Entre Transições

Retrospetivas – Transversalidades – Perspetivas

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Challenges and opportunities of decarbonization for the economic recovery post-pandemic: The question of directionality in innovation policies[1]

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Abstract

Countries face a double challenge of unprecedented scale consisting in drastically reducing carbon emissions in the time of a generation, while recovering the economy from the worst pandemic crisis in a century. Innovation is key in the response to this double challenge. Innovation policies are increasingly directed at achieving both goals, as governments seek opportunities for transforming the economic structure along with decarbonization. We raise the question of the effect of the direction in the success of the policies for the sustainability transition to achieve the economic transformation.

We start by analyzing the processes of change in the economic structure. We identify three possible strategies of transformation: decarbonization, dematerialization and digitalization. Then we compare the evolution of the economic complexity of Portugal, which aspires to transform its economy, with that of three countries that are respectively reference in each one of the three strategies: Denmark, The Netherlands, and Ireland. Successful strategies evidence specialization in products that involve extensive and sophisticated knowledge, produced with high connectivity to other activities and with low carbon footprint.

Based on these results and informed by the theory, we propose a set of conditions—related to the promotion of connectivity to growing sectors, high social return technologies and variety—that need to be aligned in the direction of the policies in order to increase their potential for transformative change.

Palavras-chave: economic complexity, innovation, recovery, decarbonization.

JEL codes: 014; 024; O38.

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Introduction

Countries face a double challenge of unprecedented scale consisting in drastically reducing carbon emissions in the time of a generation, while recovering the economy from the worst pandemic crisis in a century. Innovation is key in the response to this double challenge (Schot & Steinmueller, 2018). Innovation policies are increasingly directed at achieving both goals, as governments seek opportunities for transforming the economic structure along with decarbonization (Mazzucato, 2018; Altenburg & Rodrik, 2017). But the strong directionality can affect technological variety (Hekkert et al., 2020) and can limit the opportunities for new actors to enter with new solutions, creating new lock ins (Geels, 2014; Sabatier, 1988).

The study reflects on the socioeconomic effects of the different strategies for the transition to a low carbon society that comply with the Paris Agreement, whose implementation requires the transformation of several sectors in addition to energy, such as mobility, construction, food and industry (IPCC 2018). This sectoral transformation poses challenges to the development of countries, which are particularly pressing at a time when states have to accelerate decarbonization with more fragile finances and the need to relaunch the economy after the pandemic crisis. This is the time to investigate the conditions under which sustainable transitions can have broader socioeconomic effects, generating transformative changes in the economy (Weber and Rohracher, 2012), a crucial issue that is still little explored in the literature (Andersen et al, 2020).

To assess the transformative potential of different strategies or pathways of transition, we mobilize a combination of theories, including socio-technical transitions (Köhler et al., 2019; Markard et al., 2012) and economic geography (Boschma, 2017; Asheim et al., 2011). The ability to induce change in other sectors is contingent upon a multiplicity of factors. This change depends on the dynamic industrial and institutional structures that make up the context (Isaksen & Trippl, 2016), on the adaptation of technologies that can drive profound changes in the existing sectors (Dolata, 2009), or on the recombination of existing knowledge (Janssen & Frenken, 2019), related or not related (Boschma et al, 2017). In addition, strong complementarities with the context can accelerate technology development and system change (Markard & Hoffmann, 2016; Bergek et al., 2015).

The role of the state in promoting the transition is far from being consensual. One perspective, namely defended by the international organizations such as the World Bank, maintains that a climate crisis would be resolved with the adoption of market mechanisms that create a carbon price capable of internalizing as environmental externalities in the decisions of economic agents. Another perspective opposes with the market failures (Finon, 2019) and suggests a more interventionist approach by the state, around pre-defined missions in order to promote a sustainable and timely transition (Lamperti et al. 2019; Hekkert et al., 2020; Mazzucato, 2018). We situate in the intersection of industrial and climate policy, to focus on the characteristics that directionality should have to avoid the loss of variety and steer the transformation towards a sustainable low-carbon economy.

This research focuses on the types of transitions that are the most beneficial to the economy, namely with the capacity to generate changes in other sectors. The objective of the study is to identify the areas that will be the most affected by decarbonization and to analyze possible paths the transition can take and the respective transforming resources. The central question is what conditions the direction of innovation should have, to grasp the opportunities of decarbonization for the post-pandemics recovery? We develop a new version of the economic complexity model (Hidalgo, 2018) to analyze the low-carbon transformation of the economic structure, and discuss the implications for the direction of policies that increase the transformative potential of sustainable transitions.

This study provides an initial contribution to the discussion about the socioeconomic impacts of the different strategies for a low-carbon transition, and the role played by the directionality of policies aiming at sustainable transformation.

1. Challenges of the decarbonization for the economic recovery

The first step to discuss climate and industrial policy is to understand the bottlenecks in terms of sustainability. So, what are the challenges to the green recovery in a specific geographical and temporal context? To address this question, we start by adopting a broad perspective on sustainability, analyzing a wide set of parameters that can define green growth. It then puts the focus on the effect of the reduction of carbon intensity in industry, attempting to identify the sectors that are more exposed to carbon price in the climate policy, those sectors will be from now on the “exposed sectors”. The challenges to green recovery are thus addressed from both a structural and an industrial standpoint.

1.1. Green recovery requires structural change

1.1.1. Green growth needs

Which are the structural changes necessary to improve sustainability in a country? Inspired by the Sustainable Development Goals, sustainability can be addressed along several dimensions: carbon, energy, land, material and R&D support (data sources at Table 1). This broad approach takes into consideration how economic activity contributes to climate change, measured through carbon intensity of production. It also comprises energy in other three ways: the share of renewable sources in the national electricity mix, fossil fuel support, and the land and material utilization (embodied energy). Finally, it considers the importance of environmental issues in research and development policy.

To proceed with the multidimensional analysis of sustainability, the research used OECD databases to obtain data on six parameters that permit to connect the economic activity with the aforementioned sustainability indicators. The first parameter is the carbon intensity of production that indicates the amount of carbon emitted, measured in monetary units. The second is the share of renewable energy sources in the electricity supply, to assess how renewable the supply of energy is. The third measures the level of expenditures on mechanisms to support fossil fuels as a proportion of the country gross domestic product (GDP). The fourth is related to land use and conservation. It measures how modified were the natural areas in a specific period, comparing the periods of 1992 to 2004 (initial years) and 2004 to 2018 (final years). The fifth is related to the material flows in the society. It measures the amount of goods necessary to produce one monetary unit of value, reflecting the material intensity of production. The sixth compares environment-related research and development (R&D) expenditures with total R&D expenditures, to assess how important the environment is in scientific and innovation policies, in a specific context.

