Policy Research Working Paper 10696

Turning Risks into Reward

Diversifying the Global Value Chains of Decarbonization Technologies

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Abstract

Reaching net-zero emissions by 2050 requires unprecedented scaling up in the global deployment of critical decarbonization technologies, such as solar photovoltaics, wind turbines, and electric vehicles. This challenge is currently rife with both risks and rewards: while securing an adequate supply of these technologies has become an urgent policy priority for many countries, their high-growth global value chains also offer lucrative benefits for those able to meet the burgeoning global demand. Although recent policy responses have sought to nearshore production to reduce risks and capitalize on rewards, this paper instead lays out an evidence-based strategy to help diversify the global value chains of decarbonization technologies across countries with latent production capabilities and resource endowments. To that end, it constructs a new dataset of traded products, components, and materials associated with decarbonization technologies; develops new indexes capturing countries' current export strengths and future diversification potential in these global value chains; and highlights products with supply risks due to high market concentration levels and those with development rewards in terms of their potential for growth, knowledge spillovers, and technological upgrading. Taken together, the evidence supports the idea that there is plenty of opportunity to diversify these value chains across a larger number of countries to avoid the risks associated with reliance on only a few countries.

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Turning Risks into Reward: Diversifying the Global Value Chains of Decarbonization Technologies[1]

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1. Introduction

For the world to reach net-zero emissions by 2050, the global deployment of low-carbon technologies such as solar photovoltaics (PV), wind turbines and electric vehicles (EVs) needs to dramatically increase. Current projections suggest growth in installed capacity in solar and wind will need to increase by around 3-5-fold between now and 2030, while 18-fold increases are projected for the global scale-up of EVs (IEA, 2021). Unlike technologies such as nuclear and carbon capture, usage and storage (CCUS), persistent cost declines in solar PV, wind turbines and EVs paint a promising and predictable future for their deployment: the more we produce globally of these technologies, the cheaper they become (Way et al., 2022; Lam and Mercure, 2022).

We focus on the decarbonization value chains of solar PV, wind turbines and EVs for three reasons. First, a broad consensus exists worldwide that these technologies are critical in the green transition, irrespective of countries' economic conditions and political alignment. This contrasts with green and environmental goods whose classification is controversial and subject to countries' political sensitivities. Second, participating in the trade of

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these value chains offers important economic advantages for countries. As global demand is beginning to shift away from fossil-fuel based production and towards these technologies, developing the capabilities to competitively produce products and associated components can help countries achieve greater economic growth and export diversification prospects. This is especially true for technologically sophisticated products as they offer advantages for technological upgrading and knowledge spillovers into other industrial areas (Hidalgo & Hausmann, 2009). Third, these value chains face vulnerability to disruptions such as natural disasters, pandemics, conflict, and geopolitical events. This highlights the importance of identifying countries with requisite capabilities and resource endowments to help diversify production and enhance resilience in these value chains. This can help ensure that rewards from participating in high-growth global value chains are shared more broadly.

However, policy makers around the world are racing to re-engineer the relationship between markets and the state in industries critical for the green transition. This is apparent in the growing use of subsidies and export restrictions in developing countries to corner the market for decarbonization technologies. Conversely, recent industrial policy responses in developed countries seek to help markets reconcile economic prosperity and climate objectives while reducing dependencies. These and other examples illustrate how national policy making seeks to localize these supply chains domestically. This could weaken the efficient allocation of capital and economies of scale (Tagliapietra and Veugelers, 2023). It could also exclude developing countries with limited fiscal capacity, unable to engage in a subsidy race with industrial nations despite their local energy resources, critical inputs in the production of energy-intensive industrial commodities.

Despite calls for more diversified value chains in decarbonization technologies (IEA, 2023; IMF, 2022), there has been limited work to identify the countries that are best placed to increase their participation in the production of these technologies or to highlight what the growth opportunities could look like for individual countries. To address this gap, this paper makes several contributions. First, we construct a new dataset of key traded products, components and materials associated with solar PV, wind turbines and EVs and map this to country trade data. This enables the exploration of historical and current trade patterns for 74 high-income, 106 middle-income and 26 low-income countries between 2005-2021 in these global value chains and introduces a new dataset for future trade analysis. Overall, we find that export market concentration in decarbonization value chains is not high compared to other traded products, although a few product-specific vulnerabilities persist. Thus, concentration is not harmful per se; only excessive concentration represents a risk for security of supply. This implies that a minimum level of diversification is helpful for resilience reasons amid today's rising economic nationalism.

Second, we develop novel indices that summarize the breadth and depth of countries' current export strengths in these value chains. While China, Germany and the US are the leaders in export competitiveness across all three technologies, middle-income countries such as Türkiye, Mexico, India, South Africa and Brazil have export strengths in a variety of key value chain products, components and materials and are well positioned to capitalize on the projected future growth in these areas. We also develop a similar set of new indices that aim to capture the breadth and depth of countries' future diversification potential in these value chains. Using past evolutions and hindcasting, we show that countries scoring higher in opportunities indices are significantly more likely to develop greater competitiveness in the subsequent periods. Countries that lead in diversification potential include the Netherlands, France, and Spain, but also upper and lower middle-income countries, such as China, India and Türkiye. These insights complement existing work documenting current production trends in supply chains of energy technologies (e.g., IEA, 2022a; IEA, 2022b). Our product mapping, however, is more granular and broader in scope, using the finest internationally harmonized product classification available in solar PV, wind turbines and EVs. This allows policy makers to identify products that may present bottlenecks along each value chain and countries that are best placed to improve diversification and resilience.

Third, we set out an analytical framework to identify countries that could be best placed to help diversify a specific product market. For example, although the global production of photovoltaic cells is highly concentrated in a small number of countries, we show that Malaysia, Vietnam, and Thailand could have significant potential to expand their production and exports, diversifying the number of suppliers for this critical product. We also look at opportunities at the country level and identify product opportunities that could be advantageous in terms of their technological sophistication, growth profile and alignment with a country's existing export capabilities. In doing so, our analysis reveals granular, product-specific opportunities for exploiting existing and latent niches in decarbonization technologies and helps evaluate their trade-offs. This framework builds on the work of Mealy and Teytelboym (2022) that applied a similar approach to products that exhibit environmental benefits. Moreover, it contributes to the broader literature drawing on data-driven approaches to inform green industrial policy and economic development strategies (Montresor and Quatraro, 2019; Balland et al., 2019).

Our work is not without limitations. First, while our product mapping of value chains associated with decarbonization technologies relies on the 6-digit of the Harmonized System (HS), the most detailed internationally standardized product classification, products may have dual use. This means that a product may have additional applications or purposes beyond those relevant to the value chains of decarbonization technologies. Second, although the product classification of the 6-digit HS is remarkably detailed, a HS 6-digit code is not a single product but an average of differentiated product varieties. As a result, our product definition may be too broad to clearly identify products associated with decarbonization technologies. As it is currently not possible to determine what proportion of trade in each product relates primarily to decarbonization technology usage, the total product export volumes shown in this paper should be considered as an upper bound. The collection of more detailed input, output or supply chain data that is comparable across countries would allow for more accurate depictions of these global value chains. Finally, lags in trade data should also be kept in mind as recent developments and/or interventions are not accounted for.

2. Results

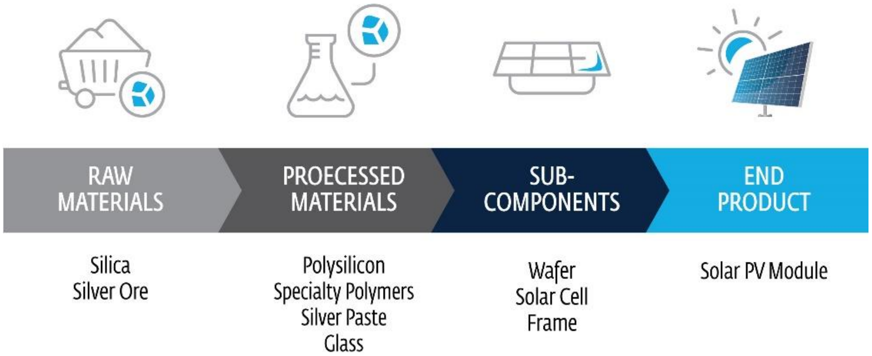
2.1 Mapping global value chains of key decarbonization technologies

To analyze trade patterns in the global value chains for solar PV, wind turbines and EVs, we collated a new dataset of end products, subcomponents, processed and raw materials classified under the 6-digit HS. The 6-digit HS is a standardized classification of traded products used by customs authorities around the world. It is also the most granular classification that is comparable across almost all countries and over time (see Methods section A1 for more detail). Figure 1 shows an illustration of the solar PV value chain, with example products listed. Due to the challenges of classifying such products under the 6-digit HS (IISD, 2020), our dataset is not exhaustive but intended to focus on the key identifiable elements of each value chain.[2]

As EV production includes products that are also used in internal combustion engine (ICE) vehicles, we construct two sets of value chain products: one more broadly defined and one more narrowly defined. The broader set includes HS products associated with the wider vehicle manufacturing value chain, e.g., products used in either ICE vehicles or EVs. The narrower EV value chain only considers products that relate specifically to EVs, e.g., battery end products and components and the assembled EV end product.

Figure 1: Mapping the solar global value chain

[2] All products included in our dataset were subject to a series of independent evaluations by selected industry specialists (see Methods section A1 for further information and Table SI 10 for a list of the included products).



A key concern raised by policy makers and international organizations is that production of these technologies is highly geographically concentrated. In Figure 2, we consider how concentrated each technology value chain is in terms of the market shares of their comprising products. For each product, we calculate the Herfindahl-Hirschman Index (HHI) based on the market shares of all countries exporting the product (see Methods section A2 for description of data sources and A3 for definition of metrics). An HHI of 1 indicates that the market is a perfect monopoly (one country exports 100% of the product), while HHI scores approaching 0 indicate a competitive market. Figure 2 shows the distribution of HHI values for all products in each technology value chain. The average HHI value for all traded products (0.174) is shown as the dotted line. Each value chain has a distinct right skew where a large proportion of products have lower than average HHI scores (indicating less concentrated markets), but a long tail of products showing higher market concentration levels. Overall, this means that the concentration in each technology value chain is not alarming, yet a few products represent vulnerabilities due to high export market concentration.

