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Developing Countries' Macroeconomic Exposure to the Low-carbon Transition

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Résumé

La transition bas carbone est un type spécifique de changement structurel rapide, où les industries à faibles émissions se développent et les industries à fortes émissions diminuent en raison de politiques délibérées, de préférences changeantes et de changements technologiques. L'exposition macroéconomique des pays en développement à cette transition est d'autant plus élevée qu'ils dépendent des industries à forte intensité de carbone comme source de devises, de recettes fiscales, d'emplois et de salaires. L'identification de ces différentes dimensions de l'exposition des pays est importante car différentes politiques vertes doivent être appliquées dans différents contextes, et les résultats de ces politiques seront plus ou moins efficaces selon les idiosyncrasies des pays.

Cet article vise à fournir des estimations des expositions macroéconomiques des pays à la transition bas carbone. Nous développons une méthode d'évaluation de l'exposition externe, fiscale et socio-économique des pays, et, compte tenu de leur capacité à adapter leur structure productive, nous analysons les vulnérabilités et les risques des pays dans ces différentes dimensions. À l'aide d'un tableau d'entrées-sorties du monde hybride pour 189 pays, nous identifions les industries à forte intensité de carbone, puis nous estimons la dépendance directe et indirecte de chaque pays vis-à-vis de ces industries, en tenant compte de la dépendance des pays pour l'augmentation des devises étrangères afin d'analyser l'exposition externe, le gouvernement revenus pour évaluer l'exposition fiscale, et la part des salaires et de l'emploi pour analyser l'exposition socio-économique.

Les résultats montrent que les pays présentent différents degrés d'exposition dans différentes dimensions, et le degré d'exposition varie considérablement lorsque les impacts indirects sont pris en compte. De plus, en analysant la capacité des pays à adapter leur structure de production et leurs facteurs de résilience, nous évaluons dans quelle mesure l'exposition macroéconomique des pays se reflète sur des vulnérabilités et des risques plus élevés pendant le processus de transition verte.

Mots-clés: Transition bas carbone, Vulnérabilités macroéconomiques, Risque pays, Tableau d'entrées-sorties.

Abstract

The low-carbon transition is a specific type of rapid structural change, where low-emission industries grow and high-emission industries decline due to deliberate policies, changing preferences and technological change. Developing countries' macroeconomic exposition to this transition is higher the higher is their dependence on carbon-intensive industries as a source of foreign currency, fiscal revenue and employment and wages. Identifying these different dimensions of countries' exposition is important because different green policies need to be applied in different contexts, and the results of these policies will be more or less effective according to countries' idiosyncrasies.

This paper aims at providing estimates of countries' macroeconomic exposures to the low-carbon transition. We develop a method to evaluate countries' external, fiscal and socio-economic exposure, and, considering their capacity to adapt their productive structure, we analyse countries' vulnerabilities and risks in these different dimensions. Using a Hybrid World Input-Output table for 189 countries, we identify the carbon-intensive industries, and then we estimate each country's direct and indirect dependence on these industries, considering countries' dependence for raising of foreign currency to analyse the external exposure, government revenue to evaluate the fiscal exposure, and the share of wages and employment to analyse the socio-economic exposure.

Results show that countries present different degrees of exposition in different dimensions, and the degree of exposition varies significantly when indirect impacts are considered. Moreover, by analysing countries' capacity to adapt their production structure and resilience factors, we evaluate to what extent countries' macroeconomic exposure reflects on higher vulnerabilities and risks during the green transition process.

Keywords: Low-carbon transition, Macroeconomic vulnerabilities, Country risk, Input-output.

JEL Classification: F18, Q58, C67

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1. Introduction

The Paris Agreement was adopted in 2015 by 196 parties officialising a common aim to limit global warming to well below 2.0 (preferably 1.5) degrees Celsius compared to pre-industrial levels (UNFCCC, 2015). To that goal, carbon neutrality should be reached in the second half of the century, meaning that the remaining emissions after this period should all be compensated by existing carbon sinks. The Paris Agreement embarks all countries in a transformative effort of structural change of their economics. The increasingly ambitious Nationally Determined Contributions (NDC), together with the Long Term Strategies officialise this thin path between short-run development necessities and longer run complete decarbonisation obligation (UNCTAD, 2021).

Most developed economies are adopting deliberate policies and fostering technological changes to promote the low-carbon transition towards the carbon neutrality. This new scenario is generating a rapid structural change, where low-emission industries (sunrise industries) are gaining importance and high-emission industries (sunset industries) are declining (Semieniuk et al., 2021). The overall dynamics at a country level will depend strongly on the domestic industrial network, its dependency to sunset or sunrise industries and its connection with the rest of the world (mostly via the trade and financial balance), the public sector (via fiscal revenues) or households (via labour income and employment). The success of a global transformation to a greener economy demands special attention for developing economies, as their access to green finance is constrained by high capital costs (Ameli et al., 2021) and the use of monetary policy to finance green investments is limited by the hierarchy international monetary system (Svartzman and Althouse, 2020; Étienne Espagne, 2020).

This paper aims at providing estimates of countries' macroeconomic exposures to the low-carbon transition. We develop a method to evaluate countries' external, fiscal and socio-economic exposure, and, considering their sensitivity to the transition and their capacity to adapt their productive structure, we analyse countries' vulnerabilities and risks in these different dimensions. Using a Hybrid World Input-Output table for 189 countries, we define potential global sunset industries considering direct, upstream and downstream emissions, since indirect emissions often constitute a significant part of its overall Greenhouse Gas (GHG) footprint (Downie and Stubbs, 2013). Once these sunset industries are defined, we estimate each country's direct and indirect dependence on these industries in different dimensions. We estimate the net raise of foreign currency by sector (exports discounted by the import content of exports) to analyse the external exposure, government revenue dependence on sunset industries to evaluate the fiscal exposure, and the share of wages and employment that depends on these industries to analyse the socio-economic exposure of all 189 economies in the EORA 26 database (Lenzen et al., 2012, 2013).

The paper contributes to the analysis of macroeconomic imbalances that emerge from rapid structural changes by providing estimates of multi-dimensional macroeconomic exposure to the low-carbon transition. Even though there are some recent publications discussing the systemic risks of the low-carbon transition, they are focused mainly on the financial risks driven by stranded assets of large fossil fuel corporations (Caldecott, 2018), their capacity to engender financial instability and crisis (Monasterolo, 2020), and their cascade effects on other industries (Cahen-Fourot et al., 2021). The macroeconomic risks of the low-carbon transition for countries that depends on these industries, however, goes further beyond these financial risks, once this are only one of the possible systemic risks that may emerge during this transformative process (Mercure et al., 2021). Especially for developing economies, other important instabilities emerge from the transition and may constraint economic growth, such as rising public debt, rising inflation, trade imbalances and unemployment (Semieniuk et al., 2021).

