existing tariffs with optimally designed carbon border taxes would, according to estimates, achieve only 3.4% of the emissions reductions that would be achievable under globally optimal carbon pricing.[51] At the same time, the existing distortion runs counter to the usual assumptions in the debate. In most countries, tariffs and non-tariff trade barriers are significantly lower for emissions-intensive sectors than for clean industries. This amounts to an implicit global subsidy for CO_2 in traded goods of several hundred billion dollars annually. According to estimates, applying a comparable trade policy to both groups would reduce global CO_2 emissions while leaving global real income essentially unchanged.[52] Removing barriers on CCM goods is therefore a step towards, rather than a step away from, a rules-based trade policy.

Taken together, these three features raise the value of trade in climate change mitigation goods. The first two increase the gains that conventional calculations already measure; the third adds a benefit those calculations completely ignore. Trade barriers are costly for these same three reasons.

Does trading climate change mitigation goods pay off in emissions terms? Trade generates emissions of its own. Across all goods, freight transport and the scale effect of higher trade volumes raise global CO_2 emissions by an estimated 5%, but the welfare gains from trade exceed these environmental costs by two orders of magnitude.[53]

Producing CCM goods can itself be emission-intensive if manufacturing relies on fossil-based electricity. A study finds that modules installed in southern Europe but manufactured in China using high-carbon energy have a lifecycle carbon footprint that is roughly twice as high as that of comparable modules manufactured in Europe. The energy payback time is 20 to 30% longer: In other words, the module must be in operation 20 to 30% longer before it has saved as much primary energy as its manufacture consumed.[54] And yet, energy payback times for photovoltaic systems have fallen from around five years in 1992 to about one year today, with a lifespan of 25 to 30 years and lifecycle emissions of some 20 to 25 g CO_2 equivalent per kWh.[55] At the level of trade flows, one analysis estimates that production of Chinese exports in the clean technology sector emitted around 110 Mt of CO_2 in 2024, while the same products, once deployed, save around 220 Mt annually and upwards of 4,000 Mt over their entire lifespan—meaning emissions from manufacturing are recovered in about six months.[56] Model-based estimates of trade liberalization in energy-related environmental goods point in the same direction, even if the reductions identified are modest.[57]

Spotlight on Germany

Germany has benefited from the growth in international trade linked to globalization in the 2000s. Between 1990 and 2018, GDP per capita grew by an average of just under 1.4% per year, and globalization accounted for almost 0.3 percentage points of this growth.[58] There is also evidence that trade gains have stagnated in the wake of "slowbalization"—a slowdown in global economic integration, where the international merchandise trade grows more slowly than world economic output.[59] Scenario analyses suggest that trend growth also depends on the pace of future globalization.[60]

Germany enjoys the benefits of global supply chains. The counterfactual analysis for solar photovoltaics provides an order of magnitude for the German case: If module supply chains had been national rather than global, module prices for German installers would have been around 83% higher in 2020, and the US, Germany and China would have missed out on total savings of approximately USD 67 billion between 2008 and 2020.[61]

As the second-largest importer of CCM goods, Germany benefits directly from this mechanism. Its import position is therefore not only a source of exposure, but also part of the cost base supporting the domestic deployment of renewable energy, energy efficiency and clean mobility technologies. Resilience measures therefore involve a trade-off between potential resilience benefits and the cost advantages of international sourcing. The appropriate balance depends on the magnitude and probability of the underlying supply risk (see Section 6.3).

True resilience for Germany does not mean costly self-sufficiency, but securing viable alternative suppliers through EU-level trade agreements and common standards.

5.2 The role of international cooperation

Greenhouse gas emissions are a global externality. The benefits of emissions reduction extend beyond the borders of the country that produces or deploys a technology, even though that country often incurs the costs of investment and adjustment. This makes a strong case for international coordination, which allows countries to pool their technological, production and financial resources.

Trade is one channel for this cooperation. Countries and businesses with comparative advantages in specific segments of mitigation technology can expand their production and tap into markets for deployment of these technologies more quickly. Importing countries, in turn, gain access to technologies and intermediate inputs that may not be available domestically at comparable costs. International production networks can help align investment incentives with global demand for the adoption of these technologies.

The benefits of international cooperation go beyond reducing tariffs. Cooperation can improve transparency, facilitate the exchange of technical expertise, promote compatible standards and enable businesses from a wider range of countries to participate in green value chains. This is particularly important for emerging and developing economies, where limited access to finance, certification capacities, technical expertise or the necessary infrastructure can restrict participation in international markets. The scale of this imbalance is considerable: Emerging and developing economies outside China account for less than 30% of global energy investment, even though they make up around two-thirds of the world's population.[62] Expanding their participation in green value chains is therefore both a development objective and, from the perspective of importing countries, a contribution to supplier diversification.