Figure 2: Market concentration of exported products in each value chain, 2021

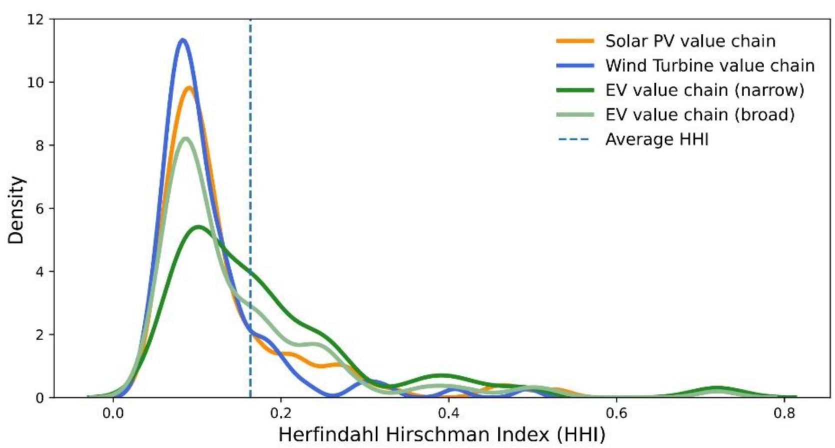
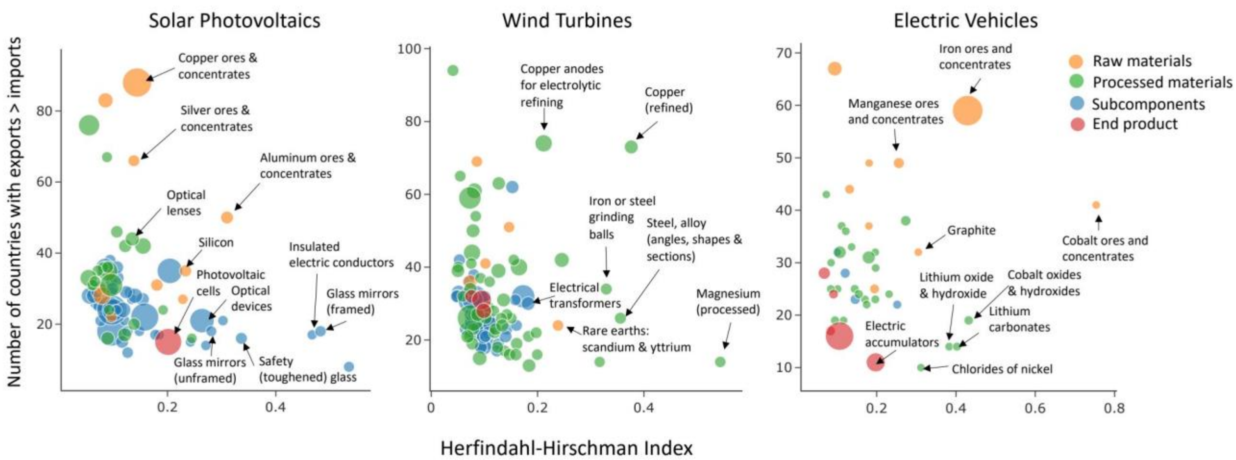


Figure 3 provides more detail on the market concentration of products in each value chain. Each node represents a product in each value chain, colored by its value chain segment and sized based on its global export value. The x-axis shows a product's market concentration, as measured by the HHI, and the y-axis shows the number of countries that are currently exporting more of that product than they are importing. The latter gives an indication of the breadth of exporter countries. Products that face higher supply-side risk are those in the bottom right corner, where the number of exporting countries is low and market share across those countries is concentrated. In the solar PV value chain, these tend to relate to more downstream subcomponents such as glass products, insulated electric conductors and optical devices. For wind turbines, these are more related to processed materials, notably larger subcomponents and end products such as blades or towers which tend to be traded less intensively due to their size and weight. For EVs, upstream raw and processed materials could pose the highest supply-side risks. However, it is important to note that this analysis does not consider the substitutability of these products. While supply disruptions in these concentrated products could create short-term production delays or cost increases, such disruptions could be overcome if producers are able to switch to alternatives in a timely and cost-efficient manner.

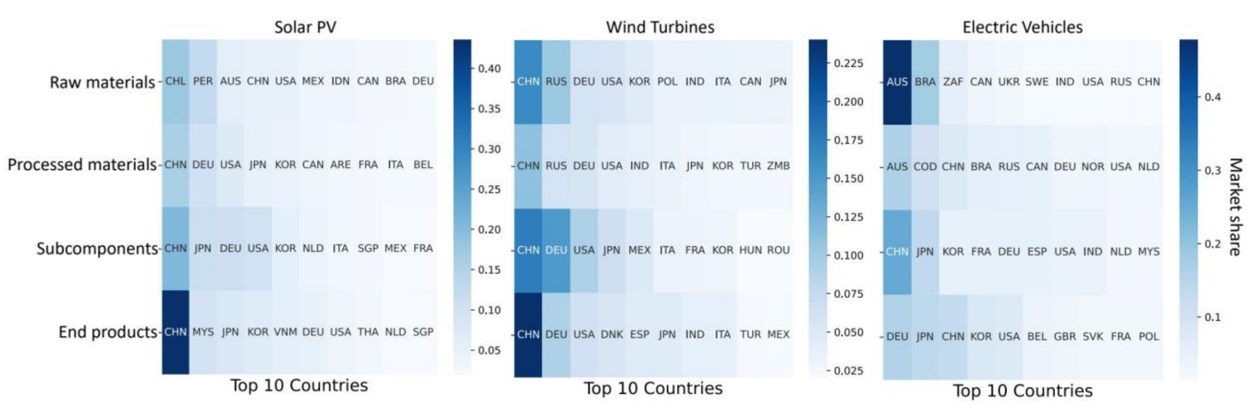
Figure 3: Export market concentration and number of exporters across value chain products, 2021



2.2 Dominant players in decarbonization technologies

Having looked at market concentration across key products in these decarbonization technology value chains, we now turn to the question of which countries are currently the most dominant players in each value chain and likely to have the greatest export strengths. We first consider the top 10 countries that have the highest market share across products in each decarbonization technology value chain segment in Figure 4. China is highly dominant across all technology value chains; it is a top 10 country in all value chain segments and the number one country across all subcomponent segments. China is also the number one country across all segments in the wind turbine value chain, and three out of four segments in solar PV. However, other countries such as Germany, the US, Japan, Australia and the Republic of Korea also feature prominently in the top 10 countries by market share.

Figure 4: Top 10 countries by export market share in each value chain segment, 2021



Note: ARG - Argentina, BRA - Brazil, CAN - Canada, COD - Democratic Republic of Congo, CHL - Chile, CHN - China, DNK - Denmark, DEU - Germany, ESP – Spain, FRA - France, HUN - Hungary, IND - India, IDN - Indonesia, ITA - Italy, JPN - Japan, MEX – Mexico, NLD - Netherlands, NOR - Norway, PER - Peru, POL - Poland, ROU - Romania, RUS – Russian Federation, ZAF - South Africa, KOR – Republic of Korea, ESP - Spain, SWE - Sweden, TUR - Türkiye, UKR - Ukraine, ZMB - Zambia.

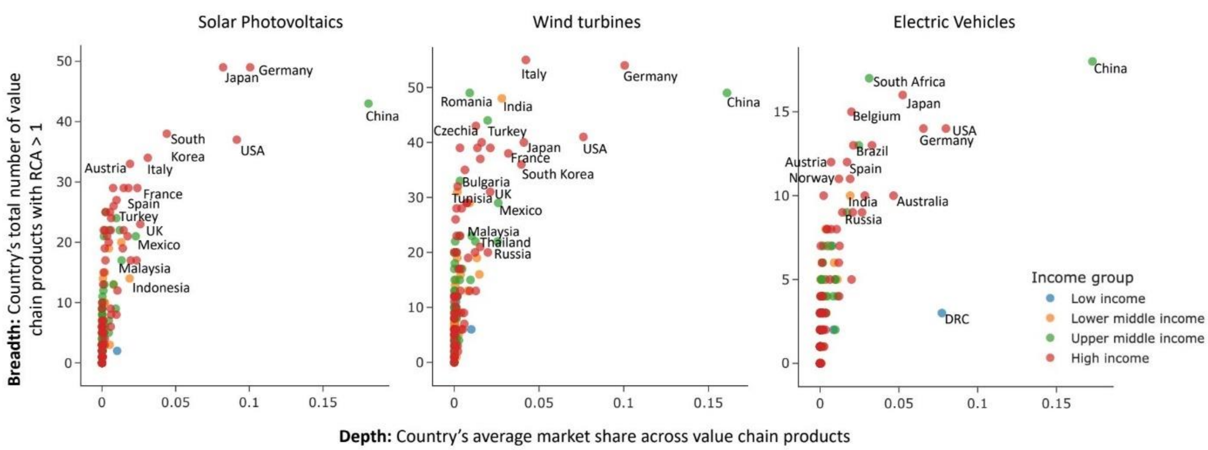
While market share provides insights into the depth of a country's export strengths in a product, it is not particularly informative about the breadth of a country's production capabilities across products in the value chain. Figure 5 represents both depth and breadth dimensions, showing a country's average market share across all value chain products on the x-axis ('depth') and the number of products a country demonstrates export competitiveness in along the y-axis ('breadth'). To measure whether a country demonstrates export competitiveness, we follow a widely used convention in the trade and competitiveness literature and draw on the Revealed Comparative Advantage (RCA) measure defined in equation 1:

$$\mathrm{RCA_{cp}} = \frac{\mathrm{X_{cp}}}{\mathrm{X_p}} \Big/ \frac{\mathrm{X_c}}{\mathrm{X}} \qquad (1)$$

where X_{cp} relates to the exports of country c of product p, X_c relates to the total exports in country c, X_p relates to the total global exports of product p and X relates to total global exports. Here, we count the number of products for which a country's export share is greater than or equal to the global average (RCA ≥1).

China is well ahead of other countries in terms of its depth of market share across value chain products in all decarbonization technologies and is one of the leaders in terms of the breadth of its competitiveness. Other leaders in terms of breadth of competitiveness are Germany and Japan, which have an export shares greater than the global average in almost 50 products in the solar PV value chain, while the US, Korea and Italy are not far behind. India, Romania and Türkiye are middle-income countries that show a strong breadth of competitiveness across a wide range of wind turbine value chain products, while South Africa, Japan and Belgium feature prominently in their breadth of competitiveness in the EV (narrowly defined) value chain.

Figure 5: Countries' breadth and depth of export competitiveness in each value chain, 2021



To summarize these depth and breadth dimensions into a single number that we can compare across countries, and over time, we develop the `Decarbonization Technology Strength' (DTS) index. First, we make the different scales and distributions of depth and breadth dimensions comparable by normalizing their values to have zero mean and unit standard deviation. We then assign equal importance to z-scores of depth and breadth dimensions to define countries in the DTS index, making it the least agnostic data mining procedure feasible (see Methods section A3.2 for more detail). This means that to fare well overall, a country must score highly on both depth and breadth dimensions. We apply this approach to calculate DTS indices for each specific value chain, and all value chain products combined. Table 1 shows the top 15 countries for each constructed DTS index.

China, Germany and the US are the leaders in export competitiveness across all three technologies globally. Japan, Korea and Western European countries follow suit. Moreover, middle-income countries like Türkiye, Mexico, India, South Africa, and Brazil show export strengths in a variety of key value chain products. They are strategically positioned to benefit from anticipated growth in these areas and have advanced manufacturing sectors. The Democratic Republic of the Congo is the only low-income country in the DTS top 15 index, given its strengths in raw materials of the EV value chain.

Table 1: DTS Index: Top 15 countries for each value chain and all value chains overall, by income group in 2021

DTS Index	All value chain products	Solar PV	Wind Turbines	Electric Vehicles
1	**China**	**China**	**China**	**China**
2	Germany	Germany	Germany	United States
3	United States	Japan	United States	Germany
4	Japan	United States	Italy	Japan
5	Italy	Korea, Rep.	Japan	**South Africa**
6	Korea, Rep.	Italy	India	Australia
7	France	Austria	Korea, Rep.	**Congo, Dem. Rep.**
8	**India**	France	France	France
9	Austria	Spain	**Türkiye**	**Brazil**
10	Spain	Hong Kong SAR, China	Romania	Belgium
11	**Türkiye**	United Kingdom	Spain	Finland
12	United Kingdom	**Mexico**	Austria	Korea, Rep.
13	Czechia	Czechia	Czechia	Spain
14	Sweden	Denmark	Sweden	Canada
15	Romania	Belgium	United Kingdom	Netherlands

Income group
- Low income
- Lower middle income
- Upper middle income
- High income

2.3 Diversification and development opportunities in decarbonization technologies

Having considered countries' current export strengths in the value chains of key decarbonization technologies, we now look to identify countries that are likely to be best placed to help further diversify these value chains. In addition to increasing market participation and building global supply chain resilience, countries that can successfully develop new areas of competitiveness in these high-growth value chains could see important economic growth and development benefits.[3]

Similar to our approach for identifying countries' export strengths, we also consider two dimensions relating to the breadth and depth of a country's future diversification opportunity in each value chain. We also summarize the depth and breadth of opportunity dimensions into a single Decarbonization Technology Opportunity (DTO) index that can be compared across countries and over time. As for the DTS index, we convert both depth and breadth opportunity dimensions into z-scores to account for their differential scales and distributions. We then take the simple average of these z-scores to define the DTO index.