Results show that countries present different degrees of exposition in different dimensions, and the degree of exposition varies significantly when indirect impacts are considered. Some countries, such as Algeria, Angola and Kuwait, present high external exposition, whilst others, such as Zimbabwe, Ethiopia and Paraguay, present high fiscal exposition or present high socio-economic exposition, such as Ecuador. Moreover, by analysing countries' capacity to adapt their production structure based on alternative tools, such as the Green Complexity (Mealy and Teytelboym, 2020), and countries' resilience, based on social protection coverage, it is possible to evaluate to what extent countries' macroeconomic exposure can constrain long-term growth and development, increasing countries' vulnerabilities and systemic risks.

Besides this introduction, the paper is divided into four sections and the discussion. The next section discusses the low-carbon transition from a structural perspective and the three different dimensions of the macroeconomic exposure (external, fiscal and socio-economic). The following section presents the methodology employed to estimate the indicators, and the data sources. Section four presents the main results at the country and sectoral levels, discussing the different dimensions that are considered to analyse countries' vulnerabilities and resilience. Finally, in section five, countries are analysed considering multidimensional exposures, and cluster analysis are applied to identify different groups of countries according to their specific types of exposition.

2. Literature review

The low-carbon transition can be seen as a unique type of rapid structural change, where low-emission industries (sunrise industries) grow and high-emission industries (sunset industries) decline due to deliberate policies, changing preferences and technological changes (PRA, 2015; Semieniuk et al., 2021). Because countries have different structures of production, with different degrees of diversification, and different policy tools at hand, this rapid structural transformation will have different social and economic impacts (Romero and Gramkow, 2021). The overall dynamics at a country level and its path dependency in a decarbonisation dynamics will thus be strongly determined by its domestic industrial network, its dependency to sunset or sunrise industries and its connection with the rest of the world (mostly via the trade and financial balance), the public sector (via fiscal revenues) or households (via labour income and employment).

There is a close relation between product sophistication and emissions, where the greener products are usually those with the highest technological content (Boleti et al., 2021). Developing economies are less diversified and less competitive in high-tech goods, as they do not have the productive and technological capabilities to produce them (Hidalgo, 2021). Therefore, on the demand side, less developed economies need to import capital goods and inputs to produce green energy and to reduce emissions. Moreover, on the production side, high-emission intensive industries may face a reduction in export revenues due to either reduction in the volume of sales or reduction in prices (Savona and Ciarli, 2019; Semieniuk et al., 2021). The capacity of countries to overcome the resulting potential balance-of-payment constraints depends on their capacity to adapt to changes in world demand and to produce domestically the goods and services necessary for this transition (Mealy and Teytelboym, 2020).

For many developing countries, sunset industries, such as fossil fuel, are a very important source of fiscal revenues, and hence the transition poses an eminent risk: governments need to increase spending while the low-carbon transition itself may reduce fiscal revenues (IEA, 2019). The transition can thus be costly for governments, and difficult to be implemented in very indebted governments, with strong path dependency on the longer run. Public expenditures are necessary to promote green industries either via direct fiscal stimulus or by investments in green infrastructure, such as public mobility and renewable energy and other green technologies (IMF, 2020), as well as to mitigate the cost of the sunset industries. Furthermore, although the net impact of low-carbon transition on employment is expected to be positive in the long run, costs for retraining re-allocated workers and social spending to guarantee basic needs for unemployed workers will be necessary (Saget et al., 2020). However, the drop in fiscal revenues due to a rapid structural change, where sunset industries decline, may lead to a higher exposition of countries that are excessively dependent on these industries as a source of revenues (Semieniuk et al., 2021).

Countries productive structure and their capacity to adapt determines not only economic growth trajectory; they also have important distributional effects. Hartmann et al. (2017) shows that countries with higher capacity to adapt and with higher product diversification tend to have more capacity to generate and distribute income. Rosemberg (2010) discusses the impacts on job creation and elimination in regions that depends on carbon-intensive industries. According to her, a "just transition" need to account for the decline of living standards in these regions. According to Saget et al. (2020), although the net impact on employment is expected to be positive, there will be important imbalances, with countries more dependent on this industries to generate employment tend to be more impacted than others. Different climate policies, such as carbon price, subsidies for green investments and direct investments in green infrastructure will have very different social and macroeconomic impacts in different contexts. Carbon pricing has the advantage of having no direct fiscal costs, but it may lowers real GDP by immediately increasing the cost of energy (IMF, 2020). Moreover, Moz-Christofoletti and Pereda (2021) shows that the distributional impacts of carbon price tends to be negative. Despite being effective in reducing emissions in the short run, carbon price imposes welfare losses, especially on the poor. Green fiscal stimulus, on the other hand, despite having high fiscal costs, boosts economic growth both directly and indirectly by increasing aggregate demand and promoting productivity growth in low-carbon sectors (IMF, 2020).

According to Peszko et al. (2020), some advanced economies, such as the EU countries that are less dependent on sunset industries, may experience low economic costs during the transition, as renewable are already part of the energy mix and imports already embed the intensive use of fossil fuels. On the other hand, countries relying heavily on current and future export revenues from sunset industries are likely to face the largest challenges. They present evidence that for some groups of countries, the low-carbon transition will have positive impacts, whilst for others, the negative impacts on the economy may not be compensated for the positive impacts of the structural transformation. Therefore, all things equal on the international side, a country-level low-carbon transition needs to navigate between a variety of idiosyncratic macroeconomic vulnerabilities and risks, which strongly determine the set of feasible pathways.

3. Methodology

The Input-output (IO) framework, initially developed by Leontief (1936, 1941), is an important tool to analyse the interdependence of industries either within an economy or across different economies. The basic IO model is built from observed data from a specific region (usually a country), and it divides the economy into industries that both produce goods (outputs) and consume goods from other industries (inputs) in the process of producing each industry's own output (Miller and Blair, 2009). Multiregional IO models (MRIO) were further developed to account also for the interrelation between industries in different regions (Chenery, 1953; Moses, 1955). In the MRIO framework, one can account not only for the relation between industries within a region, but also for the relation between different industries in different regions, which is especially interesting in globally integrated production systems.

Even though Leontief (1936) has conceived IO matrices as industry production functions, where physical quantities of inputs were necessary to produce goods, data collection requirements for producing these matrices derailed this type of treatment. Instead, most IO matrices were built upon monetary data. Nevertheless, it does not mean that one cannot evaluate physical interrelations from these matrices. Hybrid input-output matrices, which account for energy inputs, emissions and other physical relations can be constructed by considering energy and other environmental related coefficients. These hybrid IO matrices, sometimes referred as energy or environmental IO matrices, initially put forward by Cumberland (1966), and systematized by Bullard and Herendeen. (1975), allow us to identify some physical flows embodied in intermediate inputs, and hence it is an important framework to analyse the low-carbon transition. Essentially, hybrid MRIO allow us to understand the direct and indirect environmental impacts of production and demand within and across countries.

3.1. Sunset industries and emission-intensity

Before analysing countries' macroeconomic exposure, vulnerabilities and risks to the low-carbon transition, we need first to identify what are the potential sunset industries. The relative importance of some industries will change with the low-carbon transition. Industries with substantial contribution to decarbonization are expected to grow and gained momentum, whilst industries that have significant environmental harm are expected to lose importance. Despite its limitations, a first approach to the definition of these industries can be based on their GHG emission-intensity, as discussed by the EU-TEG (2020). Nevertheless, any social and economic dependence to these industries may hinder the transition process. In order to identify which are these industries, we first calculate the emission content of each industry for each country. Besides the direct emission during the production process, using hybrid MRIO, we can estimate the indirect emissions both upstream (emissions embodied in intermediate inputs) and downstream (emissions after production until final consumption).