Trade agreements can serve as a potential enforcement mechanism. Cooperation on CCM goods has a further dimension that conventional gains-from-trade analyses ignore: Trade agreements are among the few instruments that can make climate commitments self-enforcing. Voluntary climate agreements are structurally unstable, as each country benefits from the emissions reductions achieved by others while bearing its own costs domestically. A coalition analysis shows that, without sanctions against non-participants, the only stable coalition that exists is one involving minimal emissions reductions, while a system with modest trade penalties for non-participants can sustain a large coalition with substantial emissions reductions.[63] The quantitative evidence sharpens this contrast: On its own, a carbon border tax is a poor substitute for global carbon pricing. One estimate suggests that an optimally designed border tax, added to existing tariffs, would achieve only 3.4% of the emissions reduction possible under a globally optimal carbon price. According to this model, the value of such a tax lies elsewhere. The key is to make market access conditional on membership of a coalition: The tax then works mainly as an incentive to join, rather than by affecting prices directly. If such a coalition forms, the model estimates that global CO_2 emissions could fall by up to 61%.[64] Linking market access to climate commitments need not be punitive, however: Granting participants preferential market access has been shown to encourage coalition formation through the same mechanism.[65]

Empirically, the environmental provisions in existing agreements are linked to measurable outcomes. Trading partners that have signed agreements with these provisions have lower emissions than others,[66] and provisions aimed at specific outcomes can offset the environmental costs of liberalization. Studies show that regional trade agreements without forestry-related provisions lead to a 23% increase in annual deforestation—an effect that is almost entirely offset by the inclusion of such provisions.[67] The impacts are not uniform, and the literature describes some provisions as merely reaffirming existing commitments rather than building on them.[68] That said, the mechanism is well-established and provides agreements on CCM goods with a justification that goes beyond the tariff reductions they offer (see Section 6.4).

The findings and analyses set out in this study therefore point towards an approach that combines open markets with selective coordination. The aim is not to eliminate all differences between national policy regimes, but to avoid preventable fragmentation, reduce unnecessary transaction costs and ensure that we can develop, trade and deploy mitigation technologies at the required scale.

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5.3 Market access and standards

Predictable market access without unnecessary barriers is important for CCM goods, as an international dimension can reduce costs, strengthen competition and accelerate the diffusion of mitigation technologies. The findings reviewed in this chapter show that trade barriers can undermine these benefits.

A structural analysis of tariffs on crystalline-silicon solar products finds that the companies affected by the tariffs relocated their production to sites not subject to the tariffs. The lost environmental benefits and the losses in consumer surplus outweighed the modest gains made by domestic manufacturers, resulting in a decline in domestic welfare and in domestic solar employment and wages.[69] Conversely, studies estimate that trade liberalization in this product group would lead to a reduction in global emissions (see Section 5.1).

Standards, certification and technical regulations serve important purposes. They can guarantee safety, ensure product quality, promote environmental integrity and build trust in green claims. At the same time, contradictory, duplicative or opaque requirements can increase compliance costs and delay market entry, particularly for smaller businesses and suppliers with limited administrative capacity. Findings from economic policy suggest that bureaucratic efficiency is not a fixed institutional trait: It tends to erode as overlapping and frequently changing rules accumulate, particularly in the face of political or regulatory instability.[70] This suggests that the stability and coherence of a standards regime should be regarded as a policy objective in its own right.

Given the capacity constraints noted in Section 5.2, technical assistance can help smaller enterprises and suppliers, particularly in emerging and developing economies, to comply with strict standards and obtain certifications. Inclusive standardization can also further reduce the risk that technical requirements may inadvertently exclude market participants who are not as well prepared.

Trade agreements covering CCM goods, which we discuss further in Section 6.4, can combine several of these mechanisms (tariffs, standards, certification and administrative procedures) in a single framework, provided they include credible and verifiable environmental and safety requirements (see Section 5.2). A rules-based approach to market access that focuses on capacity building can reduce unnecessary trade costs and broaden participation in trade in CCM goods.

Potential welfare gains from trade are particularly high for climate change mitigation goods.

6. The way forward – A practical guide for global trade

Trade in CCM goods is growing faster than overall merchandise trade and offers real economic gains. However, supply is most concentrated in the products that are hardest to substitute, creating risks to deployment. This chapter turns these insights into practical guidance for governments, businesses and financial institutions.

6.1 Export opportunities

Key starting points for tapping into export opportunities in growing international markets include targeted segment positioning, comprehensive product strategies and innovation.

- **Focus on promising industry segments**
  The climate change mitigation domain is not a single, uniform market: growth varies considerably across segments. Yet rapid growth alone is not a sufficient basis for setting priorities. Trade specialization follows comparative advantage (see Sections 3.3 and 5.1), and the industries with the largest external economies of scale are not necessarily those in which a country is already specialized. Growth and competitive pressure can go hand in hand. Clean Mobility is currently the fastest-growing segment, but Section 3.3 shows that competitive overlap in this segment is above average. Assessing each segment along three dimensions—market growth, comparative advantage and competitive pressure—therefore provides a sound starting point for both policy and business strategy. The findings point to different types of support. Fast-growing segments in which a country only has a weak comparative advantage may be better suited to capability-building and R&D support than to subsidies aimed at winning market share. Segments with an established advantage, by contrast, may offer a more reliable basis for scaling up support, even if they only exhibit moderate growth. In every case, public support should weigh market growth against evidence on technological capabilities, financing needs and comparative advantage.

- **Analyse product portfolios and complementary goods across the value chain**
  Mitigation technologies are better assessed as complete solutions than as stand-alone products, as their use typically depends on upstream components, the necessary infrastructure, maintenance, certification and financing. An analysis from the perspective of the value chain reveals where gaps in expertise are limiting exports and whether the greatest opportunities lie in a core technology, a complementary component, systems integration or a related service. It also reduces the risk of funding being channelled into products that cannot be scaled up without the necessary supporting expertise.

