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Twin transition trade based on multi-dimensional economic complexity[*]

María de las Mercedes Menéndez[†]

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Abstract

Trade worldwide is being reshaped by two major megatrends: advanced digitalization of production and the transition towards environmentally sustainable goods. This chapter examines for the first time the perspective of twin transition export and import diversification within a multi-dimensional economic complexity approach (Nomaler & Verspagen, 2024b, 2024d) and investigate whether this type of productive transformation perpetuates path-dependency processes in 80 countries over 2000-2018. The results suggest that an export/import productive structure based on twin transition products exhibit different economic performance, sustainability, and inequality implications. Productive specialization in these products has been very *path-dependent* and with a low engagement of developing countries and hence, reinforcing the core-periphery trade division. Furthermore, results suggest that developments in digital and green technological paradigms mainly take place in a selected number of countries that are already highly developed.

JEL codes: F14, O10, Q01

Keywords: *multi-dimensional economic complexity, canonical correspondence analysis, twin transition, sustainable development.*

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1. Introduction

One of the most pressing challenges currently faced by countries worldwide is the imperative to transform their productive structure towards greener and digital products. Such transformation must be in harmony with the dimensions of sustainable development, which embrace economic growth, social inclusion, and environmental protection. Countries' productive transformation strategies that encompass products linked to information and communication (IC) and Fourth Industrial Revolution (4IR) technologies, as well as different types of goods and technologies that make up a green productive system, play a fundamental role in this context. This article provides an overview of the relationship between countries' export/import specialization on green and digital (twin) transition products and diverse dimensions of sustainable development. Additionally, it examines whether this type of productive transformation perpetuates path-dependence processes in countries' productive specialization.

Economic complexity constitutes a broad academic field for the comprehensive analysis of societal challenges (Balland et al., 2022; Caldarola et al., 2024), including the process of product diversification towards crucial products for the green and digital transition. It is a well-established academic field[3] that found its roots in Schumpeterian theory, which postulates that the economy is a complex system in constant evolution, where economic change is governed by dis-equilibrium resulting from the emergence of innovations (Nomaler & Verspagen, 2024a; Robert & Yoguel, 2016). Moreover, it draws on Albert Hirschman's growth theory and structuralist theory, where development is conceived as a process that generates sectoral and geographical imbalances and social and income inequalities (Hidalgo, 2023; Neffke et al., 2024). Increasing computational capacity for data processing has prompted a shift in the field of economic complexity away from a theory to understand economic development "big" problems to embrace a data-driven research program. This research program, known as "*economic complexity theory*" or the "*new paradigm of economic complexity*" has been characterized by employing network theory and machine learning techniques on big datasets, such as trade date, patent data, among others (Balland et al., 2022; Hidalgo & Hausmann, 2009; Tacchella et al., 2012, among others).

[3] More about the evolution of Economic Complexity as a field, see Balland et al (2022); Hidalgo (2023); Nomaler & Verspagen (2024a).

Within the economic complexity framework, the productive transformation of a country towards twin transition products can be conceived as an evolving and dynamic process dependent on the current productive specialization. Imbalances tend to occur when countries incorporate these products due to changes in comparative advantage (Coniglio et al., 2021). The fact that the pattern of productive specialization tends to persist over time, or in other words, is path-dependent, directly challenges the possibility for some countries successfully integrating into a green and digital productive path. The relationship between the path dependence concept, broadly understood as a dynamic process whose evolution depends on past decisions of economic agents and the context (Antonelli, 1997; David, 2007) and the transformation of the productive structure has been extensively studied by an evolutionary-neo-Schumpeterian perspective. This perspective explains that the persistence of countries in comparative advantage reflects the interdependence between their productive and innovation systems which are firmly rooted in the social and institutional structure (Dosi et al., 1990; Reinstaller & Reschenhofer, 2019).

The relationship between path dependence and productive structure has been operationalized by the economic complexity approach through the concept of *product relatedness*. From an export perspective, this concept postulates that a country will be more likely to develop comparative advantage in exporting (producing) twin transition products if they are related to its current exports, rather than exports that are unrelated. Therefore, the potential diversification of economies towards crucial products for digital and green transition depends on the pre-existence export basket of countries, which is determined by the re-combination of current countries' available capabilities (e.g., physical capital, human capital, technologies, institutions) (Coniglio et al., 2021). However, the method does not address how these capabilities accumulate. In other words, the concept of *product relatedness* reinforces the notion of path dependence and the assertion that countries are "*condemned*" to produce products only related to their development opportunities. This deterministic perspective of countries' possibilities for structural transformation has been recently empirically revisited by authors who argue that countries can diversify regardless of their product relatedness or characteristic products (Coniglio et al., 2018, 2021; Nomaler & Verspagen, 2024c). In this regard, Talebzadehhosseini et al (2020) found for a set of countries that their ability to diversify their green product basket is not only path-dependent on their current capabilities but also identify non-path-dependent processes to produce products unrelated to their current product basket.

The concept of *product relatedness* from the perspective of imports has been much less addressed by the economic complexity literature. A recent paper by Jun et al (2020) studies relatedness from the perspective of exporter/importer countries. Briefly, the authors introduce a measure named "*import relatedness*" to estimate "*the fraction of the geographic neighbors of a country that import a product from the same origin*" (p.250-251). They argue that it reflects the knowledge on how to distribute within a region with certain culture or knowledge on logistic information about shipping routes. Adapting the export product relatedness measure to imports, this paper assumes that a country will be more likely to develop a comparative advantage in importing (using) twin transition products if they are related to its current import basket, rather than unrelated imports. The potential diversification of economies towards products crucial for the digital and green transition through imports is determined by the recombination of import capabilities linked to the usage of these products. Unlike for exports, no study has revisited empirically the deterministic view that countries are destined to use only products related to their knowledge import opportunities. Imports of capital play a key role for countries, especially for developing countries, to achieve higher rates of investment and growth (Can et al., 2023). This is particularly important in the context of the twin transition as they constitute a key aspect for facing challenges of digitalization and climate change. In essence, following the authors, import diversification might avoid path dependence as it allows countries to access new capital goods and therefore to the production of new products, new technology and knowledge.

Path dependence on trade specialization based on product similarity can be visualized through a network representing the "*product space*" (PS). PS derives from the application of the dimensionality-reduction techniques on trade specialization matrices (Hidalgo, 2021), where the nodes are export (import) products and links represent products that are co-exported (co-imported) by a country (based on Hidalgo et al., 2018). In other words, the PS reflects the pair-wise proximity between products as conditional probabilities of co-occurrence (Nomaler & Verspagen, 2022a). The suggestion is that countries move through the PS by developing goods closer to those that they currently produce. Less sophisticated countries are in the periphery, not so well connected, while sophisticated products are connected in the core (Hidalgo et al., 2007). So far, the PS tool only allows to visualize products and countries without including how they may be associated with the different variables of sustainable development. Furthermore, economic complexity estimates the availability of capabilities embedded in the PS though indexes such as the Economic Complexity Index (ECI), which reflects the current state of a country's productive knowledge and the Product Complexity Index (PCI) that measures the productive knowledge required to produce a product. Overall, economic complexity has unraveled the relationship between economic structures and the dimensions of sustainable development[4], simply through only the parallel assessment of metrics such as the Economic Complexity Index (ECI) on economic growth, inequality, and emissions intensity[5].

On this last point, the multi-dimensional economic complexity approach introduced by Nomaler & Verspagen (2024b, 2024d) represents a more comprehensive operationalisation of the PS. This approach permits examining the changes or persistence in the countries' trade specialisation and includes countries' sustainable development characteristics in the analysis. This approach contrast with the PS from Hidalgo et al (2007), which solely includes products and countries. Briefly, the multi-dimensional economic complexity approach is based on an ordination technique, canonical correspondence analysis (CCA), commonly employed in ecological studies (Legendre & Legendre, 2012; Ter Braak, 1986). The starting point of the CCA is correspondence analysis (CA), as, for estimating the PS, it is a dimensionality reduction method that reveals the relative relationship between and within two groups of variables based on data given in a contingency table. For instance, this type of analysis can summarize the number of species (products) in different locations (countries) where the species that tend to occur in the same location are plotted together. The "*ordination diagrams*" or "*triplots*" display the result of CCA where points commonly represent species (products) and locations (countries), and arrows represent environmental (sustainable development) variables (Ter Braak, 1986). As a PS of conventional economic complexity, the ordination diagram allows to infer the specialization patterns of countries, but also includes how this specialization is associated with sustainable development variables. Like Hidalgo et al. (2007) for the PS, the proximity of the products in the ordination diagram can be interpreted as the products relying on similar capabilities for their production. Similarly, in the case of countries, the closeness of the points can be understood as indicating a similar capability endowment. Unlike PS, the

[4] See Ferraz et al (2021) and Montiel-Hernández et al (2024) for an extensive literature review on economic complexity and sustainable development dimensions.
[5] For economic performance (Hausmann et al., 2014; Hidalgo & Hausmann, 2009), inequality (Bandeira Morais et al., 2018; Hartmann et al., 2017) and sustainability[5] (Can & Gozgor, 2017; Romero & Gramkow, 2021)). So far, the way that economic complexity has explored the multidimensionality approach of sustainable development is by estimating the ECI using different sources of data (patents, trade, and publications data) and analyzing how their interactions impact on economic performance, inequality, and sustainability individually (Stojkoski et al., 2023), which limits the scope for a broader interpretation of the comprehensive impact of these indicators on sustainable development.

distance among countries and among products reflects chi-square distances and increases according further apart the countries/products are in the diagram (Ter Braak & Verdonschot, 1995).

The aim of this chapter is to unravel the relationship between countries' trade specialization towards products crucial for the green and digital (twin) transition and various dimensions of sustainable development from a multidimensional economic complexity approach. In this regard, it contributes through a novel methodology to a) examine for the first time the perspective of twin transition export and import specialization within a multi-dimensional economic complexity approach and b) investigate whether this type of productive transformation perpetuates path-dependency processes in countries productive specialization. Furthermore, it provides a basket of crucial products connected with the digital and green transition. The primary data source is trade data extracted from BACI-CEPII for 2000-2018. This work relies on Harmonized System classification correspondence tables to identify products linked to twin transition over time. Moreover, this paper collects information from several sources on to broadly contemplate the sustainable development dimensions.

The results suggest that an export/import productive structure based on twin transition products has different economic performance, sustainability, and inequality implications. High income, pollutant and less unequal countries tend to specialize in exporting green, digital and green-digital products while more unequal and high growth countries specialize in exporting critical minerals for green technologies. On the other hand, digital and digital-green products import specialization associates with higher GDP growth rates while green import product specialization associates with higher levels of inequality. Critical mineral for green technologies is the only set of products from the twin transition basket that has seen a more pronounced increase in ubiquity and shift in the diagram, confirming their key role for the European net zero strategy.

Additionally, the results confirm that twin transition exports specialization is path dependent and reinforces global trade division. In this regard, green export specialization engages only a limited group of more diversified developed countries, which puts at risk the possibility of a broader range of developing countries participating in a green productive transformation process alongside a reduction in inequalities. Furthermore, the position of these advanced economies in the green productive race, coupled with high pollutant emissions, serves to reinforce their fundamental role in the fight against climate change. The

results also suggest that the possibilities for developing countries to acquire green capabilities through imports are limited too and associated with inequality over time. Contrarily, digital, and green-digital import specialization allow countries such as Korea and Singapore to acquire technological capabilities that allow them to consolidate their position in the digital technological paradigm. Regarding critical minerals for green technologies export specialization, the findings confirmed that these products present little proximity with other more dynamic products and persist in associated with poorer countries; on the contrary, the import specialization of these products remains associated with high-income countries.
Beyond the twin transition products, the results allow identifying the existence of virtuous structural transformation process based on acquiring comparative advantage in radically different products in opposition to the hypothesis of path dependence based on the current capabilities. On the one hand, the export ordination diagram serves to corroborate the existence of a process of assimilation of technological knowledge of countries. This is observed for cases such as China, Thailand, and Turkey, where specialization shifted from being associated with higher levels of inequality and growth to achieving higher levels of income, reducing inequality, and facing high pollution levels. On the other hand, import diagrams allows identify process of technological assimilation of technological change and a pronunciation of the digital technological paradigm for countries such as Malaysia, India, and Thailand.

