Policy Research Working Paper

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 (EVs). This challenge is currently rife with risks and rewards. With global production perceived to be concentrated in a small number of countries, mitigating against possible supply-side risks has become an urgent policy priority for many countries. At the same time, these technologies' high-growth potential offer lucrative rewards for countries able to strategically position themselves to produce requisite materials, components or assemble final products. As green industrial policies have become an increasingly popular tool for shoring up supply chains and stimulating production in key green sectors, this paper presents a data-driven framework for identifying which countries could have key strengths and latent comparative advantages in the production of solar PV, wind turbines and EVs. It constructs a new dataset of traded products, components, and materials associated with decarbonization technologies and develops new indices capturing countries' current export strengths and future diversification potential in the global value chains of these technologies. It also 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. Our analysis suggests that there is plenty of opportunity to diversify these value chains across a larger number of countries and reduce risks associated with reliance on only a few countries.

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Turning Risks into Rewards: Diversifying the Global Value Chains of Decarbonization Technologies¹

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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).

A key risk however, is that production is not particularly 'global', but instead concentrated in a small number of countries. Recent analysis indicated that one out of every solar panels produced worldwide is produced by a single facility (IEA, 2022b) and over half of the cobalt, lithium and graphite processing and refining capacity for EV batteries are located in a single country (IEA, 2022c). With global value chains inherently vulnerable to disruptions such as natural disasters, pandemics, conflict and geopolitical events, such high concentration levels could create bottlenecks and supply-side shortages that could slow the roll out of these technologies around the world.

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. With industrial policy becoming a more popular policy tool – and with many recent industrial policies aiming to target key products or components in the value chains of these green technologies, it is helpful to have a sense of where latent comparative advantages are more likely to exist.

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 dataset enables the exploration of historical and current trade patterns for over 200 countries between 1995-2021 in these global value chains. We focus these specific value chains for three reasons. First, worldwide consensus exists 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 can sometimes be controversial and subject to countries' political sensitivities. Second, participating in the trade of 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 and components as they offer advantages for technological upgrading and knowledge spillovers into other industrial areas (Hidalgo & Hausmann, 2009). Third, given the potential supply-side risks facing these value chains, building greater resilience - through diversifying production across a greater number of countries with latent comparative advantage can help mitigate against potential disruptions or shortages in the global roll-out of these technologies. Further, such diversification can also help ensure that the rewards from participating in these high-growth global value chains are shared more broadly.

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. These insights complement existing work documenting current production trends in supply chains of energy technologies (e.g., IEA, 2022a; IEA, 2022b), but here we go further to develop a similar set of new indices that aim to capture the breadth and depth of countries' future diversification potential in these value chains. We show that countries scoring higher in potential 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.

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 glass mirrors, a key component in the solar PV value chain, is highly concentrated in a single country, several countries that could be well positioned to expand their export activity in this product include Lithuania, Poland, India, Türkiye and the Netherlands. These countries already have a reasonably strong track record of exports, high recent growth rates, and production capabilities that are closely aligned with this product. 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 the Methods section 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.

² All products included in our dataset were subject to a series of independent evaluations by selected industry specialists (see Methods section 4.1 for further information and Table SI 6 for a list of the included products).

Figure 1: Mapping the solar global value chain



A key concern raised by policy makers and international organizations is that the 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 the Methods section 4.2 for description of data sources and definitions of key 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, the concentration in each technology value chain does not appear to be extremely alarming, but several key products could create supply-side risks due to high their high levels of 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 specific products in each value chain. Each bubble 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. The y-axis shows the number of countries that are currently exporting more of that product than they are importing, which 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. 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 for these concentrated products could result in 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-effective 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.





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 has export competitiveness, we follow a widely used convention in the trade literature and rely on the Revealed Comparative Advantage (RCA) measure (Balassa, 1965):

$$RCA_{cp} = \frac{X_{cp}}{X_c} / \frac{X_p}{X}$$
(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 \geq 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 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

Depth: Country's average market share across value chain products

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 apply equal weight to z-scores of depth and breadth dimensions in the construction of the DTS index as we have no clear prior about weighting them differently (see Methods section 4.3 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.

According to this 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 (specifically, cobalt) in the EV value chain.

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

Table 1. DTS much, Top 15 countries for each value chain and an value chains overall, by medine group in 2021

Income group

Upper middle income

Lower middle income High income

2.3 Diversification and development opportunities in decarbonization technologies

Having considered countries' 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. Developing new competitive areas in high-growth value chains can boost market participation, enhance supply chain resilience, and lead to significant economic growth and development.³

Similar to our approach for identifying countries' export strengths, we 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 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. In the Appendix section A2, we present results for different RCA thresholds, but results do not differ qualitatively. We refer to these set of products as

Low income

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.