- **Strengthen R&D, innovation and ecosystems for leadership or participation**
  Maintaining a market presence requires continuous innovation. Governments can strengthen public-private R&D partnerships, promote emerging green technologies and connect established companies with research institutions, start-ups and technology providers. Objectives should vary by area: In selected areas, policymakers can aim for technological leadership; in others, they should ensure meaningful participation in strategically important value chains. Support should extend from research through proof of concept to commercialization, since strong performance at an early stage does not automatically make a technology commercially viable or scalable. International competition can act as a catalyst for faster innovation, cleaner production and continuous improvement, while policymakers should focus their support on areas where domestic capabilities can secure a lasting market position.

6.2 Industrial policy

To foster competitive markets, countries need a coherent framework that combines trade, climate, industrial and financing policies.

- **Assess interactions between trade, industrial and climate policy**
  Tariffs, subsidies, carbon pricing, procurement and product regulation all shape investment incentives and the diffusion of mitigation technologies, and they are not interchangeable. When objectives appear to conflict, the solution usually lies in pursuing a different policy instrument rather than abandoning one of the objectives. For solar products, the evidence suggests that border measures intended to support domestic production have mostly shifted production to third

countries rather than bringing it home. The additional costs to buyers were several times higher than the gains to domestic producers. By contrast, studies estimate that production subsidies raise output, employment and welfare at the same time. European scenarios show the same asymmetry: Countries can reach a capacity target at moderate cost, whereas creating jobs through trade restrictions costs many times more (Section 5.1). Coordinated policy instruments can expand the production of high-value goods, capitalize on existing comparative advantages and accelerate cross-border deployment. Contradictory measures increase costs and fragment markets. Policymakers should therefore set clear strategic objectives, assess the combined impact of the instruments and work with businesses and financial institutions to identify practical obstacles. Support is most effective when it is transparent, predictable and compatible with competition, rather than becoming a permanent substitute for it.

- **Use competitiveness analysis to set policy priorities**
  Ideally, industrial policy should be based on insights at the product and segment level, rather than solely on top-line export shares. Among the top 20 leading exporters of CCM goods, there is considerable variability in the number of product categories in which a country has a Revealed Comparative Advantage (RCA)—ranging from around 80 for the leading exporter to about 30 for smaller members of the group (Figure 13). This demonstrates that a high aggregate export share does not automatically imply broad-based specialization. For the 15 largest CCM goods categories, several major exporters have an RCA in only a handful of them, while others, such as the Czech Republic and China, have advantages across a wider range. Mexico, Japan and the Netherlands have the highest combined RCA scores, which suggests a high degree of specialization in a few categories rather than broad-based competitiveness. Competitive pressure also tends to be concentrated on competitors with similar technologies rather than fringe suppliers, and the resulting overlap can vary significantly from one bilateral pair to the next (Section 3.3). Governments can monitor comparative advantages, competitor dynamics and adjacent capabilities on an ongoing basis to determine where they should take a leading role, defend their position, cooperate or reposition themselves.

- **Mobilize public finance, partnerships and targeted incentives**
  Public and development financing can address identifiable funding gaps and mobilize private capital, through first-loss guarantees, concessional loans, equity co-investments and export credit guarantees. These instruments are most effective when they are tailored to the specific obstacles, such as high capital intensity, uncertain technology viability or market-entry risks, and are linked to additional private investments, so that the support boosts market participation without shielding projects from economic discipline.

- **Reduce unnecessary regulation and bureaucracy**
  Regulatory standards should ideally protect environmental integrity and market confidence without causing avoidable delays. Governments have several policy options at their disposal. They can streamline duplicated testing, certification, documentation and approval procedures; improve coordination between authorities; and set out transparent timelines. Proportionality is key here: Requirements should reflect the risk, scale and maturity of the project or product. Simplification can lower the cost of market entry, particularly for smaller businesses, and speed up the diffusion of mitigation technologies. Overlapping and frequently changing rules can undermine bureaucratic efficiency over time, suggesting that the stability and internal coherence of the regulatory framework are just as important as its content (Section 5.3). Regulatory reform should therefore focus on eliminating unnecessary friction rather than on deregulation as an end in itself.

6.3 Risk and dependency

Critical vulnerabilities require targeted policies to strengthen resilience while preserving the efficiency gains from international specialization.

- **Map bilateral trade routes, import concentration and supply chain resilience**
  Headline trade volumes alone are not sufficient to identify critical vulnerabilities. Policymakers can map upstream components, supplier countries and bilateral trade routes, focusing on products where supplier concentration, import exposure and limited substitutability overlap. This network perspective identifies geographical choke points and highlights whether it is possible to mobilize alternative routes and suppliers. It also avoids treating every concentrated market as a strategic dependency and supports proportionate, product-specific responses.

- **Take advantage of scenario and risk analysis**
  Relevant scenarios include trade disputes, tariffs, carbon border adjustment mechanisms, transport disruptions and the loss of key suppliers. At project level, a due diligence review will assess supplier reliability, diversification plans, the availability of alternative suppliers and the time and cost involved in substituting components. It is also important to monitor aggregate risks at the country level. This type of analysis makes it possible to identify vulnerabilities and, where necessary, develop strategies to address them. Our study shows that importing countries have opportunities for diversification. Even where imports are highly concentrated, the average global market share of the main supplier in most product categories falls below the 30% threshold, suggesting that concentration and dependency are not the same thing.

- **Prioritize long-term resilience and strategic autonomy over short-term cost**
  Affordable imports can accelerate the deployment of mitigation technologies; however, where disruptions could materially affect continuity, timing or cost, finding the most cost-effective sourcing is not necessarily the sole criterion. Decisions regarding procurement, finance and industrial policy should factor in the value of supplier diversity, technological capabilities and security of supply. Possible measures may include alternative trade partnerships, targeted capacity building and the promotion of technical substitution. Strategic autonomy is not synonymous with self-sufficiency or broad localization. Instead, it can mean securing sufficient options, knowledge and production capacity to be able to adapt in the event of disruptions to international supply, while continuing to benefit from trade.