Emission intensity can be defined as CO2 emissions by unit of production or as CO2 equivalent, which includes other Greenhouse Gases (GHG) emissions per unit of production. Once all monetary relations in MRIO tables are in the same currency (USD), the unit of production adopted here is US dollars. Therefore, emission intensity is defined as the relation of CO2 or CO2 equivalent emissions per dollar. The EORA-26 database provides direct emissions by industry and country. By dividing this value by total production by industry for a given country, we get the direct emission intensity (e^d) of an industry in a country (i), as follow:

$$e_i^d = \frac{Emissions_i}{x_i} \tag{1}$$

where x_i is the production of an industry in a country, and $Emissions_i$ is this industry emissions.

In order to obtain upstream indirect emissions, we need to consider emissions embodied in direct inputs, but also emissions embodied in all inputs necessary to produce these inputs. Following Miller and Blair (2009), one can obtain the Multiregional Leontief matrix by considering that total production by industry and country is given by the summation of the column-vector of intermediate inputs and the column-vector of final demand (**f**), and intermediate inputs are given by the multiplication of the technical coefficient matrix (**A**) and the column-vector of total production (**x**):

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{f} \tag{2}$$

Alternatively, one can write it as

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \tag{3}$$

where $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief matrix, which shows the direct and indirect inputs needed to produce one unit in each industry.

The backward indirect emissions can be obtained by pre-multiplying the diagonalized vector of direct emission coefficient by industry ($\hat{\mathbf{e}}$) by the Leontief matrix, and subtracting the direct emissions:

$$\mathbf{e^i} = \hat{\mathbf{e}}\mathbf{L} - \hat{\mathbf{e}} \tag{4}$$

The result is a matrix where columns are the industries under consideration (for each country) and lines are the industries responsible for emitting directly. The summation of the elements of each column gives a vector of backward indirect emissions by industry and country. We can also separate indirect upstream emissions between those embodied in electricity and those embodied in other indirect inputs by summing up only the elements corresponding to the electricity sector. From this we have for each industry and each country:

- Direct emission intensity: e_i^d
- Electricity emission intensity: e_i^{el}
- Other indirect backward (upstream) emission intensity: e_i^{ib}

With the aim of identifying the downstream emissions, which are those arising from the utilization of the goods and services produced by the industries under consideration (forward emissions), rather than using the Leontief approach, one needs to use the Ghosh (supply-side) model. Following Miller and Blair (2009), one have that

$$\mathbf{G} = (\mathbf{I} - \mathbf{B})^{-1} \tag{5}$$

where **G** is the Ghosh matrix and **B** is the direct-output coefficients.

Based on this, we have:

$$\mathbf{e^{if}} = \mathbf{G}\hat{\mathbf{e}} - \hat{\mathbf{e}} \tag{6}$$

Finally, by summing up the elements of each line of $\mathbf{e^{if}}$, we have

- Forward (indirect downstream) emission intensity: e_i^{if}

Based on these results one can analyse what are the potential sunset industries, i.e.: those industries with the higher direct and indirect emission intensity. It is important to note, however, that they are only potential sunset industries. If, despite high-emission intensity, these industries are replacing industries with even higher emission intensity, it does not mean that they will shrink due to the low-carbon transition. Instead, they will be important for reducing global emissions, and rather than reducing their share in the world economy, it is expected that they will grow relatively more. Nevertheless, investments in reducing the emissions within these industries are necessary either to change the inputs used for production or to change their process of production.

Therefore, to define what are the actual sunset industries, there is the need to first identify what are the high emission intensive industries globally, and then exclude those industries that either are not high emission intensive within the country or are important to replace other industries despite presenting high emission intensity.

3.2. External exposure

Once sunset industries are defined, one can analyse countries' dependence on these industries to evaluate their macroeconomic exposure to the low-carbon transition.

Developing countries tend to be less diversified and less competitive in in green industries, with special regards to machinery and equipment and inputs necessary to reduce emissions in other industries (Romero and Gramkow, 2021). Therefore, these countries need to import capital goods and inputs to reduce emissions, which demands high volume of foreign currency. On the other hand, emission intensive industries may face a reduction in export revenues either due to a reduction in the volume of sales or due to a reduction in prices (as a consequence of changes in international demand). The higher demand for foreign currency and the reduction of its supply due to the low-carbon transition may lead to balance-of-payment constraints in some countries, damaging macroeconomic stability and hence sustainable growth in the long run.

With the aim at accounting for countries' external exposure to the low-carbon transition, we estimate countries' dependence on sunset industries exports by calculating the sectoral net raise of foreign currency. It measures the volume of foreign currency that would be lost if the country stops exporting products of sunset industries, considering that some foreign currency is needed to produce these goods as they embody imported inputs.

Sectoral exports per unit of production (exp) is given by:

$$exp_i = \frac{Exports_i}{x_i} \tag{7}$$

where $Exports_i$ is total exports of a country by sector.

However, to produce these exported goods countries' need to import inputs. Therefore, to measure the net raise of foreign currency of the sectoral exports, it is necessary to calculate the direct and indirect embodied imported inputs. In the MRIO framework it can be obtained as

$$\mathbf{m} = \iota^{\mathbf{T}}[\mathbf{A^M}(1-\mathbf{A})^{-1}] \tag{8}$$

where

$$\mathbf{A^M} = \mathbf{A} \odot (1-\mathbf{D}) \tag{9}$$

m is the line-vector of direct and indirect embodied imported inputs, ι is a column-vector of ones, **D** is a dummy matrix of ones in the within countries' sectoral relations and zeros in the trade flows (imports and exports) and $\odot$ denotes the element-wise multiplication.

Net raise of foreign currency by unit of production (nx) discounted by the direct and indirect embodied imported inputs is thus given by

$$nx_i = exp_i(1-m_i) \tag{10}$$

where m_i is the imported content of production of a country by sector.

