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# Green product development: What does the country product space imply?

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ABSTRACT

This paper contributes to green product development by identifying the green products with the highest potential for growth in a country. To address our aim, we use the concept of product proximity and product space and, borrowing from the results of recent studies on complexity economics, we advance that the green products with the highest potential for growth among all green products in a given country are those being in close proximity to the products a country produces with high Relative Comparative Advantage (RCA). We test this hypothesis performing a regression analysis. We build the product space for 141 different countries for the years between 2005 and 2013 and for each country we compute the maximum proximity of each green product to the products with high RCA (i.e., the proximity of the product source of competitive advantage closest to the green product considered). Results confirm that green products with high maximum proximity to the products with high RCA had the highest growth. So doing, we contribute to the literature by providing a new application of the product space as a policy making tool for green development. We also provide several applications of the proposed method.



## 1. Introduction

The world population has grown by one billion in the span of the last twelve years, reaching today 7.3 billion people, and it is growing at a rate of 1.18% per year, i.e., an additional 83 million people annually (UN, 2015). This growth has been accompanied by a huge increase in the amount of natural resources extracted, to an extent never seen before (Krausmann et al., 2009; Wiedmann et al., 2015). In fact, natural resources are essential inputs for production processes supporting the needs of a growing population and the extraction, treatment, and disposal of such resources are an important source of income and jobs in many countries. In addition to their fundamental role in industry, natural resources are also part of the ecosystems that support the provision of services such as climate regulation, flood control, natural amenities, and cultural services. In this regard, the high consumption of natural resources can cause huge damages to the ecosystem, such as global climate change, landscape change, and loss of biodiversity (e.g., Donohoe, 2003; Weber et al., 2008).

The scenario thus outlined shows that the world today is facing two main challenges: on the one hand, expanding the economic opportunities for a growing global population, but on the other hand, addressing the environmental pressures which, if left unaddressed, could undermine the ability to seize these opportunities. The way to address both these issues at the same time is to promote an environmentally sustainable economic growth (UNEP, 2011). Such an economic growth has been defined as "green growth":

> *"Green growth means fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies"* (OECD, 2011).

Green growth can be promoted by applying multiple strategies, such as decarbonizing the economic systems forcing firms to adopt cleaner production processes (UNEP, 2004) as well as supporting the development of green products. In June 2009, the OECD Council Meeting at Ministerial Level adopted a Declaration on Green Growth, which invited the OECD to develop a Green Growth Strategy aimed at promoting the development of green sectors (OECD, 2009), i.e., those sectors able simultaneously to contribute

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to economic growth in the short term and to help reduce environmental pressures in the long term (Gazheli et al., 2016; de Bruyn, 2002; Porter and Van der Linde, 1995; Williams and Millington, 2004). Green products are in fact designed with the aim to reduce the environmental impacts of their design, manufacture, use, and disposal (Berchicci and Bodewes, 2005). In a recent study, Chen et al. (2017) show that in China the green sectors produce an important reduction of industrial pollution and at the same time contribute to the economic growth of the country.

To support the development of green products and meet both environmental and economic goals, it is important to analyze the factors fostering green product development. This issue can be addressed from both the demand and supply side. Literature has mainly focused attention on how to promote the demand for green products. In this regard, most of the studies have explored the marketing strategies aimed at influencing consumers' purchase behavior (e.g., de Medeiros and Ribeiro, 2017; de Medeiros et al., 2016; De Angelis et al., 2017; Ritter et al., 2015; Dangelico and Vocalelli, 2017), and the attitudes and the motivations of the consumers to buy green products (e.g., Biswas and Roy, 2015; Yu et al., 2017; Maniatis, 2016; Yadav and Pathak, 2016).

The supply side, concerning the aspects that can support firms to produce green products, has been less investigated. In this regard, the public sector plays a relevant role, because it can stimulate the economic actors to produce green products by means of adequate policy measures (Baumann et al., 2002; Wüstenhagen and Bilharz, 2006; Rehfeld et al., 2007; Fischer and Newell, 2008; Hamdouch and Depret, 2010; Nesta et al., 2014; Sonnenschein and Mundaca, 2016; Wang et al., 2016; Gazheli et al., 2016). However, designing effective government initiatives for green product development is a challenging task (Potts, 2010). Previous studies show in fact that policy measures might not be equally effective for all green sectors in every country (Eickelpasch and Fritsch, 2005; Pack and Saggi, 2006; Huberty and Zachmann, 2011). Furthermore, because of the limitation of economic resources, not all green products can be supported in a given country. Thus, one of the most critical challenges for the policy makers is the identification of those green products having the highest potential for growth, which therefore should be promoted through targeted policy actions. The relevance of the economic performance for assuring green product development is in fact widely recognized (Feng et al., 2017; Chen et al., 2017; Loiseau et al., 2016).

This paper addresses this issue by developing a method based on a recent tool coming from complexity economics, i.e., the *product space* (Hidalgo et al., 2007; Hidalgo and Hausmann, 2009). The product space shows the proximity among products, which in turns captures the similarity of the requisite capabilities to produce them. Products that require similar requisite capabilities are thus located in close proximity in the product space. The product space is also a useful tool to analyze a country's dynamics. In particular, it is shown that a country evolves by traversing the product space adding new products that are in close proximity to the products it already makes with high competitiveness compared with the other countries, i.e., those products with Relative Comparative Advantage (RCA) higher than one (Balassa, 1986). Therefore, the likelihood that a country will develop a particular product depends on how "near" that product is in the product space to the products that the country is already able to successfully make and export (Hidalgo et al., 2007).

In the green product context, the closer a green product is to a product with RCA>1, the more likely the country is to possess the requisite capability to produce that green product successfully, and thus the higher the probability is that the country will successfully introduce the green product within its product space. Based on this argument, we argue that green products closer to the products that a country produces with RCA>1 have greater potential for growth than those with low proximity. It follows that they are the best candidates for support through appropriate policy actions.

A similar intuition is proposed by Hamwey et al. (2013), who develop the "green product space methodology", an analytical approach allowing the green products for which a country is likely to be competitive in the world market to be identified, by computing their proximity with the products with RCA>1. The higher the proximity of the green product, the more competitive it should be. Hamwey et al. (2013) apply such a methodology to the product space of Brazil, built on export data of year 2009. However, they do not support their hypothesis by a statistical test. Furthermore, they do not specify a threshold value of proximity for which the green product can be considered enough close to be competitive. For this reason, their findings do not appear conclusive.

A further coherent argumentation is provided by Huberty and Zachmann (2011). They investigate whether, and in which countries, industrial policies aimed at supporting green development can improve the competitiveness of green products in export markets. In particular, they analyze the growth in RCA of two green products (wind turbines and solar cells) exported by European countries from 1996 to 2008 and sustained by national policy measures. They found that the only variable, among those investigated, positively affecting the growth of both the products is their proximity to products that are a source of competitive advantage for the country (RCA >1). In particular, the growth in RCA of a green product is higher for countries in which the green product had strong proximity to other products having RCA>1, *ceteris paribus*. This result is coherent with our hypothesis. However, the study was conducted for only two green products, so that this finding needs confirmation at a larger scale.

In this paper, we overcome these limitations. We conduct a regression analysis to test that the green products with the highest potential for growth among all green products in a given country are those being in close proximity to the products a country produces with high RCA. We build the product space for 141 different countries for the years between 2005 and 2013 and for each country we compute the maximum proximity of each green product to the products source of competitive advantage (i.e., the proximity of the product source of competitive advantage closest to the green product considered). Regression analysis confirms that a strong relationship exists between maximum proximity and growth in the export performance of green products.

Finally, we develop several applications of the concept of maximum proximity that might prove useful to both policy makers and scholars. First, we show how the concept of maximum proximity higher than a threshold value is a suitable tool to map and plan green product development, since it allows us to identify the green products to support by means of policy actions in any country on the basis of its productive structure. Furthermore, we use the concept of maximum proximity higher than a threshold value to analyze the diversification of the country's basket of green products and to investigate the role of geography in green product development, deriving interesting implications.

The paper is organized as follows. First, in Section 2 we present the theoretical background by assessing the concept of green products and presenting the product space methodology. In Section 3 the research methodology, the sources of data, and the regression analyses are presented. The results of the regression models are shown in Section 4. In the same Section, a discussion of some useful applications of the concept of maximum proximity is provided. The paper ends with conclusions in Section 5.

## 2. Theoretical background

### 2.1. Green products

The definition of green products is a difficult task, because of the many different dimensions in which the term "green" is used: ecological, political, corporate social responsiveness, fair trade, conservation, new-consumerism, and sustainability (McDonagh and Prothero, 1996). These dimensions embrace very different aspects, and each of them formalizes its own meaning of the word "green". Accordingly, no univocal definition of green products exists, but there are many different definitions developed by different parties: industry groups, labor unions, academic, and policy institutions (Dangelico and Pontrandolfo, 2010; Durif et al., 2010).

For the aim of the paper, we will use the definition focusing on the environmental dimension of the term "green". In this respect, the Commission of the European Communities (2001) defines green products as products that "*use less resources, have lower impacts and risks to the environment, and prevent waste generation already at the conception stage*". However, as observed by Pickett-Baker and Ozaki (2008), we recognize that it is not possible to define green products in such absolute terms. Thus, a product can be considered as "green" if it has higher environmental performance than the traditional ones at function parity. This performance is not limited to the production phase but is extended to the product life cycle as a whole (Albino et al., 2009).

As many different definitions exist, several green product classifications have consequently also been developed, driven by different classification purposes. For instance, green products can be classified based on product characteristics (e.g., Rombouts, 1998), the level of environmental impact (e.g., Hanssen, 1999), and the types of environmental improvement strategies (e.g., Park et al., 1999; Rose et al., 1999). However, to the best of our knowledge, there is no internationally agreed classification of green products to date. Interest in creating such a list has emerged in the World Trade Organization (WTO), but despite more than 10 years of effort by the WTO Committee on Trade and Environment (CTE) a list of green products remains elusive (Vikhlyaev, 2004; Kao, 2012).