- **Expand circularity and responsible resource strategies**
  Circular economy strategies have the potential to reduce structural exposure to volatile and concentrated raw materials supplies, while at the same time unlocking opportunities for countries to participate in international value chains. During the extraction stage, the primary supply of raw materials initially depends on geological deposits and determines trade flows. It might be possible to secure a secondary source through closed-loop models, expanding the sourcing options for domestic and potentially foreign demand and creating opportunities for diversification. Policy can support circular practices like recycling, recovery, remanufacturing, resource-efficient production and product designs that facilitate repairs and material reuse. Where primary resources are still required, manufacturers can combine closed-loop models with diversified sourcing and responsible domestic extraction. Developing reliable markets and quality standards for secondary materials can create additional supply buffers and reduce environmental impacts. The circular economy is therefore not only an environmental objective, but a complement to diversification and therefore an integral part of economic resilience and long-term competitiveness.

6.4 International cooperation

Strengthening rules-based cooperation allows mitigation technologies to reach markets efficiently, fairly and at scale.

- **Promote a global level playing field and rules-based competition**
  Trade rules can safeguard against market-distorting practices while ensuring transparency and preventing discrimination. Greater transparency around subsidies, procurement rules and local-content requirements, together with dialogue and dispute settlement, can counteract unfair practices. Climate-related border measures and public procurement should be designed so that they protect environmental integrity without becoming a form of hidden protectionism. A genuine level playing field promotes innovation-based competition and preserves political support for global trade.

- **Evaluate the costs and benefits of tariffs and non-tariff barriers**
  The tariffs applied to CCM goods are low in absolute terms in most advanced economies: UNCTAD puts the average tariff on solar and wind value-chain products in developed countries at 1.9%, compared with 2.5% in Asia and Oceania and 7.1% in Africa.[71] However, they are not low relative to competing products. On average, tariffs and non-tariff barriers are lower for high-emitting sectors than for clean industries, which amounts to

an implicit subsidy for carbon in traded goods. UNCTAD reports the same pattern for plastics: The average tariff rate for plant-based plastic substitutes is at 14.4%, compared with 7.2% for conventional plastics. The removal of trade barriers in this area therefore represents a correction of the existing structure rather than a departure from neutral trade policy. Where tariffs are already low, the remaining barriers to market access are largely non-tariff in nature—customs procedures, border formalities, testing and certification. Reforms should prioritize tackling those frictions that have the greatest impact on costs and deployment speed, while ensuring that legitimate and verifiable environmental and safety requirements are upheld. Technical assistance and capacity building help developing countries and smaller suppliers to meet strict requirements and participate in international value chains.

- **Harmonize international standards, certifications and transparency**
  A stable and fair green trade system benefits from internationally compatible standards and credible certification. Governments and standard-setting bodies can develop common definitions and methods of measurement, pursue harmonization or mutual recognition, provided the requirements are equivalent, and improve transparency on evidence, timelines and fees. Fragmented standards can exclude stakeholders who are not yet sufficiently prepared, slowing down deployment even if formal tariffs are low. Inclusive standard-setting, supported by technical cooperation, can reduce compliance costs while safeguarding environmental integrity and building trust in green claims. The objective should not be deregulation or harmonization for their own sake, but rather the removal of unnecessary barriers to market access. Governments and standardization bodies should improve transparency regarding technical requirements, documentation, testing procedures, timelines and fees. They should avoid duplicate testing and certification where equivalent evidence already exists and pursue international alignment or mutual recognition where standards lead to comparable environmental and safety outcomes. The requirements should be proportionate to the risks involved and should not undermine either environmental integrity or consumer protection.

- **Negotiate robust trade agreements covering CCM goods**
  Attempts to negotiate comprehensive trade agreements covering CCM goods have had a mixed track record. WTO talks on an Environmental Goods Agreement, launched in 2014 with 18 participants that together accounted for the majority of global trade in environmental goods, stalled in 2016 over product scope—the same classification challenge (Section 2.2) that also complicates the CLEG list used in this study.[72] Narrower configurations have proved more workable, as demonstrated by the Agreement on Climate Change, Trade and Sustainability signed in 2024 (Section 5.3). This suggests that agreements are more likely to succeed when they are negotiated incrementally around defined segments such as RES, EEH or CMO rather than as a single comprehensive package.

  The value of such agreements is not limited to tariff reductions. The removal of tariffs, as simulated in models, leads to a slight increase in trade volume and GDP and is likely to cut global emissions by around 0.6% (Section 5.1). The larger gains from trade stem from reduced fragmentation of supply chains and faster technology diffusion. More importantly, agreements are among the few instruments that make climate commitments self-enforcing: Linking market access to participation can sustain coalitions, something voluntary agreements cannot achieve, and environmental provisions in existing agreements are associated with reduce emissions among the parties involved by a measurable amount (Section 5.2). Parties can reinforce agreements through joint R&D, technology transfer, proof-of-concept projects and capacity building, public and development finance that lowers the risk of the investment needed to turn market access into deployment—provided they weigh the potential for market liberalization against the concentration risks identified in Chapter 4 (see 6.3).