Finally, to measure the importance of the sunset industries in total net raise of foreign currency, we sum up the net raise of foreign currency of these industries by country and divide by the total raise of foreign currency:

$$NX^s = \frac{\sum_{i\in s} nx_i x_i}{\sum_i nx_i x_i} \tag{11}$$

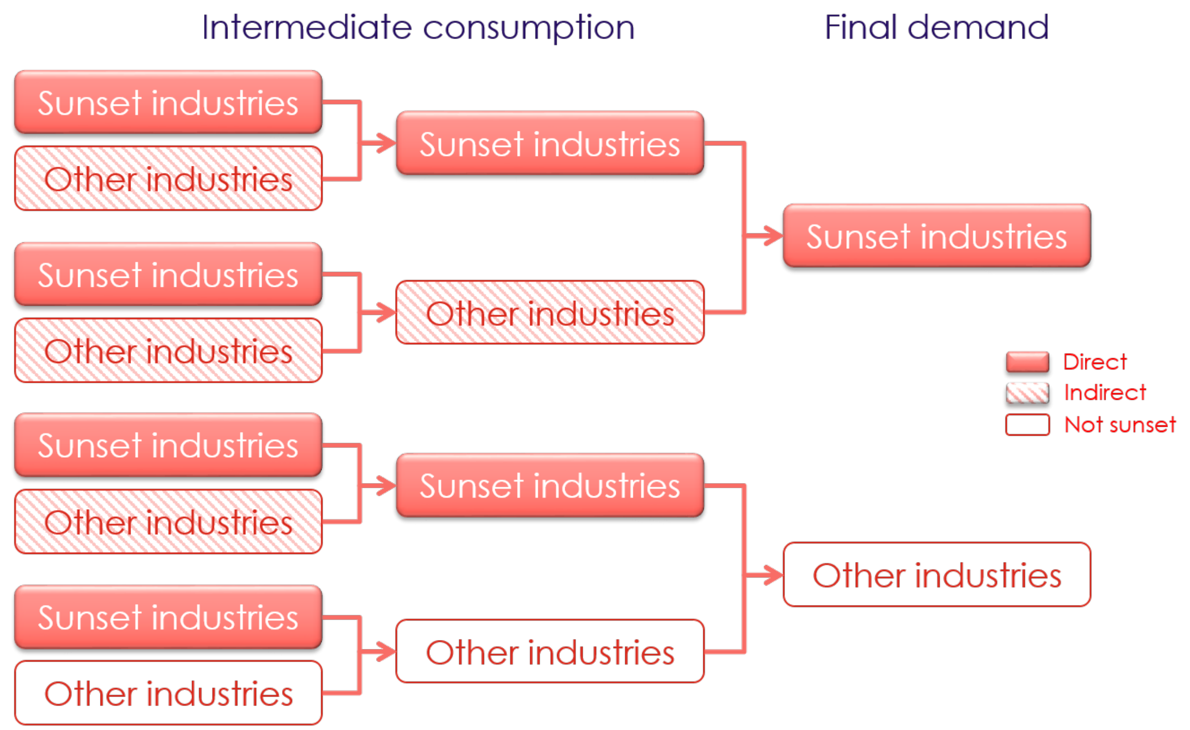
where s is the set of all the sunset industries for the country under consideration.

3.3. Fiscal exposure

The low-carbon transition depends massively on government investment in green infrastructure, subsidies for low-carbon emission solutions and other expenses. Although carbon pricing has no direct fiscal costs, it is usually a recessive policy, as it depresses the aggregate demand (IMF, 2020). Therefore, depending on countries production structure, it may be inefficient in some contexts. Fiscal stimulus, such as investment in green infrastructure or subsides for investments in green industries may be more efficient in some contexts. However, fiscal constraints may emerge, as they are costly for governments, and hence the transition process can be limited by fiscal imbalances.

With the aim of analysing what are the most exposed countries to the low-carbon transition in the fiscal dimension, we estimate the countries' fiscal revenue dependence of sunset industries. Besides considering the share of these industries in the total fiscal revenue, we considered that some non-sunset industries may be negatively affected. We considered that upstream industries that supply inputs for sunset industries (directly and indirectly), as presented in Figure 1. The direct fiscal contribution of sunset industries and their indirect contribution, which is given by the non-sunset industries that supply inputs for sunset industries domestically is thus accounted as the direct and indirect tax revenues from sunset industries.

Figure 1: Direct and indirect sunset related industries



Before estimating the direct and indirect fiscal exposure, one needs to calculate the sectoral output that is not related to sunset industries (neither directly nor indirectly). Once sectoral output is defined as

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \tag{12}$$

one can define vector of sectoral output not related to sunset industries ($\mathbf{x^n}$) as

$$\mathbf{x^n} = (\mathbf{I} - \mathbf{A^n})^{-1}\mathbf{f^n} \tag{13}$$

where $\mathbf{A^n} = \mathbf{d^n} \odot \mathbf{A}$, $\mathbf{f^n} = \mathbf{d^n} \odot \mathbf{f}$ and $\mathbf{d^n}$ is a column-vector of ones for non-sunset industries and zeros for sunset industries.

Once we have the sectoral output that is not related to sunset industries and the total output per sector, we can calculate countries' fiscal exposure to the low-carbon transition as the share of fiscal revenues that is related to sunset industries directly or indirectly:

$$FR^s = 1 - \frac{\sum_i x_i^n t_i}{\sum_i x_i t_i} \tag{14}$$

where t_i is sector i direct taxation of the country under consideration.

Taxation on products can be obtained directly from the EORA-26 database by dividing the total taxation on products by the total output

$$t_i^P = \frac{Taxes_i}{x_i} \tag{15}$$

Nevertheless, some sectors may contribute more to countries' total revenue than others if profits and wages are differently taxed. For most of the countries under consideration, however, we do not have the sectoral taxation of profits and wages. Therefore, we consider that taxation on profits is uniform across sectors within a country, as well as taxation on wages, which includes social contributions. Based on the Government Finance Statistics (GFS/IMF), we estimate the sectoral tax contributions on profits and wages as:

$$t_i^Y, = \frac{ProfTaxes}{Profits}\frac{Profits_i}{x_i} + \frac{WageTaxes}{Wages}\frac{Wages_i}{x_i} \tag{16}$$

where $ProfTaxes$ and $WageTaxes$ are profits and wages taxes, respectively (both from the GFS/IMF database), and $Profits$ and $Wages$ are total profits and total wages, respectively.

Hence, the summation of products and income taxation gives the sectoral direct contribution for the fiscal revenues:

$$t_i = t_i^P + t_i^Y \tag{17}$$

3.4. Socio-economic exposure

Socio-economic vulnerabilities are also relevant to understand the overall macroeconomic impact of the low-carbon transition. If countries depend directly and indirectly on sunset industries to generate employment and pay wages, the transition may increase inequalities, and, without well-structured social protection systems, the transition process can be excessively costly for the populations.

EORA-26 has data on wages, allowing us to calculate direct and indirect wage contributions of sunset industries directly. Direct sectoral wage contribution by unit of production is given by

$$w_{i,j} = \frac{Wages_{i,j}}{x_{i,j}} \tag{18}$$

Based on this, we can calculate the direct and indirect share of wages in sunset industries (W^s) as

$$W_j^s = 1 - \frac{\sum_i w_{i,j} x_{i,j}^n}{\sum_i w_{i,j} x_{i,j}} \tag{19}$$

EORA-26 does not contain employment data but ILOSTAT provides employment data for 177 of the 189 countries available in EORA-26. The sectoral aggregation is however different between the two data-source thus requiring conversion manipulation. We assume that sectoral employment per unit of production in ILOSTAT sectors is the same for all corresponding sectors in EORA-26 for a given country, as presented in Table 1.