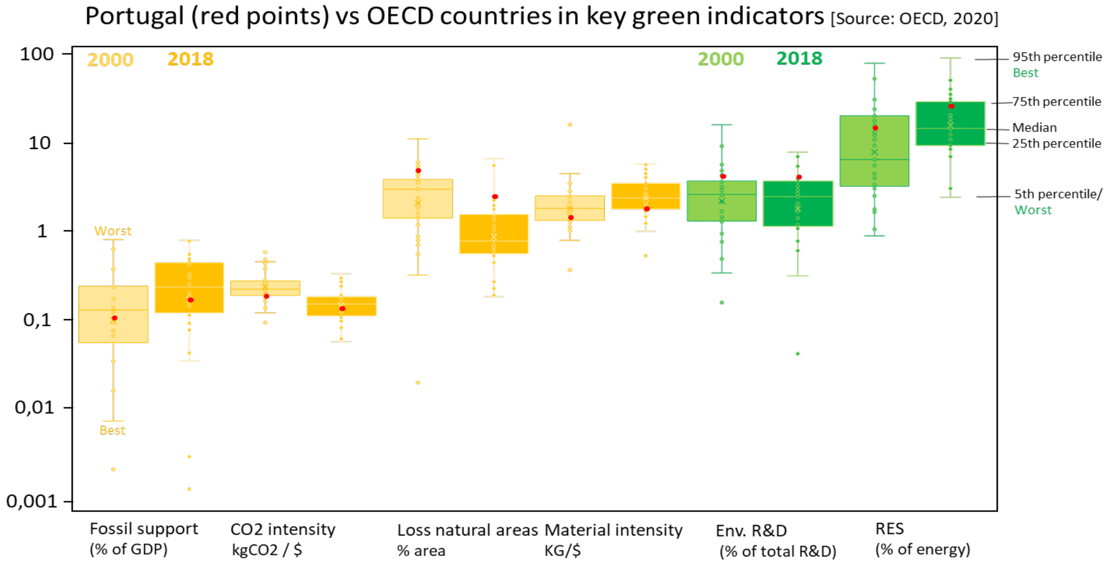
Parameter	Data	Source	Treatment
CO2 Intensity	CO_2 emissions / GDP using purchasing power parities	(IEA 2020a)	-
RES% energy	Renewables and waste total energy supply (ktoe) / total energy supply (ktoe)	(IEA 2020b)	Renewables and waste (ktoe) divided by total energy supply (ktoe)
Fossil support	Fossil fuel support expenditure (national currency) / GDP (PPP)	(OECD 2020a)	44 datasets, one for each country. Sum of expenditures in each year, each country. Consolidation in one sheet and divided by GDP (PPP) in national currency.
Loss of natural areas	Percentual change of natural and semi-natural vegetated land in total – from 1992 to 2004, and from 2004 to 2018	(OECD 2020c)	-
Material intensity	Material productivity (Gross domestic product per domestic material consumption (2015 PPP))	(OECD 2020d)	Material intensity is the inverse of material productivity
Env.R&D	Government budget allocations for environmental R&D	(OECD 2020b)	The total environment budget was divided by the total budget for R&D

Table 1 – Parameters, data and treatment
Source: own work

The indicators are represented in a "Whisker and Dot" graph in a logarithm scale for the relevant measures shown in the X-axis (Graph 1). They are divided into two groups of parameters: "as great as bad", represented by the yellow bars at the left-hand side, and "as great as good", represented by the green bars at the right-hand side. The first group comprises CO2 intensity, fossil fuel support, loss of natural areas and material intensity. The second group includes the share of renewable sources and the share of environmental R&D support. Finally, the graph compares side by side the values of the indicators in 2000 (lighter colors) and 2018 (heavier color).

Graph 1 shows the sustainability situation of the OECD countries and highlights the case of Portugal (in red), an intermediate developed economy that experienced austerity measures twice in the past two decades.

The analysis of the six sustainability indicators shows a general improvement between 2000 and 2018. In the past two decades, there was a reduction in the carbon intensity and in the loss of natural areas. The share of renewable energy in final energy consumption improved, particularly in Portugal. The expenditure in environmental research and development remained stable, although at low levels. However, the situation has clearly worsened particularly in two areas. We observe an increase in the support to fossil fuels. Concerning material intensity, the volume of material needed per unit of value generated was higher in 2018 than in 2000. The analysis already shows some of the domains that need improvement and add to the climate targets for 2030 and 2050.



Graph 1: Portugal (red points) vs OECD countries in key green indicators
Source: Own elaboration with data from OECD (2020)

1.1.2. Structural areas at climate and economic risks

Which sectors are the most exposed to mitigation of climate change and to the effects of the pandemics? Exposure is addressed in two ways: in terms of the carbon intensity of the main activities in the country specialization (by analyzing export data), and in terms of the pandemics' impact on production by sector. This research differs from other approaches (Fraccascia et al., 2018; Mealy & Teytelboym, 2020) by considering all economic sectors (not only the "green" products or sectors) under a single parameter: the carbon intensity of the added value of each industrial sector.

Three steps were followed to achieve a first identification of exposed sectors: (i) we obtained the country's exports basket from the Atlas of Economic Complexity explorer (The Growth Lab at Harvard University 2019); (ii) we estimated the sectoral carbon intensity relative to the gross added value of the sector using data from Eurostat (Eurostat, 2020a); (iii) we measured the sector resilience to the pandemic shocks through the variation of quarterly industrial activity, using national statistics data (INE, 2020b).

The exports basket was compared with the carbon intensity by overlaying layers in a Treemaps graph. We depict the carbon intensity of the sectors by using a system of four color bands: the first band (in green) goes up to 200gCO²eq/€, corresponding approximately to the European average (252.55g / €(2018) for EU28); the second band (in yellow) goes from the upper limit of the previous band up to the double of the European average (around 400gCO2eq/€); the third band (in orange) from there up to 10 times the European average (2000gCO2eq/€); and the fourth band (in red) for sectorial carbon intensities higher than this threshold. To assess the cyclical effects of the pandemics, we compared the homologue variation of the industrial production index between the second quarter of 2019 and the second quarter of 2020. Three categories were considered according to the severity of the impact: sectors in which the reduction in the industrial activity was below 25%; sectors in which the reduction was between 25% and 50%; and sectors in which the reduction was higher than 50%.