- **Safeguard environmental integrity and avoid treating market openness as an end in itself**
  The economic case for international cooperation rests not only on the benefits of trade liberalization but also on the ability to safeguard environmental integrity and address market failures. Market access must go hand in hand with legitimate and verifiable environmental requirements, transparent rules and support for capacity building. Development and export finance instruments offer a potential solution to financing bottlenecks where projects are commercially viable but face identifiable barriers such as uncertain technology performance or limited access to private capital.

Spotlight on Germany

Germany has a leading export position, combined with a narrow specialization profile and significant exposure to concentrated supplier markets. Applying our four pillars to these dynamics yields the following priorities.

Export opportunities (6.1)

- **Defend the established position rather than broaden it.** Germany holds a comparative advantage in four of the fifteen largest categories, concentrated in road vehicles and electrical equipment. Support is most likely to pay off where that advantage already exists or where expertise in similar product groups makes expansion easier, above all in Clean Mobility.

- **Treat technologies as complete solutions.** Export prospects in vehicles depend on cells, power electronics, charging infrastructure and servicing capability; assessing these together shows where capacity shortfalls are limiting exports.

- **Use research and capability support where no advantage exists.** In cells, modules and semiconductor equipment, R&D funding is a more effective tool than funding aimed at increasing market share.

Industrial policy (6.2)

- **Pair demand-side with supply-side instruments.** Purchase incentives, fleet regulations and public procurement only partly translate into domestic value added, as some of the demand they create is met by imported cells and modules. They can still complement supply-side instruments, such as R&D and innovation initiatives, financial support for manufacturers and export financing.

- **Set priorities based on product- and segment-level evidence.** Germany illustrates why: Although it is the world's second-largest exporter of CCM goods, it is specialized in only four of the fifteen largest categories.

- **Reduce administrative friction.** This applies in particular to duplicate testing and certification requirements, which weigh most heavily on smaller exporters.

Risk and dependency (6.3)

- **Let the availability of alternatives decide the instrument.** In most categories, the main supplier's average global market share is below 30%, and no German product group meets all seven dependency criteria outlined in Section 4.3. The development of alternative suppliers is therefore the first option in most cases, while building domestic or European capacity is reserved for instances where substitution is genuinely not possible or where national security interests take precedence.

- **Reserve capacity building for the critical intersection** of high supplier concentration, high import exposure and low substitutability. Import exposure in battery cells is a case in point, as they are used as inputs for Germany's exports, particularly in the electric vehicle segment. A one-month disruption to the Chinese battery supply chain would cost electric car factories worldwide some USD 17 billion in output, with more than half of those losses in the European Union—in Clean Mobility, the segment that is Germany's main area of specialization.[73]

- **Keep resilience measures proportionate.** Strategic autonomy means having viable alternatives, not self-sufficiency: Module prices for German installers would have been around 83% higher in 2020 if they had relied solely on domestic supply chains.

International cooperation (6.4)

- **Work on standards and market access with partners that have similar export profiles.** German exports overlap most with other European economies, so mutual recognition and harmonization of standards at EU level have a direct impact on German export performance.

- **Pursue rules-based supply partnerships** that widen the supplier base through technical assistance and investment, without discriminating against third countries.

Across all four pillars, **de-risking instruments** such as guarantees, concessional finance and export finance can be deployed for commercially sound projects that face high upfront costs or uncertain technological performance.

7. Conclusion

Climate change mitigation goods are a dynamically growing market. Their trade value rose by 8.0% annually between 2017 and 2025, compared with 4.7% for merchandise trade as a whole, with Clean Mobility displacing Renewable Energy Systems as the main driver of growth. Supply relies on a few key players: China accounts for 26% of global exports and Germany 10%, both well above their respective shares in merchandise exports of 14% and 7%.

The level of concentration in CCM goods is no greater than in overall global trade. 24% of the respective product categories exceed the concentration threshold on the export side, compared with 34% in merchandise trade as a whole. However, it affects precisely those areas where substitution is most difficult: lithium-ion batteries and photovoltaic cells, which together account for about half the export value in concentrated categories. Trade data even understate the degree of concentration in global production capacity. China has close to 85% of the global battery cell production capacity, compared with a 59% share of exports of finished batteries and more than 80% of solar manufacturing capacity. Concentration is nevertheless not the same as dependency. In most categories, the main supplier's average global market share is below 30%, indicating potential scope for supplier diversification. What remains is narrow but not small: a risk concentrated in the categories that are crucial for deployment, where any disruption would take time and money to absorb.

That risk is offset by gains that are likely to be higher for CCM goods than in the merchandise trade more broadly. Measured by the number of product categories, most of these goods are capital goods or intermediate inputs, and studies generally find larger gains from trade for such goods. Their costs have fallen in line with cumulative global rather than national production, so fragmenting these markets would raise costs everywhere rather than merely relocating production. A case in point: Module prices for German installers would have been around 83% higher in 2020 had they relied entirely on domestic supply chains. These cost reductions relied on an international division of labour that no single country could have achieved alone. And deployment addresses a global externality that market prices do not reflect, providing a benefit that far outweighs the emissions from producing and shipping the goods. In 2024, China's manufacturing of clean-technology exports resulted in around 110 Mt of CO_2 emissions, while avoiding some 4,000 Mt CO_2 over their operating lifetimes.