Table 1: Sectoral correspondence

Sector in ILOSTAT	Sector in EORA-26
Agriculture; forestry and fishing	Agriculture
	Fishing
Mining and quarrying	Mining and Quarrying
Manufacturing	Food & Beverages
	Textiles and Wearing Apparel
	Wood and Paper
	Petroleum, Chemical and Non-Metallic Mineral Products
	Metal Products
	Electrical and Machinery
	Transport Equipment
	Other Manufacturing
	Recycling
Utilities	Electricity, Gas and Water
Construction	Construction
Wholesale and retail trade; repair of motor vehicles and motorcycles	Maintenance and Repair
	Wholesale Trade
	Retail Trade
Transport; storage and communication	Transport
	Post and Telecommunications
Accommodation and food service activities	Hotels and Restaurants
Financial and insurance activities	Financial Intermediation and Business Activities
Real estate; business and administrative activities	
Public administration and defence; compulsory social security	Public Administration
Education	Education, Health and Other Services
Human health and social work activities	
Other services	Private Households
	Others
	Re-export & Re-import

Therefore, direct employment per output (n) in sector i for country j is given by:

$$n_{i,j} = \frac{Empl_{k,j}}{x_{k,j}} \tag{20}$$

where k is the sector according to ILOSTAT database.

Once we have direct sectoral employment per output we can calculate the direct and indirect share of employments in sunset industries (N^s):

$$N_j^s = 1 - \frac{\sum_i n_{i,j} x_{i,j}^n}{\sum_i n_{i,j} x_{i,j}} \tag{21}$$

4. Countries' exposure and vulnerabilities

4.1. Defining sunset industries

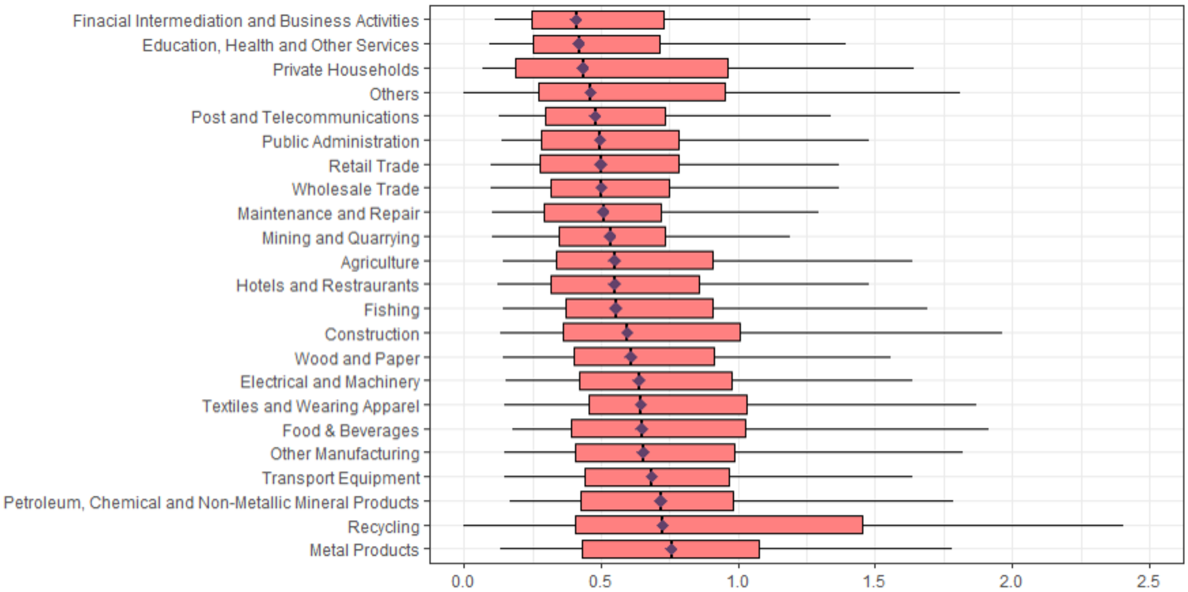
The first step in analysing countries' vulnerabilities is the identification of potential sunset industries. It is based on the direct and indirect share of these industries in different dimensions that we analyse countries' exposure and, considering their capacity to migrate to other industries, we can finally evaluate what are the most exposure economies.

Total GHG emission-intensity, from PRIMAP, is considered here as the key variable to determine what are the sunset industries. Even though other environmental variables are relevant, because GHG emissions are central in policy designs, such as the definition of carbon prices, one could expect that the higher the GHG emission-intensity of an industry, the higher is the chance of this industry to be negatively impacted by low-carbon transition policies. There are, however, some industries that may present high GHG emission-intensity, but should not be considered a sunset industry because they will replace industries with higher environmental impacts. This is the case of Recycling, which is among the most GHG emission-intensive industries, but is excluded from being considered a potential sunset industry, as it is an industry capable of substituting many other industries with much higher environmental impacts.

Figures 2 and 3 presents a box-plot for GHG emission-intensity (measured in tons of CO2 equivalent per USD) for 23 of the 26 sectors of the EORA-26 database. The Re-export sector, as well as Electricity and the Transport were excluded both for better visualization and because they cannot be considered a sunset industry *per se*. Although Electricity and Transport may present high emission-intensity levels, because they can be produced using less carbon-intensive methods, such as renewable sources, they cannot be considered as potential sunset industries. Moreover, we exclude indirect downstream emissions from electricity for all other sectors to avoid the bias of having different types of electricity production among countries, which ends up being an important determinant of the sectoral emission-intensity.

From Figure 2, which accounts for direct and upstream indirect emissions, we can see that three sectors present higher levels of emission-intensity: Petroleum, chemical and non-

Figure 2: Direct and upstream indirect GHG emission-intensity (Kg of CO2e/USD), excluding electricity



metallic mineral products; Metal products and Recycling. Moreover, Construction, Wood and Paper, Electrical and Machinery, Textiles and Wearing Apparel, Food & Beverages, Other manufacturing and Transport equipment also present high levels of GHG emission-intensity, but not as high as the sectors discussed before.

From Figure 3, which accounts for downstream emissions, we can see that Mining and Quarrying is the sector with the highest GHG emission-intensity. Wood and Paper, Recycling, Petroleum, chemical and non-mineral metals, and Metal products also present high levels of GHG emissions per unit of production even though not as high as Mining and Quarrying.

Based on this, Table 2 organises these sectors according to their emission intensity levels. There are no industries with high emission-intensity considering upstream and downstream emissions. However, Mining and Quarrying presents a very high downstream emission-intensity, and hence it may be classified as a potential sunset industry. Metal products, Recycling and Petroleum, chemical and non-metallic mineral products present high emission-intensity upstream and medium emission-intensity downstream. Because Recycling is a special industry, as discussed before, besides these other two industries are, together with Mining and Quarrying the most important sectors in terms of emission per unit of production, and hence they are the potential sunset industries. Moreover, Wood and paper presents medium levels of emission intensity both downstream and upstream with high maximum levels of downstream emission-intensity, and it hence deserves special attention. This indicates that, for some countries, the intra-sector composition of this industry is very GHG emission-intensive, and hence it is potentially a sunset industry.