Graph 2 summarizes the evolution of the weight of the sectors in exports, the sectoral carbon intensity and the variation in industrial activity between 2000 and 2018. Comparing the economic structure as represented by the structure of exports, that is the weight of the products in the export basket for the years 2000 and 2018, it is possible to observe that the textile industry reduced its importance from 24% of the exports in 2000 to only 15% in 2018. In the opposite direction, the share of transport material (vehicles) slightly increased from 13% in 2000 and to over 14% in 2018. And the chemical industry (a carbon intensity activity) gained weight, increasing from 7.5 to 15% of the exports.

The second information in Graph 2 concerns carbon intensity. Green indicates that carbon intensity is below the European average. In the period between 2000 and 2018, we observe an increase in number of less carbon-intensive sectors, as well as an increase in their part in the exports. This finding points to a reduction in the carbon intensity of the exporting sectors, through lowering emissions of the activities and (to some extent) structural change.

Graph 2: Portugal Treemap of exportation by product
Source: The Growth Lab of Harvard University, INE and Eurostat

The third set of information concerns the effect of the pandemic crisis. The most exposed sectors in the decarbonization process are not necessarily the most affected by the pandemics. The pulp and paper sector, a carbon-intensive sector which is relevant for exports, showed some resilience to the pandemic crisis. Conversely, the sectors that were the most strongly affected by the pandemics are not the ones with the highest carbon intensities. The vehicle sector, which is important for exports and relatively low carbon intensive, was highly affected by the pandemic. Therefore, the pandemic crisis came to aggravate the vulnerabilities of the country, adding the needs of the economic recovery to the existing pressures for the low-carbon transition.

A second way to identify sectoral exposures is considering the whole industrial production, including the domestic consumption. By doing this, it is possible to have more details in terms of the gross added value and number of employees of each sector, although with less sectoral granularity. Table 2 complements the previous analysis and shows the exposure of the central sectors in the Portuguese economy to a change in climate policy. It presents indicators of the economic performance by sector of economic activity, namely the value added, the number of employees and the sector emissions (INE, 2020a).

The data show a large variety of situations in terms of carbon intensity (CO2eq/Added value), ranging from 46 kg CO2eq/ ‘000 euros in vehicles to 2,439 kg CO2eq/ ‘000 euros in chemistry. Similarly, the carbon emission per job is two orders of magnitude higher in the chemical sector than in the vehicle sector.

A systemic perspective is needed to understand the potential socioeconomic impacts of more stringent climate policy. The impact of sectoral transformation on employment should be quite diverse. For example, food industry and construction have a similar level of emissions, but the latter employs three times more people than the former. Therefore, production reductions will have greater impacts on the employment intensive sectors.

Sector		**Added value-AV**	**Employees-N**	**GHG emissions**	**CO2eq/AV**	**CO2/N**
Description	**NACE R2**	**millions euros**	**thousands**	**ton CO2eq**	**kg CO2eq/ ‘000 euros**	**kg CO2eq/ job**
Food and beverage	10_12	4 263	109	1 173 208	275	10 754
Textile	13_15	4 266	205	776 037	182	3 784
Paper and pulp	16_18	2 600	69	1 742 517	670	25 145
Chemistry	19_23	4 258	104	10 384 953	2 439	99 568
Metallurgic	24_25	3 019	115	453 451	150	3 946
Machines and equipment	26_28;33	2 982	84	405 315	136	4 831
Vehicles	29_30	1 985	92	90 930	46	985
Furniture	31_32	1 232	55	70 301	57	1 276
Construction	F	7 464	307	1 326 211	178	4 320

Table 2: Portugal environmental and economic indicators

Source: INE, Eurostat

1.2. Process of change in the economic structure

How is it possible to achieve a green transition? More specifically, how does the structural change for the low carbon transition and economic recovery take place? These questions are timely as the European Union decided to dedicate 37% of the recovery funds to the green transition.[2] In Portugal, the Recovery and Resilience Plan (PRR) devotes 21% to energy transition and 18% to digitalization, according to the document submitted to public consultation (Ministério do Planeamento, 2021).

We adopt a novel approach that combines economic complexity with structural change analysis in two types of analysis. The first one (Section a.) looks at the relative position of the low/high emitting products in the international specialization of the countries (i.e. the product space). We combine the information on the products in which Portugal has a relevant competitive advantage (Revealed Comparative Advantages, RCA, greater than 2) with the carbon intensity of these products. The objective is to assess whether the most carbon-intensive products occupy a central or peripheral position—i.e. among the most competitive products or not—in the product space network. The second one (Section b.) assesses the importance of the lowest/highest emitting sectors in the export structure (here proxy of the economic structure). We relate the information on both the connectivity of the sectors (number of links) and their complexity (product complexity index) to the carbon intensity of the sectors. The goal here is to examine whether the most carbon-intensive sectors are central or peripheral in the economic structure. These analyses are conducted for Portugal and for three other countries which have undergone different types of strategies—the Netherlands, Ireland and Denmark—and performed for two points in time, 2000 and 2018.

1.2.1. Carbon intensity and economic complexity

What is the relationship between the carbon intensity of activities and the complexity of the economy? A Product Space for Portugal was built to identify the carbon intensity and the connectivity of sectors according to the economic complexity framework. The structure of the Product Space network (X and Y and connections between nodes) was obtained from *www.michelecoscia.com* and plotted using the network analysis software *Cytoscape*.

In the product space, nodes correspond to products (866) and links represent the probability of two products being co-exported. A table was built with the attributes of the nodes: the revealed comparative advantage (RCA) in Portugal in 2018; and the carbon intensity. It was necessary to solve data compatibility issues in order to build these datasets. Data for RCA are in HS (harmonized sectors) (The Growth Lab at Harvard University (2019), while data for carbon intensity and economic activity are in NACE Rev2, so NACE data had to be converted to HS. Box 1 explains the procedure followed to convert the NACE codes into HS codes.