'opportunity products' for a given country in each value chain. The depth dimension aims to capture how these opportunity products are aligned or related to a country's existing export capabilities (see Methods section 4.3.3).

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 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

Depth: Country's average capability alignment of value chain products with 0.1 < RCA < 1

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.

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

Table 2: DTO Index: To	p 15 countries for ea	ch value chain and al	l value chains overall. b	v income grou	p in 2021
TUDIC EL DI O INUCALIO	p 15 countries for co	en value enant ana a	i valac chamb ovcran, s	y meenic grou	P 2021

Income group

- Low income
- Upper middle income
- Lower middle income
 High income

2.4 Analysis of decarbonization technology indices

We now turn to the question of whether the quantification of countries' opportunities in key value chains is associated with greater competitive strengths in that value chain in future periods. Here we estimate the relationship between the DTO index and future changes in the DTS index. Our estimation approach takes the following form:

$$\Delta DTS_{c,t-(t-1)} = \alpha + \beta DTO_{c,t-1} + X'_{c,t-1}\gamma + \theta_t + \epsilon_{c,t}$$
⁽²⁾

where $\Delta DTS_{c,t-(t-1)}$ represents the 1-year change of country c's decarbonization technology strength (DTS) index in each value chain VC; $DTO_{c,t-1}$ 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, CO₂ emissions and population. θ_t represents year fixed effect. Because we observe limited within-country variation in the DTS and DTS indices for the relatively short period covered by our data, we do not use country fixed effects in our baseline specification. ϵ_{ct} captures the random error term. We estimate equation (2) with Ordinary Least Squares (OLS), using robust standard errors.

Table 3 shows the resulting analysis. For each specific value chain, higher DTO scores (representing greater decarbonization opportunities) are positively associated with greater decarbonization strengths (see columns 2-4). We note a small effect size. For example, a one standard deviation increase in a country's EV decarbonization opportunities is associated with a 1.3% increase in its decarbonization strengths (column 2). This result is robust to the inclusion of relevant control variables. Interestingly, aggregating opportunities across value chains remains significantly associated with overall changes in the aggregate DTS index, though this association is weaker (column 1).

The results are robust to alternative lag structures (Appendix Table SI4) and more demanding country fixed effect panel regression (Appendix Table SI5), which increases the explanatory power by an order of magnitude.

ΔDTS Index _{c,t-(t-1)}	(1)	(2)	(3)	(4)
	All VCs	EV narrow	Solar	Wind
DTO Index c, t-1	0.004*	0.013***	0.008***	0.008***
	(0.002)	(0.004)	(0.003)	(0.003)
DTS Index c, t-1	-0.003	-0.016***	-0.007*	-0.007**
	(0.004)	(0.005)	(0.004)	(0.004)
GDP per capita _{c, t-1} , log	-0.007***	-0.004	-0.008***	-0.006**
	(0.002)	(0.004)	(0.003)	(0.003)
Exports/GDP c, t-1	0.000**	0.000	0.000	0.000*
	(0.000)	(0.000)	(0.000)	(0.000)
CO2 emission c, t-1, log	0.003**	0.000	0.005***	0.003
	(0.002)	(0.003)	(0.002)	(0.002)
Population _{c, t-1} , log	-0.001	0.002	-0.003	-0.001
	(0.002)	(0.004)	(0.002)	(0.002)
Observations	3,579	3,425	3,545	3,568
R-squared	0.015	0.013	0.016	0.013
Year Fixed Effects	YES	YES	YES	YES

Table 5. OLS regression results of equation (2)	Table	3:	OLS rea	gression	results	of e	quation	(2)	
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Note: Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

2.5 Country-specific diversification opportunities in decarbonization technologies

We next illustrate how to identify countries that could be best placed to help diversify a specific product market. We explore this for 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 countries' RCA (y-axis) and capability alignment between their current export structure and glass mirrors (x-axis). Country bubbles are sized by their current export volumes in the product and colored by their compound annual growth rate in exports over the last five years. The left panel shows all countries, while the right panel zooms in to better visualize countries with RCA < 1.