For the purposes of this study, coherently with the definition of green product we adopt, the green product classification "*The environmental goods and services sector*" developed by EUROSTAT (2009) is considered. This classification, in fact, focuses on the environmental dimension of the "green" concept rather than other dimensions.

### 2.2. A tool from complexity economics: the product space

The product space is a tool developed by Hidalgo et al. (2007) representing the proximity among products. It is defined as a PxP matrix, where P is the total number of products the countries export and each element *i* x *j* of the matrix denotes the proximity between the products *i* and *j*.

The proximity is a statistical measure of the similarity between goods, which formalizes the idea that similar goods (e.g., apples and pears) are more likely to be produced in tandem than dissimilar goods (e.g., apples and bikes). Therefore, if a country produces (exports) a given type of goods (apples), it is very likely that it also produces (exports) other goods that are very close to this one (pears).

The concept of product similarity is related to the requisite capabilities that go into a product. Hidalgo and Hausmann (2009) propose the idea that products require a variety of non-tradable factors of production, called requisite capabilities, and that countries make all the goods for which they have the requisite capabilities. Therefore, if two goods require similar capabilities such as infrastructure, technology, or physical assets, it is highly likely that they will be produced in tandem. Accordingly, two products requiring similar production capabilities will be characterized by high proximity (Hidalgo et al., 2007). Thus, the proximity between goods *i* and *j* is defined as the minimum of the pairwise conditional probabilities of a country exporting product *i* competitively given that it is competitive in exporting product *j*. Formally, it can be expressed as:

$$\varphi_{ij} = \min\left\{\mathrm{Prob}\left(\mathrm{RCAx}_i > 1 | \mathrm{RCAx}_j > 1\right); \mathrm{Prob}\left(\mathrm{RCAx}_j > 1 | \mathrm{RCAx}_i > 1\right)\right\} \tag{1}$$

where $\mathrm{Prob}(\mathrm{RCAx}_i > 1 | \mathrm{RCAx}_j > 1)$ is the probability that product *i* is competitively exported, since product *j* is competitively exported, too. Similarly, $\mathrm{Prob}(\mathrm{RCAx}_j > 1 | \mathrm{RCAx}_i > 1)$ is the probability that product *j* is competitively exported, while the export of product *i* is also competitive. Formally, these probabilities are computed as follows:

$$\mathrm{Prob}\left(\mathrm{RCAx}_i > 1 | \mathrm{RCAx}_j > 1\right) = \frac{\sum_c \mathrm{M}_{ci} \cdot \mathrm{M}_{cj}}{\sum_c \mathrm{M}_{ci}} \tag{2}$$

$$\mathrm{Prob}\left(\mathrm{RCAx}_j > 1 | \mathrm{RCAx}_i > 1\right) = \frac{\sum_c \mathrm{M}_{cj} \cdot \mathrm{M}_{ci}}{\sum_c \mathrm{M}_{cj}} \tag{3}$$

where $\mathrm{M}_{ci}$ ($\mathrm{M}_{cj}$) is equal to one if $\mathrm{RCA}_{ci}$>1 ($\mathrm{RCA}_{cj}$>1), otherwise it is equal to zero. $\mathrm{RCA}_{ci}$ ($\mathrm{RCA}_{cj}$) is the Revealed Comparative Advantage of product *i* (*j*) for country *c*, computed using the Balassa (1986) index as follows:

$$\mathrm{RCA}_{ci} = \frac{\frac{\mathrm{E}_{ci}}{\sum_i \mathrm{E}_{ci}}}{\frac{\sum_c \mathrm{E}_{ci}}{\sum_c \sum_i \mathrm{E}_{ci}}} \tag{4}$$

$$\mathrm{RCA}_{cj} = \frac{\frac{\mathrm{E}_{cj}}{\sum_j \mathrm{E}_{cj}}}{\frac{\sum_c \mathrm{E}_{cj}}{\sum_c \sum_j \mathrm{E}_{cj}}} \tag{5}$$

where $\mathrm{E}_{ci}$ ($\mathrm{E}_{cj}$) is the economic value of product *i* (*j*) exported by country *c*. Generally, country *c* having $\mathrm{RCA}_{ci}$>1 is considered to have high competitive advantage in producing type *i* goods.

As an alternative to the matrix approach, the product space can be shown using a visual network representation, applying the Maximum Spanning Tree algorithm and following the procedure suggested by Hidalgo et al. (2007). This visual representation shows in an intuitive manner several items of information: 1) the size of the node is proportional to the amount of world trade associated with the product; 2) the color of the node follows the Leamer classification giving information about the class of product; and 3) the length of the link between the nodes is inversely proportional to the proximity between the products.

This representation of the product space is useful in order to model the production structure of a country and study its evolution. The production capabilities possessed by the country can easily be mapped by adding information on the country's products with RCA>1. Thus, the evolution of the country's production capabilities can be traced by following the trajectory of the products with RCA>1 introduced over time.

Countries evolve by adding new products close to those having high RCA. Two different evolutionary trends can be distinguished. The most industrialized countries are characterized by products with high RCA located in the core of the product space, where they are strongly connected with many other products. For this reason, such countries are able to upgrade their export basket more quickly than other nations, thus showing high potential for growth. On the contrary, the less developed countries have products with high RCA located at the periphery of the product space, characterized by a limited number of connections with other products. Therefore, these countries have more growth problems (poverty trap) (Hidalgo et al., 2007).

Hidalgo et al. (2007) also demonstrate that the likelihood that a country will develop a particular type of goods depends on how near in the product space that type of goods is to the goods that the country is already able to produce successfully. They test this proposition showing that goods able to pass from RCA<0.5 to RCA>1 in five years have a higher density than goods whose RCA stays lower than 1. High density means that those products are surrounded by many developed products. Furthermore, they also show that there is a monotonic relationship between the probability that a product with RCA<0.5 turns into RCA>1 after five years and the proximity of the nearest product with RCA>1.

With the present paper, we bring this concept in the green product context, building on the intuition by Hamwey et al. (2013).

## 3. Methods

To test the hypothesis that the proximity of a green product to products with RCA>1 positively affects its growth, we performed the following steps: 1) we built the product spaces and identified the products with RCA>1 for each country; 2) we classified the green products; 3) we computed the proximity of green products with those with RCA>1 for each country; 4) we identified the regression model to test the hypothesis, defined the measures, and ran the statistical analysis on the collected data. We describe each step below.

To build the product space, we followed the procedure proposed by Hidalgo et al. (2007). First, we collected data on the international trade for years 2005, 2009, and 2013. We used the data from the UN-COMTRADE database (UN, 2016a). It contains the export data (in monetary value) of 1345 products exported by 243 countries toward any other country for each year. We used the product classification SITC Rev 2 at 5-digit level of detail (UN, 2016b), which offers the highest possible level of detail. Based on the export data, we computed the RCA of each product for each country in each year considered, using Equation (4). The proximity between each pair of products was then computed using Equation (1). So doing, we built the product space in the years considered. For each country, we then identified all the products with RCA >1 for all the years considered.

Our study also required the green products within the product space to be clearly identified. As stated above, we adopted the green product classification "*The environmental goods and services sector*" developed by the EUROSTAT (2009). This classification identifies which products of the WTO product list can be considered as green products. Then, we converted these products accordingly with the SITC classification in order to be consistent with the data provided by the UN-COMTRADE database (UN, 2016a). As a result, we identified 41 green products organized in seven families in accordance with the SITC classification (Table 1). Since the export data on the green products are available in the considered years only for 141 countries, we restricted our analysis to these 141 countries. For these countries, we were able to distinguish the green products from the other products using this classification. Thus, we were able to clearly identify the proximity of the green products from all the other products with RCA>1 in each country and for each year considered.

### 3.1. Statistical analysis

To test our hypothesis we adapted the statistical model used by Barro (1996) to investigate the effect of a few socio-economic parameters on the GDP growth in different countries. He regressed the investigated parameters measured at the *t*-th year (independent variables) with the percentage variation of GDP measured between the year *t* and the year $t+\tau$ and controlled for the value of the GDP in the *t*-th year. In the following subsections, we first describe the dependent, independent, and control variables with attendant measures. Then, we present the regression models.

#### 3.1.1. Variables and measures

Our dependent variable is the growth of a given green product (*GreenProd Growth*). We measured it by computing the percentage variation of the export value of the green product in each country over a 4-year time range. For a given green product *p* exported by the country *c*, it is computed as follows:

$$\Delta E_{cp}(t+4) = \frac{E_{cp}(t+4) - E_{cp}(t)}{E_{cp}(t)} \tag{6}$$

The data on the export value of the green products were obtained from the UN-COMTRADE database (UN, 2016a). We excluded from the analysis green products having RCA higher than one at time *t*. In fact, when $RCA_{cp}(t) > 1$, the product *p* is already a source of competitive advantage for country *c* at year *t* and therefore it does not need to be sustained by policy measures.

The independent variable is the proximity between the green product and the products the country exports with high RCA. We measured it by using the maximum value of proximity that a green product has to the products with RCA>1 (*Max proximity*) which the country exports. Alternatively, we could have used the average proximity which relates the selected green product to all country exports with RCA>1. The information provided by the maximum proximity, however, appears to be more useful than its average counterpart, especially in cases of countries exporting many different products with RCA>1. In fact, while the maximum value of proximity can clearly identify whether the country possesses the requisite capability to produce it, the average value could not. A low average value, in fact, could be possible, even though one product has a high proximity. This limits the applicability of the average value, as it would imply that the country does not possess the requisite production capability to produce the green product, which is not true. Thus, for the any given green product *p* exported by the country *c* in the year *t*, we computed the maximum proximity as follows:

$$\Phi_{cp}(t) = \max\{\varphi_{pi}(t)\}_{\ \forall\ i\ \in\ \Pi(c)} \tag{7}$$

where $\Pi(c)$ is the set of products with RCA>1 for country *c*.