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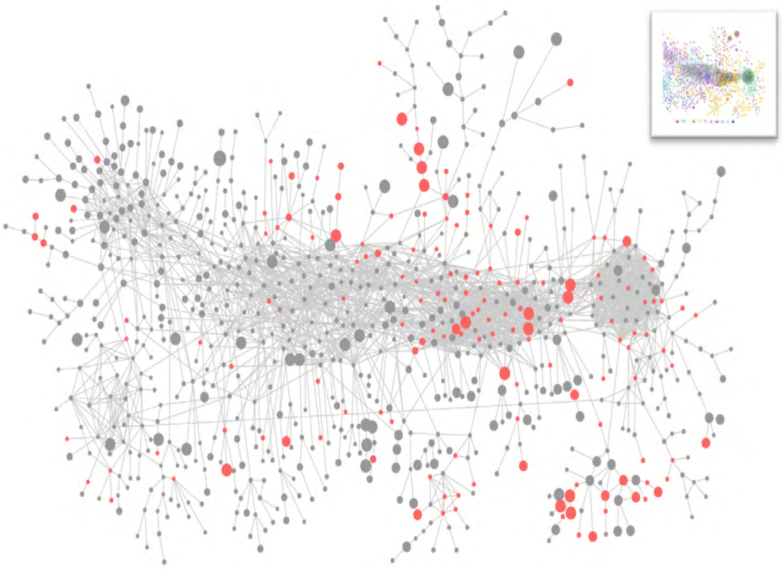
[2] https://www.euractiv.com/section/energy-environment/news/eu-agrees-to-set-aside-37-of-recovery-fund-for-green-transition/ (last access 30/3/2021).

Box 1. Conversion between different classifications of economic activity (HS-NACE)

Carbon intensity data was only available at two digits, it was necessary to systematically analyze and compare the description of each sector at 4 and 2 digits in order to make the conversion (Eurostat, 2008). The first step was to organize the 866 sectors of economic complexity databases in HS92 with four digits by the two first digits. The second step was to make subsets of sectors, one for each of the 85 categories of HS at 2 digits. The third step was to analyze the description of each sector (at 4 digits) that were at each subset and find the best fit of NACE at 2 digits category by comparing the description of both, the subset and the NACE at 2 digits. The table is available upon request for reasonable purposes.

An alternative attempt to perform the conversion was made with less success using the RAMON (Reference and Management of Nomenclatures) system of Eurostat. The HS1992 codes were converted to SITC (Standard International Trade Classification); then the SITC codes were converted to ISIC (International Standard Industrial Classification of All Economic Activities) codes and finally, the ISIC codes were converted to NACE codes. After the whole conversion processes, some random sectors were selected to compare the description of HS and NACE codes to verify the validity of the approach, but the number of mismatches found was significant.

The 2018 Portuguese product space has a large number of sectors (153) with revealed comparative advantages greater than 2, as shown in Graph 3. In comparison, in the same year, the product space of The Netherlands only includes 121 sectors. Sectors with comparative advantages (red dots) are in the central and peripheral zones. Concerning the connections of the sectors and their carbon intensity, the analysis shows that, in the Portuguese case, the most carbon intensive sectors are not the ones in the most central position, i.e. the most related to other sectors.

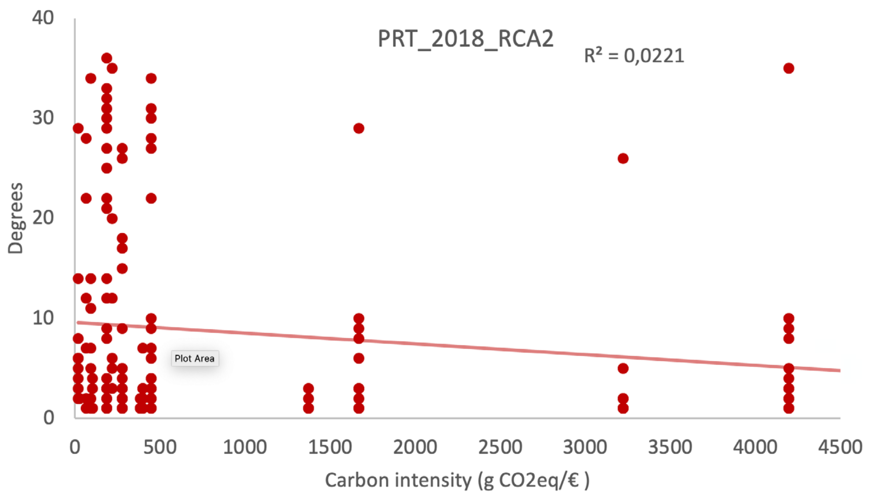


Graph 3: Portuguese Product Space with carbon intensity (size) and RCA>2 highlighted in red
Source: The Growth Lab of Harvard University and OECD.

The results show that the most carbon-intensive sectors occupy a more peripheral position. This can be interpreted as a positive sign. Still, a more in-depth analysis is necessary to understand how Portugal could diversify towards low-carbon products with a lower ubiquity (rarer specialization of the countries, i.e. more valuable) like machinery and electronics. Other possible positive evolutions would entail diversifying towards sectors that are highly connected and have low carbon intensity, or (more risky) diversifying towards sectors with high carbon intensity, to innovate in order to produce in a less carbon intensive manner.

In order to further understand the relationship between connectivity and carbon intensity, the paper investigates whether the more connected sectors (in which the country has comparative advantages) are more or less carbon-intensive. For this, we created a Cartesian plot (Graph 4) in which each dot represents a sector positioned according to its number of linkages (degrees) in the product space (as presented in Graph 3) and its carbon intensity.

For Portugal, in 2018, the majority of the competitive sectors are not carbon-intensive. The most carbon-intensive sectors are not very connected, so the slope of the linear trend line is declining, indicating a negative relationship between connectivity and carbon intensity.



Graph 4: Comparison of the connectivity of sectors and their carbon intensity
Source: The Growth Lab of Harvard University and OECD

1.2.2. Comparing strategies of economic transformation

What are the possible strategies for transformation towards a low carbon economy? It has been argued that there are three generic strategies which can help in the economic transformation of countries, in order to achieve the goal of limiting the rise in the temperatures to 1.5°C (Grubler et al., 2018): energy transition, dematerialization and digitalization.