The breadth dimension considers the number of products in each value chain for which a country's RCA (defined in equation 1) falls between 0.1 and 1. This metric aims to identify how many products a country shows some existing export capabilities, but at a level that is still not greater than the global average. The RCA threshold of 0.1 corresponds to country's median export intensity, including products that are significantly established (in relative

[3] We acknowledge that the exploration of export diversification opportunities for natural resource products differs from that of knowledge-based products. While raw material availability determines the former, the latter hinges on a country's productive capabilities, such as a skilled labor force, among other factors. Our geographic-based relatedness measure is agnostic about the economic forces driving how countries diversify their export baskets into new products.

terms). In the Methods appendix A3.3, we present results for different RCA thresholds, but results do not differ qualitatively. We refer to these set of products as 'opportunity products' for a given country in each value chain.

The depth dimension aims to capture how aligned or related these opportunity products are to a country's existing export capabilities. Countries that have existing export strengths that involve related production capabilities to new products have been shown to be significantly more likely to develop export strengths in those products in future periods (Hidalgo et al., 2007). Drawing on methods developed in the economic geography literature, we define capability alignment as the extent to which a country's basket of existing export strengths are related to each decarbonization opportunity. Following Hausmann et al. (2014), we follow three steps to define capability alignment.[4] First, we define a country's productive capabilities embodied in its export structure. To that end, we rely on RCA as our indicator of relative export intensity (Balassa, 1965). We binarize RCA_{cp} to define M_{cp}, our matrix of export competitiveness of country c in product p, which takes value 1 if RCA_{cp} for country c in product p exceeds 1, and 0 otherwise.

Second, we construct a measure of technological relatedness between products. We define product relatedness $\varphi_{p,p'}$ the conditional probability of co-exporting two given products with joint comparative advantage. This measure, which is always distributed between 0 and 1, posits that two products are more related to each other the higher the probability that countries co-export them with joint comparative advantage. Specifically, product relatedness $\varphi_{p,p'}$ between products p and p' for a particular year is defined as:

$$\varphi_{p,p'} = \frac{\sum_c M_{cp} M_{cp'}}{\sum_c M_{cp}} \tag{2}$$

Third, to define the proximity of a product as it relates to other existing products, we still need a measure that can be expressed at the country, product and year level. To that end, we construct capability alignment around each product which captures the intensity with which the product under consideration p is related to the current export basket of the same country c. Note that we define products at the HS 6-digit level to achieve the most granular distinction, for example to distinguish cars with and without combustion engine. Relatedness $\varphi_{p,p'}$ refers here to the relatedness measure defined above. More formally,

$$\text{Capability Alignment}_{cp} = \frac{\sum_{p'} M_{cp} \varphi_{p,p'}}{\sum_{p'} \varphi_{p,p'}} \tag{3}$$

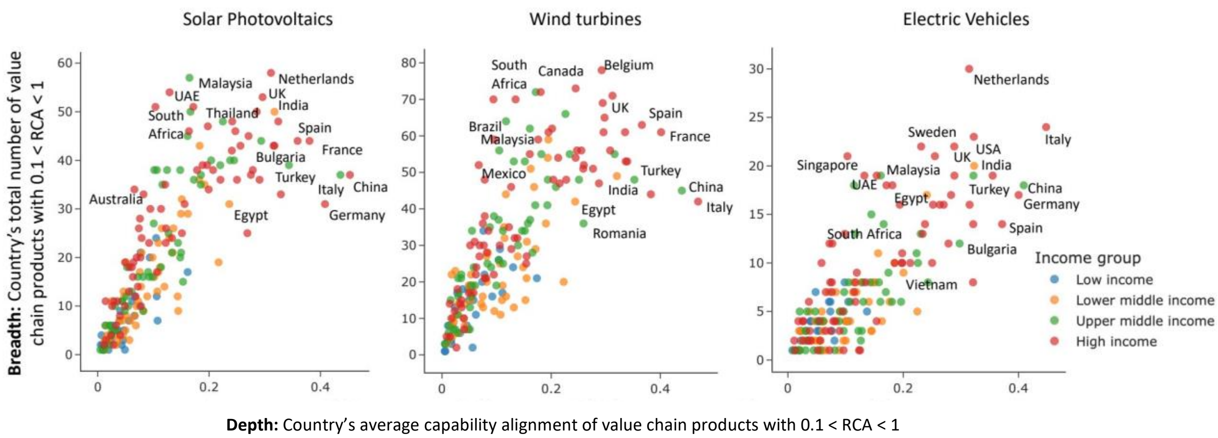
To define depth, we then take the simple average of countries' (normalized) capability alignment across opportunity products in each value chain.

Figure 6 shows countries' depth and breadth of export opportunities for each value chain. European countries such as Italy, the Netherlands and Spain consistently show the greatest diversification opportunities into new products across value chains. Moreover, a few upper and lower middle-income countries show significant future potential in

[4] In the appendix section A3.4, we present results for capability alignment based on the machine learning model XGBoost, drawing from Albora et al. (2023). While capability alignment based on XGBoost has higher predictive power for countries' diversification pathways than that based on the co-location of activities, it has some of limitations: First, its black box approach complicates interpretation of countries' opportunities. Second, we documented inconsistencies in predictions for the same country over time, compounding issues to derive stable policy recommendations. Finally, capability alignment based on XGBoost exhibits high computational costs relative to gains in predictive performance. For all these reasons, we focus on capability alignment based on co-location of activities.

terms of both breadth and depth of opportunity products. China is well positioned in all three value chains, and Türkiye and India show diversification opportunities in the solar and EV value chains.

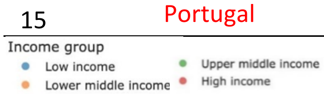
Figure 6: Countries' breadth and depth of export opportunities in each value chain, 2021



We also summarize the depth and breadth of opportunity dimensions into a single Decarbonization Technology Opportunity (DTO) index that can be compared across countries and over time. As for the DTS index, we convert both depth and breadth opportunity dimensions into z-scores to account for their differential scales and distributions. We then take the simple average of these z-scores to define the DTO index. Country DTO for each value chain and across all value chain products are shown in Table 2.

Table 2: DTO Index: Top 15 countries for each value chain and all value chains overall, by income group in 2021

DTO Index	All value chain products	Solar PV	Wind Turbines	Electric Vehicles
1	Italy	Italy	Spain	Italy
2	Netherlands	Netherlands	Belgium	Netherlands
3	Spain	China	France	China
4	China	Spain	Italy	United States
5	France	France	Netherlands	Germany
6	Belgium	India	China	France
7	United Kingdom	United Kingdom	Poland	India
8	Poland	Poland	Lithuania	United Kingdom
9	Germany	Germany	United Kingdom	Türkiye
10	United States	Belgium	Hong Kong SAR, China	Spain
11	India	Türkiye	Portugal	Belgium
12	Türkiye	Portugal	Germany	Sweden
13	Lithuania	United States	Austria	Hong Kong SAR, China
14	Hong Kong SAR, China	Bulgaria	Denmark	Poland
15	Portugal	Austria	United States	Japan



2.4 Analysis of decarbonization technology indices

We now turn to the question of whether countries' improvements in decarbonization opportunities influence their decarbonization strengths. To that end, we present some preliminary evidence to suggest that exploring opportunities makes a difference. Specifically, we estimate how changes in the DTO index explain future changes in the DTS index. Our estimation approach takes the following form:

$$\Delta \mathrm{DTS}_{c,t-(t-1)} = \alpha + \beta \mathrm{DTO}_{c,t-1} + X'_{c,t-1}\gamma + \theta_c + \theta_t + \epsilon_{c,t} \quad (4)$$

where $\Delta \mathrm{DTS}_{c,t-(t-1)}$ represents the 1-year change of country c's decarbonization technology strength (DTS) index in each value chain VC; $\mathrm{DTO}_{c,t-1}$ is country c's decarbonization technology opportunity (DTO) index in each value chain 1-year earlier. $X'_{c,t-1}$ represents a vector of lagged control variables: country c's baseline DTS index, GDP per capita, exports of goods and services to GDP ratio, $C0_2$ emissions and population. Θ_c and θ_t represent year and country fixed effect while ϵ_{ct} captures the random error term. We estimate equation (4) with Ordinary Least Squares (OLS), using robust standard errors.

Table 3 shows that increases in decarbonization opportunities are positively associated with greater decarbonization strengths. We find that this effect is consistent across all three value chains, as shown in columns (2) to (4). Moreover, we document that countries with higher initial decarbonization strengths have less room to improve their strengths in the future – a convergence effect. That is why we observe negative coefficients of countries' initial DTS in all specifications. Control variables have the anticipated positive sign and are statistically significant for GDP per capita and export to GDP ratio. Overall, our model has reasonable explanatory power, as reflected in its R^2. Moreover, we show in the Method section A4 that changes in the breadth of opportunities – the number of exported products – rather than depth of opportunities drive future changes in the DTS index.