The remainder of the paper is structured as follows. The methods section introduces the core economic complexity concepts and the multi-dimensional economic complexity approach using the canonical correspondence analysis (CCA) (Sections 2.1 to Section 2.3). Section 2.4 reviews the attempts towards identifying products linked to twin transition, such as environmental goods, digital, and critical minerals for green techs. Section 3 presents the results of the multi-dimensional approach for twin transition products. Section 4 concludes, identifies limitations and draft future agenda.

2. Methods and Data

2.1 Economic complexity metrics: the main concepts

As was mentioned in the Introduction of this article, the recent economic complexity research program constitutes a data-driven framework aiming to explain the development of countries by employing network theory and machine learning techniques on big data (Balland et al., 2022; Hidalgo & Hausmann, 2009; Mealy et al., 2018; Tacchella et al., 2012). Economic complexity analysis begins with the construction of a bipartite network that connects geographical such as countries and different types of products in which they specialize. Economic complexity literature has centered on exports data. In this regard, the network is constructed using export value data in US$ for p products exported by *c* countries. Just as previous works on the topic, the bipartite network can be expressed in a pxc matrix (M) of revealed comparative advantage (RCA) indicators, where the binary elements of this matrix represent the share of country c in the sum of export value of product p divided by the global share country c in the sum of all export value. An RCA matrix of dimensions is constructed, where each element $m_{cp} = 1$ if $\left(X_{cp}/X_c\right)/\left(X_p/X\right)$ and $m_{cp} = 0$ otherwise. This matrix reflects which products are present/absent in the export specialization portfolio of which country. The elements of the matrix that are equal to 1 indicate that country *c* has an export comparative advantage to produce product p.

The economic complexity literature has vastly omitted import data on the comparative advantage index (Stellian & Danna-Buitrago, 2022). Therefore, a matrix (N) is built from the perspective of the importer country. The binary elements of this matrix represent the share of importer country d in the sum of export value of product p divided by the global share of importer country *d* in the sum of all export value. A binary import RCA[6] matrix of dimensions is constructed from this, where each element $m_{dp} = 1$ if $\left(X_{dp}/X_d\right)/\left(X_p/X\right)$ and $m_{dp} = 0$ otherwise. This matrix reflects which products are present/absent in the import specialization portfolio of which country. The elements of the matrix that are equal to 1 indicate that country *d* has an import comparative advantage to produce product p.

The matrices (M) and (N) are the bipartite network behind the PS. Furthermore, they are also the starting point to estimate ECI and PCI through the "*Method of Reflections*" introduced by Hidalgo & Hausmann (2009) that was later reformulated as an eigenvalue problem.[7] Basically, this method begins by summing of rows and columns of matrices (M) and (N), that reflect measures of country export (import) diversity

[6] The literature refers to this index as the relative import penetration index (see Frohberg & Hartmann (1997).

[7] Following Balland et al (2022), the starting point of the problem formulation is two row stochastic matrices: $A = D_{cc}M$ and $B = MU_{pp}$, where D_{cc} is the diagonal matrix formed from the vector of country diversity values and U is the diagonal matrix formed from the vector of product ubiquity values. Due to the stochastic nature of the matrices, their first eigenvector of the solution of equations is 1. The ECI is the eigenvector associated with the second largest eigenvalue of the matrix AB^T and the PCI is the eigenvector associated with the second largest eigenvalue of the matrix A^TB.

and export (import) product ubiquity, respectively. These initial values are used to iteratively calculate successive reflections generating new indicators at the country and product level. This method can be understood as a recursion in which diversity and ubiquity are corrected using each other's information. For instance, in the case of countries this method demands calculating the average ubiquity of the products that it exports (imports) and the average diversity of the countries that make (use) those products and so forth. For the case of exported (imported) products, it requires calculating the average diversity of the countries that make (usage) them, and then average ubiquity of the other products that these countries make (usage) (Hausmann et al., 2014). On the one hand, and from the point of view of exports, economic complexity is based on the idea that complex products are produced by few countries (e.g. have low ubiquity) and these countries produce many other products (e.g. are highly export diversified), and therefore countries need specific capabilities to start producing products thus, achieving a more diversified export basket requires an accumulation of capabilities, while ubiquity can be understood as the production capabilities liked to products: products with low (high) ubiquity require (less) advanced production capabilities. On the other hand, from the point of view of imports, the main idea behind this approach is that complex products are used by many countries (e.g. have high ubiquity) and these countries use many other products (e.g. are highly import diversified) and therefore countries need specific capabilities to start using products thus, achieving a more diversified imports basket requires an accumulation of capabilities, while ubiquity can be understood as the usage/import capabilities liked to products: products with high (low) ubiquity require (more) advanced production capabilities.

Since the publication of the paper by Hidalgo & Hausmann (2009), the measures of economic complexity have been subject to strong criticism and revision such as the Economic Fitness and Complexity (EFC) algorithm (Tacchella et al., 2012), the canonical correlation complexity method (Nomaler & Verspagen, 2022b) and correspondence analysis (CA)[8] (Mealy et al., 2018; Nomaler & Verspagen, 2024b; van Dam et al., 2021). ECI and PCI can be understood as an application of CA. In essence, following Mealy et al. (2024), the simple (multiple) CA is a multivariate statistical method frequently used to visualize the association between row and column categories of a contingency table, such as the RCA matrix, in a lower-dimensional space. In this regard, the authors highlight that when performing a simple correspondence analysis in *M*, the first dimension of the products and country scores are the PCI and ECI, respectively.

[8] The literature also refers to this method as *reciprocal average*, see Hill (1973).

2.2 Canonical correspondence analysis (CCA): a reinterpretation for economic complexity

An extension and variation of the correspondence analysis (CA) is the canonical correspondence analysis (CCA). CCA is a multivariate analysis technique introduced in the 1980s by Cajo J.F ter Braak (1986) in the ecology field to study how species in different sites respond to changes in environmental variables like humidity or temperature. It was widely applied to social sciences, too (Greenacre, 2010, 2017). Formally, CCA integrates, on the one hand, the ordination technique such as CA, which extracts the dominant pattern of variation in community composition from the species data, and, on the other hand, regression analysis (Legendre & Legendre, 2012; Ter Braak, 2014). Similarly, as complexity economics, CCA operates on data occurrences or abundancies of species (products), sites (countries), and environmental (sustainable development) variables at sites (countries) (See Table 1). Specifically for this study, CCA provides a more comprehensive method for unravelling how countries' product specialisation towards twin transition products simultaneously responds to variables related to sustainable development. Moreover, this method does not aim to identify causal interpretations, as it is only possible to identify associations between different outcome variables.

Table 1: CCA components: ecology vs. economics

Ecology	Economics
Species	Products
Sites	Countries
Environmental Variables (humidity, temperature, altitude)	**Sustainable development variables: (GDP per capita, Growth, Gini, CO2 emissions)**

The starting point for CCA is a matrix **M** (response matrix), which is the same as used in the complexity economic approach (see Section 2.1), containing information about products and countries. It also includes a second matrix comprising information about a number of aggregate (country-level) variables linked to sustainable development such as GDP per capita, inequality and pollution. To understand how well sustainable variables correlate to product variation, CCA builds a set of products scores which are like Hidalgo & Hausmann product complexity indicators. In this regard, for each product a score can be calculated by taking the weighted average of each of the sustainable development variables of the countries. This score is calculated as: $u_p = \sum_{c=1}^{n} {m_{cp}x_c}/{m_{+p}}$ where u_p is the weighted average of the *p-th* (out of *m*) product, x_c is the value of the sustainable development variables of the *c-th* (out of *n*) country and m_{cp} is the abundance of products p at the country c, and m_{+p} is the total abundance of products p. The different sustainable development variables, expressed in various scales, are standardized to have a mean of zero and a variance of one. Then, the country scores are estimated as the average of product scores of the products for which the country has comparative advantage. This score is like ECI for Hidalgo & Hausmann's complexity approach.

Subsequently, CCA estimates what are the possible combinations of sustainable development variables that maximize the correlation to product specialization of the countries. In this regard, and following Ter Braak (1987), CCA selects the weighted linear combinations of sustainable development variables that maximizes the dispersion of the products scores. The weights are the countries totals. The linear combination adopts the following form: $x_c = b_1 z_{c1} + b_2 z_{c2} + \cdots + b_d z_{cd}$ where z_{cd} is the value of the *j*-th (out of *d*) environmental variable at country *c*, and b_j is the weight (not necessarily positive belonging to that variable); x_c is the value of a compound environmental variable at country *c*. In other words, CCA chooses the optimal weights b_j for the environmental variables. As in the "Method of Reflections", finding the optimal weights of this linear combination can be formulated as an eigenvalue problem[9].

The "*ordination diagrams*" or "*triplots*" display the result of CCA where points commonly represent species (products) and locations (countries), and arrows represent environmental (sustainable development) variables (Ter Braak, 1986). As a PS of conventional economic complexity, the ordination diagram allows to infer the specialization patterns of countries, but also includes how this specialization is associated with sustainable development variables. Ordination diagram axis represent the variation in the data based on products- countries, and sustainable development variables. Formally, each canonical axis has an eigenvalue associated that represents the variance explained. For example, CCA1 captures the maximum variance in product composition that the selected sustainable development variables can explain. Each subsequent axis (CCA2 and so forth) explains additional variation in the product data not explained by the previous axes. The amount of variation explained decreases with each additional axis. Additionally, each axis is orthogonal (independent) to the others, and hence, they capture different patterns