Figure 3: Downstream indirect GHG emission-intensity (Kg of CO2e/USD)

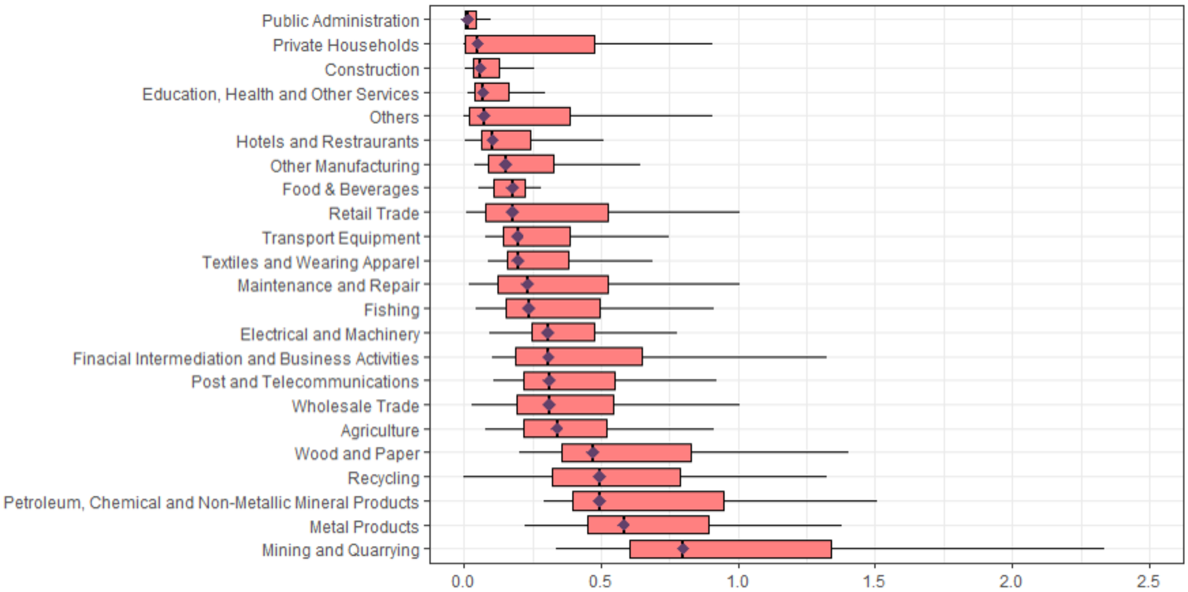


Table 2: Upstream and downstream GHG emission-intensity

	Low upstream	Medium upstream	High upstream
Low downstream	All other sectors	Construction Electrical and machinery Textiles Food & beverages Other manufacturing Transport equipment	
Medium downstream		Wood and Paper	Metal Products Recycling Chemicals*
High downstream	Mining and Quarrying		

(*) Petroleum, chemicals and non-metal minerals

Data on GHG emissions from the EORA-26 database are not available for almost half of the 189 countries. Therefore, the definition of potential sunset industries may be biased because most of the countries where GHG emission data are available are developed economies. If we use emission data of EDGAR, which considers only CO2 emissions, but data is available for almost all countries, we obtain very similar results, as one can see in Appendix A.

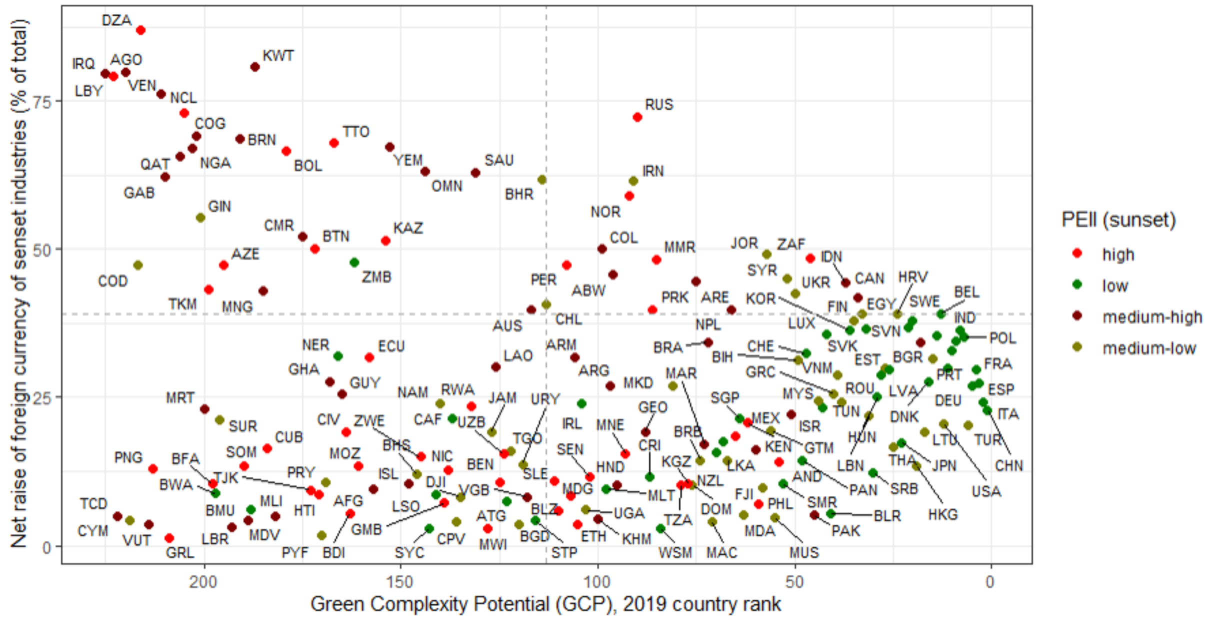
4.2. External exposure

Once the potential sunset industries are defined, one can calculate the external exposure of each country considering its dependency on these industries to raise foreign currency. As discussed before, we have to consider the net raise of foreign currency, as export industries use directly and indirectly imported inputs to produce, which means that despite raising foreign currency by exporting, they consume foreign currency to be produced by importing intermediate inputs.

The higher the dependence of these industries, the higher is the country exposure. However, countries with high productive and technological capabilities can easily migrate from one product to another, which means that despite being exposed to the low-carbon transition, they are less vulnerable. Based on the Economic Complexity Approach (Hidalgo, 2021), Mealy and Teytelboym (2020) developed a method to estimate countries' capabilities in green products. Based on the complexity of products that countries' are competitive, the authors estimate the Green Complexity Potential (GCP). The GCP indicates what are the countries with the higher technological and productive capabilities to migrate to green products based on the products the country already is competitive.

Figure 4 presents countries' external exposure in the vertical axis, measured by net raise of foreign currency of sunset industries, and the GCP rank in the horizontal axis. Moreover, the colour of the points are the weighted average of the Product Emission Intensity Index (PEII) for the potential sunset industries of a country. The PEII, developed by Romero and Gramkow (2021), is a product-level index of emission-intensity calculated based for a very high level of disaggregation (SITC Rev 2, 4 digits). The weighted average (based on the country export basket) allow us to evaluate to what extent the product mix within the potential sunset industries are indeed high emission-intensive. Countries such as Zambia (ZMB), despite depending on sunset industries, are not as exposed to the low-carbon transition as Bhutan (BTN) and Kazakhstan (KAZ) because the product mix of potential sunset industries present a lower weighted average PEII.