China clearly dominates exports in this product, with exports of around \$1.38 billion being around 20 times larger than the second largest exporter (Germany) and 22 times larger than the third largest exporter (Vietnam). China's RCA in glass mirrors is also twice as large as the second and third largest countries by RCA (Lithuania and Poland). Countries that could be well placed to expand their exports in this product due to high capability alignment, and high recent export growth rates include India, Türkiye and the Netherlands.



Figure 7: Countries' export diversification opportunities in glass mirrors

Bubbles are sized by countries' export volumes (averaged over the 2017-2021 period)

3. Conclusion

This paper has advanced a 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. Second, we introduced two new indices summarizing countries' strengths and opportunities in the value chains of these technologies. Third, we illustrated a policy-oriented framework for identifying which countries are likely to have the requisite latent capabilities to diversify into a given product in these value chains. Taken together, the empirically grounded approach we set out in this paper can inform trade-led growth strategies that exploit growing demand in decarbonization

technologies. This can also help reduce supply-side risks and contribute to the global public good of greater resilience in these global value chains.

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 mineralsoriented development strategies, and to take active strategies to reduce resource-curse risks.

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.

4.) Methods

The analysis in this paper involved (i) developing a new mapping of global value chain products for solar PV, wind turbines and EVs, (ii) merging this mapping with export data, and (iii) constructing and calculating several metrics.

4.1) 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 classification⁴, it has some limitations, notably dual use and product specificity.

⁴ 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.

However, the 6-digit HS classification has the advantage that it enables analysis of comparable trade data for almost all countries, and over time.⁵

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 5 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 4.

Value Chain Seg- ment	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 Materi- als	Materials that have been transformed or refined from basic raw materials as an intermedi- ate 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 pre- cursors 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

⁵ 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 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 data5. 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.

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.

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

Table 5: Number of HS 6-digit products by value chain and segment

4.2) 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, CO₂ emissions and population - from the World Bank World Development Indicators (WDI), available from <u>https://databank.worldbank.org/source/world-development-indicators</u>.

4.3) Key metrics

4.3.1) 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.⁶ It is defined as follows:

$$HHI_{p} = \sum_{c} \left[\frac{X_{cp}}{X_{p}} \right]^{2}$$
(3)

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.

4.3.2) 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):

Export Market Share_{c,vc} =
$$\frac{1}{N_p} \sum_{p \in vc} \frac{X_{cp}}{X_p}$$
 (4)

⁶ For ease of exposition, we leave out the time subscript in all equations.

where N_p is the number of HS 6-digt products in a given value chain, X_{cp} relates to the exports of country *c* of product p and 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:

$$z_{c,vc}^{d} = \frac{x_{c,vc}^{d} - \mu_{vc}^{d}}{\sigma_{vc}^{d}}$$
(5)

where $x_{c,vc}^d$ is country's c value in strength dimension d (depth or breath) in value chain vc; μ_{vc}^d represents the mean of dimension d in value chain vc; σ_{vc}^d 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.

4.3.3) 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 6digit 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 2 and SI 3 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.

To define the depth of countries' decarbonization opportunities, we draw on existing work in the economic geography and economic complexity literature which has shown that countries are more likely to develop future export strengths that involve similar (or related) production capabilities to their existing exports (Hidalgo et al., 2007). Following Hausmann et al. (2014), we follow three steps to define capability alignment. 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, as defined in equation 1 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 calculate a measure of relatedness between products based on the conditional probability of co-exporting two given products with RCA > 1 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. Specifically, product relatedness $\varphi_{p,p}$, between products p and p' for a particular year is defined as:

$$\varphi_{\mathrm{p,p'}} = \frac{\sum_{\mathrm{c}} \mathrm{M_{\mathrm{cp}}} \mathrm{M_{\mathrm{cp'}}}}{\sum_{\mathrm{c}} \mathrm{M_{\mathrm{cp}}}} \tag{6}$$

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,

Capability Alignment_{cp} =
$$\frac{\sum_{p'} M_{cp} \phi_{p,p'}}{\sum_{p'} \phi_{p,p'}}$$
 (7)