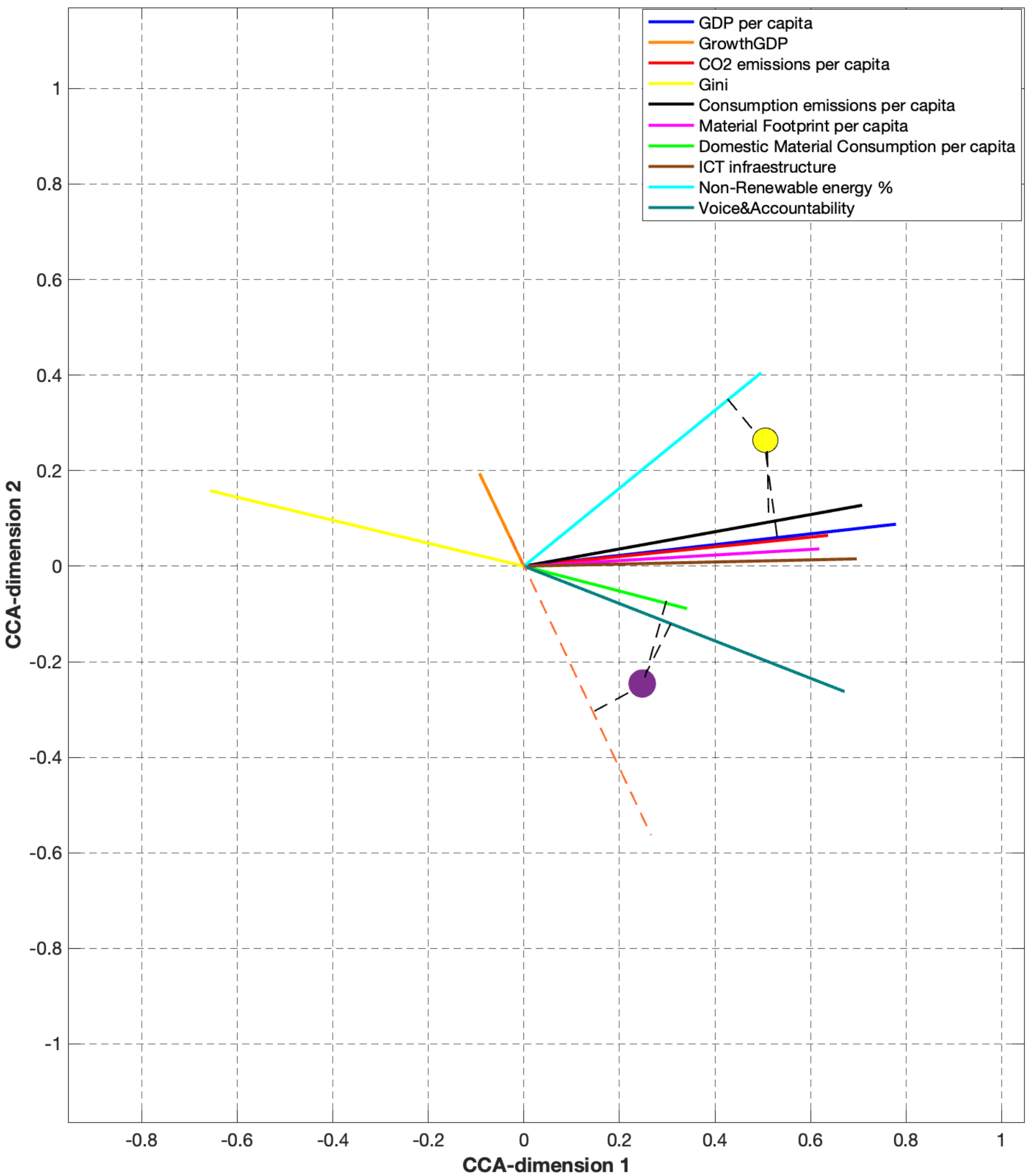
[9] See Ter Braak (1986) and (Nomaler & Verspagen, 2024b) for a detailed explanation of this procedure.

of products-sustainable development relationships that are not redundant with those captured by earlier axes. Studies usually maintain the canonical dimensions that capture the most significant proportion of variation through canonical analysis.

Figure 2.3 serves for illustrating the ordination diagram. First, the distance between points reflects dissimilarity. Therefore, if the points representing countries and products are far apart, the occurrence of those products in those countries is shallow. Second, the length of the arrows indicates the correlation of the sustainable development variables with the axes of the plot: for example, sustainable development long arrows indicate that are more strongly correlated with the ordination axes than those with shorter arrows and hence more closely related to the pattern of the community variation shown in the ordination diagram (Ter Braak, 1987). Third, the angles between the vectors indicate the correlation between the sustainable development variables.

Additionally, Figure 2.3 shows with an example the projection of a country on one of the coloured lines, as it is indicated in by the dotted lines for country X relates the country's scores on the associated variables with it trade specialisation pattern. In this regard, country X projects positively on the GDP per capita, growth per capita, sustainable emission variables, governance and voice accountability and ICT infrastructure. For understanding the position of product X it is necessary to extend the arrow of GDP growth per capita in both directions to be able to visualise the "negative" projection. Then, it is possible to infer that "Product X" specialization has a lower weighted average with respect to growth GDP per capita.

Figure 2.3 Triplot with CCA dimensions 1 and 2



2.3 Twin transition products

Although identifying twin transition products is difficult because there is no standardized classification in the academic literature for detecting these products, several efforts have been made to identify and analyze the evolution of products involved in green and digital transition using trade data. The following subsections review the approaches used to identify these products.

2.2.1 Green products

To begin, there is not an internationally accepted classification of green products (Mealy & Teytelboym, 2022) nor a single definition for the classification of green products (or green exports). In this regard, the Harmonized System (HS) does not identify green/non-green products. Despite all these limitations, efforts to identify green/sustainable/clean products or "*products with environmental benefits*" are several and emerge because of international negotiations to trade liberalization on a group of products that are relevant for decarbonization and sustainable development (Bontadini & Vona, 2023). As it is pointed out by the authors, some of these attempts were guided more towards political aspects rather than the real green content and not having as a result and unification of a list of products (Mao et al., 2023; Sauvage, 2014).

In a broad sense, attempts to identify green environmental goods can be divided into three main groups: traditional environmental goods, environmentally preferable products (EPPs), and environmental technologies goods. The first are *those whose main function is to address or contribute to solving an environmental issue or challenge.* EPPs *are products produced in ways that are less detrimental to the environment, such as organic cotton* (Brenton & Chemutai, 2021). Finally, environmental technologies goods are broadly understood as those used solely for solving environmental problems.

A pioneering attempt to identify the environmental goods and services industry is a report by the OECD (1999) that defines environmental goods:

"The environmental goods and services industry consists of activities which produce goods and services to measure, prevent, limit, minimise or correct environmental damage to water, air and soil, as well as

problems related to waste, noise and eco-systems. This includes cleaner technologies, products and services that reduce environmental risk and minimise pollution and resource use."

The environmental goods are classified into eleven categories: 1) air pollution control, 2) Cleaner or more resource efficient technologies and products, 3) environmentally preferable products based on end use or disposal characteristics, 4) heat and energy management, 5) environmental monitoring, analysis and assessment equipment, 6) natural resources protection, 7) noise and vibration abatement , 8) renewable energy plant, 9) management of solid and hazardous waste and recycling systems, 10) clean up or remediation of soil and water and 11) waste water management and potable water treatment.

For instance, the Asian Pacific Economic Cooperation (APEC) list of Environmental Goods[10] introduced in 2012 include 54 environmental goods. Approximately three-quarters of the list are goods related to renewable energy production, environmental monitoring analysis, and management of solid and hazardous waste and recycling systems. Additionally, the list comprises a reduced number of products for air pollution control, wastewater management, and potable water treatment. Finally, the list includes one environmentally preferable product and one associated with natural risk management. Furthermore, the International Monetary Fund (IMF) defines environmental goods as those that

"*include both goods connected to environmental protection (connected goods) and goods that have been adapted to be more environmentally friendly or "cleaner" (adapted goods). Connected goods are goods whose use directly serves environmental protection purposes…Adapted goods are goods whose use is beneficial for environmental protection"*[11].

IMF identifies the products based on OECD and Eurostat, The Environmental Goods & Services Industry: Manual for Data Collection and Analysis, 1999, and IMF research.

The most recent attempt to identify green products was carried out by (Mealy & Teytelboym, 2022), whose main aim was to bring together various lists of environmental goods classifications from the WTO, the Organization for Economic Co-operation and Development (OECD), and the Asia-Pacific Economic

[10] https://www.apec.org/meeting-papers/leaders-declarations/2012/2012_aelm/2012_aelm_annexc
[11] https://climatedata.imf.org/documents/ad5179b954ed4a8389bf6400324a901e/explore

Cooperation (APEC) into a single and comprehensive data set of green product lists. This study defines green products as those products with environmental benefits. The list includes 293 products classified as HS1992.[12]

Within environmental technologies goods, it is possible to identify several product classifications. Low Carbon technology products are *those "that produce less pollution than their traditional energy counterparts and will play a vital role in the transition to a low carbon economy. LCTs include mechanics like wind turbines, solar panels, biomass systems and carbon capture equipment.* The identification is based on (Pigato et al., 2020). One hundred twenty-four products are identified according to this methodology. Another attempt is provided by Rosenow & Mealy (2024). The authors identify decarbonization technologies that include tradable products associated with the value chains of solar PV, wind turbines, and electric vehicles. The identification of these products relies on three steps: review of academic literature, destock research to classify each product into four value chain segments: raw material, processed materials, subcomponents, and end products. The products were then validated by industry experts.

2.2.2 Digital products

As is often the case when identifying digital technologies, when it comes to products, there does not seem to be agreement on a set of products associated with the digital transition. In many of these classifications, digitisation is more closely associated with Information and Communication Technologies (ICT), while in others, it is more closely associated with technologies related to the Fourth Industrial Revolution. To a greater or lesser extent, several international organizations have focused on the relevance and challenges of measuring digital trade. For the latter, the product-level classifications are more complex. This is due to the intangible capital component of the digital transition, which is often not captured in export products.

Andreoni et al. (2023) built a novel Digital Production Technology Classification based on Harmonized System (HS2017- 6 Digits) with products connected to digital production technologies (DPTs). The products linked to DPTs are clustered into different categories: *final digital technologies, components of digital technologies, and instrumentation for digital technologies*. Authors identify products based on

[12] More information about green products available in https://green-transition-navigator.org/.

selecting HS relevant chapters for digital production (1) Chapter 84, "*Nuclear reactors, boilers, machinery, and mechanical appliances; parts thereof*"; 2) Chapter 85, "*Electrical machinery and equipment and parts thereof; sound recorders and reproducers; television image and sound recorders and reproducers, parts and accessories of such articles*"; and 3) Chapter 90 "*Optical, photographic, cinematographic, measuring, checking, medical or surgical instruments and apparatus; parts and accessories*") and BECs (Chapter 41, Chapter 42, Chapter 22). Then, to narrow the selection a systematic identification of DPTs was carried out using keywords selection and product analysis product in consultation with experts to assess its connection to digitalization.

UNCTAD developed a list of ICT goods broadening the definition proposed by (OECD, 2011) defining ICT goods as those that "*primarily fulfil or enable the function of information processing and/or communication by electronic means, such as transmission or display*"[13]. The products identified are grouped into the following categories: 1) computers and ICT peripheral equipment, 2) communication equipment, 3) consumer electronic equipment, 4) electronic components and 5) miscellaneous.

Foster-McGregor et al. (2022) identify a list of Fourth Industrial Revolution products linked to CAD-CAM, robots, automate welding, 3D printing, regulating instruments and ICT based on a Foster-McGregor et al. (2019) and Acemoglu & Restrepo (2022). The former identify products linked to Fourth Industrial Revolution (4IR) associated with four specific technologies: (i) industrial robots; (ii) additive manufacturing (or 3D printing); (iii) computer-aided design and computer aided manufacturing (CAD/CAM) techniques; (iv) big data and cloud computing; and (v) artificial intelligence and machine learning. Identifying this type of products presents some limitations: most part of this technology is software, and it is complicated to identify using trade data, these technologies depend on hardware, and it is usually a multi-purpose hardware, technologies are embodied in manufacturing capital goods and hence there is not a distinction between smart and normal version of these products. Authors selected products linked to robots, 3D printing and CAD CAM. The products belong to the HS Chapter 84 and the authors warn the readers that there are possibilities that these classifications retrieve information of products from older technological revolutions.

[13] https://unctad.org/system/files/official-document/tn_unctad_ict4d20_en.pdf

Finally, another attempt is provided by Zhang et al. (2023) identify digital products using *Statistical Classification of the Digital Economy and Its Core Industries (2021)*" released by the National Bureau of Statistics of China (NBSC) and the list of information and communications technology (ICT) products published by the United Nations Conference on Trade and Development (UNCTAD) to construct a digital product catalogue manually. 209 products are identified.[14] The products (HS2017) identified by the authors belong to Chapter 84, Chapter 85, Chapter 95, Chapter 90, Chapter, Chapter 88, Chapter 87 Chapter 86, and Chapter 98.

2.2.3 Green-Digital products

Since no universally accepted definition exists for products involved in the twin transition, this document creates a basket by combining lists of green-digital products and identifying potential overlaps. To the best of my knowledge, no other study focused on identifying these products. I define green-digital products as those included in the Green Products & Decarbonisation Technologies and Digital lists. These products are a small sample (less than 50 products). Broadly, this category includes products belonging to Chapters 84, 85 and 90 from COMTRADE classification and include machine tools and mechanical appliances, machinery for semiconductor manufacturing, telecommunication equipment, electronic components, optical and scientific instruments and regulating and control instruments.