Figure 4: Countries' external exposure to the low-carbon transition



The countries with the higher systemic risks to the low-carbon transition are those in the top left part of the graph (excluding the green points), as these countries have higher exposure and have low technological and productive capabilities to migrate to green products. The horizontal dashed line is on the third quartile and the vertical is on the median, indicating that countries in the top left are those with very high external dependence on potential sunset industries and low green complexity levels. The countries in green (and olive) present a product mix favourable despite depending on potential sunset industries. The countries in red and brown in the top left square, in turn, present very high external dependence, low green complexity and a less favorable product mix.

As shown in the Figure 4, countries such as Russia (RUS), Iran (IRN) and Norway (NOR), despite presenting high exposure to the low-carbon transition (more than 50% of the net raise of foreign currency is in sunset industries), are relatively capable of moving to green industries, which means that they are less vulnerable economies. Bahrain (BHR), Saudi Arabia (SAU) and Oman (OMN) also present a high level of exposure, but they have less technological and productive capabilities to produce green products, which means that they are more vulnerable than Russia, Iran and Norway.

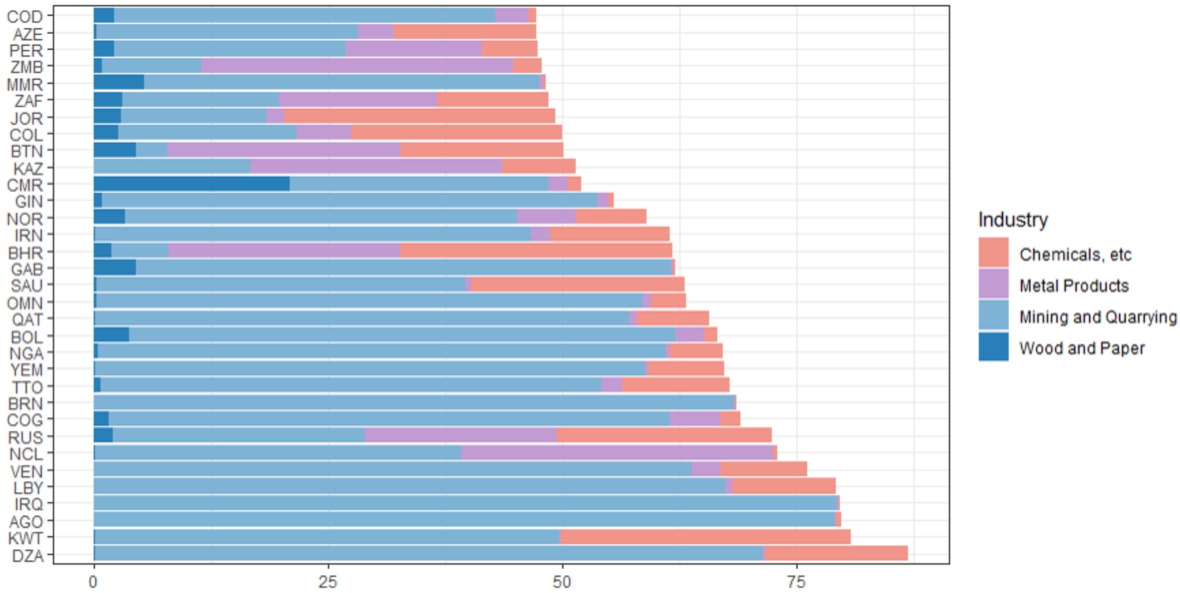
On the extreme top left of Figure 4, we have the countries with the higher risk. Algeria (DZA), Angola (AGO), Venezuela (VEN), Iraq (IRQ), Libya (LYB) and Kuwait (KWT) are extremely exposed to the low-carbon transition (more than 75% of the net raise of foreign currency are from sunset industries, and they rank among the countries with less GCP, indicating that they have low capabilities to migrate to green products. These economies, as well as the others that are also in the top left part of the graph are expected to be the most impacted by the low-carbon transition, as they depend on sunset industries to avoid large current account deficits and hence balance-of-payment crisis, and they are not capable of migrating to green products.

Some economies, such as Belgium (BEL) and India (IND) present a degree of exposure higher than the average (about 35% of the raise of foreign currency is from sunset industries), but they rank among the countries with the higher potential to migrate to green products, according to the GCP index. Therefore, even though these economies are exposed to the low-carbon transition in terms of the external dimension, they are present lower risks, as they can easily migrate to green products,ù and replace sunset industries for green industries.

Figure 5 decompose the net raise of foreign currency by potential sunset industry. Most of the economies with the highest exposition are dependent of Mining and Quarrying to raise foreign currency. Among the twenty most exposed economies, only Kuwait (KWT), New Caledonia (NCL), Russia (RUS), Bahrain (BHR) and, in a lesser instance, Saudi Arabia (SAU) are not dependent exclusively of Mining and Quarrying. In the case of Kuwait, Saudi Arabia, Russia and Bahrain, Petroleum, chemicals and non-mineral metals is also an important industry for guaranteeing the external sustainability. Morover, for Russia and Bahrain, Metal products are also an important industry, as it it for New Caledonia.

Russia and Bahrain can be seen as less exposed compared to the other top-twenty if one considered that they have more diversified sources of foreign currency. Despite coming from potential sunset industries, this diversification reduces the dependence of specific potential sunset industries. Among the other countries presented in Figure 5, Kazakhstan (KAZ), Bhutan (BUT) and Colombia (COL) are in similar situations, once the contribution of three of these

Figure 5: Net raise of foreign currency by sector, most exposed countries



sunset industries is relevant for the high external exposure.