The energy transition refers to the substitution of fossil energy (oil, gas, coal, etc.) by renewable energies (wind, solar, etc.) as the main sources of primary energy. Denmark is a reference in energy transition, particularly in the decarbonization of electricity production. The share of renewable energy in total energy supply increased from 7% to almost a third (31%) between 1990 and 2019.[3]

The process of dematerialization consists of a reduction in the consumption of material goods due to a lower material intensity, or a change in consumption patterns. An example of dematerialization is the Netherlands, which had a 18% reduction in domestic consumption of materials between 2000 and 2019, compared to only 4% of the average in the other European countries (EU27) (Eurostat, 2020b).

Digitalization refers to the growth of Information and Communication Technologies (ICT) in the economy. This can be measured using composite indicators, including several parameters such as connectivity, human capital, use of internet services, integration of digital technologies and digital public services. A good example of digitalization is Ireland, the European country with the highest growth in the Digital Economy and Society Index (DESI) in the last five years (European Commission, 2020). Policy mechanisms such as “Success in integrating digital technologies”, one of the pillars of industrial policy, and “Encouraging SMEs” were determinant in the Irish success.

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3 https://www.iea.org/countries/denmark (last access on 30/3/2021).

We analyze the three strategies comparing the case of Portugal with the three representative countries (Denmark, the Netherlands and Ireland), for the years 2000 and 2018.[4] The Cytoscape programme was again used to calculate the number of connections of each node. Using the data on the number of connections and the carbon intensity of each node, by country and by year, it is possible to identify the most competitive sectors of these economies that have the highest carbon intensity, and how connected or influential they are.[5] Graphically, the carbon intensity of sectors was combined with the number of connections in these sectors and a best fit equation was plotted showing the respective R^2 for 2000 and 2018.

Following this approach, each of the 866 products may (or may not) be produced by each country in each year (we only included those with RCA greater than 2). Each product has a connectivity (number of linkages) that is fixed, and a carbon intensity that varies by country and by year. Graph 5a shows the relation between connectivity and carbon intensity in the four countries (by colour) for two periods, 2000 and 2018, the first year as a slashed line and the final year as a solid line. The inverse relation for the countries under analysis implies that more carbon intensive countries show lower connections. In addition, the number of connections decreased more in the high carbon intensive sectors than in the less carbon intensive sectors between 2000 and 2018, for all countries except Denmark.

The more complex economies are those that can produce more complex products, besides producing diverse products. The complexity of products indicates both the ubiquity of the product and the diversity of countries that produce it, and is measured by the product complexity index or PCI. A higher value for the PCI denotes the production of more technologically sophisticated products (Mealy and Teytelboym, 2019). Graph 5b shows the relation between the carbon intensity of the sectors and the PCI. It shows how the products that Portugal produces are consistently less complex (technologically sophisticated) than those produced by the other three countries for all levels of carbon intensity.

Finally, Graph 5c synthesizes the previous graphs showing the PCI combined with the degrees. This metric indicates the effect of the product complexity after considering the level of connectivity of the sectors. The relation between this indicator (connectivity and complexity) and carbon intensity reveals the effect of the less or more pollutant sectors in producing highly connected and complex products. In 2018, Portugal showed the worst results for all levels of carbon intensity while Ireland presented the best scores. Though Portugal improved the results for the low carbon intensity sectors between 2000 and 2018, they are still far from the scores seen in the other countries.

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4 2008 and 2017 were used in the case of carbon intensity, for data availability reasons.

5 Data on carbon intensity for Ireland are limited by an industrial protection decision. The most recent Eurostat data on sectoral carbon intensity is from 2008 and only for some sectors. Thus, the research used data from the Irish national statistical agency, combining data from three reports (CSO 2020a, CSO 2020b, CSO 2010) in which it is possible to find data similar to those found in Eurostat for the same years.

Box 2. Complexity and connectivity indicator

This work provides a new indicator for sectorial relevance in the country's economic structure, a complexity_connectivity indicator. This indicator results from the product of the number of degrees of each sector (connectivity) by the product complexity index of that product at that year(complexity). Formally it would be for each year:

$$CC_{sn} = degrees_s * PCI_{sn}$$

Where **CC**$_{\mathbf{sn}}$ indicates the complexity_connectivity of sector **s** in year **n**. The **degreess**, indicates the number of links of sector s in the product space and **PCIsn** is the product complexity index of sector **s** in the year **n**.

This parameter is joint with the carbon intensity of each sector s in each year **n** for each country **c**. In graph 5c, the lines are the fits of the set of complexity_connectivity and carbon_intensity points. Formally:

$$P_{scn} = (CC_{sn}, CI_{scn})$$

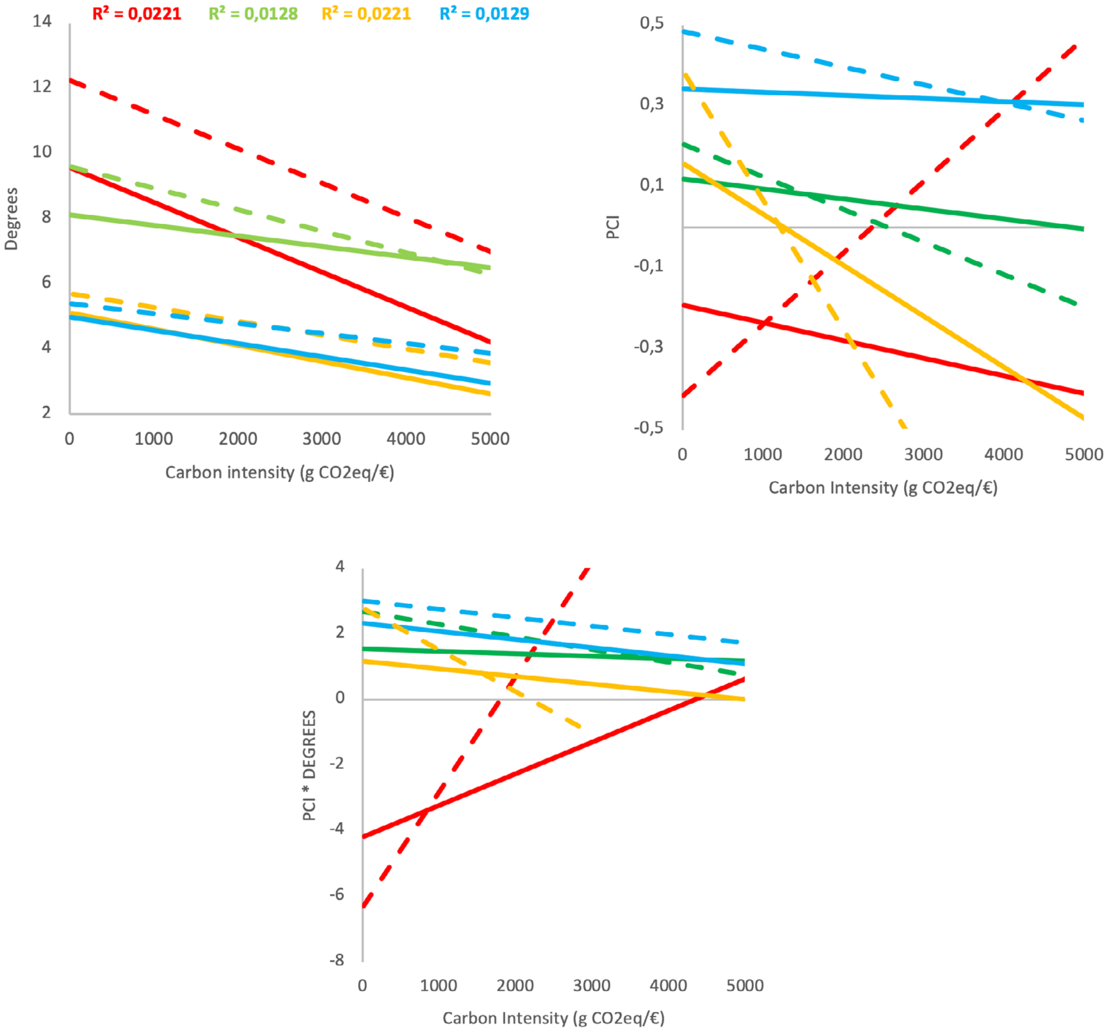
Where **P**$_{\mathbf{scn}}$ is a pair of complexity_connectivity and carbon_intensity points and **CI**$_{\mathbf{scn}}$ is the carbon intensity for sector **s** in country **c** in year **n**. It is worthy that the number of degrees is an intrinsic feature of the sector in the product space; what varies is whether the country is competitive or not in that sector in that year (RCA>2). The PCI varies from year to year and is constant in all countries for a specific sector.

This approach is under the "umbrella of economic complexity" because it considers that the identity of the elements (in this case, the sectors) and their interaction are relevant (Hidalgo, 2021). The identity here is the connectivity and complexity features combined that matter to analyze the sectorial carbon intensity.

The decarbonization of an economy happens in two ways, when the carbon intensity of the sectors is reduced, the best situation, or when the development of the economy goes in the direction of the less intensive carbon sectors. In the latter, the trajectory change can affect the country's diversification choices, especially to more complex products. For example, in a country where the connectivity_complexity is directly related to sectors' carbon intensity, a specific industrial policy promotes a shift to less carbon-intensive sectors. However, this new sector or sector targeted is more peripheral or less connected and less technologically sophisticated or complex. In the medium and long term, the consequences for the development of that economy could be detrimental in terms of diversification options.

A positive relation between complexity_connectivity and carbon_intensity indicates that the more connected and complex sectors are also the more significant emitters. On the other hand, if the relationship is negative, the better positions in terms of complexity_connectivity are less intensive in carbon and consequently less exposed to a carbon price.

Comparing the three main strategies described above, the Netherlands (dematerialization), Ireland (digitalization) and Denmark (energy transition) showed similar trends in 2018. These trends become flatter from 2000 and 2018 for the Netherlands and more striking for Denmark. Even though these results can vary every year, mainly because of the changes in the more conjunctural indicator (PCI), the relative position of the countries is unlikely to significantly change in the short term. Therefore, and given the similarity of results and evolution of the three countries representative of the generic strategies, we conclude that the three strategies present positive effects but there is not one that stands out. Instead, decarbonization may adopt a combination of the three strategies. Based on these results, we will discuss the conditions for the directionality of the policies to influence the pace of innovation and transition in the next part.



Graph 5: Connectivity and carbon intensity of products, 2000 and 2018
Portugal (red), Netherlands (yellow), Denmark (green) and Ireland (blue)
Source: The Growth Lab of Harvard University and OECD

2. Conditions for the direction of innovation policies to grasp the opportunities of decarbonization for the post-pandemics recovery

2.1. Promoting connections with growing sectors

How to achieve structural change, minimizing impacts on activities that have a strong weight in the economy but are threatened by decarbonization? A strategy for attaining this goal is to mobilize the new technologies to induce transformative changes in these exposed sectors (Andersen et al., 2020; Fontes et al., 2019).

This can be accomplished by opening a space of connection between the exposed sectors and new sustainable ones, facilitating processes of cross-fertilization. Along these processes, competences and resources present in the exposed sectors can be re-used and upgraded through their (re)combination with knowledge present or being developed in the new ones, supporting diversification strategies (Dolata, 2009; Janssen & Frenken, 2019; Makitie et al., 2020; Malhotra et al, 2019).

It is therefore important to strengthen new sectors or growing sectors, namely sectors identified as having transformative potential in contexts that engaged in successful decarbonization trajectories, as well as to create a context favorable to connections between them and exposed sectors. In this way, it is possible to promote hybridization processes that can lead to the reconfiguration of activities or the creation of completely new ones. This can ultimately result in an increase in competiveness of both growth and established sectors, along more sustainable trajectories.

An example of these transformative processes can be found in the ongoing interaction between the emerging marine renewable energy technologies (offshore wind and wave energy) and a number of established sectors that are providing complementary resources and competences to the experimental projects being conducted in Portugal (see Box 3). Previous research has shown that such interaction has already led a number of companies, from a variety of sectors, to engage in innovative activities in answer to the new needs created and that, in some cases, these activities have also induced organizational changes in the supplier companies (Fontes et al, 2019).

Box 3. : Transformative interactions in Marine Renewable Energy Technologies (MRET)

Incidence: 127 firms identified as involved in collaborative or supplier relationships with MRET.

Principal sectors: Metalwork; Transport equipment; Transportation services; Installation & Repair or Wholesale of Machinery and Equipment; Electricity production; Engineering; Consultancy; Professional & Scientific Activities.