2.2.3 Critical minerals for green technologies

I decided to include critical minerals into the twin transition basket of products as that are a crucial input for low carbon and digital technologies. Valverde-Carbonell et al. (2024) pointed out that there is no unique list of critical minerals since there is no standardized definition of mineral criticality or a standard methodology to estimate it. While the concept of critical minerals has long been part of national security agendas, efforts to conceptualize and identify these types of minerals have intensified because of the high demand for these products in the green and digital transition.

Recently, the innovation studies agenda has been attracted to study the association between countries' natural resources and the supply of materials in the evolution of technological paradigms. These studies

[14] See Appendix in the paper.

have identified critical materials based on their intensity in technological innovations related to the information and communication technologies (ICT) paradigm and have found an association between technological dynamics and the demand for critical materials over time (Diemer et al., 2022; Li et al., 2024). For instance, Diemer et al. (2022) concentrate on six minerals: tin, tungsten, tantalum, gold, cobalt and lithium while Li et al. (2024) identify 13 different rare earth metals. The intensive use of critical raw materials is also found in green technologies, especially the more mature ones, such as metal processing innovations (de Cunzo et al., 2023). These authors identify a list of 39 critical raw materials in which is possible to identify overlaps with more ICT minerals-oriented studies. Valverde-Carbonell et al. (2024) built a list of critical minerals most intensively used by energy transition technologies based on an extensive literature review including recent studies by International Energy Agency and the World Bank. The final sample consisted in 42 mineral products distributed as follows: iron products (6); aluminum/bauxite products (4); copper products (4); nickel products (4); molybdenum products (3); lithium products (3); zinc products (3); graphite products (2); silicon products (2); chromium products (1); silver products (1); rare earths product (1); cobalt product (1); niobium, tantalum & vanadium products (1); manganese product (1); lead product (1); ruthenium, osmium and iridium product (1); rhodium product (1); palladium product (1); and platinum product (1)[15].

2.2.4 Toward the identification of twin transition product basket

As mentioned at the beginning of this document, one of the contributions of this paper is the identification of a basket of products connected with twin transition based on an extensive literature review (See Section **Error! Reference source not found.**). For the final decision on which classification of digital and green products to adopt, I opted for those that have the greatest possible overlap between both types of products. In this regard, digital products comprise digital production technologies products classification proposed by Andreoni et al. (2023). Green products comprise green products (Mealy & Teytelboym, 2022) and decarbonization technologies products (Rosenow & Mealy, 2024). Green-Digital products are those that fall at the intersection of the last two lists mentioned. Critical Minerals for green technologies comprise those products collected by (Valverde-Carbonell et al., 2024) (See Annex). **Error! Reference source not found.** displays the number of products for 2000 (HS96) and 2018 (HS17).

[15] See Annex A in Valverde-Carbonell et al (2024) for more information about the products.

Table 2: Total Number of products

	2000 (HS96)	2018 (HS17)
Digital	111	127
Green	542	563
Digital∩Green	47	52
No Digital	5000	5254
No Green	4569	4818
No Digital∩No Green	4505	4743
Total products	**5111**	**5381**
Spin-off		
Critical Minerals for green tech	42	42

Source: own elaboration based on BACI-CEPII and literature review

To illustrate the products that constitute the twin transition trade basket, Table 3 exhibits some examples.

Table 3: Description the twin transition products

Type	HS	Description
Green	**850.231**	Electric generating sets: wind-powered, (excluding those with spark-ignition or compression-ignition internal combustion piston engines).
Digital	**847.180**	Data processing machines: automatic, units thereof n.e.s. in heading no. 8471.
Green-Digital	**901.042**	Photographic laboratory apparatus and equipment (including cinematographic): for the projection or drawing of circuit patterns on sensitised semiconductor materials, step and repeat aligners.
Critical Minerals for green tech	**281.820**	Aluminum oxide: other than artificial corundum.

Source: own elaboration

2.3 Data

I use trade data extracted from BACI-CEPII[16] for the period 2000-2018. This dataset contains information about trade flows by country exporter and importer and by products classified by Harmonized System (HS) 6-digit nomenclature. The value of trade is expressed in thousand USD. This study extracts information for exporter and importer countries for two years, 2000 and 2018. For each time observation, the HS version native to that year is used. Consequently, the number of product codes varies yearly (See Table A 2). I use the trade data for more than 200 countries and calculate the RCA matrices based on the complete dataset. Finally, our analysis limits to a set of 80 countries (Africa (12), Americas (17), Asia (20), Europe (29), and Oceania (2))[17] based on the availability of sustainable development indicators, use RCA as calculated for the more extensive set of countries.

The HS products classification frequently undergoes revisions to take into consideration technological changes reflected in the decline of old and the rise of new products. This aspect is especially relevant for twin transition related products. Consequently, the products in export/import data are not comparable between years, and hence, this paper adopts a pooling scheme, as in Nomaler & Verspagen (2024), that assumes no such comparability, leaving space for changes in products and countries ordination to be reflected in the results. In this regard, each product-year combination and each country-year combination can appear as a single observation in the biplots. Based on this point, the authors claim that it is possible to connect observations of a single country or product (or groups of products or countries) through time, and hence, it is possible to create a trajectory for the product (group) or country (group). The pooling procedure consists of stacking the two yearly country variable matrices on top of each other for exports and imports. In this regard, the RCA matrices are stacked, ensuring that the order of the years is the same as the order used in constructing the Y matrix. This will form a large matrix (25,957 by 180).

Products are also classified in terms of the technological classification for exports introduced by Lall (2000) based on the nature of technology within industries (See Table A 4). Relying on this classification for the interest of this paper is of major relevance as allows relating groups of products with technological revolutions (Fagerberg & Verspagen (2021). For example, high tech class includes products linked to the

[16] Version 202401b
[17] See the detailed list in the Annex.

last technological revolution pushed by ICT technologies and expected to be closer to the digital products group identified in Section 2.2.4.

I use 10 different sustainable development variables for 80 countries. The economic dimension includes the log of GDP per capita in constant international $ and the average annual compound growth rate of GDP per capita (over 8 years with year of the trade data in the center). The sustainability dimension includes CO2 emissions per capita, consumption emissions per capita, material footprint per capita, domestic material consumption per capita, and non-renewable energy %. The social dimension includes Gini index, ICT infrastructure to contemplate digital divide and governance qualities (see details of the sources in the Annex). All the variables are z-scored each year to remove the influence of differences in scales and units.

3 Results

3.2 Twin transition export *triplots*

Figures 3.1 and 3.2 show the results of the CCA for exports, for 2000 and 2018, respectively. These triplots display the 11 Lall product categories and products linked to twin transition (green, digital, green-digital, and critical minerals demanded by green technology). Each category represents a centroid, which is a weighted average of all the products in that category. The arrows represent the variables linked to sustainable development. The size of the bubbles expresses, for product classes, the average export products ubiquity, and for countries, their export diversity.

The sustainable development variables represented by the arrows confirm that the selected variables are strongly and positively correlated with CCA1, except for GDP per capita growth and the Gini index. This suggests a trade-off between improving economic performance (measured by GDP per capita), decoupling the environment, and achieving social equity.[18] Additionally, the diagram confirms a close to -180 degrees

[18] CCA operates under the assumption that the relationship between the sustainable development variables is linear. Nevertheless, I acknowledged that a substantial body of literature exists which tests for non-linear relationships among the variables. The existing literature was developed around testing the inverted U-curve proposed by Simon Kuznets and later the U-shaped Environmental Kuznets Curve (EKC).

angle between the Gini index and voice and accountability, suggesting a substitution among these variables. However, as was already mentioned, considering the angles between variables as indications of causation is wrong, as they only serve to interpret the relative position of countries and products in the summary product space and their movement over time.

The analysis using CCA presented in Figure 3.1 and Figure 3.2 is consistent with findings of Hidalgo et al. (2007) that more sophisticated products are in a densely connected core of the PS, while less sophisticated products occupy a less connected periphery, and this structure conditions the development of nations. The figures suggest that the location of products connected with twin transition remains unchanged over time and, therefore, confirms that trade specialization on twin transition products exhibits a strong path dependence determining the possibilities of countries for structural transformation even within the twin transition. For example, for both years, the left side of the biplot retains PPo, LTt, and critical mineral for green tech products closer to the less diversified countries and associated with higher levels of inequality and high growth. Contrarily, the rest of the twin transition products (green, digital and green-digital) remain in the right side of the diagram over the years closer to more diversified countries scoring high with CCA1 and therefore, highly associated with higher GDP per capita and pollution.

At first glance, it is not possible to identify a clear pattern of association between the sustainable dimension variables and product ubiquity. Additionally, beyond the persistences identified, Figures 3.1 and 3.2 serve to confirm certain movements of countries, particularly among those scoring high in CCA2. The variation of countries along the CCA2 axis is relatively small in 2000, can be an indication of similar capability endowments among countries. By 2018, the variation along the CCA2 axis became more dispersed. This may indicate a greater distinction in capabilities and, consequently, a higher degree of heterogeneity and specificity in the abilities of each country.

However, overall, a comparison of the two figures reveals that the relative positions of countries and products remain largely unchanged over time, which serves to substantiate the assertion that global export specialization patterns are persistent and enduring. Over time, PPo products locate in the left extreme of the diagram, closer to developing countries from America Latina and Africa, and are associated with higher inequality. LTt products remain closer to East Asian countries. In addition, RBa products remain closer to countries where the engine of growth has been the exploitation of natural resources successfully such as New Zealand or Australia and are associated with good governance institutions. LTo products remain closer to peripheral European countries, which are associated with higher GDP and pollution. Products such as HTe and HTo persist at the right upper extreme of the diagram, closer to well-known technologically advanced economies such as Japan, the USA, Israel and South Korea. Less extreme on the right side of the diagram are products associated with medium-tech technologies, which remain closer to high-income European countries.