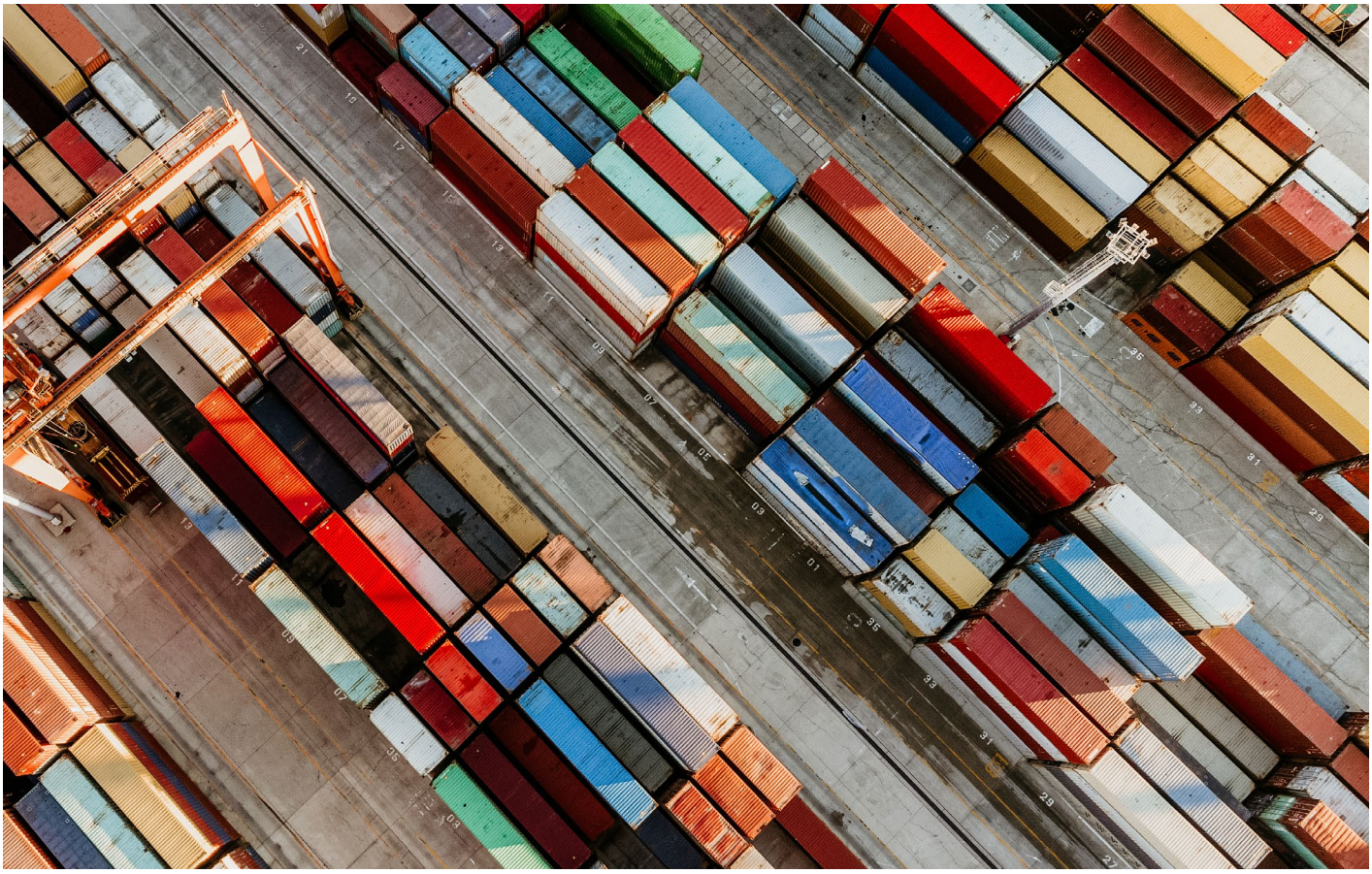
Our findings therefore support a policy mix rather than any single instrument: targeting export support where a comparative advantage exists or can be built; establishing a coherent framework that combines trade, industrial, climate and financing instruments based on evidence at the product and segment level; focusing resilience measures on the narrow intersection of supplier concentration, import exposure and limited substitutability; and safeguarding rules-based, predictable markets through lower barriers and compatible standards. Getting this mix right will determine whether trade in CCM goods continues to reduce the costs and accelerate the pace of decarbonization, in Germany and beyond.

8. Glossary

Abbreviation	Full Term (English)	Definition/Explanation
BACI	Base pour l'Analyse du Commerce International	A detailed global database for international trade at the product level, maintained by CEPII.
CCM	Climate change mitigation	Goods that can be used to reduce, avoid or capture greenhouse gas emissions, for example by generating renewable energy, improving energy efficiency or enabling low-emission transport.
CCS	Carbon capture and storage	Technologies for capturing and storing carbon dioxide (not covered in the primary CLEG scope of this study).
CEPII	Centre d'Etudes Prospectives et d'Informations Internationales	French research centre in international economics that produces and maintains the BACI database.
CLEG	Combined List of Environmental Goods	The OECD classification list used to identify and group green and environmentally friendly goods.
CMO	Clean Mobility	Technologies offering clean mobility alternatives to fossil fuels (e.g., electric vehicles).
EEH	Energy Efficient Housing	Products designed to improve energy efficiency in buildings (e.g., insulation, LED lamps).
EV	Electric vehicle	A vehicle propelled by one or more electric motors using electricity stored in a rechargeable battery.
GDP	Gross domestic product	A monetary measure of the market value of all final goods and services produced in a specific time period.
HHI	Herfindahl-Hirschman Index	A widely accepted measure of market concentration used to identify monopolistic or highly concentrated markets.
HS	Harmonized system	A standardized numerical method of classifying traded products (used by customs authorities worldwide).
ITC	Index of Trade Competition	An index measuring the extent to which two countries compete directly with similar product mixes.
LED	Light-emitting diode	An energy-efficient light source mentioned in HS 853950 (categorized under the EEH segment) as well as HS 854140 (categorized under the RES segment).
OECD	Organisation for Economic Co-operation and Development	An intergovernmental economic organization founded to stimulate economic progress and world trade.
PV	Photovoltaic	Technology that converts sunlight into electricity using photovoltaic cells or modules.
R&D	Research and development	Creative and systematic work undertaken to increase the stock of knowledge and to devise new applications.
RCA	Revealed Comparative Advantage	An index used to calculate a country's relative export specialization and strength in specific product groups.
RES	Renewable Energy Systems	Technologies supporting renewable energy plants and systems (including lithium-ion batteries).
SWM	Solid waste management	Facilities and goods for the recovery, sorting and processing of waste materials (circular economy and recycling).
USD	United States dollar	The official currency of the United States of America.