Two control variables were added to the analysis. We considered the effect of the export value of the green product at the beginning of the time range (*LogExport*). In particular, as the control variable, we introduced the logarithm of this value $(\ln[E_{cp}(t)])$. Consistently with Barro (1996), we expect a negative impact of this variable, since the percentage export growth is supposed to be lower for products with high export. We also included the GDP value of the country at the beginning of the time range as a control variable $(GDP_c(t))$. We expect a positive impact of this variable, since countries with a high GDP tend to have more exports than countries with lower GDP (e.g., Narayan and Smyth, 2009). Data on GDP were obtained from the World Bank online database (The World Bank, 2016).

**Table 1**
The green products classification by EUROSTAT (2009).

| FAMILY | SITC code | Green product |
|---|---|---|
| Crude materials, inedible, except fuels | 23201 | Natural rubber latex; pre-vulcanized natural rubber latex |
| | 23202 | Natural rubber (other than latex) |
| | 28201 | Waste and scrap metal of iron or steel of pig or cast iron |
| | 28202 | Waste and scrap metal of iron or steel of alloy steel |
| | 28209 | Waste and scrap metal of iron or steel of other iron or steel |
| | 28821 | Copper waste and scrap |
| | 28822 | Nickel waste and scrap |
| | 28823 | Aluminum waste and scrap |
| | 28824 | Lead waste and scrap |
| | 28825 | Zinc waste and scrap (other than dust) |
| | 28826 | Tin waste and scrap |
| | 28902 | Precious metal, waste and scrap |
| Mineral fuels, lubricants and related materials | 34131 | Liquefied propane and butane |
| | 34139 | Liquefied gaseous hydrocarbons, nes |
| Animal and vegetable oils, fats and waxes | 43143 | Vegetable waxes |
| | 43144 | Spermaceti, crude or refined; insect waxes |
| Chemicals and related products | 51211 | Methyl alcohol (methanol) |
| | 52391 | Hydrogen peroxide |
| | 53222 | Dyeing extracts of vegetable or animal origin |
| | 58361 | Acrylic and methacrylic polymers; acrylo-methacrylic copolymers in primary forms |
| | 58362 | Acrylic and methacrylic polymers; acrylo-methacrylic copolymers in plate, sheet, strip, film or foil form |
| | 58369 | Acrylic and methacrylic polymers; acrylo-methacrylic copolymers in other forms (including waste and scrap) |
| Manufactured goods classified chiefly by materials | 65121 | Wool tops |
| | 65122 | Carded sheep's or lambs' wool (woolen yarn), not for retail sale |
| | 65123 | Combed sheep's or lambs' wool (worsted yarn), not for retail sale |
| | 65124 | Fine hair yarn (carded or combed), not for retail sale |
| | 65125 | Coarse hair yarn, not for retail sale |
| | 65126 | Yarn of sheep's or lamb's wool or of fine animal hair, for retail |
| | 65127 | Yarn of carded sheep's or lamb's wool, blended, not for retail |
| | 65128 | Yarn of combed sheep's or lamb's wool, blended, not for retail |
| | 65129 | Wool etc. blend yarn for retail |
| | 65498 | Fabrics, woven, of other vegetable textile fibers; of paper yarn |
| | 69211 | Iron, steel, aluminum reservoirs, tanks, etc., capacity 300 lt plus of iron or steel |
| | 69213 | Iron, steel, aluminum reservoirs, tanks, etc., capacity 300 lt plus of aluminum |
| Machinery and transport equipment | 71621 | Electric motors (including ac/dc motors), other than direct current |
| | 71881 | Water turbines |
| | 71882 | Other hydraulic engines and motors (including waterwheels) |
| | 79381 | Tugs |
| | 79382 | Special purpose vessels, floating docks, etc. |
| | 79383 | Floating structures, other than vessels |
| Miscellaneous manufactured articles | 89471 | Fishing and hunting equipment |

*3.1.2. Regression models*

We performed two panel data regressions with fixed effects played respectively by countries (*Model 1*) and products (*Model 2*). The two models correspond to the following equations:

$$\Delta E_{cp}(t+4) = [\alpha_0 + \beta_1 \cdot C_c] + \alpha_1 \cdot \Phi_{cp}(t) + \alpha_2 \cdot \ln\left[E_{cp}(t)\right] + \alpha_3 \cdot GDP_c(t) \tag{8}$$

$$\Delta E_{cp}(t+4) = \left[\alpha_0 + \beta_1 \cdot P_p\right] + \alpha_1 \cdot \Phi_{cp}(t) + \alpha_2 \cdot \ln\left[E_{cp}(t)\right] + \alpha_3 \cdot GDP_c(t) \tag{9}$$

where *C* and *P* stand for the regressors for the countries and the products, respectively.

To run the regression with fixed effects, we added the correspondent dummy variables: 140 in Model 1 and 40 in Model 2.

## 4. Results and applications

### 4.1. Results of the regression analyses

Table 2 shows the correlation matrix among the model variables. No evident correlation appears.

Table 3 shows the results of the regression analyses for models 1 and 2, respectively. The results of both models confirm that the maximum proximity of the green product from the products with high RCA positively and significantly ($\alpha_1 = 4.9382$ and $\alpha_1 = 4.8006$ for Model 1 and Model 2, respectively) influences the growth of the export of the green product. As expected, the export value of the green product also has a negative and significant effect on the growth of the export of the green product ($\alpha_2 = -1.8553$ and $\alpha_2 = -2.1162$ for Model 1 and Model 2, respectively). As to the effect of the GDP on the green product, we found it to be positive but not significant in Model 1 ($\alpha_3 = 1.07\text{e-}12$), and positive and significant in Model 2 ($\alpha_3 = 1.35\text{e-}11$), as expected.

### 4.2. Applications

We present several applications of the concept of maximum

**Table 2**
Correlation matrix among the variables of the statistical models.

| | GreenProd Growth | Max Proximity | LogExport | GDP |
|---|---|---|---|---|
| *GreenProd Growth* | 1.0000 | | | |
| *Max Proximity* | −0.0496 | 1.000 | | |
| *LogExport* | −0.2748 | 0.2510 | 1.0000 | |
| *GDP* | −0.0700 | 0.0096 | 0.4106 | 1.000 |

**Table 3**
Fixed Effect Regression Models with GreenProd Growth as dependent variable.

| Parameters | Model 1 | Model 2 |
|---|---|---|
| Constant | 33.0970*** | 29.2499*** |
| | (6.8876) | (2.4055) |
| Max Proximity | 4.9382* | 4.8006* |
| | (2.2635) | (2.6450) |
| LogExport | −1.8553*** | −2.1162*** |
| | (0.1309) | (0.1234) |
| GDP | 1.07e-12 | 1.35e-11*** |
| | (1.47e-11) | (3.17e-12) |
| Model fits statistics | | |
| Number of Observations | 3117 | 3117 |
| Degrees of freedom | 142 | 42 |
| F | 3.7 | 8.57 |
| Prob > F | 0 | 0 |
| R-squared | 0.1503 | 0.1070 |
| Adj R-squared | 0.1097 | 0.0946 |
| Root MSE | 17.831 | 17.982 |

*p < 0.1; ***p < 0.001; Model 1 contains fixed effect on countries, Model 2 contains fixed effect on products.

proximity of green products to products with high RCA, useful to policy makers as well as scholars, in order to map and plan green product development, to analyze the diversification of a country's basket of green products, and to investigate the role of geography in green product development.

#### 4.2.1. The green product maximum proximity matrix

We define the *green product maximum proximity* matrix $\Phi^{MAX}$ as a CxP matrix, where *C* is the number of countries and *P* the number of green products, and whose element $\Phi_{cp}^{MAX}$ contains the value of the highest proximity to the products with RCA>1 for green product *p* in country *c* (Equation (7)). As an example, we computed the matrix (see Supplementary Material) using data referring to 2013 and ordered rows and columns for decreasing average values.

The matrix is a map of world green product development in 2013. It shows: 1) the green products that each country currently produces with high competitive advantage ($\Phi_{cp}^{MAX} = 1$); 2) the green products that the country could produce given the proximity to products with high RCA ($\Phi_{cp}^{MAX} > 0.5$); and 3) the green products that it is very unlikely could be introduced into the country's basket of green products ($\Phi_{cp}^{MAX} \leq 0.5$). Fig. 1 shows the matrix $\Phi^{MAX}$ with the cells colored from red to green as the highest proximity increases for visual analysis.

Because of space limitations, we have extracted data from the matrix for just 8 countries to discuss (Table 4). The data show that the UK and Germany are currently competitive on 20 and 18 green products, respectively. Italy produces 16 green products with high RCA and France 15. China and US currently and successfully produce a high number of green products (14 and 16, respectively), with no product in common. India and South Korea are competitive in 7 and 6 green products.