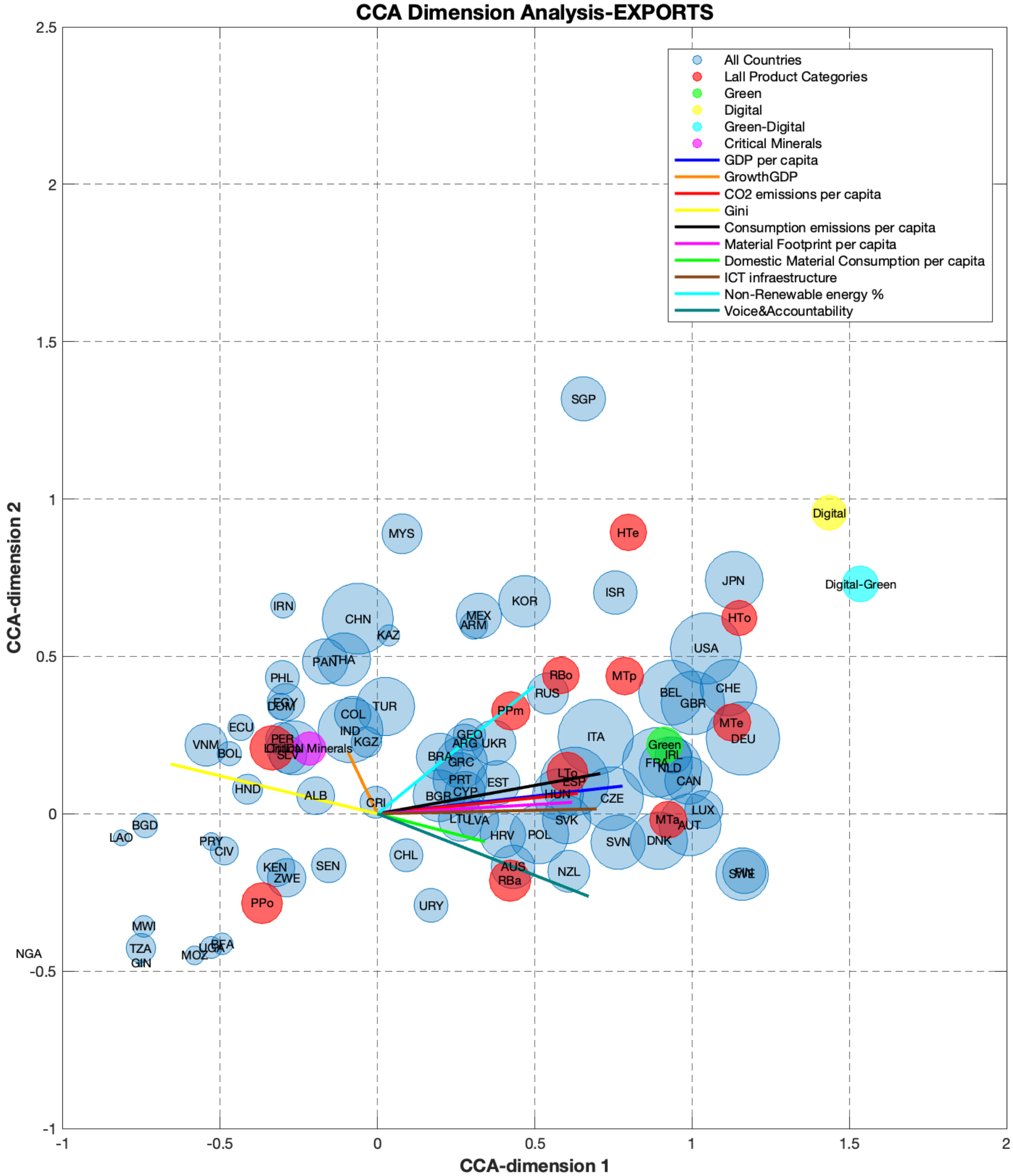
The multi-dimensional economic complexity approach confirms that the implications of sustainable development dimensions in countries that begin a process of productive diversification towards green, digital, green-digital products or critical minerals for the green techs seem to be very different. For example, projecting the products points on the axis of GDP per capita, growth per capita, pollution variables, governance and ICT infrastructure shows that green products were mainly specialized by the already developed pollutant high growth income countries with high quality of institutions and ICT infrastructure that also produce high-tech. Closer to this product are identified mainly EU countries what confirms the leadership position of this region in the green race. So, the figure not only confirms path dependence in terms of the products that remain in the same location over the time but also in terms of the countries that produce them that are already developed. The fact that the green products remain in the same position over the time and occur in the already developed part of the triplot suggest that suggest that green productive specialization only seems to include a small group of advanced countries, which puts at risk the possibility of other countries inserting into a green diversification process and limits the possibilities of reducing climate change and the possibility of sustainability going hand in hand with social justice. The empirical results tie with previous studies from (Mealy & Teytelboym, 2022; Talebzadehhosseini et al., 2020) that suggest that the green products specialization requires accumulation of green -capabilities and that it is path dependence. According to the triplots, proximity of green products to products linked to medium tech in one way or another suggests that “green capabilities” are like “medium technologies products” capabilities and hence, the production of the latter can provide a path to green diversification. Additionally, the position of the green dot reflects that a country that does not necessarily specialize in green products is reducing CO2 emissions. However, it is possible to observe a slight movement of the green dot between 2000 and 2018 to the left, which can be interpreted as the result of the still limited decarbonization process carried out by advanced European economies hand in hand with a greater intensification in the use of green technologies.

A similar story of path dependency can be seen for digital and digital-green products. In essence, already highly developed countries have been responsible for the production of these products over time. Specifically, the projection of the point in the diagram corresponding to digital products on the sustainable development variables suggest that these products are mainly specialized by even more than green products pollutant already high growth income countries with high quality of institutions and ICT infrastructure countries. Closer to these products are located countries such as Japan, Korea, USA, and Israel. Digital products remain relatively in the same location for both periods, which would confirm that the productive transformation process relies heavily on past accumulated technological capabilities. This is a pattern that we have already seen repeated in the case of green exports. Again, it is possible to identify a slight movement to the left, indicating that these products are slightly less associated with high pollution and high GDP per capita. About the green-digital products, the position of green-digital products in the diagram does not reveal substantial differences with respect to digital. They remain very close to each other, suggesting that the capabilities required for countries to specialize in these types of products are highly similar. Consequently, it can be inferred that countries that have accumulated the capabilities for exporting digital products are better prepared to produce those that combine digital and green.

The projection of critical minerals for green technologies on the sustainable development variables unveils that a productive specialization of these products scores high in Gini index. A comparison of the position of these products through the different periods reveals a shift from a similar set of capabilities to low-tech products to a more significant divergence in the latter period. In this regard, low-tech technology products are associated with higher growth rates by 2018, which aligns with this type of product's role in catching up. This pattern has also been identified by Nomaler & Verspagen (2024a) but without considering the inequality dimension. This also serves to demonstrate the limited dynamic role for growth of inserting in twin transition through the production of minerals for green technologies. This observation is aligned with the findings of (Coniglio et al., 2021) in which countries with abundant natural resources are less likely to diversify and move away from their current comparative advantage.

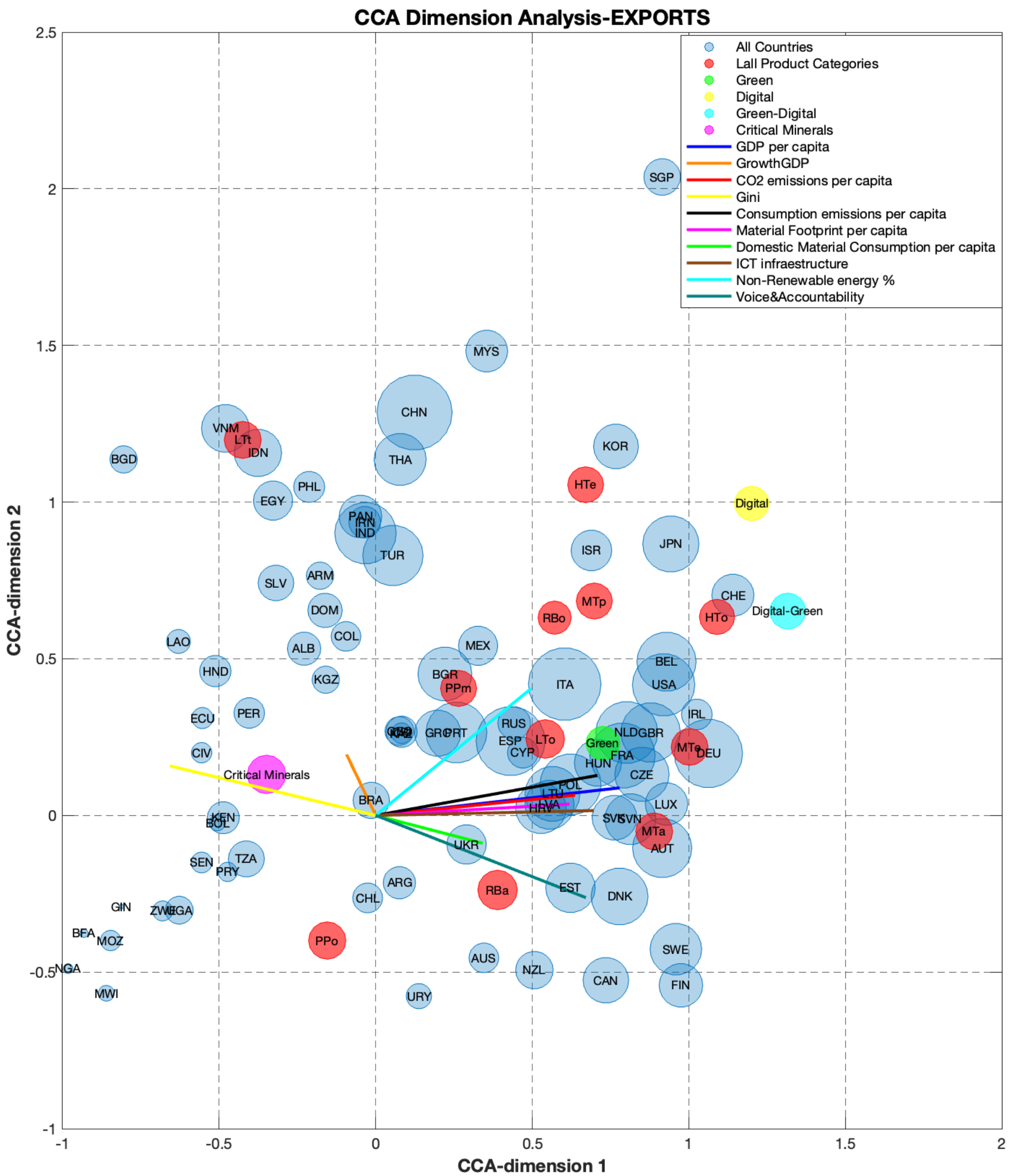
Finally, the role of Asian economies in the race of transforming the productive structure towards more green and digital products is undeniable. For instance, China has become a key leader in the exports of green products and digital: exports rose from around 7% in 2000 to almost 20% of global exports by 2018. Figures 3.1 and 3.2 do not offer a discernible association between the twin transition products and this country. However, the triplots make clear that this country underwent a period of growth and inequality at the outset of the new century based on diversifying their productive structure through unrelated to their initial specialization pattern. For instance, China, by 2000, was correlated with CCA1 and therefore with high inequality and growth. After two decades, the diagram exhibits that it has reached a point of relative prosperity, exhibiting positive associations with variables such as per capita growth and emissions and reducing inequality. From the productive diversification this country broadly passed from being closer to products linked to LTt to HTe. This means that this country does not deviate from the idea that countries diversify according to their current basket of products. It has been able to integrate a structural transformation based on the acquisition of a comparative advantage in analogous products, thereby demonstrating path dependence.

Figure 3.1 Exports: Triplot with CCA dimensions 1 and 2 (2000, pooling)



Source: own elaboration based on BACI-CEPII and sustainable development variables (see Table A 3)

Figure 3.2 Exports: Triplot with CCA dimensions 1 and 2 (2018, pooling)



Source: idem Figure 3.1

3.3 Twin transition import triplots

Figure 3.3 and Figure 3.4 display the correlation of sustainable development and specialization in importing twin transition products. The size of the bubbles expresses, for products, the average import products ubiquity, and for countries, their import diversity. Compared to exports, a different location of the products is identified. For both 2000 and 2018, countries' import baskets are more diversified, as can be seen from the size of the blue bubbles. In 2000, green, digital, and green-digital products remain closer to the center of the graph, which means that these products are imported with high intensity across most countries. Another noteworthy aspect is that from 2000 to 2018, import specialization becomes more pronounced, with higher intensity especially in the vertical (CCA2) dimension. Contrarily, the group of more diversified countries remains in the same position with similar diversification in the horizontal (CCA1) dimension. This group of countries consists of the advanced European economies, the United States and Japan. For example, for both years, CCA2 retains green, digital and green-digital products associated with higher levels of inequality and high growth. Contrarily, critical minerals for green technologies remain in the horizontal dimension (CCA1) over the years closer to more diversified countries.

As was visualized in Figures in Section 3.1 for exports, Figure 3.3 and Figure 3.4 confirm a clear specialization of imports following the core-periphery logic. For instance, the right side of the diagram in which countries such as European advanced economies, the USA and Japan, are closer to products PPm, PPo and critical mineral products associated with clean technology. The left side of the diagram contains a broader variety of countries and is associated with the rest of the countries. In turn, it identifies that between 2000 and 2018 all the categories of products move out, which suggests that the capabilities or knowledge required for their usage became not so similar. The change appears to be of greater magnitude for products in the categories than for those associated with the twin transition (except for products linked to critical minerals). Furthermore, both figures confirmed that the ubiquity of the most technologically advanced products is greater than that of the less advanced ones.