ISO 3-Letter Country Codes used in this study

Code	Country
CHN	China
DEU	Germany
ESP	Spain
FRA	France
GBR	United Kingdom
ITA	Italy
KOR	South Korea
MEX	Mexico
NLD	Netherlands
POL	Poland
USA	United States
JPN	Japan



9. Appendix

Appendix A: Top 15 goods according to share of global export of CCM goods (in %)

HS code	Description	Segment	Share
870380	Vehicles: with only electric motor for propulsion	Clean Mobility	8.4
870340	Vehicles: with both spark-ignition internal combustion reciprocating piston engine and electric motor for propulsion, incapable of being charged by plugging to external source of electric power	Clean Mobility	7.8
850760	Electric accumulators: lithium-ion, including separators, whether or not rectangular (including square)	Renewable Energy Systems	6.9
850440	Electrical static converters	Renewable Energy Systems	5.7
853710	Boards, panels, consoles, desks and other bases: for electric control or the distribution of electricity, (other than switching apparatus of heading no. 8517), for a voltage not exceeding 1000 volts	Renewable Energy Systems	5.1
854140	Electrical apparatus: photosensitive, including photovoltaic cells, whether or not assembled in modules or made up into panels, light-emitting diodes (LED)	Renewable Energy Systems	4.7
848620	Machines and apparatus of a kind used solely or principally for the manufacture of semiconductor devices or of electronic integrated circuits	Renewable Energy Systems	4.7
870360	Vehicles: with both spark-ignition internal combustion reciprocating piston engine and electric motor for propulsion, capable of being charged by plugging to external source of electric power	Clean Mobility	3.8
730890	Iron or steel: structures and parts thereof, n.e.c. in heading 7308	Renewable Energy Systems	2.9
840734	Engines: reciprocating piston engines, of a kind used for the propulsion of vehicles of chapter 87, of a cylinder capacity exceeding 1000cc	Clean Mobility	2.3
848690	Machines and apparatus of heading 8486: parts and accessories	Renewable Energy Systems	2.0
841590	Air conditioning machines: with motor-driven fan and elements for temperature control, parts thereof	Energy Efficient Housing	1.8
841199	Turbines: parts of gas turbines (excluding turbo-jets and turbo-propellers)	Renewable Energy Systems	1.6
850300	Electric motors and generators: parts suitable for use solely or principally with the machines of heading no. 8501 or 8502	Renewable Energy Systems	1.5
903289	Regulating or controlling instruments and apparatus: automatic, other than hydraulic or pneumatic	Renewable Energy Systems	1.4