Table 3: OLS regression results of equation (5)

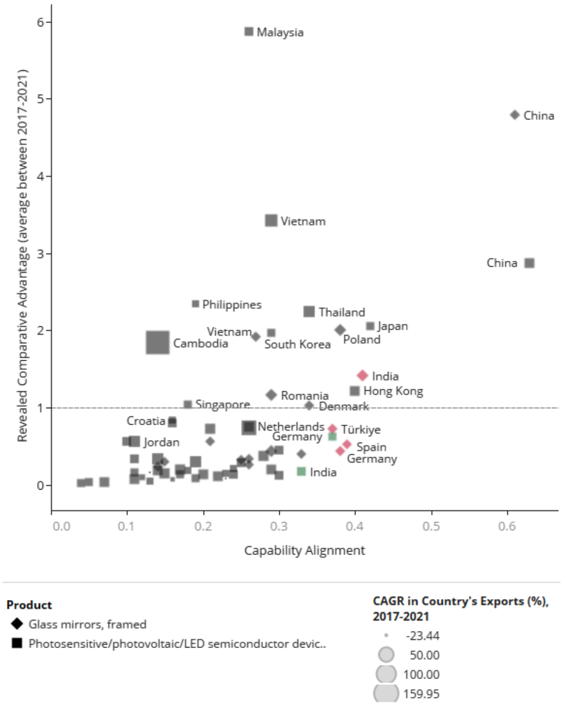
Δ**DTS Index** $_{c,t-(t-1)}$	(1) All VCs	(2) EV narrow	(3) Solar	(4) Wind
DTO Index $_{c,\,t-1}$	0.003	0.068***	0.019**	0.028***
	(0.010)	(0.011)	(0.009)	(0.010)
DTS Index $_{c,\,t-1}$	-0.077***	-0.158***	-0.095***	-0.108***
	(0.013)	(0.015)	(0.014)	(0.014)
GDP per capita $_{c,\,t-1}$, log	0.025***	0.026**	0.029***	0.030***
	(0.006)	(0.011)	(0.009)	(0.007)
Exports/GDP $_{c,\,t-1}$	0.000**	0.000	0.000	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)
CO2 emissions $_{c,\,t-1}$, log	0.009	0.012	0.014*	0.020***
	(0.006)	(0.013)	(0.007)	(0.008)
Population $_{c,\,t-1}$, log	0.001	0.011	-0.022	0.008
	(0.014)	(0.032)	(0.017)	(0.019)
Observations	3,579	3,425	3,545	3,568
R-squared	0.186	0.138	0.165	0.146
Year Fixed Effects	YES	YES	YES	YES
Country Fixed Effects	YES	YES	YES	YES

Note: Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

2.5 Product-specific diversification opportunities in decarbonization technologies

We next show how to identify countries that could be best placed to help diversify a specific product market. We explore this for two products whose exports are highly concentrated. On the one hand, we focus on the solar end-product photovoltaic cells (HS 6-digit: 854140), which China exports disproportionately. On the other hand, we choose glass mirrors, framed (HS 6-digit: 700992), an important subcomponent in the solar PV value chain with high market concentration and few exporters, as seen in the bottom right of Figure 3. Figure 7 shows the extent to which countries exhibit export competitiveness in (y-axis) and capability alignment between their overall export structure and the two products under consideration (x-axis). Each node represents a country and is sized by the country's compound annual growth rate (CAGR) in exports over the last five-year period (2017-2021) to capture export dynamics. China represents a positive outlier for both photovoltaic cells and glass mirrors, possessing superior export competitiveness and productive capabilities in related products. Malaysia, Vietnam, Philippines, and Thailand also show export competitiveness in photovoltaic cells, as seen by their square nodes above the horizontal line of unit RCA. In contrast, Germany and India show promising capabilities in photovoltaic cells (green nodes), even though they lack export competitiveness. Similarly, India, Türkiye, but also Spain and Germany (red nodes) show significant capability alignment with glass mirrors. This provides some evidence that these countries are well positioned to expand their exports, diversifying the number of suppliers for these critical products in the solar value chain.

Figure 7: Countries' export diversification opportunities in photovoltaic cells and glass mirrors, 2021



2.6 Country-specific strengths and opportunities in decarbonization technologies

We finally show how to apply our product mapping of decarbonization technologies to identify products of strategic importance for countries and evaluate their trade-offs. To that end, we set out a simple analytical framework to identify product-level strengths and opportunities across decarbonization technologies for specific countries. Consistent with our definition of countries' breadth dimension, we define strengths as products in which a country has achieved export competitiveness, as measured by its RCA≥1. Conversely, we define opportunities as products which a country exports yet without export competitiveness; its RCA needs to fall between 0.1 and 1. To measure the attractiveness of strengths, we consider the evolution of each product's degree of export competitiveness, technological sophistication (as measured by its product complexity index (PCI)) and export growth profile. Gaining competitiveness in products with higher PCI enhances countries' overall economic growth and diversification prospects as they offer advantages for technological upgrading and knowledge spillovers into other industrial areas. For opportunities, instead of considering export competitiveness we study each product's alignment with a country's existing export capabilities. That helps us to evaluate the extent to which a country's productive capabilities are developed to facilitate knowledge spillovers and technological upgrading in related products. We next apply this framework to India, exploring its strengths (Figure 8) and opportunities (Figure 9) in decarbonization technologies. Each node represents a product that is sized by its compound annual growth rate (CAGR) in global exports over the last five-year period (2017-2021) and colored by its value chain.

India's most salient strengths lie in the wind value chain of decarbonization technologies. While India exhibits export competitiveness in processed materials such as semi-finished iron or aluminum, these products lack technological sophistication, as reflected by their low product complexity index. However, India also has strengths in several manufacturing subcomponents in the EV value chain, notably components for motor vehicle chassis. While these products are less competitive, they are significantly more complex than India's strengths in the wind value chain. This suggests its firms acquired specialized capabilities to export these products, typically of higher margin, lower competition and differentiated nature. Moreover, exploiting India's existing capability stock in motor vehicle parts can help generate jobs and technological spillovers, especially relative to its processed materials that have fewer linkages with other sectors of the economy. Global demand for motor vehicles subcomponents has also been growing steadily, painting a favorable picture for India's export growth in this market. This type of analysis, coupled with information on the evolution of India's market shares and additional qualitative evidence, can help policy makers explore existing niches in the trade of decarbonization technologies and evaluate their trade-offs.

India's opportunities in decarbonization technologies reflect a common trade-off in low and middle-income countries: technologically sophisticated products tend to be less aligned with the nation's current capabilities. Figure 9 attests to this, highlighting India's opportunities at the frontier that balance both dimensions. One potential opportunity could be battery cells or shock absorbers for motor vehicles, subcomponents in the manufacturing of cars. While India has not yet gained a comparative advantage in these products, they are reasonably aligned with India's existing capabilities, a stepping-stone to develop competitiveness in the future. Moreover, they are relatively downstream in the value chain, generating a range of industries, services, and skills. However, further analysis is required to understand the likely export destinations for these products, existing competitors and barriers to growth. In this sense, the results may serve as a starting point to inform discussions on trade-led growth strategies.

Figure 8: India's Strengths in Decarbonization Technologies, 2021

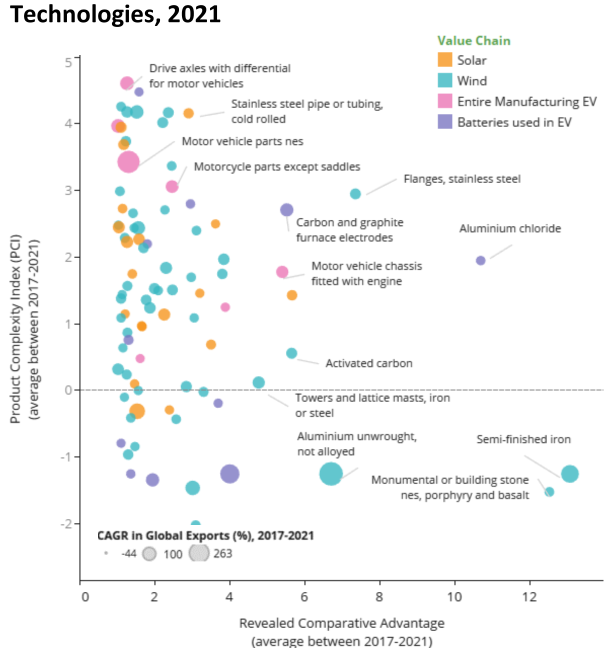
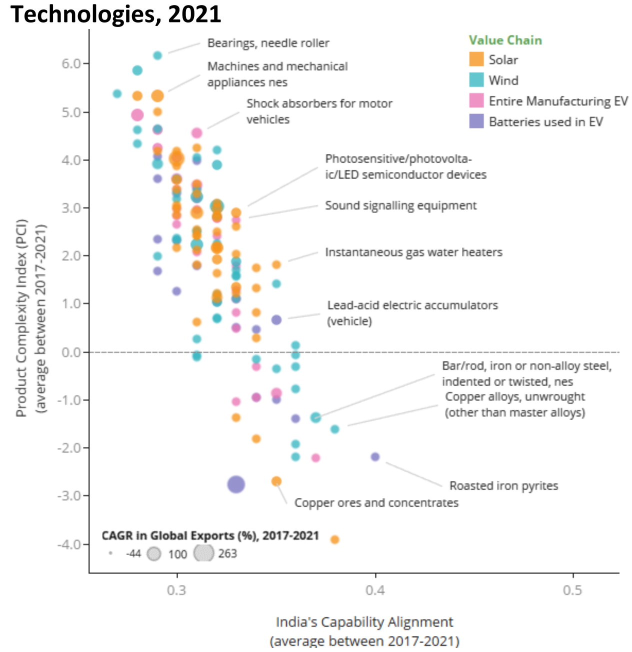


Figure 9: India's Opportunities in Decarbonization Technologies, 2021



3. Conclusion

This paper has advanced a novel, data-driven approach to identify countries' strengths and opportunities in the global value chains of critical decarbonization technologies. First, we developed a new dataset of key traded products, components and materials associated with solar PV, wind turbines and EVs. Our dataset provides a robust, peer-reviewed list of tradeable products associated with these decarbonization technologies. Second, we introduced two new indices summarizing countries' strengths and opportunities in these decarbonization technologies. To that end, we captured and aggregated the breadth and depth of countries' current export competitiveness and opportunities in these value chains, respectively. We also demonstrated that these indices capture unique information on how countries' latent productive capabilities can predict future strengths in decarbonization technologies and in turn build overall value chain resilience. Third, we showed how policy makers can identify product-specific opportunities in the trade of decarbonization technologies. To that end, we put forward a simple analytical framework, structured around strengths and opportunities. We then applied it to India to exemplify the heuristics used and insights gained.

The goal in building these green value chains is not only to create activity and jobs. Technologically sophisticated products also generate important spillovers, accelerate growth and create jobs in the rest of the economy, but this does not usually occur with raw materials. As a result, it is important to distinguish between products relating to minerals and raw materials, and those relating to manufacturing. Both are important for solar, wind and EV technologies, but these two product categories entail different types of development strategies and considerations. Developing export competitiveness in manufacturing products – particularly products that are more technologically sophisticated – has been linked to a wide range of economic benefits such as higher economic growth, employment growth, productivity increases and technological upgrading (Hausmann et al., 2006; Anand et al., 2012). Export-oriented manufacturing growth strategies also played an important role in the East Asian 'growth miracles' of the 20th century (Stiglitz, 2018). Although recent premature de-industrialization trends across many countries have led scholars and policy makers to question whether manufacturing-led growth is still a viable development path (Rodrik, 2016), growth in demand for green technologies and products could unleash sizable new growth opportunities (Hausmann, 2023).

While minerals-oriented development strategies have been successful in certain countries and contexts, they generally create less productivity benefits, fewer growth-enhancing linkages across other economic sectors (Hirschman, 1958) and are also associated with greater resource curse risks (Papyrakis, 2016). However, with the overall demand for critical minerals projected to increase by nearly 500% by 2050 to meet decarbonization goals (Hund et al., 2020), it will be increasingly important to encourage economically and environmentally responsible minerals-oriented development strategies, and to take active strategies to reduce resource-curse risks.

Taken together, the empirically grounded approach we set out in this paper can inform trade-led growth strategies that exploit burgeoning demand in decarbonization technologies. Globally, this can help relax value chain bottlenecks and enhance resilience. The evidence put forward gives credence to the idea that policies should not just allocate production towards countries able to spend more, but rather towards those with the requisite economic structure. It also challenges the economic efficiency behind the recent wave of interventionism in developed countries, which prioritizes national interests over suppliers' productive capabilities. Domestically, it can generate jobs and income, important co-benefits of climate policy. This will help reframe the green transition in favor of opportunities rather than demands for national constituencies, encouraging greater political buy-in for the climate agenda.