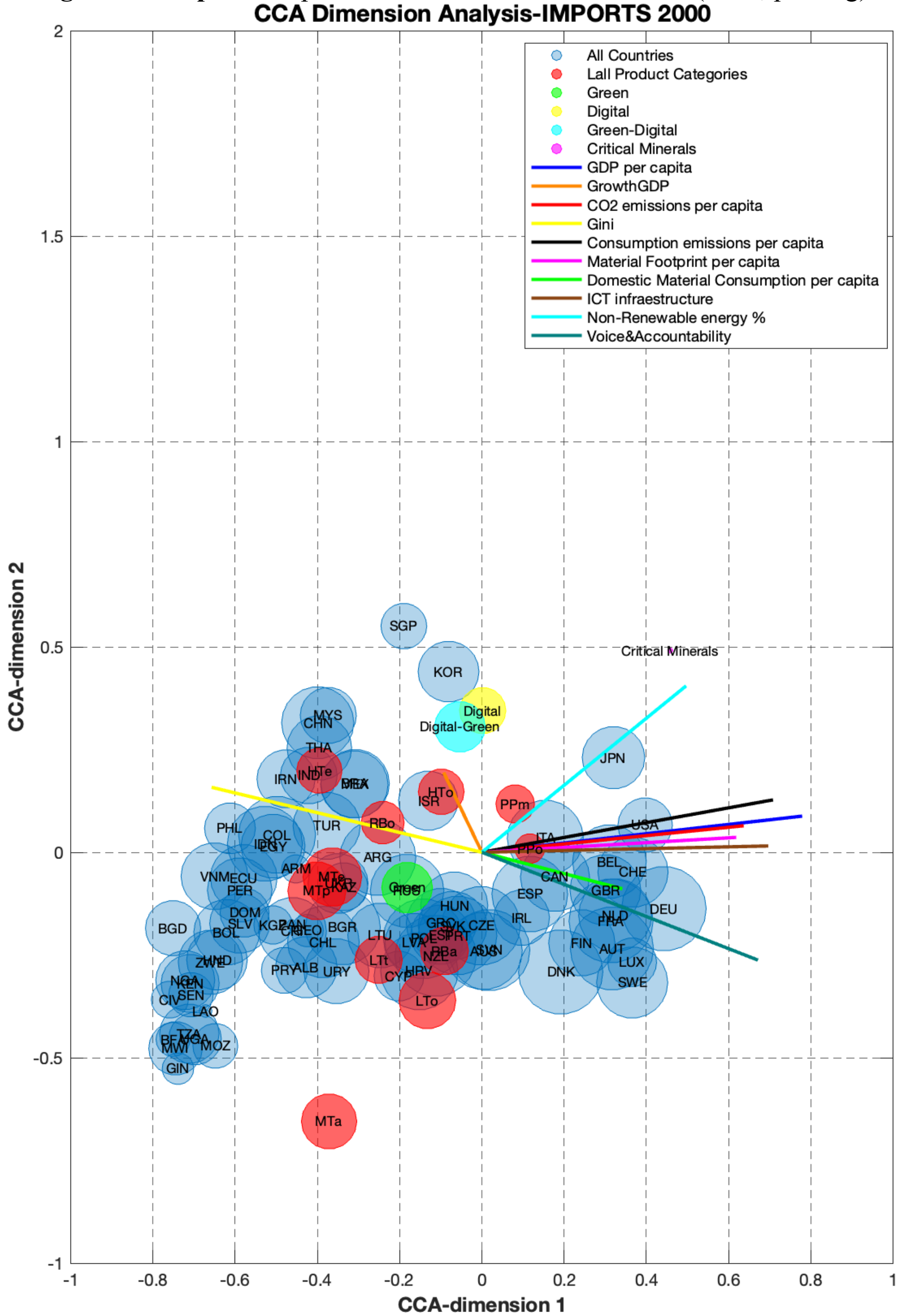
The path dependence story seems to be repeated when analyzing the import specialization on twin transition products. The projection of green products centroid on sustainable development variables confirms that import specialization on these products focuses on unequal, and high growth countries.

Green import specialization is closer to a wide variety of countries, and by 2000, this type of products is closer to medium tech and low-tech technologies. By 2018, not only the ubiquity of green products reduces, but also, it remains separated from the other products categories which can reflect a process of green diversification. In other words, the capabilities required for green import specialization become more specific, and hence involving very reduced number of countries that are importing "green capabilities" in exports. It is expected that the increase in the diversity of imported green products will potentially contribute to the increase in the countries' green product diversity. In other words, the potentialities increasing the diversity of imported green products seem to be very limited according to the triplots. At the same time, the comparable positioning of green products between 2000 and 2018 in the diagram might indicate the presence of path dependence in the green import specialization. However, it is possible to identify a slight movement to the left of the green dot. Green import specialization seems to be becoming more associated with higher levels of inequality.

Regarding digital products imports, for 2000 and 2018, the ordination diagram verifies that the import productive specialization of digital and digital-green products is associated with higher GDP growth rates. By 2000, this specialization was closer to countries such as Korea and Singapore. Interestingly, by 2018, it is possible to identify a shift in countries, such as Malaysia, India, and Thailand, that 2000 were more associated with higher levels of inequality towards a higher association with higher growth GDP. This process can be understood as a process of assimilating technological change and pronouncing the digital technological paradigm. Also, this diagram confirms the low engagement of the least developed countries in the trade of digital and digital green goods.

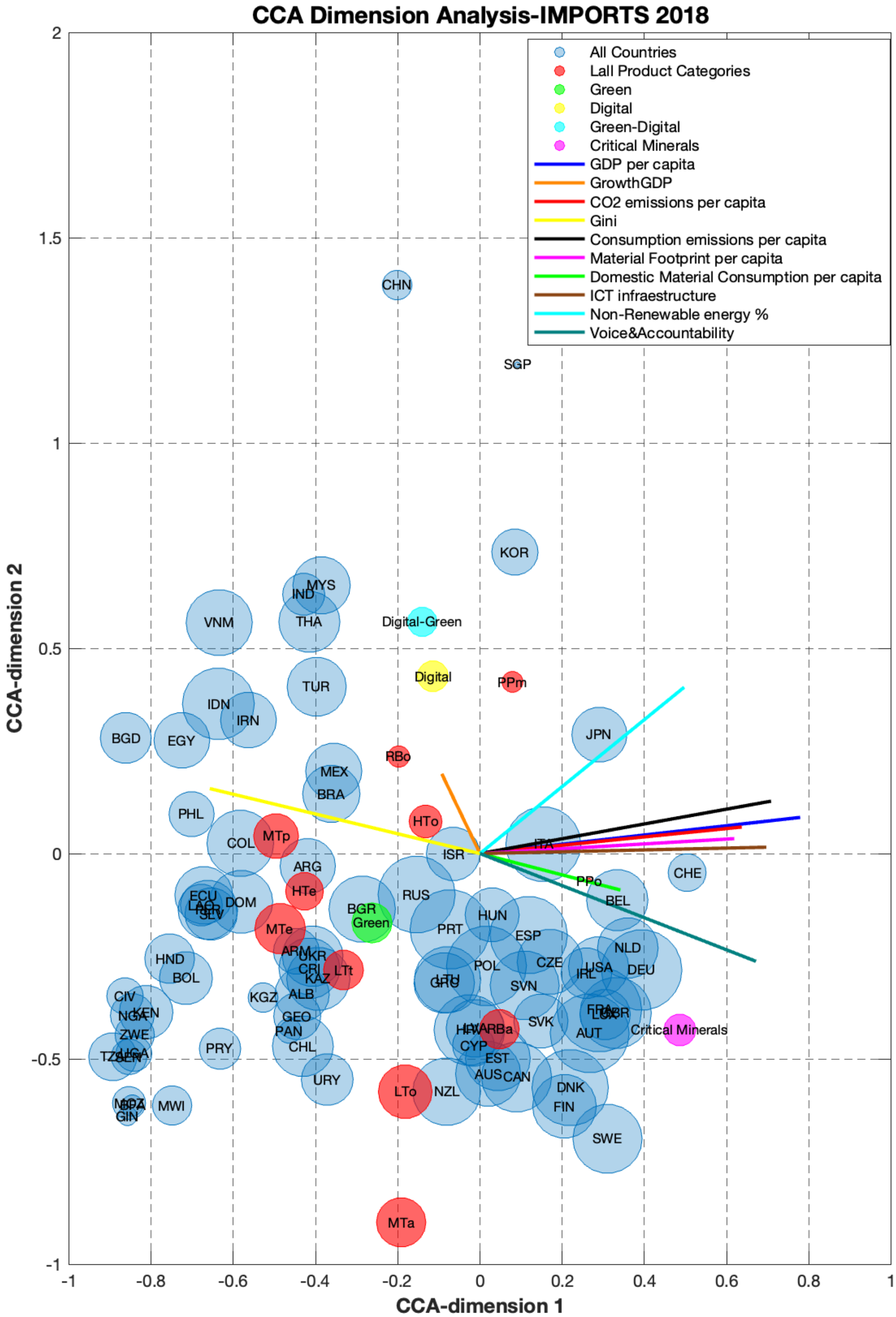
By 2000, the ordination diagram verifies that the import productive specialization of these critical minerals products for green tech is associated with elevated levels of pollution, specifically of nonrenewable energy. Simultaneously, it is possible to identify that the size of the imports of these products is very low what confirms that only few countries specialize in this type of products. By 2018, these products change completely their position in the diagram. These products become being imported by more countries what is reflected in the size of the purple bubble but also, they change completely their position in the diagram and now are more associated with variables such as voice and accountability and closer to EU countries. In this sense, this could be shedding some light on the deepening of the green transition and the role of critical minerals in sustaining the European net-zero strategy, the digital industry, aerospace, and defence sectors.

Figure 3.3 Imports: Biplot with CCA dimensions 1 and 2 (2000, pooling)



Source: idem Figure 3.1

Figure 3.4 Imports: Biplot with CCA dimensions 1 and 2 (2018, pooling)



Source: idem Figure 3.1

4 Concluding remarks and limitations

Trade worldwide is being reshaped by two major megatrends: advanced digitalization of production and the transition towards environmentally sustainable goods. This chapter examines for the first time the perspective of twin transition export and import diversification within a multi-dimensional economic complexity approach and investigates whether this type of productive transformation perpetuates path-dependency processes in 80 countries productive specialization over 2000-2018. Furthermore, it provides a basket of crucial products connected with the digital and green transition.

In this chapter, I argue that the multidimensional economic complexity approach confirms a more comprehensive picture for understanding the response of the different twin transition export/import specialisation to sustainable development variables. The implications for these variables in countries that begin a process of productive specialization towards green, digital, green-digital products or critical minerals for the green tech seem to be very different. On the one hand, export of green, green digital and digital products is associated with higher income levels, less inequality and higher pollution levels. The productive specialization of critical minerals for green tech minerals confirms being associated with higher levels of inequality and high growth. On the other hand, the import productive specialization of digital and digital-green products is associated with higher GDP growth rates while the specialization of green imports is associated with higher levels of inequality. For the critical minerals, this diagram confirms the increasing of the ubiquity of these critical also, it is confirmed a shift from nonrenewable to voice and accountability.

The key finding of this research is the confirmation of the strong source of path dependence of the twin transition pattern of specialization that reinforces the country's center-periphery trade division. Green export specialization engages only a limited group of more diversified developed countries, which puts at risk the possibility of a broader range of developing countries participating in a green productive transformation process alongside a reduction in inequalities. The results also suggest that the possibilities for developing countries to acquire green capabilities through imports are limited too and associated with inequality over time. Contrarily, digital, and green-digital import specialization allow countries such as Korea and Singapore to acquire technological capabilities that allow them to consolidate their position in the digital technological paradigm. Regarding critical minerals for green technologies export specialization, the findings confirmed that these products present little proximity with other more dynamic products and persist in associated with poorer countries; on the contrary, the import specialization of these products remains associated with high-income countries.