Survey: 64 firms involved in MRET provided evidence of some change effects of interaction:

Innovation: 42 firms (66%) were engaged in innovation activities targeting MRET, of which 29 are developing new products/services & 13 adapting existing ones.

Organizational changes: 38 firms (60%) introduced changes as a result of MRET oriented activities, in particular: development of new competences through recruitment or training of human resources; establishment of new partnerships/alliances; material investments; reorganization of product portfolio.

Future perspectives can reinforce these effects: 96 other firms expressed willingness or interest in becoming involved with MRET in the future, 74 of which envisaging engagement in dedicated innovative activities. This data confirms the interest of the above mentioned sectors, but also reveals the potential interest of a still largely absent sector: Manufacture of Machinery and Equipment, including Electronic Equipment.

Therefore, the strategic approach to sustainable transformative change can involve the following measures: strengthen sectors with transformative potential; establish or reinforce their links with exposed sectors; support diversification processes and the creation of new "hybrid" activities. At the minimum, for transformative effects, the direction of innovation policies should provide the conditions to promote effects in the other sectors.

2.2. Prioritizing technological alternatives with the highest social returns

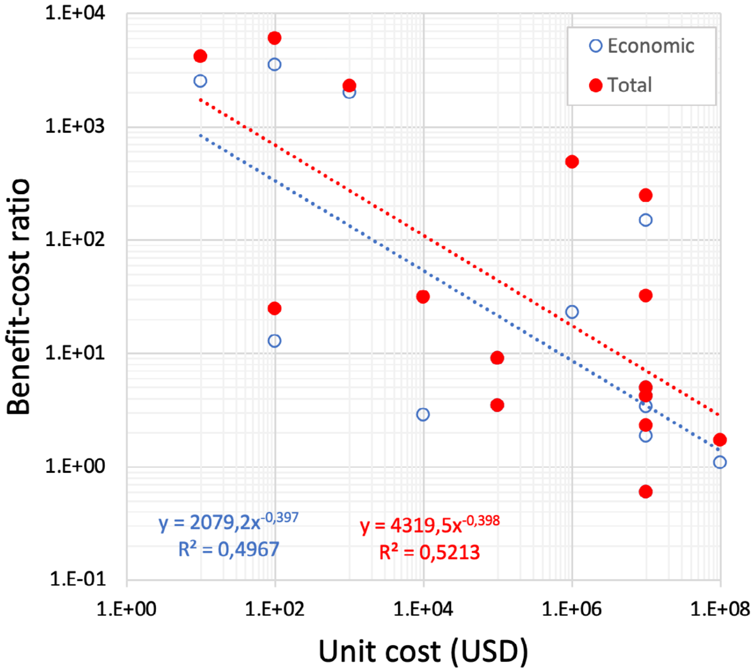
How to define the technology strategy in order to maximize transformative impact? The complexity of the sustainability challenges requires a science, technology and innovation policy capable of transforming the socio-technical systems (Schot and Steinmueller, 2018). The socioeconomic spillovers (activity, job creation, productivity increases, etc.) are an important dimension to consider in the definition of the technology strategy, particularly in the context of economic recovery.

Previous research in sustainable transitions already shows some factors which are favorable to increase the socioeconomic spillovers. In a study about the growth of onshore wind energy in

Portugal, Bento & Fontes (2016) identify the following conditions for success: wind technology created opportunities for suppliers from a large spectrum of different sectors and competition; shared benefits to local communities (e.g. a part in the revenues return to the municipalities); and used knowledge available locally that was developed across time through experimentation projects.

The characteristics of the investments can affect the social returns. Wilson et al. (2020) review the historical evidence about the relation between the scale of technology innovations and the outcomes in several dimensions (rate of diffusion, cost improvements, etc.). The authors argue that successful transformations in the past present at least three characteristics: rapid technology deployment, escaping lock-in and social legitimacy. The analysis of the evidence shows that small, more granular technologies consistently present advantages in these three domains (Wilson et al., 2020).

In particular, the authors compare the social benefit to cost ratio by scale of technology innovations. Social returns include the economic returns of the technology innovations and contributions to other important economic aspects such as security of supply and reduction of environmental externalities, and thus might be an important determinant of social legitimacy (NRC, 2001). Graph 6 shows strong evidence that smaller technologies present consistently higher benefit-cost ratios than larger technologies.



Graph 6: Social returns of several technologies in terms of their benefit-cost ratio. Source: Wilson et al. (2020) and NRC (2001).

Therefore, these insights about the relevant dimensions and determinants of the social returns of technologies are helpful to assess the directions of the innovation policies and activities. For example, the multiannual Portuguese investment programme for 2030 has 13 billion € to distribute between several projects in the energy field. The main project is the 1GW hydrogen plant in Sines with an estimated cost of 2,850 billion €, representing 22% of the total planned investment for 2030. Independently of the merits that such a project can have to improve the sustainability of the existent system, the arguments under which the decision is based should demonstrate clear evidence that this investment ensures a rapid deployment low-carbon capacity, overcomes existing lock ins (without creating new ones) and enjoys of social acceptability. More generally, these three criteria should apply to every technology policy to ensure allocation to the projects with the highest social returns, for which the benefits generated over their lifetime are the greatest comparing to the costs.

2.3. Promote variety and economic transformation

A final dimension to assess the directionality of innovation (and of policy intervention) deals with the capacity to accelerate the transformation of the economy. More specifically, how to use technological change as a lever of industrial policy? This raises another related question that is: how to design a strategy to address societal and economic goals without creating new types of lock ins?

Industrial policy directs efforts to promote the allocation of the resources into promising sectors. In the current context of climate urgency, these policies should promote the decoupling of the economic growth (and human well-being) and pollutant emissions. Green industrial policies have been defined as “any government measure aimed to accelerate the structural transformation towards a low-carbon, resource-efficient economy in ways that also enable productivity enhancements in the economy” (Altenburg & Rodrik, 2017). This influential definition highlights the importance of policies (including those that direct innovation) to avoid environment externalities including climate catastrophes as well as the importance of acting urgently to transform the structure of the economy in a way that benefits both the competitiveness and the fight against climate change.