There are plenty of avenues for future research. First, one could extend the product mapping to other tradeable decarbonization technologies and services with pro-development characteristics (OECD, 2017). For example, understanding countries' productive capabilities to recycle and maintain solar panels could help generate labor demand in small and medium sized enterprises. Second, exploring how countries' policy space relates to their strengths in decarbonization technologies is another open question. Do countries with competitive exports in decarbonization technologies have lower trade costs, more ambitious nationally determined contributions (NDCs) and decarbonization targets, benefit from domestic subsidies and low regulatory barriers to FDI or other policies? Finally, diffusion of decarbonization technologies beyond production hubs is critical to help countries transition to a more low-carbon economy. This requires a better understanding of the structural and policy drivers behind countries' and firms' adoption of decarbonization technologies.

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Methods

Our empirical exercise requires combining a mapping of tradeable products associated with value chains of key decarbonization technologies with international export data. Thus, we need two main inputs: (i) a mapping of tradeable products associated with value chains of key decarbonization technologies and (ii) international export data. Then we need to construct variables to summarize countries' strengths and opportunities within these value chains.

A1. Mapping global value chains of key decarbonization technologies

We used the 6-digit product classification of the Harmonized System (HS) to identify tradeable products associated with the value chains of solar PV, wind turbines and EVs. The 6-digit HS classification is the most granular, internationally harmonized classification of products. While many existing classifications of environmental goods have been based on the 6-digit HS coding classification,[5] it has some limitations, notably dual use and product specificity. However, the 6-digit HS classification has the advantage that it enables analysis of comparable trade data for almost all countries, and over time.[6]

[5] Steenblik, R. (2005). Environmental goods: A comparison of the APEC and OECD lists (No. 2005/4). OECD Publishing; Sugathan, M. (2013). Lists of environmental goods: an overview. International Center for Trade and Sustainable Development.

[6] The analysis of value chain relationships, such as determining which input products are used to make other downstream products, generally requires the use of input-output tables or supply chain data. Unfortunately, consistent and comparable input-output or supply chain data is not presently available for products at the 6-digit HS classification. For example, the World Input Output Database (WIOD) currently only covers 43 countries and 56 sectors identified under the International Standard Industrial Classification (ISIC Rev. 4). Only a handful of these countries are developing countries and while a mapping exists from the HS classification to the ISIC classification, too much information is lost when trying to aggregate one classification with around 5,000 products to another with 56 industries. An alternative approach that is sometimes used in the literature is to draw on more detailed input-output data that are only available for certain countries and assume these relationships hold for other

To identify HS 6-digit products associated with the value chains of solar PV, wind turbines and EVs, we followed three steps: First, we undertook a review of the academic and grey literature, finding key papers that have previously identified HS 6-digit products associated with wind turbines, solar PV, and EVs (see Table SI 1 for key sources used). Second, after collating the various HS 6-digit codes for each technology, we drew on further desktop research to classify each product into four value chain segments: raw materials, processed materials, subcomponents, and end products (see Table SI 2 for a definition of each segment). Third, we validated our product mapping for each green value chain with industry specialists in the supply chains of wind, solar and batteries for EVs. Reviewing the technical specifications of products in these value chains with our product description helped us trim the list of HS 6-digit products for each value chain – and ensured consistency across the three value chains. The final mapping and classification of HS 6-digit codes into value chain segments can be seen in Table SI 3.

Table SI *1:* Academic and grey literature sources used to identify HS 6-digit codes associated with each decarbonization technology

Technology	Key sources
Wind Turbines	• Jing, S., Zhihui, L., Jinhua, C., & Zhiyao, S. (2020). *China's renewable energy trade potential in the" Belt-and-Road" countries: A gravity model analysis.* Renewable Energy, *161*, 1025-103; • Surana, K., Doblinger, C., Anadon, L. D., & Hultman, N. (2020). *Effects of technology complexity on the emergence and evolution of wind industry manufacturing locations along global value chains*. Nature Energy, *5*(10), 811-821; • Kuik, O., Branger, F., & Quirion, P. (2019). *Competitive advantage in the renewable energy industry: Evidence from a gravity model*. Renewable energy*, 131*, 472-48; • Matsumura, A. (2021). *Gravity analysis of trade for environmental goods focusing on bilateral tariff rates and regional integration.* Asia-Pacific Journal of Regional Science*,* 1-35; • Sandor, D., Keyser, D., Reese, S., Mayyas, A., Ramdas, A., Tian, T., & McCall, J. (2021). *Benchmarks of Global Clean Energy Manufacturing, 2014-2016* (No. NREL/TP-6A50-78037). National Renewable Energy Lab.(NREL), Golden, CO (United States); • Mishnaevsky, L., Branner, K., Petersen, H., Beauson, J., McGugan, M. and Sørensen, B. (2017). *Materials for Wind Turbine Blades: an Overview.* Materials, [online] 10(11), p.1285. doi:https://doi.org/10.3390/ma10111285; • USGS (n.d.). *What Materials Are Used to Make Wind turbines?* [online] www.usgs.gov. Available at: https://www.usgs.gov/faqs/what-materials-are-used-make-wind-turbines [Accessed 27 Sep. 2023].
Solar Photovoltaics	• Jing, S., Zhihui, L., Jinhua, C., & Zhiyao, S. (2020). *China's renewable energy trade potential in the" Belt-and-Road" countries: A gravity model analysis.* Renewable Energy, 161, 1025-103; • Surana, K., Doblinger, C., Anadon, L. D., & Hultman, N. (2020). *Effects of technology complexity on the emergence and evolution of wind industry manufacturing locations along global value chains.* Nature Energy, 5(10), 811-821; • Kuik, O., Branger, F., & Quirion, P. (2019). *Competitive advantage in the renewable energy industry: Evidence from a gravity model.* Renewable energy, 131, 472-48; Science, 1-35; • Sandor, D., Keyser, D., Reese, S., Mayyas, A., Ramdas, A., Tian, T., & McCall, J. (2021). *Benchmarks of Global Clean Energy Manufacturing, 2014-2016* (No. NREL/TP-6A50-78037). National Renewable Energy Lab.(NREL), Golden, CO (United States); • IRENA and WTO. (2021). *Trading into a bright energy future;* • Carrara, S., Alves Dias, P., Plazzotta, B. and Pavel, C. (2020). *Raw Materials Demand for Wind and Solar PV Technologies in the Transition Towards a Decarbonised Energy System.* Joint Research

countries. For example, a more detailed input-output table (covering 400 industries) is available from the Bureau of Economic Analysis (BEA) for the United States, and this has been mapped to estimate value chain relationships for HS trade data6. However, aggregation issues remain in mapping 400 industries to 5,000 products, and it is questionable whether the input-output relationships of the US are generalizable to other countries.

	Centre. European Commission Joint Research Centre (JRC), [online] JRC119941. doi:https://doi.org/10.2760/160859;
Electric Vehicles	• Coffin, D., & Horowitz, J. (2018). *The supply chain for electric vehicle batteries.* J. Int'l Com. & Econ.; • LaRocca, G. M. (2020). *Global Value Chains: Lithium in Lithium-ion Batteries for Electric Vehicles.* Office of Industries, US International Trade Commission; • Scott, S., & Ireland, R. (2020). *Lithium-Ion battery materials for electric vehicles and their global value chains*. Office of Industries, US International Trade Commission; • ISD. (2021). *Driving demand: assessing the impacts and opportunities of the electric vehicle revolution on cobalt and lithium raw material production and trade.* International Institute for Sustainable Development; • Matthews, D. (2020). *Global value chains: cobalt in lithium-ion batteries for electric vehicles.* Office of Industries Working Paper, ID-067 • Zhao, G., Wang, X. and Negnevitsky, M. (2022). Connecting Battery Technologies for Electric Vehicles from Battery Materials to Management. iScience, [online] 25(2), p.103744. doi:https://doi.org/10.1016/j.isci.2022.103744.

Table SI 2: Definitions of value chain segments

Value Chain Segment	Definition
Raw Materials	Basic materials that are mined, extracted or harvested from the earth. Also referred to as ‘unprocessed material’, examples include raw biomass and iron ore. In this link of the supply chain, value added comes from extracting, harvesting, and preparing raw materials for international marketing in substantial volumes.
Processed Materials	Materials that have been transformed or refined from basic raw materials as an intermediate step in the manufacturing process. Processed materials include steel, glass and cement. In this link of the supply chain, value added comes from processing raw materials into precursors that can be easily transported, stored and used for downstream subcomponent fabrication.
Subcomponents	Unique constituent parts or elements that contribute to a finished product. Clean energy technology examples include generation sets for wind turbines and crystalline wafers for crystalline silicon PV modules. Note that what is considered a component by the manufacturer may be considered the finished product by its supplier. In this link of the supply chain, value added comes from fabricating processed materials into subcomponents that can then be assembled (with other subcomponents) into end products
End Products	The finished product of the manufacturing process, assembled from subcomponents and ready for sale to customers as a completed item. Clean energy examples include photovoltaic modules and lithium-ion battery cells. In this link of the supply chain, value added comes from assembling components into a marketable product that customers value.

Table SI 3: Number of HS 6-digit products by value chain and segment

VC	Raw Materials	Subcomponents	Processed	End products	Total
EV	9	43	32	5	89
Solar	13	53	22	1	89
Wind	5	44	55	3	107
Total	27	140	109	9	285

A2. Description of data sources

Bilateral export flows for 226 countries in 5,000 HS 6-digit products (HS 92 nomenclature) between 1995-2021 come from the BACI international trade dataset, reported by the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII). Gaulier and Soledad (2010) reconcile declarations of the exporter and the importer in the United Nations Commodity Trade Statistics Database (COMTRADE). To smooth out data anomalies such as re-exports and focus on structural patterns, we take 5-year rolling averages of export data. Where 5 years of export data for country-product cells is not available, we take the average over the number of available years.

For the regression analysis, we define control variables - GDP per capita, exports (of goods and services) to GDP ratio, $C0_2$ emissions and population - from the World Bank World Development Indicators (WDI), available from https://databank.worldbank.org/source/world-development-indicators.

A3. Definition of metrics

A3.1 Hirschman-Herfindahl Index

To study market concentration in products associated with decarbonization technologies, we compute the Hirschman-Herfindahl Index (HHI) for each HS 6-digit product p.[7] It is defined as follows:

$$\mathrm{HHI_p} = \sum_{\mathrm{c}} \left[\frac{\mathrm{X_{cp}}}{\mathrm{X_p}}\right]^2 \tag{5}$$

where $\frac{X_{cp}}{X_p}$ is the market share of country c's export value in total global exports of product p. A HHI of 1 indicates that the market is a perfect monopoly (one country exports 100% of the product), while HHI scores approaching 0 indicate a much more competitive market.

A3.2 Decarbonization Technology Strength (DTS) index

To define countries' Decarbonization Technology Strength (DTS) index, we first quantify their strengths in products, using depth and breadth dimensions. To measure breadth, we count the number of HS 6-digit products in each value chain for which a country's export share is greater than the global average (RCA > 1), as defined in equation (1). To measure depth in decarbonization technologies, we compute a country c's average market share in export values of HS 6-digit products across value chains (vc):

$$\text{Export Market Share}_{\mathrm{c,vc}} = \frac{1}{\mathrm{N_p}} \sum_{\mathrm{p} \in \mathrm{vc}} \frac{\mathrm{X_{cp}}}{\mathrm{X_p}} \tag{6}$$

where $\mathrm{N_p}$ is the number of HS 6-digt products in a given value chain, $\mathrm{X_{cp}}$ relates to the exports of country c of product p and $\mathrm{X_p}$ relates to the total global exports of product p. To make the different scales and distributions of depth and breadth dimensions comparable, we normalize both into z-scores with zero mean and unit standard deviation:

$$\mathrm{z^d_{c,vc}} = \frac{\mathrm{x^d_{c,vc}} - \mu^\mathrm{d}_\mathrm{vc}}{\sigma^\mathrm{d}_\mathrm{vc}} \tag{7}$$

where $\mathrm{x^d_{c,vc}}$ is country's c value in strength dimension d (depth or breath) in value chain vc; $\mu^\mathrm{d}_\mathrm{vc}$ represents the mean of dimension d in value chain vc; $\sigma^\mathrm{d}_\mathrm{vc}$ captures the standard deviation of dimension d in value chain vc. To define the DTS index, we then take the simple average of depth and breadth's z-scores, making it the least agnostic data mining procedure feasible.