Looking at green products with $\Phi_{cp}^{MAX} > 0.5$, we note that Italy has the requisite capabilities to produce several green products. Hence, it is highly recommended that Italy should primarily invest in “Waste and scrap metal of iron or steel of other iron or steel”, “Other hydraulic engines and motors (including waterwheels)”, and “Floating structures, other than vessels”. Similarly, for example Germany should invest in “Acrylic and methacrylic polymers; acrylo-methacrylic copolymers in primary forms” and “Yarn of combed sheep's or lamb's wool, blended, not for retail”, and the UK in “Wool tops” and “Combed sheep's or lambs' wool (worsted yarn), not for retail sale”. China also has a large number of green products

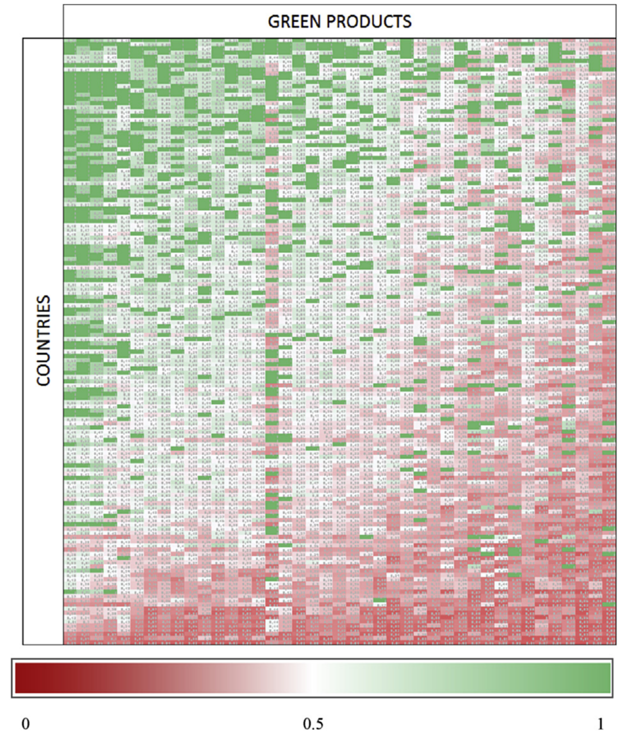



**Fig. 1.** Highest proximity for each green product (columns) to products with RCA>1 for each country (rows) (Data refer to 2013). Green cell: high proximity; Red cell: low proximity. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

with high potential for growth: “Methyl alcohol (methanol)”, “Acrylic and methacrylic polymers; acrylo-methacrylic copolymers in primary forms”, “Acrylic and methacrylic polymers; acrylo-methacrylic copolymers in plate, sheet, strip, film or foil form”, “Iron, steel, aluminum reservoirs, tanks, etc., capacity 300 lt plus of iron or steel”, and “Water turbines” (Table 4). By looking at green products with $\Phi_{cp}^{MAX} > 0.5$, similar considerations can be extended to all the other countries.

#### 4.2.2. Country diversification on green product development

We define two indices based on the matrix $\Phi^{MAX}$: 1) *Country Green Diversity* (CGD) and 2) *Country Green Diversity Development* (CGDD).

Country Green Diversity (CGD) is the number of green products with RCA>1 currently exported by the country. The higher the CGD, the more diversified is the green product basket. The CGD is computed as follows:

$$CGD_c = \sum_{p=1}^{P} A_{cp} \text{ where } \begin{cases} A_{cp} = 1 & \text{if } \Phi_{cp}^{MAX} = 1 \\ A_{cp} = 0 & \text{if } \Phi_{cp}^{MAX} < 1 \end{cases} \quad (10)$$

Country Green Diversity Development (CGDD) is the number of green products with $\Phi^{MAX}$ between 0.5 and 1. This is a measure of how the current green product basket could be further diversified in the next few years. The higher the CGDD, the higher the number of green products that can be added to the current basket. It is defined as follows:

$$CGDD_c = \sum_{p=1}^{P} B_{cp} \text{ where } \begin{cases} B_{cp} = 1 & \text{if } 0.5 < \Phi_{cp}^{MAX} < 1 \\ B_{cp} = 0 & \text{if } \Phi_{cp}^{MAX} \leq 0.5 \end{cases} \quad (11)$$

**Table 4**
Data from Fig. 1 for selected countries.

| Green product code | Green products name | Italy | Germany | France | UK | China | USA | India | South Korea |
|---|---|---|---|---|---|---|---|---|---|
| 23201 | Natural rubber latex; pre-vulcanized natural rubber latex | 0.5570 | 0.3457 | 0.5570 | 0.2562 | 0.5570 | 0.4216 | 0.4632 | 0.5567 |
| 23202 | Natural rubber (other than latex) | 0.4150 | 0.3189 | 0.4214 | 0.3148 | 0.4214 | 0.3559 | 0.4155 | 0.4155 |
| 28201 | Waste and scrap metal of iron or steel of pig or cast iron | 0.4433 | 0.2648 | 1 | 1 | 0.4433 | 0.2573 | 0.2583 | 0.1527 |
| 28202 | Waste and scrap metal of iron or steel of alloy steel | 0.4213 | 1 | 1 | 1 | 0.4559 | 1 | 0.4070 | 0.4070 |
| 28209 | Waste and scrap metal of iron or steel of other iron or steel | 0.6486 | 1 | 1 | 1 | 0.6486 | 1 | 0.64856 | 0.3825 |
| 28821 | Copper waste and scrap | 0.5613 | 1 | 1 | 1 | 0.5612 | 1 | 0.5613 | 0.4517 |
| 28822 | Nickel waste and scrap | 0.5349 | 0.5349 | 1 | 1 | 0.4732 | 1 | 0.4698 | 0.4416 |
| 28823 | Aluminum waste and scrap | 0.5808 | 1 | 1 | 1 | 0.5808 | 1 | 0.5145 | 0.5119 |
| 28824 | Lead waste and scrap | 1 | 0.4819 | 1 | 1 | 0.4819 | 1 | 0.3917 | 0.3354 |
| 28825 | Zinc waste and scrap (other than dust) | 0.5599 | 1 | 1 | 0.5757 | 0.5334 | 1 | 0.4678 | 0.5598 |
| 28826 | Tin waste and scrap | 0.5630 | 1 | 1 | 1 | 0.5623 | 1 | 0.5630 | 0.4873 |
| 28902 | Precious metal, waste and scrap | 0.4954 | 1 | 0.4954 | 1 | 0.4954 | 1 | 1 | 0.4954 |
| 34131 | Liquefied propane and butane | 0.3386 | 0.3191 | 0.3191 | 1 | 0.3191 | 1 | 0.3386 | 0.3386 |
| 34139 | Liquefied gaseous hydrocarbons, nes | 0.2084 | 0.2203 | 0.2203 | 0.2378 | 0.2203 | 0.3463 | 0.3463 | 0.3463 |
| 43143 | Vegetable waxes | 0.5873 | 1 | 0.5487 | 0.5873 | 0.6251 | 1 | 0.6251 | 0.8185 |
| 43144 | Spermaceti, crude or refined; insect waxes | 0.4425 | 0.5618 | 1 | 0.2888 | 1 | 0.4425 | 0.4011 | 0.4425 |
| 51211 | Methyl alcohol (methanol) | 0.3363 | 0.3316 | 0.3586 | 0.4071 | 0.7038 | 0.4071 | 0.3864 | 0.3586 |
| 52391 | Hydrogen peroxide | 0.5209 | 1 | 0.5209 | 0.4310 | 0.4654 | 0.5964 | 0.5441 | 1 |
| 53222 | Dyeing extracts of vegetable or animal origin | 1 | 1 | 1 | 1 | 0.4736 | 0.7123 | 0.5151 | 0.4548 |
| 58361 | Acrylic and methacrylic polymers; acrylo-methacrylic copolymers in primary forms | 0.5978 | 0.6582 | 1 | 1 | 0.6582 | 1 | 0.5978 | 1 |
| 58362 | Acrylic and methacrylic polymers; acrylo-methacrylic copolymers in plate, sheet, strip, film or foil form | 1 | 0.5912 | 0.5912 | 0.6782 | 0.6356 | 1 | 0.6782 | 1 |
| 58369 | Acrylic and methacrylic polymers; acrylo-methacrylic copolymers in other forms (including waste and scrap) | 0.5360 | 0.5289 | 0.4729 | 0.2984 | 0.6136 | 0.4821 | 1 | 0.5987 |
| 65121 | Wool tops | 1 | 1 | 0.2738 | 0.6840 | 1 | 0.2738 | 1 | 0.1613 |
| 65122 | Carded sheep's or lambs' wool (woolen yarn), not for retail sale | 1 | 0.2332 | 0.2965 | 1 | 1 | 0.27573 | 0.3609 | 0.4486 |
| 65123 | Combed sheep's or lambs' wool (worsted yarn), not for retail sale | 1 | 1 | 0.5457 | 0.7664 | 1 | 0.4456 | 1 | 0.5411 |
| 65124 | Fine hair yarn (carded or combed), not for retail sale | 1 | 0.4954 | 0.4745 | 1 | 1 | 0.4084 | 0.4954 | 0.3799 |
| 65125 | Coarse hair yarn, not for retail sale | 1 | 1 | 0.4217 | 1 | 1 | 0.4400 | 0.3806 | 0.3806 |
| 65126 | Yarn of sheep's or lamb's wool or of fine animal hair, for retail | 1 | 0.4147 | 0.5205 | 0.2486 | 1 | 0.4385 | 0.4171 | 0.1998 |
| 65127 | Yarn of carded sheep's or lamb's wool, blended, not for retail | 1 | 0.4799 | 0.5671 | 1 | 1 | 0.4374 | 0.5923 | 0.4526 |
| 65128 | Yarn of combed sheep's or lamb's wool, blended, not for retail | 1 | 0.7664 | 0.6154 | 1 | 1 | 0.5391 | 1 | 0.5453 |
| 65129 | Wool etc. blend yarn for retail | 1 | 1 | 0.5559 | 0.5559 | 0.5559 | 0.4178 | 0.4349 | 0.4099 |
| 65498 | Fabrics, woven, of other vegetable textile fibers; of paper yarn | 0.4910 | 0.4910 | 0.4310 | 0.3128 | 1 | 0.3452 | 0.3401 | 0.4310 |
| 69211 | Iron, steel, aluminum reservoirs, tanks, etc., capacity 300 lt plus of iron or steel | 1 | 0.6382 | 0.4795 | 0.4634 | 0.6561 | 0.6382 | 0.4779 | 1 |
| 69213 | Iron, steel, aluminum reservoirs, tanks, etc., capacity 300 lt plus of aluminum | 1 | 1 | 1 | 1 | 0.3863 | 1 | 0.3863 | 0.3374 |
| 71621 | Electric motors (including ac/dc motors), other than direct current | 1 | 1 | 1 | 0.6418 | 1 | 0.6667 | 0.6536 | 0.6536 |
| 71881 | Water turbines | 1 | 1 | 0.7078 | 0.6089 | 0.6710 | 0.7078 | 0.6710 | 0.6572 |
| 71882 | Other hydraulic engines and motors (including waterwheels) | 0.6718 | 1 | 1 | 1 | 0.5727 | 1 | 0.5501 | 0.5727 |
| 79381 | Tugs | 0.2719 | 0.2495 | 0.1945 | 0.4720 | 1 | 0.5746 | 1 | 0.6390 |
| 79382 | Special purpose vessels, floating docks, etc. | 0.3340 | 0.2724 | 0.1328 | 0.3186 | 1 | 0.2135 | 1 | 1 |
| 79383 | Floating structures, other than vessels | 0.6745 | 0.4226 | 0.6745 | 1 | 0.4591 | 1 | 0.4591 | 0.3640 |
| 89471 | Fishing and hunting equipment | 0.5711 | 0.5711 | 0.5711 | 0.5711 | 1 | 0.5711 | 0.5577 | 1 |