Beyond the twin transition products, the results allow identifying the existence of virtuous structural transformation process based on acquiring comparative advantage in radically different products in opposition to the hypothesis of path dependence based on the current capabilities.

Some of the results obtained in this paper can inform policymakers in the development of strategies to structural transformation under twin transition. From the point of view of the sources of path dependence and broaden the possibilities of other countries, specially developing, to transit a digital and green path of structural transformation, the results of this paper are more aligned with the necessity of more general diversification policies (Nomaler & Verspagen, 2024c). This more general diversification policies must have as a core to generate the mechanisms to facilitate knowledge among countries and products.

This study is limited in several ways. First, this study only considers international trade of goods, not services, as the latter is a crucial component of digital technologies products. Secondly, due to the topic's novelty, the magnitude of the number of products linked to twin transition products is few and of course, only cover a reduced sample of countries. Thirdly, CCA has the disadvantage of assuming that the response of countries and products to sustainable dimension is lineal. Still, I believe there is space to study changes in the location of countries/products within at the level of the industries (e.g., All categories) to identify if the position of countries/products varies depending on the technological level of the products. Also, these types of analysis can be used to analyse sets of specific countries, which I did not contemplate because they are beyond the aim of this chapter. Also, it is possible to include more variables connected with sustainable development.

References

Acemoglu, D., & Restrepo, P. (2022). Demographics and automation. *The Review of Economic Studies*, *89*(1), 1–44.

Andreoni, A., Anzolin, G., Labrunie, M., & Spinola, D. S. (2023). *Unveiling structure and dynamics of global digital production technology* (044; UNU-MERIT Working Papers). https://www.merit.unu.edu/publications/wppdf/2023/wp2023-044.pdf

Antonelli, C. (1997). The economics of path-dependence in industrial organization. *International Journal of Industrial Organization*, *15*(6), 643–675. https://doi.org/10.1016/S0167-7187(97)00006-4

Balland, P.-A., Broekel, T., Diodato, D., Giuliani, E., Hausmann, R., O'Clery, N., & Rigby, D. (2022). The new paradigm of economic complexity. *Research Policy*, *51*(3), 104450. https://doi.org/https://doi.org/10.1016/j.respol.2021.104450

Bandeira Morais, M., Swart, J., & Jordaan, J. (2018). Economic Complexity and Inequality: Does Productive Structure Affect Regional Wage Differentials in Brazil? *Utrecht School of Economics.*, *(No. 18-11)*.

Bontadini, F., & Vona, F. (2023). Anatomy of Green Specialisation: Evidence from EU Production Data, 1995–2015. *Environmental and Resource Economics*, *85*(3–4), 707–740. https://doi.org/10.1007/s10640-023-00781-7

Brenton, P., & Chemutai, V. (2021). *The Trade and Climate Change Nexus: The Urgency and Opportunities for Developing Countries*. The World Bank. https://doi.org/doi:10.1596/978-1-4648-1770-0

Caldarola, B., Mazzilli, D., Napolitano, L., Patelli, A., & Sbardella, A. (2024). Economic complexity and the sustainability transition: a review of data, methods, and literature. *Journal of Physics: Complexity*, *5*(2), 022001. https://doi.org/10.1088/2632-072X/ad4f3d

Can, M., Ahmed, Z., Ahmad, M., & Oluc, I. (2023). Economic progress in emerging countries: the roles of diversification of import and export products and energy consumption. *Environment, Development and Sustainability*, *26*(7), 18207–18229. https://doi.org/10.1007/s10668-023-03386-8

Can, M., & Gozgor, G. (2017). The impact of economic complexity on carbon emissions: evidence from France. *Environmental Science and Pollution Research*, *24*(19), 16364–16370. https://doi.org/10.1007/s11356-017-9219-7

Coniglio, N. D., Lagravinese, R., Vurchio, D., & Armenise, M. (2018). The pattern of structural change: testing the product space framework. *Industrial and Corporate Change*, *27*(4), 763–785. https://doi.org/10.1093/icc/dty009

Coniglio, N. D., Vurchio, D., Cantore, N., & Clara, M. (2021). On the evolution of comparative advantage: Path-dependent versus path-defying changes. *Journal of International Economics*, *133*, 103522. https://doi.org/10.1016/j.jinteco.2021.103522

David, P. A. (2007). Path dependence: a foundational concept for historical social science. *Cliometrica*, *1*(2), 91–114. https://doi.org/10.1007/s11698-006-0005-x

de Cunzo, F., Consoli, D., Perruchas, F., & Sbardella, A. (2023). *Mapping Critical Raw Materials in Green Technologies* (2322; Papers in Evolutionary Economic Geography (PEEG)).

Diemer, A., Iammarino, S., Perkins, R., & Gros, A. (2022). Technology, resources and geography in a paradigm shift: the case of critical and conflict materials in ICTs. *Regional Studies*, 1–13. https://doi.org/10.1080/00343404.2022.2077326

Dosi, G., Pavitt, K., & Soete, L. (1990). Technology and trade: An overview of the literature. In *The Economics of Technical Change and International Trade* (Issue 2, pp. 15–39). Laboratory of

Economics and Management (LEM), Sant'Anna School of Advanced Studies, Pisa, Italy. https://EconPapers.repec.org/RePEc:ssa:lemchs:dosietal-1990-2
Fagerberg, J., & Verspagen, B. (2021). Technological Revolutions, Structural Change, and Catching up. In *New Perspectives on Structural Change* (pp. 131–155). Oxford University Press. https://doi.org/10.1093/oso/9780198850113.003.0007
Ferraz, D., Falguera, F. P. S., Mariano, E. B., & Hartmann, D. (2021). Linking Economic Complexity, Diversification, and Industrial Policy with Sustainable Development: A Structured Literature Review. *Sustainability*, *13*(3), 1265. https://doi.org/10.3390/su13031265
Foster-McGregor, N., Nomaler, Ö., & Verspagen, B. (2019). Measuring the Creation and Adoption of New Technologies using Trade and Patent Data. In *UNU-MERIT Working Paper Series* (Vol. 053). https://doi.org/10.20955/r.85.67
Foster-McGregor, N., Nomaler, Ö., & Verspagen, B. (2022). *The ADB-ADBI Innovation and Structural Transformation Database: A Guide*. ADB-ADBI Innovation and Structural Transformation Database.
Frohberg, K., & Hartmann, M. (1997). *Comparing measures of competitiveness* (Issue 2). Institute of Agricultural Development in Central and Eastern Europe (IAMO). https://hdl.handle.net/10419/28566
Greenacre, M. (2010). Canonical correspondence analysis in social science research. *Classification as a Tool for Research: Proceedings of the 11th IFCS Biennial Conference and 33rd Annual Conference of the Gesellschaft Für Klassifikation EV, Dresden, March 13-18, 2009*, 279–286.
Greenacre, M. (2017). *Correspondence analysis in practice*. chapman and hall/crc.
Hartmann, D., Guevara, M. R., Jara-Figueroa, C., Aristarán, M., & Hidalgo, C. A. (2017). Linking Economic Complexity, Institutions, and Income Inequality. *World Development*, *93*, 75–93. https://doi.org/10.1016/j.worlddev.2016.12.020
Hausmann, R., Hidalgo, C. A., Bustos, S., Coscia, M., & Simoes, A. (2014). *The atlas of economic complexity: Mapping paths to prosperity*. MIT Press.
Hidalgo, C. A. (2023). The policy implications of economic complexity. *Research Policy*, *52*(9), 104863. https://doi.org/10.1016/j.respol.2023.104863
Hidalgo, C. A., Balland, P.-A., Boschma, R., Delgado, M., Feldman, M., Frenken, K., Glaeser, E., He, C., Kogler, D. F., Morrison, A., Neffke, F., Rigby, D., Stern, S., Zheng, S., & Zhu, S. (2018). *The Principle of Relatedness* (pp. 451–457). https://doi.org/10.1007/978-3-319-96661-8_46
Hidalgo, C. A., & Hausmann, R. (2009). The building blocks of economic complexity. *Proceedings of the National Academy of Sciences*, *106*(26), 10570–10575. https://doi.org/10.1073/pnas.0900943106
Hidalgo, C. A., Klinger, B., Barabási, A.-L., & Hausmann, R. (2007). The Product Space Conditions the Development of Nations. *Science*, *317*(5837), 482–487. https://doi.org/10.1126/science.1144581
Hill, M. O. (1973). Reciprocal Averaging: An Eigenvector Method of Ordination. *The Journal of Ecology*, *61*(1), 237. https://doi.org/10.2307/2258931
Jun, B., Alshamsi, A., Gao, J., & Hidalgo, C. A. (2020). Bilateral relatedness: knowledge diffusion and the evolution of bilateral trade. *Journal of Evolutionary Economics*, *30*(2), 247–277. https://doi.org/10.1007/s00191-019-00638-7
Lall, S. (2000). The Technological Structure and Performance of Developing Country Manufactured Exports, 1985-98. *Oxford Development Studies*, *28*(3), 337–369. https://doi.org/10.1080/713688318
Legendre, P., & Legendre, L. (2012). *Numerical ecology*. Elsevier.

Li, G. Y., Ascani, A., & Iammarino, S. (2024). The material basis of modern technologies. A case study on rare metals. *Research Policy*, *53*(1), 104914. https://doi.org/10.1016/j.respol.2023.104914
Mao, X., Liu, H., Gui, J., & Wang, P. (2023). Toward inclusive list-making for trade liberalization in environmental goods to reduce carbon emissions. *Geography and Sustainability*, *4*(3), 200–212. https://doi.org/10.1016/j.geosus.2023.04.002
Mealy, P., Farmer, J. D., & Teytelboym, A. (2018). A new interpretation of the economic complexity index. *Alexander, A New Interpretation of the Economic Complexity Index (February 4, 2018)*.
Mealy, P., Farmer, J. D., & Teytelboym, A. (2024). Interpreting economic complexity. *Science Advances*, *5*(1), eaau1705. https://doi.org/10.1126/sciadv.aau1705
Mealy, P., & Teytelboym, A. (2022). Economic complexity and the green economy. *Research Policy*, *51*(8), 103948.
Montiel-Hernández, M. G., Pérez-Hernández, C. C., & Salazar-Hernández, B. C. (2024). The Intrinsic Links of Economic Complexity with Sustainability Dimensions: A Systematic Review and Agenda for Future Research. *Sustainability*, *16*(1), 391. https://doi.org/10.3390/su16010391
Neffke, F., Sbardella, A., Schetter, U., & Tacchella, A. (2024). *Economic Complexity Analysis* (2430).
Nomaler, Ö., & Verspagen, B. (2022a). *Some New Views on Product Space and Related Diversification*.
Nomaler, Ö., & Verspagen, B. (2022b). *The canonical correlation complexity method* (015; UNU-MERIT Working Papers). Maastricht Economic and Social Research Institute on Innovation and …. https://unu-merit.nl/publications/wppdf/2022/wp2022-015.pdf
Nomaler, Ö., & Verspagen, B. (2024a). Complexity Research in Economics: Past, Present, and Future. In *Technological Revolution and New Driving Forces for Global Sustainable Development* (pp. 109–124). Springer Nature Singapore. https://doi.org/10.1007/978-981-97-7332-9_15
Nomaler, Ö., & Verspagen, B. (2024b). Reinterpreting economic complexity in multiple dimensions. *ArXiv Preprint*.
Nomaler, Ö., & Verspagen, B. (2024c). Related or unrelated diversification: What is smart specialization? *Structural Change and Economic Dynamics*, *70*, 503–515. https://doi.org/10.1016/j.strueco.2024.05.019
Nomaler, Ö., & Verspagen, B. (2024d). *The evolution of development with trade in global value chains* (013; UNU-MERIT Working Papers). https://cris.maastrichtuniversity.nl/ws/files/206011394/wp2024-013.pdf
Nomaler, Ö., & Verspagen, B. (2024e). The evolution of development with trade in global value chains. In *Forthcoming* (013; UNU-MERIT Working Papers). https://cris.maastrichtuniversity.nl/ws/portalfiles/portal/206011394/wp2024-013.pdf
OECD. (2011). ICT Products. In *OECD Guide to Measuring the Information Society 2011* (pp. 19–47). OECD. https://doi.org/10.1787/9789264113541-4-en
Pigato, M., Black, S., Dussaux, D., Mao, Z., Rafaty, R., & Touboul, S. (2020). *Technology transfer and innovation for low-carbon development*. World Bank Publications.
Reinstaller, A., & Reschenhofer, P. (2019). The impact of the scope of technological search on path-dependence in export specialization: evidence for European countries. *Industrial and Corporate Change*, *28*(6), 1611–1635. https://doi.org/10.1093/icc/dtz026
Robert, V., & Yoguel, G. (2016). Complexity paths in neo-Schumpeterian evolutionary economics, structural change and development policies. *Structural Change and Economic Dynamics*, *38*, 3–14. https://doi.org/10.1016/j.strueco.2015.11.004
Romero, J. P., & Gramkow, C. (2021). Economic complexity and greenhouse gas emissions. *World Development*, *139*, 105317. https://doi.org/https://doi.org/10.1016/j.worlddev.2020.105317