[7] For ease of exposition, we leave out the time subscript in all equations.

A3.3 Decarbonization Technology Opportunity' (DTO) index

To define countries' Decarbonization Technology Opportunity' (DTO) index, we similarly take the simple average of z-scores related to depth and breadth opportunity dimensions. To measure breadth, we count the number of HS 6-digit products that a country exports with 0.1>RCA>1. Thus, breadth captures all products that a country has not gained export competitiveness in, yet that are established. While the choice of an RCA of 0.1 is arbitrary, we choose it to include products that are significantly established (in relative terms). We do so to avoid that decarbonization opportunities result from small exports for a given country-product, which could be explained by idiosyncratic reasons. Tables SI 4 and SI 5 show that the DTO index of countries is robust to RCA thresholds of 0.2 and 0.5, respectively. Moreover, both variants of the DTO index are highly correlated (coefficients of 0.98 and 0.95) with our DTO index that uses an RCA threshold of 0.1.

Depth of decarbonization opportunities is defined as the average of countries' capability alignment, as defined in equation (3) of the main text, across products in each value chain.

Table SI 4: Decarbonization Technology Opportunity (DTO) Index with Breadth defined by 0.2>RCA>1: Top 10 countries for each value chain in 2021

DTO Index	Solar PV	Wind Turbines	Electric Vehicles
1	Netherlands	Spain	China
2	China	Italy	Italy
3	Italy	France	Netherlands
4	Spain	China	United Kingdom
5	United Kingdom	Netherlands	United States
6	France	Lithuania	Spain
7	United States	Poland	India
8	Germany	United Kingdom	Germany
9	Poland	Belgium	Türkiye
10	Türkiye	Türkiye	Belgium

Table SI 5: Decarbonization Technology Opportunity (DTO) Index with Breadth defined by 0.5>RCA>1: Top 10 countries for each value chain in 2021

DTO Index	Solar PV	Wind Turbines	Electric Vehicles
1	Italy	China	China
2	China	France	United States
3	United Kingdom	Spain	Spain
4	United States	Austria	Germany
5	Spain	Italy	Italy
6	Poland	United Kingdom	Netherlands
7	Netherlands	Poland	United Kingdom
8	Germany	Netherlands	India
9	France	Germany	Belgium
10	Türkiye	United States	Türkiye

A3.4 Alternative depth dimension for the DTO index

To measure depth of decarbonization opportunities, we present an alternative to capture capability alignment. Following Albora et al. (2023) and S. Edet (2022), we use extreme Gradient Boosting (XGBoost) to derive countries' productive capabilities from their basket of existing export strengths. This model-free machine learning approach helps us then derive a country's ease of seizing decarbonization opportunities. Introduced by Chen and Guestrin (2016), XGBoost addresses the issue of overfitting by introducing regularization parameters. Based on a sequential learning process, XGBoost iteratively combines regression trees that are considered weak learners and assigns continuous scores to each of the leaves in the tree.

Since the target variable M_{cp} is binary, this prediction exercise is a classification problem. The XGBoost model learns the structure of comparative advantages for all countries in products to derive probabilities (a measure of capability) of a country competitively exporting each of the 5,000 products in 5 years. The prediction exercise unfolds in two steps. First, we derive probabilities based on the unconditional prediction of Mcp in 2021. Second, we derive probabilities based on the conditional prediction of M_{cp} in 2021. This prediction is based on sub-samples where a transition in export capabilities is observed i.e., observations where RCA_{cp} is less than 1 in 2017, but exceeds 1 in 2021. Such cases of transitions are rare but meaningful, and as such, prediction exercises of this kind hold more economic value to policy makers.

The XGBoost model used in this exercise is applied to a training set $[\mathbf{RCA}_{cp}^{t}, \mathrm{I}^{t} \mid \mathbf{M}_{cp}^{t+5}]$ where RCA is the feature, I captures year effect, M is the target variable, and t is between 1995 and 2016. For each product, the XGBoost model is trained to learn the structural relationship between RCA_{cp} and the M_{cp} specifically for that product in 5 years' time. The relationship inferred is applied to the test set $[\mathbf{RCA}_{cp}^{2017}, \mathbf{I}^{2017} \mid \mathbf{M}_{cp}^{2021}]$. However, since we do not want the model to leverage the autocorrelation in RCA_{cp}, but to identify the genuine similarities between products, during testing, we partition the N=226 countries to k=10 disjoint sets of countries. For each set k, we train the XGBoost model on the data for (N-k) countries and test the trained model on the data for the k-set of countries. Hence, we train 50,000 models (i.e., 5,000 products and 10 disjoint sets). The results of the test set are combined to construct the probabilities of each of the countries to export competitively (i.e., M_{cp}=1) in each of the 5,000 products. The implementation of the XGBoost model is done using the default parameters of XGBoost package in python.

The resulting machine learning-based capability alignment exhibits superior predictive power of countries' diversification pathways than that based on co-location of exports. That is evident when considering the Precision recall (PR) Area under the Curve (AUC), a standard metric to evaluate model performance with class imbalance, which characterizes our RCA variable (Table SI 6?) While XGBoost outperforms the capability alignment based on co-location patterns across the board, it is especially pronounced for raw and processed materials and for countries in Latin America & Caribbean and Sub-Saharan Africa.

Table SI 6: PR AUC of capability alignment based on co-location and XGBoost, 2021

Product subset	Co-location	XGBoost
All tradeable HS 6-digit products	0.36	0.69
All decarbonization value chains	0.37	0.69
EV	0.35	0.71
Solar	0.40	0.71
Wind	0.37	0.66
Raw materials	0.28	0.76
Processed materials	0.36	0.73
Subcomponents	0.39	0.64
End product	0.48	0.67
East Asia & Pacific	0.42	0.72
Europe & Central Asia	0.41	0.73
Latin America & Caribbean	0.26	0.63

Middle East & North Africa	0.32	0.68
North America	0.60	0.77
South Asia	0.51	0.79
Sub-Saharan Africa	0.19	0.53
High income	0.39	0.70
Low income	0.23	0.56
Lower middle income	0.35	0.71
Upper middle income	0.37	0.70
Knowledge products	0.38	0.69
Natural resources	0.25	0.78

However, XGBoost has serious limitations relative to the parametric approach of using co-location to define capability alignment. First, its black box approach complicates interpretation of countries' opportunities. Indeed, we only observe the input variable and the output variable yet lack any understanding of the underlying process to capture non-linear relationships. Further, relatedness based on XGBoost exhibits high computational costs relative to gains in prediction performance. Most importantly, however, we document inconsistencies in predictions owing to XGBoost's bimodal distribution of our outcome variable. This pertains to low-income countries with few product opportunities, yet disproportionately high capability alignment. Table SI 7 showcases these irregularities in a DTO index that averages z-scores of breadth and XGBoost depth dimensions. Yemen, Guinea-Bissau and Cuba are placed in the top 10 of the DTO index for wind and the EV, compounding issues to derive stable policy recommendations. For all these reasons, we focus on capability alignment based on co-location of activities rather than XGBoost.

Table SI 7: Decarbonization Technology Opportunity (DTO) Index with Breadth defined by 0.1>RCA>1 and Depth defined by Capability Alignment based on XGBoost: Top 10 countries for each value chain in 2021

DTO Index	Solar PV	Wind Turbines	Electric Vehicles
1	United Kingdom	Yemen, Rep.	Guinea-Bissau
2	Czechia	China	Cuba
3	United States	Austria	Netherlands
4	Malaysia	France	United Kingdom
5	China	Sweden	China
6	Italy	Czechia	Belgium
7	Netherlands	United Kingdom	Guinea
8	Austria	Finland	India
9	Bulgaria	Poland	Sweden
10	Ukraine	Slovak Republic	Denmark

A4. Drivers of Changes in DTS index

We now turn to the question regarding the extent to which the two opportunity dimensions drive countries' improvements in decarbonization strengths. To that end, we estimate how changes in (normalized) breadth and depth of opportunities explain future changes in the DTS index. Our estimation approach takes the following form:

$$\Delta \mathrm{DTS\_VC}_{c,t-(t-1)} = \alpha + \beta_1 \mathrm{Breadth\_VC}_{c,t-1}^{\mathrm{Opportunity}} + \beta_2 \mathrm{Depth\_VC}_{c,t-1}^{\mathrm{Opportunity}} + X'_{c,t-1}\gamma + \theta_c + \theta_t + \epsilon_{c,t} \quad (8)$$

where breadth and depth refer to the normalized (z-scores) of countries' number of opportunities and average capability alignment in each value chain, respectively. All else remains the same as in equation (4), including estimation with OLS.

Table SI 8 shows that countries' changes in breadth of opportunities – rather than depth – drive their future strengths in decarbonization technologies. Specifically, increases in countries' number of opportunities – products with 0.1>RCA>1 – are statistically correlated with improvements in decarbonization strengths. This positive effect is consistent across all decarbonization value chains. Conversely, however, improvements in countries' capability alignment – our measure of depth of opportunities – are only associated with improvements in decarbonization strengths in the EV value chain. Depth of opportunities yields a positive, yet statistically insignificant effect for the other value chains, as seen in column (3) and (4). Furthermore, we document the same convergence effect that countries with higher initial decarbonization strengths have less room to improve their strengths in the future. Taken together, these results suggest that the breadth of decarbonization opportunities plays a disproportional role in shaping countries' strengths in decarbonization technologies.