In Fig. 2 all countries are depicted as a function of their CGD (x-axis) and CGDD (y-axis). The figure shows that the UK is the country currently exporting the highest number of green products (20), whereas Poland is the country that can expand most its current basket of exported green products (17). On average, each country currently exports 5.8 green products and can potentially add 6.98 green products to its basket. Three clusters are recognizable. The first cluster is made up of the countries having high CGD (i.e., successfully producing a diversified basket of green products) and high CGDD (i.e., that can potentially increase their basket with a high number of green products). The second cluster contains countries having low CGD but high CGDD. These countries currently have quite specialized baskets of green products but they can potentially diversify their basket, adding many other green products to those currently produced. The third cluster involves countries with both low CGD and low CGDD. These countries currently have specialized baskets of green products and do not have the potential to diversify their baskets.

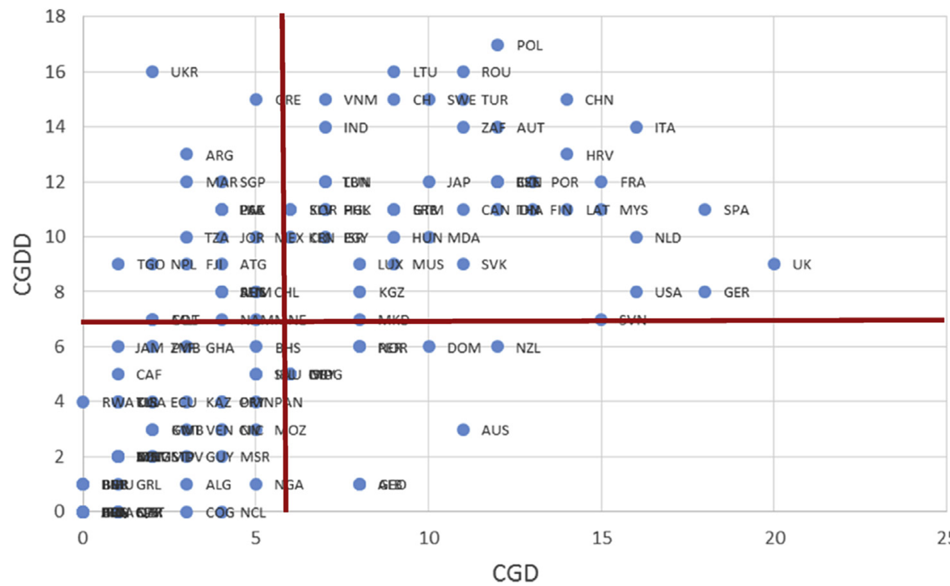



**Fig. 2.** CGD and CGDD for all countries (data refer to 2013). Red lines denote the average values of CGD and CGDD. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 3a and b show the world map where each country is characterized by its CGD and CGDD, respectively. In particular, Fig. 3a shows that the countries with the widest basket of exported green products are located in Europe, North America (Canada and USA), Oceania, and South-East Asia. Alternatively, countries in South America, Africa (except for South Africa), and the Middle East tend to have more specialized baskets. This is in line with the general trend that the exports basket (considering not only green products but all the exported products) of African countries are on average 6.5 times lesser wide than the exports basket of European countries (Ofa et al., 2012). Moreover, Fig. 3b shows that countries in Eastern Europe have the highest CGDD. Similarly, countries in Western Europe and South Asia also have high CGDD, as well as some African countries, Argentina, and Canada.

Almost all European countries currently have diversified baskets of green products and also have the potential to further increase the number of green products exported. Argentina, El Salvador, Morocco, and Pakistan are examples of countries currently having specialized baskets of green products, but that can easily diversify their baskets. Finally, almost all the African countries have specialized baskets of green products and they cannot diversify them. Moreover, note that almost none of the countries currently producing no green products (black countries in Fig. 3) can easily add any green product to their basket.

An interesting finding is shown in Fig. 4a (4b), which depicts country's CGD (CGDD) as a function of the GDP. In both cases, a positive and significant correlation is found between the two variables. This suggests that the richest countries are currently characterized by the widest basket of green products. This evidence is in line with the results of other studies, which highlighted the positive relationship between the country GDP and the number of products exported by that country (Amurgo-Pacheco and Pierola, 2008; Hu et al., 2012). Furthermore, the richest countries have also the highest likelihood to add a large number of green products to their current basket. Conversely, less developed countries are not competitive in green products and also have difficulty in adding new green products to their basket, because they lack the production capability required for their production. Hence, poor countries will be unable to develop green products, unless the country makes intensive investments on the requisite capabilities currently lacking. This situation identifies a green development trap for these countries.

#### 4.2.3. Country similarity on green product development

We computed two indices comparing all couples of the countries in order to analyze their similarity in terms of green products currently co-produced and that could be co-produced.

We define the *Similarity Green Product* index (SGP) as the normalized number of green products currently competitively co-exported by two countries. This index ranges between 0 and 1: the higher the index, the higher the similarity between the two countries in terms of green products successfully produced. For countries $c_1$ and $c_2$, it is computed as follows:

$$\mathrm{SGP}(c_1, c_2) = \frac{1}{41} \sum_{k=1}^{41} \sum_{\substack{l=1 \\ l \neq k}}^{41} A_{c_1 k} \cdot A_{c_2 l} \tag{12}$$

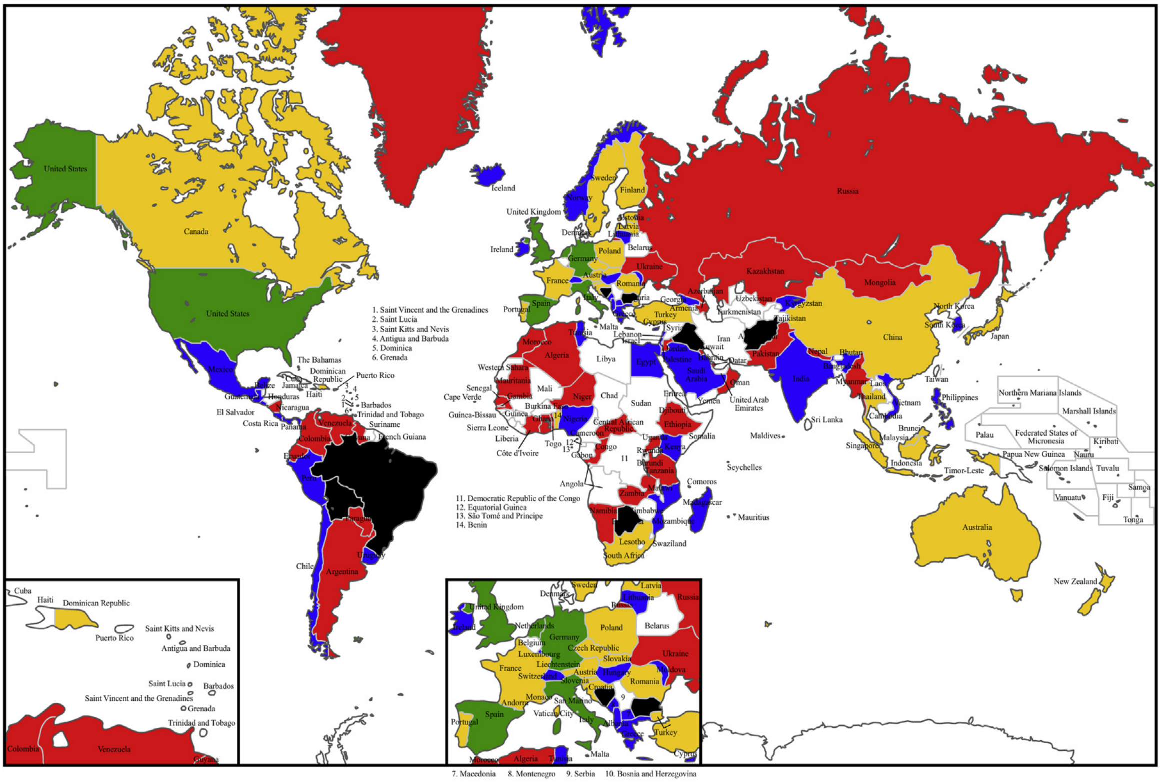
where $A_{c_1 k} = 1(A_{c_2 l} = 1)$ if $\Phi_{c_1 k}^{MAX} = 1(\Phi_{c_2 l}^{MAX} = 1)$, otherwise it is equal to zero.