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

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Appendix

A1. Mapping global value chains of key decarbonization technologies

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). <i>China's renewable energy trade potential in the"</i> <i>Belt-and-Road" countries: A gravity model analysis.</i> Renewable Energy, <i>161</i> , 1025-103;
	• Surana, K., Doblinger, C., Anadon, L. D., & Hultman, N. (2020). <i>Effects of technology complexity on the emergence and evolution of wind industry manufacturing locations along global value chains</i> . Nature Energy, <i>5</i> (10), 811-821;
	• Kuik, O., Branger, F., & Quirion, P. (2019). <i>Competitive advantage in the renewable energy indus-</i> <i>try: Evidence from a gravity model</i> . Renewable energy, <i>131</i> , 472-48;
	• Matsumura, A. (2021). Gravity analysis of trade for environmental goods focusing on bilateral tar- iff 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). <i>Benchmarks</i> of Global Clean Energy Manufacturing, 2014-2016 (No. NREL/TP-6A50-78037). National Renewa- ble 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 Photovolta-	• Jing, S., Zhihui, L., Jinhua, C., & Zhiyao, S. (2020). <i>China's renewable energy trade potential in the</i> "
ics	 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). <i>Competitive advantage in the renewable energy indus-</i> <i>try: Evidence from a gravity model</i> . Renewable energy, 131, 472-48; Science, 1-35;
	• Sandor, D., Keyser, D., Reese, S., Mayyas, A., Ramdas, A., Tian, T., & McCall, J. (2021). <i>Benchmarks of Global Clean Energy Manufacturing, 2014-2016</i> (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 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). <i>Global Value Chains: Lithium in Lithium-ion Batteries for Electric Vehicles.</i> Office of Industries, US International Trade Commission;
• Scott, S., & Ireland, R. (2020). <i>Lithium-Ion battery materials for electric vehicles and their global value chains</i> . Office of Industries, US International Trade Commission;
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• Zhao, G., Wang, X. and Negnevitsky, M. (2022). Connecting Battery Technologies for Electric Vehi- cles from Battery Materials to Management. iScience, [online] 25(2), p.103744. doi:https://doi.org/10.1016/j.isci.2022.103744.

A2. Robustness analysis for DTO indices with different RCA thresholds

Table SI 2: Decarbonization Technology Opportunity (DTO) Index with Breadth defined by 0.2>RCA>1: Top 10countries 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 3: Decarbonization Technology Opportunity (DTO) Index with Breadth defined by 0.5>RCA>1: Top 10countries 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. Robustness analysis of decarbonization technology indices

$\Delta DTS Index_{c,t-(t-3)}$	(1)	(2)	(3)	(4)
	All VCs	EV narrow	Solar	Wind
DTO Index c, t-3	0.004	0.009**	0.008***	0.005*
	-0.002	-0.004	(0.003)	(0.003)
DTS Index c, t-3	-0.006	-0.016***	-0.009**	-0.008**
	(0.004)	(0.005)	(0.004)	(0.004)
GDP per capita _{c, t-3} , log	-0.006***	-0.001	-0.009***	-0.005**
	(0.002)	(0.004)	(0.003)	(0.003)
Exports/GDP c, t-33	0.000**	0.000	0.000	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)
CO2 emission c, t-3, log	0.003**	-0.002	0.006***	0.003
	(0.002)	(0.003)	(0.002)	(0.002)
Population c, t-3, log	-0.001	0.005	-0.005**	-0.000
	(0.002)	(0.004)	(0.002)	(0.002)
Observations	3,249	3,117	3,219	3,238
R-squared	0.015	0.011	0.018	0.011
Year Fixed Effects	YES	YES	YES	YES

Table SI4: OLS regression results of equation (2) with 3-year lag structure

Note: Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table SI5: OLS regression results of equation (2) with additional country fixed effects

ΔDTS Index _{c,t-(t-1)}	(1)	(2)	(3)	(4)
	All VCs	EV narrow	Solar	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 emission 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

A3. Detailed list of 6-digit HS products in decarbonization technologies

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, nest
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 fly- wheels
852721	EV - Broad	Subcomponents	Radio receivers, external power, sound repro- duce/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 repro- ducer
870839	EV - Broad	Subcomponents	Brake system parts except linings for motor vehi- cles
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 vehi- cles
870810	EV - Broad	Subcomponents	Bumpers and parts thereof for motor vehicles
870891	EV - Broad	Subcomponents	Radiators for motor vehicles

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

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 vehi- cles
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 vehi- cle
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, agglomer- ated
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, unagglomer- ate
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 fur- naces
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/pow- ders
811240	Solar	Raw materials	Vanadium, articles thereof, waste or scrap/pow- ders
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, un- mounted
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 tereph- thal
392051	Solar	Subcomponents	Sheet/film not cellular/reinf polymethyl methacry- late
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 polyes- ters
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 connect- ors
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 ma- chiner
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 re- finin
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 alu- minium, 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,un- wrough
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/fin- ishe
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/ex- trude

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-re- cording
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 me- ters
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 con- verte
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 bear- ing
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