Table SI 8: OLS regression results from equation (8)

$\Delta DTS_{c,t-(t-1)}$	(1) All VCs	(2) EV narrow	(3) Solar	(4) Wind
Number of Opportunities $_{c,\,t-1}$	0.012*	0.036***	0.018**	0.020***
	(0.007)	(0.008)	(0.007)	(0.007)
Depth of Opportunities $_{c,\,t-1}$	0.013	0.030**	0.005	0.002
	(0.012)	(0.013)	(0.013)	(0.014)
DTS Index $_{c,\,t-1}$	-0.071***	-0.157***	-0.089***	-0.103***
	(0.014)	(0.015)	(0.015)	(0.015)
GDP per capita $_{c,\,t-1}$, log	0.024***	0.025**	0.027***	0.029***
	(0.007)	(0.011)	(0.009)	(0.007)
Exports/GDP $_{c,\,t-1}$	0.000**	0.000	0.000	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)
CO_2 emissions $_{c,\,t-1}$, log	0.007	-0.012	0.013*	0.019**
	(0.006)	(0.013)	(0.007)	(0.008)
Population $_{c,\,t-1}$, log	0.001	0.010	-0.021	0.008
	(0.014)	(0.032)	(0.017)	(0.019)
Observations	3,579	3,425	3,545	3,568
R squared	0.187	0.138	0.165	0.147
Year Fixed Effects	YES	YES	YES	YES
Country Fixed Effects	YES	YES	YES	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

A5. Detailed list of 6-digit HS products in decarbonization technologies

Table SI 10: HS 6-digit products (HS 92 nomenclature) by value chain and segment

HS Code	Value Chain	Value Chain Segment	Description
750300	EV - Broad	Processed materials	Nickel waste or scrap
790200	EV - Broad	Processed materials	Zinc waste or scrap

720449	EV - Broad	Processed materials	Ferrous waste or scrap, nes
720429	EV - Broad	Processed materials	Waste or scrap, of alloy steel, other than stainless
720421	EV - Broad	Processed materials	Waste or scrap, of stainless steel
740400	EV - Broad	Processed materials	Copper/copper alloy waste or scrap
720430	EV - Broad	Processed materials	Waste or scrap, of tinned iron or steel
851120	EV - Broad	Subcomponents	Ignition magnetos, magneto-generators and flywheels
852721	EV - Broad	Subcomponents	Radio receivers, external power,sound reproduce/recor
870790	EV - Broad	Subcomponents	Bodies for tractors, buses, trucks etc
850620	EV - Broad	Subcomponents	Primary cells, primary batteries nes, volume > 300 cc
851220	EV - Broad	Subcomponents	Lighting/visual signalling equipment nes
870821	EV - Broad	Subcomponents	Safety seat belts for motor vehicles
852729	EV - Broad	Subcomponents	Radio receivers, external power, not sound reproducer
870839	EV - Broad	Subcomponents	Brake system parts except linings for motor vehicles
850612	EV - Broad	Subcomponents	Mercuric oxide primary cell, battery, volume < 300 cc
870850	EV - Broad	Subcomponents	Drive axles with differential for motor vehicles
871411	EV - Broad	Subcomponents	Motorcycle saddles
870840	EV - Broad	Subcomponents	Transmissions for motor vehicles
850740	EV - Broad	Subcomponents	Nickel-iron electric accumulators
853910	EV - Broad	Subcomponents	Sealed beam lamp units
871419	EV - Broad	Subcomponents	Motorcycle parts except saddles
870894	EV - Broad	Subcomponents	Steering wheels, columns & boxes for motor vehicles
870810	EV - Broad	Subcomponents	Bumpers and parts thereof for motor vehicles
870891	EV - Broad	Subcomponents	Radiators for motor vehicles
830230	EV - Broad	Subcomponents	Motor vehicle mountings, fittings, of base metal, nes
851150	EV - Broad	Subcomponents	Generators and alternators
870893	EV - Broad	Subcomponents	Clutches and parts thereof for motor vehicles
850611	EV - Broad	Subcomponents	Manganese dioxide primary cell/battery volume < 300 c
870600	EV - Broad	Subcomponents	Motor vehicle chassis fitted with engine

851210	EV - Broad	Subcomponents	Lighting/signalling equipment as used on bicycles
870710	EV - Broad	Subcomponents	Bodies for passenger carrying vehicles
851240	EV - Broad	Subcomponents	Windscreen wipers/defrosters/demisters
910400	EV - Broad	Subcomponents	Instrument panel clocks etc for vehicles/aircraft etc
870870	EV - Broad	Subcomponents	Wheels including parts/accessories for motor vehicles
870860	EV - Broad	Subcomponents	Non-driving axles/parts for motor vehicles
851230	EV - Broad	Subcomponents	Sound signalling equipment
940120	EV - Broad	Subcomponents	Seats, motor vehicles
870899	EV - Broad	Subcomponents	Motor vehicle parts nes
870829	EV - Broad	Subcomponents	Parts and accessories of bodies nes for motor vehicle
870880	EV - Broad	Subcomponents	Shock absorbers for motor vehicles
870831	EV - Broad	Subcomponents	Mounted brake linings for motor vehicles
854800	EV - Broad	Subcomponents	Electrical parts of machinery and apparatus, nes
850613	EV - Broad	Subcomponents	Silver oxide primary cells, batteries volume < 300 cc
854430	EV - Broad	Subcomponents	Ignition/other wiring sets for vehicles/aircraft/ship
260112	EV - Narrow	Raw materials	Iron ore, concentrate, not iron pyrites, agglomerated
260120	EV - Narrow	Raw materials	Roasted iron pyrites
260400	EV - Narrow	Raw materials	Nickel ores and concentrates
260111	EV - Narrow	Raw materials	Iron ore, concentrate, not iron pyrites,unagglomerate
250410	EV - Narrow	Raw materials	Natural graphite in powder or flakes
250490	EV - Narrow	Raw materials	Natural graphite, except powder or flakes
260200	EV - Narrow	Raw materials	Manganese ores, concentrates, iron ores >20% Manganes
271312	EV - Narrow	Raw materials	Petroleum coke, calcined
260500	EV - Narrow	Raw materials	Cobalt ores and concentrates
281820	EV - Narrow	Processed materials	Aluminium oxide, except artificial corundum
282732	EV - Narrow	Processed materials	Aluminium chloride
283322	EV - Narrow	Processed materials	Aluminium sulphate
380190	EV - Narrow	Processed materials	Graphite based products nes

380110	EV - Narrow	Processed materials	Artificial graphite
282735	EV - Narrow	Processed materials	Nickel chloride
282110	EV - Narrow	Processed materials	Iron oxides and hydroxides
280519	EV - Narrow	Processed materials	Alkali metals other than sodium
282200	EV - Narrow	Processed materials	Cobalt oxides and hydroxides
282540	EV - Narrow	Processed materials	Nickel oxides and hydroxides
380120	EV - Narrow	Processed materials	Colloidal or semi-colloidal graphite
810510	EV - Narrow	Processed materials	Cobalt, unwrought, matte, waste or scrap, powders
281830	EV - Narrow	Processed materials	Aluminium hydroxide
750210	EV - Narrow	Processed materials	Nickel unwrought, not alloyed
750220	EV - Narrow	Processed materials	Nickel unwrought, alloyed
282612	EV - Narrow	Processed materials	Aluminium fluoride
282734	EV - Narrow	Processed materials	Cobalt chloride
282690	EV - Narrow	Processed materials	Complex fluorine salts except synthetic cryolite
750400	EV - Narrow	Processed materials	Nickel powders and flakes
282739	EV - Narrow	Processed materials	Chlorides of metals nes
283691	EV - Narrow	Processed materials	Lithium carbonates
282010	EV - Narrow	Processed materials	Manganese dioxide
282090	EV - Narrow	Processed materials	Manganese oxides other than manganese dioxide
283324	EV - Narrow	Processed materials	Nickel sulphates
282520	EV - Narrow	Processed materials	Lithium oxide and hydroxide
850730	EV - Narrow	Subcomponents	Nickel-cadmium electric accumulators
854511	EV - Narrow	Subcomponents	Carbon and graphite furnace electrodes
854280	EV - Narrow	Subcomponents	Electronic integrated circuits/microassemblies, nes
850790	EV - Narrow	Subcomponents	Parts of electric accumulators, including separators
854519	EV - Narrow	Subcomponents	Carbon and graphite electrodes, except for furnaces
850710	EV - Narrow	End product	Lead-acid electric accumulators (vehicle)
850619	EV - Narrow	End product	Primary cells, primary batteries nes, volume < 300 cc
850780	EV - Narrow	End product	Electric accumulators, nes

870390	EV - Narrow	End product	Other Vehicles Including Gas Turbine Powered
870290	EV - Narrow	End product	Buses except diesel powered
761610	Solar	Raw materials	Aluminium nails, tacks, staples, bolts, nuts etc,
260600	Solar	Raw materials	Aluminium ores and concentrates
260800	Solar	Raw materials	Zinc ores and concentrates
280450	Solar	Raw materials	Boron, tellurium
280461	Solar	Raw materials	Silicon, >99.99% pure
280469	Solar	Raw materials	Silicon, <99.99% pure
761690	Solar	Raw materials	Articles of aluminium, nes
280490	Solar	Raw materials	Selenium
261610	Solar	Raw materials	Silver ores and concentrates
811230	Solar	Raw materials	Germanium, articles thereof, waste or scrap/powders
811240	Solar	Raw materials	Vanadium, articles thereof, waste or scrap/powders
260300	Solar	Raw materials	Copper ores and concentrates
810710	Solar	Raw materials	Cadmium, unwrought, waste or scrap, powders
381800	Solar	Processed materials	Chemical element/compound wafers doped for electronic
321410	Solar	Processed materials	Mastics, painters' fillings
283030	Solar	Processed materials	Cadmium sulphide
790120	Solar	Processed materials	Zinc alloys unwrought
390422	Solar	Processed materials	Polyvinyl chloride nes, plasticised in primary forms
392010	Solar	Processed materials	Sheet/film not cellular/reinf polymers of ethylene
740110	Solar	Processed materials	Copper mattes
730890	Solar	Processed materials	Structures and parts of structures, iron or steel, ne
711590	Solar	Processed materials	Articles of, or clad with, precious metal nes
700510	Solar	Processed materials	Float glass etc sheets, absorbent or reflecting layer
391000	Solar	Processed materials	Silicones in primary forms
722610	Solar	Processed materials	Flat rolled silicon-electrical steel, <600mm wide
381010	Solar	Processed materials	Metal pickling preps, solder and brazing flux, etc.

721090	Solar	Processed materials	Flat rolled iron or non-alloy steel, clad/plated/coated, w >600mm, nes
900190	Solar	Processed materials	Prisms, mirrors and optical elements nes, unmounted
392030	Solar	Processed materials	Sheet/film not cellular/reinf polymers of styrene
740931	Solar	Processed materials	Plate/sheet/strip, copper-tin alloy, coil, t > 0.15mm
284329	Solar	Processed materials	Silver compounds other than silver nitrate
760120	Solar	Processed materials	Aluminium unwrought, alloyed
760612	Solar	Processed materials	Aluminium alloy rectangular plate/sheet/strip,t >0.2m
901390	Solar	Processed materials	Parts and accessories of optical appliances nes
760611	Solar	Processed materials	Pure aluminium rectangular plate/sheet/strip, t >0.2m
392072	Solar	Subcomponents	Sheet/film not cellular/reinf vulcanised rubber
760421	Solar	Subcomponents	Profiles, hollow, aluminium, alloyed
730830	Solar	Subcomponents	Doors, windows, frames of iron or steel
700992	Solar	Subcomponents	Glass mirrors, framed
392059	Solar	Subcomponents	Sheet/film not cellular/reinf acrylic polymers nes
850440	Solar	Subcomponents	Static converters, nes
392061	Solar	Subcomponents	Sheet/film not cellular/reinf polycarbonates
392071	Solar	Subcomponents	Sheet/film not cellular/reinf regenerated cellulose
830630	Solar	Subcomponents	Photograph, picture, etc frames, mirrors of base meta
392073	Solar	Subcomponents	Sheet/film not cellular/reinf cellulose acetate
732290	Solar	Subcomponents	Non-electric heaters (with fan), parts, of iron/steel
850230	Solar	Subcomponents	Electric generating sets, nes
700991	Solar	Subcomponents	Glass mirrors, unframed
850132	Solar	Subcomponents	DC motors, DC generators, of an output 0.75-75 kW
841280	Solar	Subcomponents	Engines and motors nes
853610	Solar	Subcomponents	Electrical fuses, for < 1,000 volts
392520	Solar	Subcomponents	Plastic doors and windows and frames thereof
901020	Solar	Subcomponents	Equipment for photographic laboratories nes
847989	Solar	Subcomponents	Machines and mechanical appliances nes