We also define the *Similarity Green Product Development* index (SGPD) as the normalized number of green products that two countries could potentially co-add to their green product baskets. Also this index ranges between 0 and 1: the higher the index, the higher the similarity between the two countries, in terms of green products that can be potentially added. It follows that:

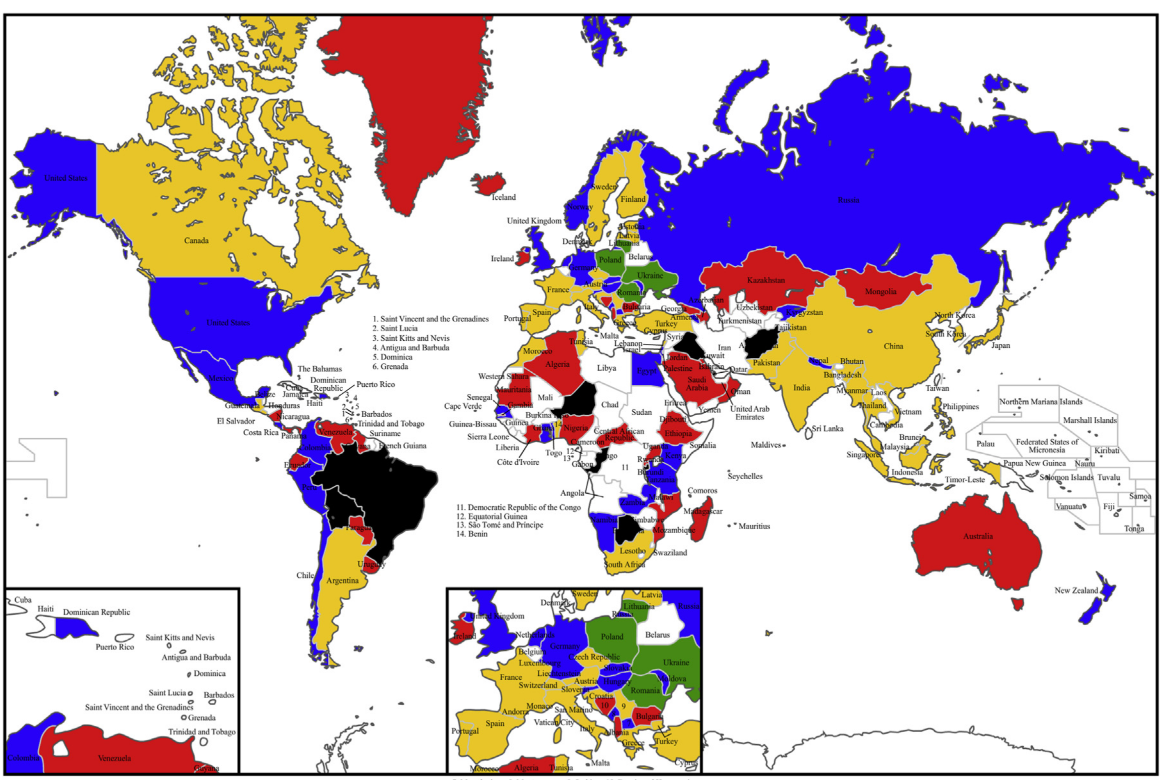
$$\mathrm{SGPD}(c_1, c_2) = \frac{1}{41} \sum_{k=1}^{41} \sum_{\substack{l=1 \\ l \neq k}}^{41} B_{c_1 k} \cdot B_{c_2 l} \tag{13}$$

where $B_{c_1 k} = 1(B_{c_2 l} = 1)$ if $0.5 < \Phi_{c_1 k}^{MAX} < 10.5 < (\Phi_{c_2 l}^{MAX} < 1)$, otherwise it is equal to zero.

In Fig. 5, the SGP and SGPD values are shown in the network graph form. In particular, in these graphs, two countries are linked to each other if they currently co-export (Fig. 5a) or are potentially able to co-export (Fig. 5c) at least five green products.

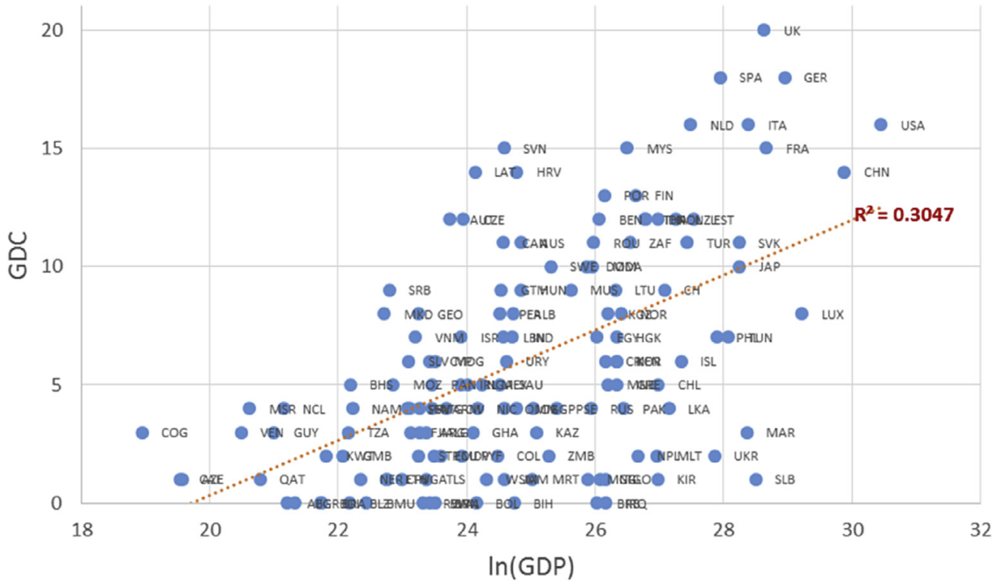


a)

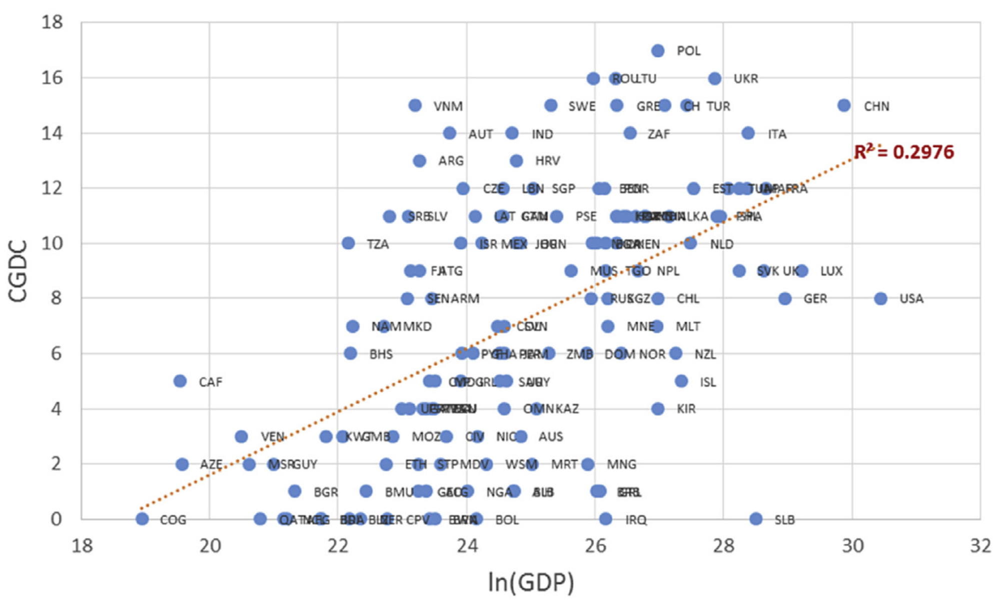


b)

**Fig. 3.** CGD (a) and CGDD (b) for each world country (data refer to 2013). Legend: black = 0 green products; Red = 1÷5; Blue = 6÷10; Yellow = 11÷15; Green >15. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)




a)




b)

**Fig. 4.** Correlation between country GDP and CGD (a) and between country GDP and CGPD (b) (data refer to 2013).

The analysis of the SGP index for each couple of countries reveals that that geography matters in green production. In fact, countries in close geographical proximity to each other currently co-export a high number of green products. For instance, France, the Netherlands, and the UK currently co-export 11 green products as well as France and Slovenia. Italy co-exports at least 5 green products with 21 countries, 14 of them are European countries (Fig. 5b). The Netherlands co-export 10 green products with Spain and Germany. Moreover, China co-exports at least five green products with four relatively nearby countries (India, Hong Kong, Thailand, and Malaysia), while Indonesia co-exports at least five green products with three neighboring countries (Malaysia, Thailand, and Japan).

Moreover, geography seems also to affect green product development. In fact, from the analysis of the SGPD index for each couple of countries, we found India can potentially co-export at least five additional green products with China, Sri Lanka, Indonesia, Malaysia, Pakistan, South Korea, Hong Kong, Singapore. Moreover, Italy could co-export at least five green products with 43 other countries, 18 of them are geographically neighbors (Fig. 5d). This information could be useful to develop green product supporting policies at transnational level suggesting where there is potential for growth. A policy targeted to support the development of a green product with high SGPD can in fact be beneficial for several countries.