Rosenow, S. K., & Mealy, P. (2024). Turning Risks into Reward: Diversifying the Global Value Chains of Decarbonization Technologies. In *Policy Research Working Papers*. The World Bank. https://doi.org/doi:10.1596/1813-9450-10696
Sauvage, J. (2014). *The stringency of environmental regulations and trade in environmental goods*.
Solt, F. (2020). Measuring Income Inequality Across Countries and Over Time: The Standardized World Income Inequality Database. *Social Science Quarterly*, *101*(3), 1183–1199. https://doi.org/https://doi.org/10.1111/ssqu.12795
Stellian, R., & Danna-Buitrago, J. P. (2022). Revealed Comparative Advantage and Contribution-to-the-Trade-Balance indexes. *International Economics*, *170*, 129–155. https://doi.org/10.1016/j.inteco.2022.02.007
Stojkoski, V., Koch, P., & Hidalgo, C. A. (2023). Multidimensional economic complexity and inclusive green growth. *Communications Earth & Environment*, *4*(1), 130. https://doi.org/10.1038/s43247-023-00770-0
Tacchella, A., Cristelli, M., Caldarelli, G., Gabrielli, A., & Pietronero, L. (2012). A New Metrics for Countries' Fitness and Products' Complexity. *Scientific Reports*, *2*(1), 723. https://doi.org/10.1038/srep00723
Talebzadehhosseini, S., Scheinert, S. R., & Garibay, I. (2020). Growing Green: the Role of Path Dependency and Structural Jumps in Green Economy Expansion. *Journal on Policy and Complex Systems*, *6*(1). https://doi.org/10.18278/jpcs.6.1.2
Ter Braak, C. J. F. (1986). Canonical Correspondence Analysis: A New Eigenvector Technique for Multivariate Direct Gradient Analysis. *Ecology*, *67*(5), 1167–1179. https://doi.org/10.2307/1938672
Ter Braak, C. J. F. (1987). The analysis of vegetation-environment relationships by canonical correspondence analysis. *Vegetatio*, *69*(1–3), 69–77. https://doi.org/10.1007/BF00038688
Ter Braak, C. J. F. (2014). History of canonical correspondence analysis. *Visualization and Verbalization of Data*, 61–75.
Ter Braak, C. J. F., & Verdonschot, P. F. M. (1995). Canonical correspondence analysis and related multivariate methods in aquatic ecology. *Aquatic Sciences*, *57*, 255–289.
Valverde-Carbonell, J., Pietrobelli, C., & Menéndez, M. de las M. (2024). Minerals' criticality and countries' mining competitiveness: Two faces of the same coin. *Resources Policy*, *98*, 105359. https://doi.org/10.1016/j.resourpol.2024.105359
van Dam, A., Dekker, M., Morales-Castilla, I., Rodríguez, M. Á., Wichmann, D., & Baudena, M. (2021). Correspondence analysis, spectral clustering and graph embedding: applications to ecology and economic complexity. *Scientific Reports*, *11*(1), 8926. https://doi.org/10.1038/s41598-021-87971-9
Zhang, H., Liu, Q., & Wei, Y. (2023). Digital product imports and export product quality: Firm-level evidence from China. *China Economic Review*, *79*, 101981. https://doi.org/https://doi.org/10.1016/j.chieco.2023.101981

Annex

Table A 1: Countries selected

Albania, Argentina, Australia, Austria, Bangladesh, Armenia, Belgium, Bolivia (Plurinational State of), Brazil, Bulgaria, Canada, Chile, China, Colombia, Costa Rica, Croatia, Cyprus, Czechia, Denmark, Dominican Republic, Ecuador, El Salvador, Estonia, Finland, France, Georgia, Germany, Greece, Guinea, Honduras, Hungary, Indonesia, Iran, Ireland, Israel, Italy, Côte d'Ivoire, Japan, Kazakhstan, Kenya, Republic of Korea, Kyrgyzstan, Lao People's Democratic Republic, Latvia, Lithuania, Luxembourg, Malawi, Malaysia, Mexico, Mozambique, Netherlands, New Zealand, Nigeria, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Russian Federation, Senegal, India, Singapore, Slovakia, Vietnam, Slovenia, Zimbabwe, Spain, Sweden, Switzerland, Thailand, Türkiye, Uganda, Ukraine, Egypt, United Kingdom, United Republic of Tanzania, USA, Burkina Faso, Uruguay

Table A 2: Total Number of products and countries

	Number of products	Number of countries
2000 (HS1996)	5111	222
2018 (HS2017)	5381	226

Table A 3: Sustainable development variables

Variable	Source
GDP per capita, PPP (constant 2017 international $)	World Bank
Growth GDP per capita	World Bank
Fossil CO2 per capita by country	EDGAR
Gini Index	Standardized World Income Inequality Dataset (SWIID) (Solt, 2020).
Consumption emissions in tCO_2/person	https://globalcarbonatlas.org/emissions/carbon-emissions/
Material Footprint per capita	UNDP-United Nations Database: https://unstats.un.org/sdgs/dataportal/database
Domestic Material Consumption per capita	UNDP-United Nations Database: https://unstats.un.org/sdgs/dataportal/database
Individuals using the Internet (% of population)	World Bank
Non-Renewable energy consumption (% of total final energy consumption)	World Bank
Voice & Accountability	The Worldwide Governance Indicators

Table A 4: Lall product categories

PPm	Primary Products - mining
PPo	Primary Products - agriculture etc.
RBa	Resource-based: agro-forest-based
RBo	Resource-based: other (e.g., ore, petroleum, rubber, cement)
LTt	Low-tech: textiles, clothing, etc.
LTo	Low-tech: other (e.g., pottery, metal products, plastic products)
MTa	Medium-tech: automotive
MTp	Medium-tech: process industries (chemicals, basic metals)
MTe	Medium-tech: engineering (machinery, engines, ships, pumps)
HTe	High tech: electronics & electricals
HTo	High tech: other (pharma, optical, aerospace)

Table A 5: Green-Digital products

DPTs products × Green Products	842381, 842382, 842389, 846599, 847989, 847990, 854140, 901380, 901390, 901540, 901580, 901590, 902580, 902610, 902620, 902680, 902690, 902710, 902720, 902730, 902750, 902780, 902790, 902810, 902820, 902830, 902890, 903010, 903031, 903081, 903039, 903089, 903090, 903140, 903180, 903190, 903210, 903220, 903281, 903289, 903290
DPTs products × Decarbonisation technologies	845610, 847989, 901020, 847990, 854140, 854190, 901380, 901390, 902830, 903031, 903081, 903039, 903289

Identification of the twin transition products basket

This section of the Annex displays the number of products of each HS classification of a selected classification of green and digital products and their overlapping. For the final decision of which classification to stick to having the most significant number of overlaps between digital and green products.

Table A 6:Twin transition products (HS correspondence)

Digital	**HS Classification**					
	92	**96**	**02**	**07**	**12**	**17**
DPTs products (Andreoni et al., 2023)	103	111	111	124	124	127
UNCTAD ICT Goods	90	110	108	93	91	92
4IR products (Foster-McGregor et al., 2022)	120	141	139	129	128	137

Green						
Environmental Goods (IMF)	210	212	212	212	215	222
Low Carbon Technologies (IMF)	115	117	117	117	119	124
Decarbonisation technologies (Rosenow & Mealy, 2024)	284	297	299	296	300	314
Green Products (Mealy & Teytelboym, 2022)	293	312	312	321	321	339

Note: Shaded cells represent the year each classification was initially expressed. The totals of the products in the remaining cells are obtained employing tables of correspondence.

Table A 7: Overlapping products

	Classification					
Digital-Green	**HS92**	**HS96**	**HS02**	**HS07**	**HS12**	**HS17**
DPTs products × Green Products	41	44	44	48	45	48
DPTs products × Decarbonisation technologies	13	14	14	17	17	19
ICT UNCTAD × Green Products	2	2	2	2	1	2
ICT UNCTAD × Decarbonisation technologies	4	4	4	4	3	3
4IR × Green Products	9	10	10	11	12	19
4IR × Decarbonisation technologies	8	9	9	12	12	18
Green						
Green Products × Decarbonisation technologies	62	67	67	74	74	90
Green Products × Environmental Goods (IMF)	174	176	176	177	177	184
Green Products × Low Carbon Technologies (IMF)	96	98	98	99	99	103
Low Carbon Technologies (IMF) × Decarbonisation technologies	39	41	41	41	43	48
Digital-Digital						
DPTs products × 4IR	41	47	47	55	55	60
ICT UNCTAD × 4IR	90	110	108	92	91	90
DPTs products × ICT UNCTAD	18	23	23	32	32	32
Brown-Digital						
DPTs products × Brown products	0	0	0	0	0	0
ICT UNCTAD × Brown products	0	0	0	0	0	0

Table A 8: Sustainable development correlation

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1,000	-0,109	0,763	-0,614	0,803	0,751	0,566	0,851	0,746	0,733
2	-0,109	1,000	-0,060	-0,139	-0,062	-0,118	-0,126	-0,124	0,058	-0,140
3	0,763	-0,060	1,000	-0,610	0,872	0,688	0,608	0,746	0,623	0,540
4	-0,614	-0,139	-0,610	1,000	-0,591	-0,546	-0,295	-0,598	-0,473	-0,532
5	0,803	-0,062	0,872	-0,591	1,000	0,787	0,604	0,769	0,578	0,585
6	0,751	-0,118	0,688	-0,546	0,787	1,000	0,643	0,750	0,454	0,625

7	0,566	-0,126	0,608	-0,295	0,604	0,643	1,000	0,527	0,382	0,416
8	0,851	-0,124	0,746	-0,598	0,769	0,750	0,527	1,000	0,565	0,691
9	0,746	0,058	0,623	-0,473	0,578	0,454	0,382	0,565	1,000	0,374
10	0,733	-0,140	0,540	-0,532	0,585	0,625	0,416	0,691	0,374	1,000

Note: 1) GDP per capita, 2) Growth of GDP per capita, 3) C02 emissions, 4) Gini index, 5) Consumption emissions per capita, 6) material footprint per capita, 7) domestic material consumption per capita, 8) ICT infrastructure, 9) Non-renewable energy share, 10) voice and accountability.

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