392690	Solar	Subcomponents	Plastic articles nes
850131	Solar	Subcomponents	DC motors, DC generators, of an output < 750 watts
841911	Solar	Subcomponents	Instantaneous gas water heaters
730431	Solar	Subcomponents	Iron/non-alloy steel pipe, cold drawn/rolled, nes
392091	Solar	Subcomponents	Sheet/film not cellular/reinf polyvinyl butyral
730441	Solar	Subcomponents	Stainless steel pipe or tubing, cold rolled
392079	Solar	Subcomponents	Sheet/film not cellular/reinf cellulose derivs nes
392069	Solar	Subcomponents	Sheet/film not cellular/reinf polyesters nes
392062	Solar	Subcomponents	Sheet/film not cellular/reinf polyethylene terephthal
392051	Solar	Subcomponents	Sheet/film not cellular/reinf polymethyl methacrylate
850490	Solar	Subcomponents	Parts of electrical transformers and inductors
850161	Solar	Subcomponents	AC generators, of an output < 75 kVA
392094	Solar	Subcomponents	Sheet/film not cellular/reinf phenolic resins
392190	Solar	Subcomponents	Plastic sheet, film, foil or strip, nes
854190	Solar	Subcomponents	Parts of semiconductor devices and similar devices
841989	Solar	Subcomponents	Machinery for treatment by temperature change nes
901380	Solar	Subcomponents	Optical devices, appliances and instruments, nes
900580	Solar	Subcomponents	Monoculars, telescopes, etc
900290	Solar	Subcomponents	Mounted lenses, prisms, mirrors, optical elements nes
845610	Solar	Subcomponents	Laser, light and photon beam process machine tools
392063	Solar	Subcomponents	Sheet/film not cellular/reinf unsaturated polyesters
392093	Solar	Subcomponents	Sheet/film not cellular/reinf amino-resins
700719	Solar	Subcomponents	Safety glass, toughened (tempered), non-vehicle use
853650	Solar	Subcomponents	Electrical switches for < 1,000 volts, nes
841919	Solar	Subcomponents	Instantaneous/storage water heaters, not electric nes
392092	Solar	Subcomponents	Sheet/film not cellular/reinf polyamides
847990	Solar	Subcomponents	Parts of machines and mechanical appliances nes
854451	Solar	Subcomponents	Electric conductors, 80-1,000 volts, with connectors

392099	Solar	Subcomponents	Sheet/film not cellular/reinf plastics nes
730451	Solar	Subcomponents	Alloy steel pipe or tubing, cold rolled
853690	Solar	Subcomponents	Electrical switch, protector, connecter for < 1kV nes
841950	Solar	Subcomponents	Heat exchange units, non-domestic, non-electric
853641	Solar	Subcomponents	Electrical relays for < 60 volts
841990	Solar	Subcomponents	Parts, laboratory/industrial heating/cooling machiner
854140	Solar	End product	Photosensitive/photovoltaic/LED semiconductor devices
251910	Wind	Raw materials	Natural magnesium carbonate (magnesite)
280530	Wind	Raw materials	Rare-earth metals, scandium and yttrium
280300	Wind	Raw materials	Carbon (carbon blacks and other forms of carbon, nes)
251690	Wind	Raw materials	Monumental or building stone nes, porphyry and basalt
440723	Wind	Raw materials	Lumber, Baboen, Mahogany, Imbuia, Balsa
681099	Wind	Processed materials	Articles of cement, concrete or artificial stone nes
730792	Wind	Processed materials	Threaded fittings, iron or steel except stainless/cas
740200	Wind	Processed materials	Unrefined copper, copper anodes, electrolytic refinin
720260	Wind	Processed materials	Ferro-nickel
721430	Wind	Processed materials	Bar/rod, iron or non-alloy steel, of free cutting steel, nes
720130	Wind	Processed materials	Alloy pig iron, in primary forms
760110	Wind	Processed materials	Aluminium unwrought, not alloyed
730723	Wind	Processed materials	Pipe fittings, butt welding of stainless steel
721060	Wind	Processed materials	Flat rolled iron or non-alloy steel, coated with aluminium, width>600mm
740319	Wind	Processed materials	Refined copper products, unwrought, nes
732690	Wind	Processed materials	Articles of iron or steel, nes
810430	Wind	Processed materials	Magnesium raspings/turnings/etc, size graded, powder
722810	Wind	Processed materials	Bar/rod of high speed steel not in coils
721410	Wind	Processed materials	Bar/rod, iron or non-alloy steel, forged
740322	Wind	Processed materials	Copper-tin base alloys, unwrought
740323	Wind	Processed materials	Copper-nickel, copper-nickel-zinc base alloy,unwrough

740329	Wind	Processed materials	Copper alloys, unwrought (other than master alloys)
281000	Wind	Processed materials	Oxides of boron, boric acids
732611	Wind	Processed materials	Balls, iron/steel, forged/stamped for grinding mills
730791	Wind	Processed materials	Pipe flanges, iron or steel except stainless/cast
720719	Wind	Processed materials	Semi-finished product, iron or non-alloy steel <0.25%C, nes
740321	Wind	Processed materials	Copper-zinc base alloys, unwrought
390590	Wind	Processed materials	Vinyl polymers, halogenated olefins, primary form, ne
722820	Wind	Processed materials	Bar/rod of silico-manganese steel not in coils
740500	Wind	Processed materials	Master alloys of copper
720270	Wind	Processed materials	Ferro-molybdenum
730722	Wind	Processed materials	Threaded elbows, bends and sleeves of stainless steel
722850	Wind	Processed materials	Bar/rod nes, alloy steel nes, nfw cold formed/finishe
720712	Wind	Processed materials	Semi-finished bars, iron or non-alloy steel <0.25%C, rectangular, nes
720711	Wind	Processed materials	Rectangular iron or non-alloy steel bars, <.25%C, width< twice thicknes
283699	Wind	Processed materials	Carbonates of metals nes
720720	Wind	Processed materials	Semi-finished product, iron or non-alloy steel >0.25%C
730721	Wind	Processed materials	Flanges, stainless steel
290314	Wind	Processed materials	Carbon tetrachloride
721440	Wind	Processed materials	Bar/rod, iron or non-alloy steel, hot formed <0.25%C, nes
400510	Wind	Processed materials	Compounded (carbon black, silica) unvulcanised rubber
721420	Wind	Processed materials	Bar/rod, iron or non-alloy steel, indented or twisted, nes
722830	Wind	Processed materials	Bar/rod, alloy steel nes,nfw hot rolled/drawn/extrude
730711	Wind	Processed materials	Pipe fittings of non-malleable cast iron
730719	Wind	Processed materials	Pipe fittings of malleable iron or steel, cast
722860	Wind	Processed materials	Bar/rod, alloy steel nes
291090	Wind	Processed materials	Epoxides, epoxy-alcohols,-phenols,-ethers nes, derivs
390730	Wind	Processed materials	Epoxide resins, in primary forms

730793	Wind	Processed materials	Butt weld fittings, iron/steel except stainless/cast
722840	Wind	Processed materials	Bar/rod nes, alloy steel nes, nfw forged
560710	Wind	Processed materials	Twine, cordage, ropes and cables, of jute, bast fibre
732619	Wind	Processed materials	Articles, iron or steel nes, forged/stamped, nfw
732620	Wind	Processed materials	Articles of iron or steel wire, nes
730799	Wind	Processed materials	Fittings, pipe or tube, iron or steel, nes
560729	Wind	Processed materials	Twine nes, cordage, ropes and cables, of sisal
380210	Wind	Processed materials	Activated carbon
722880	Wind	Processed materials	Hollow drill bars and rods of alloy/non-alloy steel
701939	Wind	Processed materials	Webs, mattresses, other nonwoven fibreglass products
730729	Wind	Processed materials	Pipe fittings of stainless steel except butt welding
722870	Wind	Processed materials	Angles, shapes and sections, alloy steel, nes
903081	Wind	Subcomponents	Electrical measurement recording instruments
850423	Wind	Subcomponents	Liquid dielectric transformers > 10,000 KVA
890790	Wind	Subcomponents	Buoys, beacons, coffer-dams, pontoons, floats nes
853510	Wind	Subcomponents	Electrical fuses, for voltage > 1kV
848360	Wind	Subcomponents	Clutches, shaft couplings, universal joints
850422	Wind	Subcomponents	Liquid dielectric transformers 650-10,000KVA
853890	Wind	Subcomponents	Parts, electric switches, protectors & connectors nes
848350	Wind	Subcomponents	Flywheels and pulleys including pulley blocks
854459	Wind	Subcomponents	Electric conductors, 80-1,000 volts, no connectors
903039	Wind	Subcomponents	Ammeters, voltmeters, ohm meters, etc, non-recording
853521	Wind	Subcomponents	Automatic circuit breakers for voltage 1-72.5 kV
848320	Wind	Subcomponents	Bearing housings etc incorporating ball/roller bearin
853810	Wind	Subcomponents	Elictrical boards, panels, etc, not equipped
850431	Wind	Subcomponents	Transformers electric, power capacity < 1 KVA, nes
848230	Wind	Subcomponents	Bearings, spherical roller
903289	Wind	Subcomponents	Automatic regulating/controlling equipment nes

848280	Wind	Subcomponents	Bearings, ball or roller, nes, including combinations
903020	Wind	Subcomponents	Cathode-ray oscilloscopes, oscillographs
850163	Wind	Subcomponents	AC generators, of an output 375-750 kVA
847740	Wind	Subcomponents	rubber or plastic vacuum moulders, thermoformers
903031	Wind	Subcomponents	Electrical multimeters
853720	Wind	Subcomponents	Electrical control and distribution boards, > 1kV
902830	Wind	Subcomponents	Electricity supply, production and calibrating meters
850421	Wind	Subcomponents	Liquid dielectric transformers < 650 KVA
850432	Wind	Subcomponents	Transformers electric, power capacity 1-16 KVA, nes
850162	Wind	Subcomponents	AC generators, of an output 75-375 kVA
854441	Wind	Subcomponents	Electric conductors, nes < 80 volts, with connectors
848390	Wind	Subcomponents	Parts of power transmission etc equipment
848340	Wind	Subcomponents	Gearing, ball screws, speed changers, torque converte
853710	Wind	Subcomponents	Electrical control and distribution boards, < 1kV
854460	Wind	Subcomponents	Electric conductors, for over 1,000 volts, nes
853530	Wind	Subcomponents	Isolating and make-and-break switches, voltage >1 kV
848220	Wind	Subcomponents	Bearings, tapered roller, including assemblies
850434	Wind	Subcomponents	Transformers electric, power capacity > 500 KVA, nes
848210	Wind	Subcomponents	Bearings, ball
848299	Wind	Subcomponents	Bearing parts, nes
848330	Wind	Subcomponents	Bearing housings, shafts, without ball/roller bearing
848250	Wind	Subcomponents	Bearings, cylindrical roller, nes
853540	Wind	Subcomponents	Lightning arresters & voltage or surge limiters > 1kV
850433	Wind	Subcomponents	Transformers electric, power capacity 16-500 KVA
850164	Wind	Subcomponents	AC generators, of an output > 750 kVA
848240	Wind	Subcomponents	Bearings, needle roller
853529	Wind	Subcomponents	Automatic circuit breakers for voltage > 72.5 kV
853590	Wind	Subcomponents	Electrical apparatus for voltage > 1kV, nes

841290	Wind	End product	Parts of hydraulic/pneumatic/other power engines
850300	Wind	End product	Parts for electric motors and generators
730820	Wind	End product	Towers and lattice masts, iron or steel