## 5. Conclusions

Which green products should the policy makers of a country support by means of policy actions so as to meet both the economic

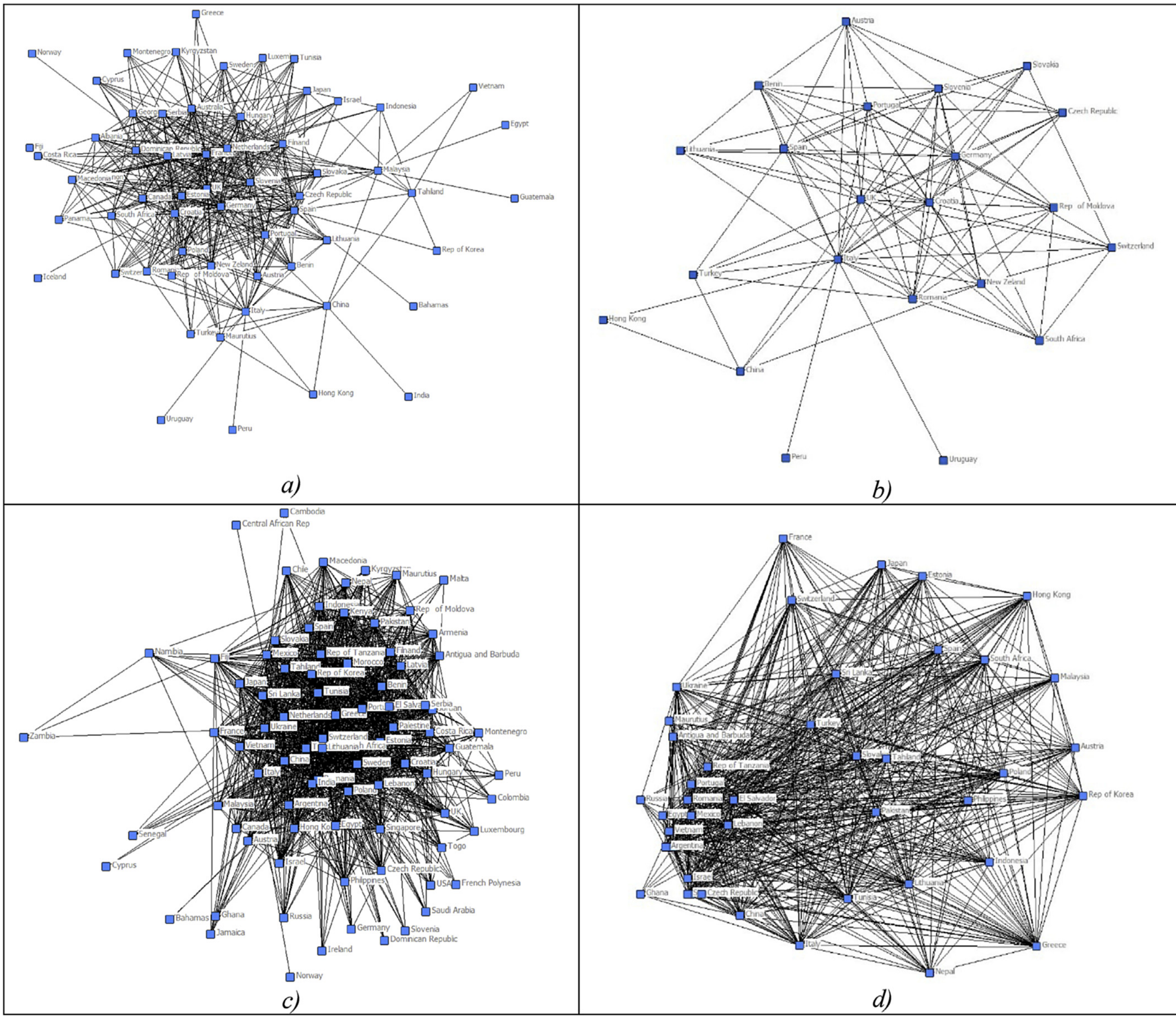



**Fig. 5.** Network representation of SGP among countries (a), with special focus on Italy (b) and SGPD among countries (c), with special focus on Italy (d) (data refer to 2013).

and environmental aims, or in other terms reach sustainable economic development?

Our analysis proves that the green products with the highest potential for growth in a given country are those in close proximity to the products the country produces with high competitiveness compared with other countries. Choosing to support these products makes sense because it would exploit the requisite capabilities the country already possesses in terms of infrastructure, human capabilities, and natural resources for economic development in an environmental direction. In fact, those countries where a given green product has high proximity to products with RCA>1 have already the requisite capabilities within their productive structure to successfully produce it. Hence, policy measures should be devoted to supporting investments into this product, because it has a great likelihood of growing in the next few years. In this way, high efficacy is assured to the policy action. On the contrary, countries where a given green product has low proximity to the products with RCA>1 do not have the requisite capabilities needed for its production. Therefore, sustaining such a product by simply "pumping money" will not be enough to assure its development. For these products, governments should take "strategic bets" by focusing their efforts on accumulating the capabilities required to produce green products (Abdon and Felipe, 2011; Hausmann and Hidalgo, 2011; Felipe et al., 2014). This outcome is important especially considering that literature is often limited to highlighting the benefits of green development and the need to support it, with emphasis on the capabilities required for green development from the demand side but with limited concern for the supply side.

This study wishes to contribute to the literature on the application of the *product space* as a policy making tool for green development. First, it provides statistical significance to the intuition by Hamwey et al. (2013) who, by developing the green product space of Brazil and using this tool, identified the green products that should be supported by means of policy actions. Moreover, it also extends the application by Huberty and Zachmann (2011), who used the concept of product proximity to green products and provided preliminary results for two green products exported by two countries.

In particular, from a methodological point of view, we offer a more detailed and structured approach to compute the green product space and to identify the green products with the highest potential for growth. In this regard, we introduced the concept of maximum proximity higher than a threshold value (the 0.5 limit of Equations (11) and (13)).[1] We believe this approach is more precise, because better captures the reason why these green products can be competitively produced, i.e., the availability of the production capabilities to produce them by the country.

Furthermore, compared with Hamwey et al. (2013) who use the SITC product classification at 4-digit level of detail, we adopt the product classification SITC Rev 2 at 5-digit level of detail. This allows us to provide a more accurate analysis and, consequently, more precise policy implications.

As implications of our study, we developed a set of indices based on the concept of maximum proximity, useful for policy makers as well as researchers interested in green product development. In particular, we defined the map of the current world green product development. This provides important information to policy makers in a user-friendly form: 1) it shows the green products in which the country is already competitive and 2) it shows which green products have the best chance of becoming competitive for the country in the next few years. In particular, the latter information offers very useful implications for the policy makers of a country, because it suggests which green products should be supported by targeted policy measures and which green products are ineffective to sustain. For example, our analysis suggests that Italian policy makers should invest in “Waste and scrap metal of iron or steel of other iron or steel”, “Other hydraulic engines and motors (including waterwheels)”, and “Floating structures, other than vessels”. Conversely, for Italy it could be ineffective to invest in “Liquefied gaseous hydrocarbons, nes” and “Tugs”. In fact, the low proximity of these products to other products with RCA>1 suggests that Italy does not have sufficient capabilities to self-sustain the development of these green products. Similar arguments can be developed for all the countries analyzed, based on information provided in the green product development matrix (see Supplementary Material). Thus, the contributions of our study are not limited to one country (Italy) but are extendable to all the countries analyzed, confirming the importance of this study and the usefulness of the matrix proposed.

We also proposed measures of country green product diversity and similarity. By using them, some interesting relationships with country development were derived. We noted that countries with the highest current and future diversification on green products are those with the highest GDP. This confirms that the diversification of the export basket can be a fundamental strategy to enhance the economic competitiveness of developing countries (Lederman and Klinger, 2006; Cadot et al., 2011). Developing countries can improve their economic performance by investing in green sectors. In this regard, our study provides an interesting implication because we can advise developing countries in which green industries to invest, by identifying those green products for which the countries have requisite production capabilities. Simply by computing the proximity of green products to the products with RCA >1 and choosing those which are closest, our study can be used to identify in which green sectors developing countries should invest, to increase the efficacy of their policy actions and at the same time improve their GDP.

Moreover, we found that countries which are geographically close by show high current and future similarity on the production of green products. This confirms that geography matters for green product development and provides an interesting direction for future research, suggesting that attention should be concentrated on the role of geography in green development.

There are certain limitations to this study that should be borne in mind. Firstly, since there are several classifications of green products, the results obtained may be contingent to the specific list adopted. Secondly, we have considered the maximum proximity as a measure of proximity of green products to the country's high RCA products, i.e., the proximity to only one product. Although this measure has its merits, it does not take into account the effect when a given green product has high proximity to more than one high RCA product. Although this does not change the main outcome of our study, i.e., that the maximum proximity is positively related to the growth potential, it might be possible that the green products in close proximity to more than one product may have a better potential to grow than products in close proximity to only one product, *ceteris paribus*. Furthermore, in suggesting to policy makers which green products to support, we do not take into account the environmental impact of the green products but only their economic performance (i.e., growth). Green products, however, can contribute to a different extent to the environmental performance of a country, so that we intend to overcome this limitation in the next step of our research. More sophisticated proximity measures could also be developed in future research to combine, for example, average and maximum proximity.

[1] This is the reason why Hamwey et al. (2013) found some potential for green product development in Brazil, while our study did not.

## Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jclepro.2017.09.190.

## References


Abdon, A., Felipe, J., 2011. The Product Space: what Does it Say about the Opportunities for Growth and Structural Transformation of Sub-saharan Africa? Levy Economics Institute Working Papers No. 670.

Albino, V., Balice, A., Dangelico, R.M., 2009. Environmental strategies and green product development: an overview on sustainability-driven companies. Bus. Strategy Environ. 18, 83–96.

Amurgo-Pacheco, A., Pierola, M.D., 2008. Patterns of Export Diversification in Developing Countries. The World Bank.

Balassa, B., 1986. Comparative advantage in manufactured goods: a reappraisal. Rev. Econ. Statistics 68, 315–319.

Barro, R.J., 1996. Determinants of Economic Growth: a Cross-country Empirical Study. NBER Working Paper 5698. National Bureau of Economic Research.

Baumann, H., Boons, F., Bragd, A., 2002. Mapping the green product development field: engineering, policy and business perspectives. J. Clean. Prod. 10, 409–425.

Berchicci, L., Bodewes, W., 2005. Bridging environmental issues with new product development. Bus. Strategy Environ. 14 (5), 272–285.

Biswas, A., Roy, M., 2015. Green products: an exploratory study on the consumer behaviour in emerging economies of the East. J. Clean. Prod. 87, 463–468. https://doi.org/10.1016/j.jclepro.2014.09.075.

Cadot, O., Carrère, C., Strauss-Kahn, V., 2011. Export diversification: what's behind the hump? Rev. Econ. Statistics 93 (2), 590–605.

Chen, W., Chen, J., Xu, D., Liu, J., Niu, N., 2017. Assessment of the practices and contributions of China's green industry to the socio-economic development. J. Clean. Prod. 153, 648–656.

Commission of the European Communities, 2001. Green Paper on Integrated Product Policy. http://eur-lex.europa.eu/LexUriServ/site/en/com/2001/com2001_0068en01.pdf.