Appendix B: Main competitors of the Top 20 exporting countries of CCM goods

Rank of competitors based on ITC index, 2024

Main exporter of CCM goods

Rank of competitor	Asia								Europe									America		
	CHN	KOR	JPN	MYS	OA*	THA	VNM	SGP	FRA	CZE	DEU	ESP	GBR	POL	ITA	HUN	NLD	USA	CAN	MEX
1	HGK	CZE	KOR	VNM	MYS	VNM	MYS	NLD	CZE	ESP	CZE	CZE	SVK	HUN	AUS	POL	SGP	DEU	TUR	DEU
2	POL	JPN	GBR	OA*	CHE	HKG	CHN	MYS	GBR	KOR	ESP	FRA	FRA	CZE	IND	CZE	MYS	FRA	FRA	CZE
3	CZE	DEU	USA	NLD	SGP	MYS	THA	OA*	ESP	DEU	BEL	GBR	ESP	CHN	FRA	USA	CHN	GBR	GBR	AUT
4	VNM	FRA	FRA	SGP	IND	IND	CYP	JPN	CAN	FRA	FRA	DEU	CAN	AUT	CHE	HKG	USA	JPN	BRA	FRA
5	ITA	ESP	CZE	CHN	VNM	PHL	PHL	USA	DEU	BEL	USA	BEL	JPN	CAN	DNK	FRA	DEU	KOR	CZE	HUN
6	IDN	USA	CAN	THA	USA	PAN	IDN	CHN	USA	POL	KOR	ZAF	DEU	FRA	AUT	CHN	JPN	AUT	ZAF	ESP
7	PAN	BEL	DEU	USA	NLD	IDN	IND	KOR	ITA	GBR	GBR	TUR	USA	ESP	CHL	DEU	OA*	CAN	ESP	CAN
8	HUN	GBR	TUR	IDN	CHN	MUS	HKG	TLS	KOR	CAN	MEX	KOR	CZE	HKG	SWE	CAN	AUT	ITA	POL	MAR
9	FRA	SVN	ESP	CYP	IDN	CMR	NAM	CHE	JPN	TUR	SWE	CAN	ZAF	DEU	USA	MEX	KOR	SWE	USA	POL
10	NLD	AZE	SVK	HKG	JPN	ITA	OA*	FRA	BRA	HUN	AFG	BRA	TUR	USA	CHN	AUT	FRA	POL	ROU	SVN
11	MYS	CAN	NLD	JPN	HKG	CHN	MUS	AUT	ZAF	MEX	SVN	SWE	SWE	FIN	CAN	GBR	ESP	HUN	ITA	USA
12	KOR	CHN	BEL	CHE	THA	NZL	WSM	DEU	TUR	CHN	AUT	SVK	BRA	ITA	POL	ESP	CZE	CZE	HUN	ITA
13	DEU	TUR	SGP	PHL	PHL	CYP	ITA	HKG	SWE	ZAF	POL	POL	JAM	IDN	ESP	FIN	GBR	NLD	HUN	KOR
14	AUS	MAR	OA*	KOR	ITA	OA*	PAN	VNM	POL	BRA	HUN	AUT	KOR	ZAF	CZE	IDN	MEX	OA*	JPN	AUS
15	AUT	ZAF	ZAF	AUT	PRT	MEX	POL	THA	BEL	SVN	ITA	ITA	BEL	TUR	FIN	SWE	POL	CHE	KOR	BGR
16	FIN	MEX	BRA	NZL	ISR	ISR	PRT	IDN	ROU	AUT	CHN	ROU	GEO	MEX	DEU	KOR	ITA	MYS	MEX	LTU
17	DNK	POL	AUT	IND	AUT	CHE	CMR	ISR	HUN	JPN	JPN	MEX	BRB	NOR	TUR	ROU	CHE	MEX	BEL	GBR
18	IND	HUN	MYS	NAM	AUS	FIN	DNK	IND	MEX	MAR	NLD	SVN	AZE	SWE	BRA	ITA	TLS	AUS	BEL	ROU
19	ESP	BRA	JAM	CZE	KOR	AUS	NOR	ITA	CHN	ROU	MAR	JPN	HUN	KOR	NOR	NOR	NLZ	CHN	AUS	NOR
20	USA	AUT	MAR	IRL	CHL	DNK	CHE	NZL	AUT	ITA	CAN	CHN	ROU	GBR	IRL	BRA	BEL	ESP	EST	LVA

Major exporter as competitior

Another country than a major exporter as competitor

* OA is Other Asia, esp. Taiwan

Source: CEPII BACI, HS2017, 2017–2024; authors' calculations (see methodology note on p. 10 for more details).



Appendix C: Intensity of competition between the Top 20 exporters of CCM goods
ITC index, 2024

		Asia								Europe									America		
		CHN	KOR	JPN	MYS	OA*	THA	VNM	SGP	FRA	CZE	DEU	ESP	GBR	POL	ITA	HUN	NLD	USA	CAN	MEX
Asia	CHN		49	39	50	45	45	55	35	50	55	49	46	40	58	53	51	50	46	41	41
	KOR	49		65	38	38	30	32	33	59	70	60	59	53	45	39	45	43	56	49	46
	JPN	39	65		41	44	27	24	45	56	52	48	48	61	34	34	37	46	56	49	28
	MYS	50	38	41		56	49	56	52	34	37	33	26	26	35	33	31	52	47	31	32
	OA*	45	38	44	56		42	48	49	33	29	33	25	25	32	41	28	46	47	29	26
	THA	45	30	27	49	42		53	26	38	38	36	33	30	35	45	32	27	35	34	41
	VNM	55	32	24	56	48	53		28	33	38	32	32	24	41	42	33	28	31	31	30
	SGP	35	33	45	52	49	26	28		31	23	28	18	24	24	26	22	73	44	25	23
Europe	FRA	50	59	56	34	33	38	33	31		67	62	65	67	54	59	51	40	61	63	50
	CZE	55	70	52	37	29	38	38	23	67		67	70	59	59	50	55	36	50	58	55
	DEU	49	60	48	33	33	36	32	28	62	67		63	59	52	50	50	47	61	45	56
	ESP	46	59	48	26	25	33	32	18	65	70	63		64	53	51	46	36	46	56	49
	GBR	40	53	61	26	25	30	24	24	67	59	59	64		44	45	47	35	59	62	43
	POL	58	45	34	35	32	35	41	24	54	59	52	53	44		51	62	34	52	55	47
	ITA	53	39	34	33	41	45	42	26	59	50	50	51	45	51		43	33	53	51	46
	HUN	51	45	37	31	28	32	33	22	51	55	50	46	47	62	43		29	52	50	49
	NLD	50	43	46	52	46	27	28	73	40	36	47	36	35	34	33	29		49	27	34
USA	USA	46	56	56	47	47	35	31	44	61	50	61	46	59	52	53	52	49		54	46
	CAN	41	49	49	31	29	34	31	25	63	58	45	56	62	55	51	50	27	54		49
	MEX	41	46	28	32	26	41	30	23	50	55	56	49	43	47	46	49	34	46	49	

* OA is Other Asia, esp. Taiwan
The darker the colour the higher the index and therefore the competition
Source: CEPII BACI, HS2017, 2017–2024; authors' calculations (see methodology note on p. 10 for more details).

10. Endnotes

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