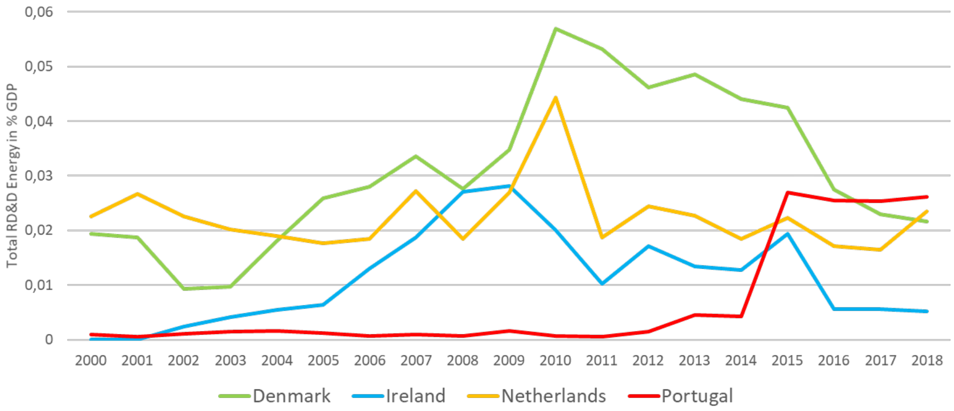
The co-benefits of the decarbonization help to sustain the public support to climate policies. Promoting technological options which have the highest social returns is fundamental (see the previous sections). This has been particularly shown in the case of jobs creation. The low-carbon transition causes jobs losses in high polluting sectors and areas; the social groups affected by these losses can increase resistance to change, affecting the public support to climate policies, even if decarbonization is likely to have a positive effect in the overall creation of jobs in the economy (Vona, 2019). Thus, particular attention should be given to the extent to which the supported solutions use and redeploy existing knowledge and resources (see also Section II-1.).

The level of policy coordination has been subject to debate in the literature (Jacobsson et al., 2017). The proponents of “mission-oriented” innovation policies aim at turning grand societal challenges into concrete problems that can drive innovation across multiple sectors and actors (Mazzucato, 2018; Foray et al, 2012). Under this perspective, the formulation of clearly defined missions would enable governments to influence the direction of growth by “making strategic investments throughout the innovation chain and creating the potential for greater spillovers across multiple sectors, including low-tech sectors” (Mazzucato, 2018: 806). But these interventions raise the question of directionality and stress the need for the promotion of variety.

Past experience already provides useful insights for analyzing directionality. As Grubler et al. (2012) point out with the following example: "*The creation of a viable and successful Brazilian ethanol industry through consistent policy support over several decades, including agricultural R&D, guaranteed ethanol purchase prices, and fuel distribution infrastructures, as well as vehicle manufacturing (flex fuel cars), is a good example of a stable, aligned, and systemic technology policy framework*" (Grubler et al., 2012: 1670). The authors also caution that successful processes take time: "*It is worth noting that even in this highly successful policy example, it has taken some three decades for domestic renewable ethanol to become directly cost competitive with imported gasoline*" (Grubler et al., 2012: 1670). This is in line with the conclusions from research on the duration of the formative phase of the technologies in past that was rarely shorter than two decades (Bento et al., 2018; Gross et al., 2018; Bento & Wilson, 2016).

The experience also shows that failure is inherent to innovation policies. The unsuccessful cases again provide helpful lessons for policy direction: "*The debilitating consequences on innovation outcomes of stop-go policies are well illustrated by the wind and solar water heater programs in the United States through the 1980s, as well as the large-scale (but fickle) US efforts to develop alternative liquid fuels (Synfuels). The legacy of such innovation policy failures can be long lasting*" (Grubler et al., 2012: 1670). Another failure was the attempt to speed up the scaling up of wave energy technology in Portugal with the project of Pelamis, which left a long mark in the sector that was partly compensated, in the meanwhile, by the more promising results obtained in the experiments with floating offshore wind (Fontes et al., 2016).

The innovation policy should be coherent with the objectives and consistent over time. Graph 7 shows the share of energy RD&D expenditures in GDP of four countries (the same as in I-2.b), including Portugal. The levels are generally small for the countries in the sample, considering the importance of the energy sector to the low-carbon transition. It is interesting to note the recent jump in the effort of energy RD&D in Portugal, but questions remain about the sustainability of this jump (against possible austerity) and the direction in the period of economic recovery after the pandemics.



Graph 7: Total RD&D expenditures in energy in percentage of the GDP of Denmark, Ireland, Netherlands and Portugal. Source: OECD (2020b).

Finally, the promotion of variety is important to achieve both the climate and the industrial goals. New technologies create new actors that can counterbalance the resistance from the vested interests in incumbent systems and by this way overcome existing lock ins (Geels, 2014; Sabatier, 1988). In these terms, it is important that the supporting policies (or the mission-oriented approaches) remain compatible with the emergence of several technologies and open to the entry of new actors.

Therefore, innovation policy should consider the existing knowledge and structure of the economy. It should promote the reduction of emissions of the sectors as well as the structural change that decreases the average carbon intensity of the country. This could also have positive effects in competitiveness (Porter and Linde, 1995). In addition, the innovation policy should align with the objectives of the industrial policy in terms of enhancing productivity and creating other co-benefits such as "climate jobs" that improve the public support to policies. Finally, the policy should enable the entry of new actors in the new industries that bring innovation and overcome existing lock ins.

3. Conclusion

A tale of two crisis challenges the countries as the pandemics added the economic crisis to the existing climate urgency. Under these circumstances, economic recovery must be compatible with the reduction of carbon emission, while the low carbon transition should have large effects in the economic structure. The efforts to accelerate the sustainable transformation of the economy will benefit from a combination of decarbonization, digitalization and dematerialization. For that, an integrated strategy is necessary, one that addresses sectoral change, social returns and technology variety. These three dimensions should be present in the directionality of innovation policies.

This paper contributes to an emerging literature on green industrial policies by discussing the conditions under which decarbonization can be an opportunity to transform the economy and to pursue other socio-economic objectives, such as competitiveness, distributional goals and inequality reduction. More specifically, this research develops a methodology to identify the sectors most exposed to a more stringent climate policy, as well as those that more rapidly need to change, in order to be in line with the impending 2030 targets, which require halving carbon emissions. The work also contributes to the debate on the policies for promoting the sustainable transformation, namely by discussing the directionality of the policies. We developed a model to analyze the carbon intensity of the economic complexity that can be helpful to assess the environment effectiveness of structural change. Future research could apply this model to more countries, which would improve its features and enable the generalization of the findings.

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