Dangelico, R.M., Pontrandolfo, P., 2010. From green product definitions and classifications to the Green Option Matrix. J. Clean. Prod. 18, 1608–1628.

Dangelico, R.M., Vocalelli, D., 2017. “Green Marketing”: an analysis of definitions, strategy steps, and tools through a systematic review of the literature. J. Clean. Prod. 165, 1263–1279.

De Angelis, M., Adıgüzel, F., Amatulli, C., 2017. The role of design similarity in consumers' evaluation of new green products: an investigation of luxury fashion brands. J. Clean. Prod. 141, 1515–1527. https://doi.org/10.1016/j.jclepro.2016.09.230.

de Bruyn, S., 2002. Dematerialization and rematerialization as two recurring phenomena of industrial ecology. In: Ayres, R.U., Ayres, L.W. (Eds.), A Handbook for Industrial Ecology, pp. 209–222. Cheltenham, UK.

de Medeiros, J.F., Ribeiro, J.L.D., 2017. Environmentally sustainable innovation:

expected attributes in the purchase of green products. J. Clean. Prod. 142, 240–248. https://doi.org/10.1016/j.jclepro.2016.07.191.

de Medeiros, J.F., Ribeiro, J.L.D., Cortimiglia, M.N., 2016. Influence of perceived value on purchasing decisions of green products in Brazil. J. Clean. Prod. 110, 158–169. https://doi.org/10.1016/j.jclepro.2015.07.100.

Donohoe, M., 2003. Causes and health consequences of environmental degradation and social injustice. Soc. Sci. Med. 56, 573–587.

Durif, F., Boivin, C., Julien, C., 2010. In search of a green product definition. Innov. Mark. 6, 25–33.

Eickelpasch, A., Fritsch, M., 2005. Contests for cooperation—a new approach in German innovation policy. Res. Policy 34 (8), 1269–1282.

EUROSTAT, 2009. The Environmental Goods and Services Sector. European Commission.

Felipe, J., Kumar, U., Abdon, A., 2014. How rich countries became rich and why poor countries remain poor: it's the economic structure…duh! Jpn. World Econ. 29, 46–58.

Feng, C., Wang, M., Liu, G.C., Huang, J.B., 2017. Green development performance and its influencing factors: a global perspective. J. Clean. Prod. 144, 323–333.

Fischer, C., Newell, R.G., 2008. Environmental and technology policies for climate mitigation. J. Environ. Econ. Manag. 55 (2), 142–162.

Gazheli, A., van den Bergh, J., Antal, M., 2016. How realistic is green growth? Sectoral-level carbon intensity versus productivity. J. Clean. Prod. 129, 449–467. https://doi.org/10.1016/j.jclepro.2016.04.032.

Hamdouch, A., Depret, M.H., 2010. Policy integration strategy and the development of the 'green economy': foundations and implementation patterns. J. Environ. Plan. Manag. 53 (4), 473–490.

Hamwey, R., Pacini, H., Assunção, L., 2013. Mapping green product spaces of nations. J. Environ. Dev. 22 (2), 155–168.

Hanssen, O.J., 1999. Sustainable product systems – experiences based on case projects in sustainable product development. J. Clean. Prod. 7, 27–41.

Hausmann, R., Hidalgo, C.A., 2011. The network structure of economic output. J. Econ. Growth 16, 309–342.

Hidalgo, C.A., Klinger, B., Barabási, A.L., Hausmann, R., 2007. The product space conditions the development of nations. Science 317 (5837), 482–487.

Hidalgo, C.A., Hausmann, R., 2009. The building blocks of economic complexity. Proceeding Natl. Acad. Sci. 106, 10570–10575.

Hu, L., Tian, K., Wang, X., Zhang, J., 2012. The "S" curve relationship between export diversity and economic size of countries. Phys. A Stat. Mech. Its Appl. 391 (3), 731–739.

Huberty, M., Zachmann, G., 2011. Green exports and the global product space: prospects for EU industrial policy. Bruegel Working Paper.

Kao, P.K., 2012. Environmental Goods and Services Negotiations. Geneva, Switzerland. WTO. In International Trade Policies and Climate Change Governance. SpringerBriefs in Economics.

Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K.-H., Haberl, F., Fischer-Kowalski, M., 2009. Growth in global materials use, GDP and population during the 20th century. Ecol. Econ. 68, 2696–2705.

Lederman, D., Klinger, B., 2006. Diversification, Innovation, and Imitation Inside The Global Technological Frontier. Policy Research Working Papers. The World Bank. https://doi.org/10.1596/1813-9450-3872.

Loiseau, E., Saikku, L., Antikainen, R., Droste, N., Hansjürgens, B., Pitkänen, K., Leskinen, P., Kuikman, P., Thomsen, M., 2016. Green economy and related concepts: an overview. J. Clean. Prod. 139, 361–371.

Maniatis, P., 2016. Investigating factors influencing consumer decision-making while choosing green products. J. Clean. Prod. 132, 215–228. https://doi.org/10.1016/j.jclepro.2015.02.067.

McDonagh, P., Prothero, A., 1996. Green Management: a Reader. The Dryden Press, Harcourt Brace & Company Limited, London, UK.

Narayan, P.K., Smyth, R., 2009. Multivariate Granger causality between electricity consumption, exports and GDP: evidence from a panel of Middle Eastern countries. Energy Policy 37, 229–236.

Nesta, L., Vona, F., Nicolli, F., 2014. Environmental policies, competition and innovation in renewable energy. J. Environ. Econ. Manag. 67 (3), 396–411.

OECD, 2009. Declaration on Green Growth Adopted at the Meeting of the Council at Ministerial Level on 25 June 2009. http://www.oecd.org/env/44077822.pdf.

OECD, 2011. Towards Green Growth. OECD, Paris.

Ofa, S.V., Spence, M., Mevel, S., Karingi, S., 2012. Export diversification and intra-industry trade in Africa. In: Kayizzi-Mugerwa, S., Shimeles, A., Lusigi, A., Moummi, A. (Eds.), Inclusive Growth in Africa. Routledge, pp. 1–61.

Pack, H., Saggi, K., 2006. Is there a case for industrial Policy? A critical survey. World Bank Res. Observer 21 (2), 267–297.

Park, J.H., Seo, K.K., Jang, D.S., 1999. Recycling cell formation using group technology for disposal products. In: Proceedings of the First International Symposium on Environmentally Conscious Design and Inverse Manufacturing. IEEE, pp. 830–835.

Pickett-Baker, J., Ozaki, R., 2008. Pro-environmental products: marketing influence on consumer purchase decision. J. Consumer Mark. 25, 281–293.

Porter, M.E., Van der Linde, C., 1995. Green and competitive: ending the stalemate. Harv. Bus. Rev. 73, 120–134.

Potts, T., 2010. The natural advantage of regions: linking sustainability, innovation, and regional development in Australia. J. Clean. Prod. 18 (8), 713–725.

Rehfeld, K.-M., Rennings, K., Ziegler, A., 2007. Integrated product policy and environmental product innovations: an empirical analysis. Ecol. Econ. 61 (1), 91–100.

Ritter, Á.M., Borchardt, M., Vaccaro, G.L.R., Pereira, G.M., Almeida, F., 2015. Motivations for promoting the consumption of green products in an emerging country: exploring attitudes of Brazilian consumers. J. Clean. Prod. 106, 507–520. https://doi.org/10.1016/j.jclepro.2014.11.066.

Rombouts, J.P., 1998. A knowledge-based system for ranking DfE-options. In: Proceedings of the 1998 IEEE International Symposium on Electronics and the Environment. IEEE, pp. 287–291.

Rose, C., Beiter, K., Ishii, K., 1999. Determining end-of-life strategies as a part of product definition. In: Proceedings of the 1999 IEEE International Symposium on Electronics and the Environment. IEEE, pp. 219–224.

Sonnenschein, J., Mundaca, L., 2016. Decarbonization under green growth strategies? The case of South Korea. J. Clean. Prod. 123, 180–193.

The World Bank, 2016. World Bank Open Data. http://data.worldbank.org/.

UN, 2015. World Population Prospects. New York: United Nations.

UN, 2016a. UN-contrade Database. https://comtrade.un.org/data/.

UN, 2016b. Search SITC Code Description.

UNEP, 2011. Decoupling Natural Resource Use and Environmental Impacts from Economic Growth. http://www.unep.org/resourcepanel/decoupling/files/pdf/decoupling_report_english.pdf.

UNEP, 2004. How to Establish and Operate Cleaner Production Centres. http://www.unep.fr/shared/publications/pdf/WEBx0072xPA-CPcentre.pdf.

Vikhlyaev, A., 2004. Environmental goods and services–defining negotiations or negotiating definitions? J. world trade 38, 93–122.

Wang, Z., Zhang, B., Zeng, H., 2016. The effect of environmental regulation on external trade: empirical evidences from Chinese economy. J. Clean. Prod. 114, 55–61.

Weber, C.L., Peters, G.P., Guan, D., Hubacek, K., 2008. The contribution of Chinese exports to climate change. Energy Policy 36, 3572–3577.

Wiedmann, T.O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J., Kanemoto, K., 2015. The material footprint of nations. Proc. Natl. Acad. Sci. 112 (20), 6271–6276.

Williams, C.C., Millington, A.C., 2004. The diverse and contested meaning of sustainable development. Geogr. J. 170, 99–104.

Wüstenhagen, R., Bilharz, M., 2006. Green energy market development in Germany: effective public policy and emerging customer demand. Energy Policy 34 (13), 1681–1696.

Yadav, R., Pathak, G.S., 2016. Young consumers' intention towards buying green products in a developing nation: extending the theory of planned behavior. J. Clean. Prod. 135, 732–739.

Yu, T., Yu, T., Chao, C., 2017. Understanding Taiwanese undergraduate students' pro-environmental behavioral intention towards green products in the fight against climate change. J. Clean. Prod. 161, 390–402.