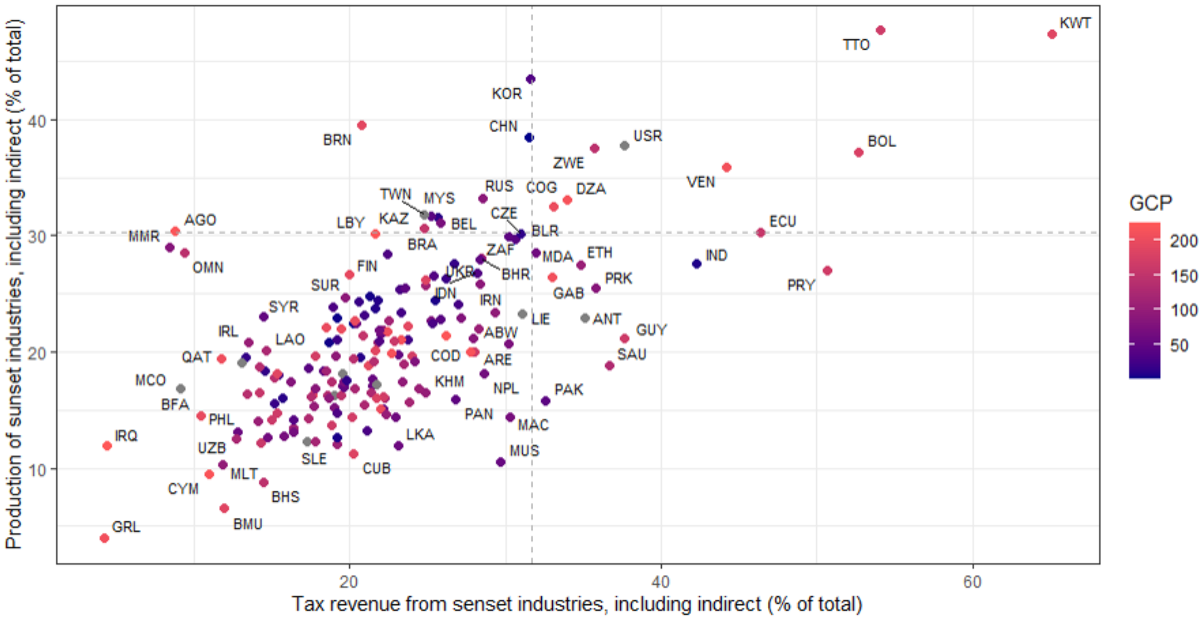
4.3. Fiscal exposure

Countries' direct and indirect fiscal dependence on sunrise industries is measured as the share of government revenues that depends on sunrise industries either due to their production or due to their demand for inputs. The higher the dependence of sunset industries as a source of fiscal revenue, the higher the fiscal impact of reducing the size of these industries if the country could not find other sources of revenue. Therefore, direct and indirect tax revenue from sunset industries measures countries' exposure to the low-carbon transition.

Figure 6 presents, in the horizontal axis, this exposure. It does not mean, however, that these are the most vulnerable economies. Besides considering the capacity of the country to migrate from sunset industries to green products, such as presented in the last section, to account for the fiscal vulnerability, one also needs to consider the potential the country has to change the composition of its taxation towards non-sunset industries as sunset industries shrink. Therefore, in Figure 5, the vertical axis presents the production of sunset industries and their demand of inputs as a share of total production. The higher this value, the lower is the possibility of the country to move taxation towards non-sunset industries as sunset industries shrink. Moreover, the colour of the points denotes the GCP, where the bluest ones are the best ranked, and the reddest ones, the worst. By this analysis one can see that some countries, despite depending on sunset industries, can migrate to green products more easily, which means that they present lower risks than those in the same situation but with a lower GCP index.

Countries located in the top right corner of the graph are those with the highest vulnerability, as they depend directly and indirectly on sunset industries to raise government revenue,

Figure 6: Countries' fiscal exposure to the low-carbon transition



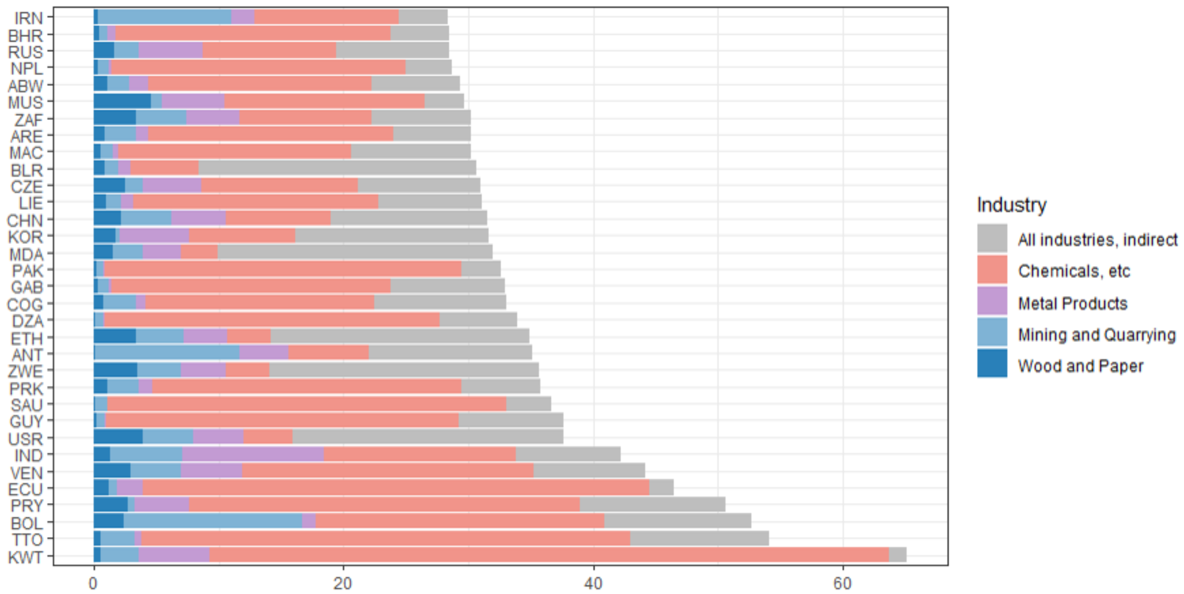
and they do not have alternatives to move from taxation of these industries to non-sunset industries if the importance of these industries in the economy decreases. This is the case of Kuwait (KWT), Trinidad and Tobago (TTO), Bolivia (BOL) and Venezuela (VEN), which depend on the fiscal contribution of these industries and cannot move taxation towards other industries. Moreover, because none of these economies ranks well in the GCP ranking, they are less capable of migrating their productive structure to green industries, which means that the low-carbon transition may impose relevant fiscal risks for these countries.

India (IND), Ecuador (ECU) and Paraguay (PRY) present a high level of fiscal exposure to the low-carbon transition, as the share of direct and indirect tax revenues from sunset industries is high (higher than 40%). Nevertheless, these industries are relatively less relevant in terms of total production (even though their dependence is higher than three-forth of the countries under consideration). It means that they can tax more non-sunset industries to compensate for the fall of government revenues arising from the reduction of importance of sunset industries. In the case of Paraguay, for example, despite the importance of these industries for government revenues, only about 25% of the production is directly or indirectly related to sunset industries. In the case of India, as presented in the colour of the point, there is also the possibility of migrating production to green products, as they rank among the most complex countries in the GCP ranking. Therefore, despite the higher fiscal exposure, these economies are relatively less vulnerable.

Other interesting cases are China (CHN), South Korea (KOR) and Brunei (BRN), which are on the top left side of the dashed line. Although sunset industries are relevant for these economies (they represent directly and indirectly around 40%), the fiscal exposure is low, as these industries are not very taxed. In these three economies, less than one third of taxation comes directly and indirectly from these industries, which means that the reduction of these industries will impact relatively less on these economies than on those that, despite having the same share of production, tax relatively more sunset industries. In the case of China and South Korea, the fiscal risk is even lower due to their higher capacity to migrate to green products, as shown by the GCP rank.

Figure 7 shows the sectoral contribution for the aggregate fiscal exposure level. Different from the sectoral contribution for the external exposure, the fiscal exposure also accounts for indirect impacts, which considers other industries (non sunset) that supplies for sunset industries. Moreover, as one can see from this figure, the sectors that contributes for the fiscal exposure are different from those that contributes for the external exposure. Whilst in the external exposure Mining and Quarrying is the most relevant industry for the majority of countries, here is the Petroleum, chemical and non-mineral metals the most important one. The lower importance of Mining and Quarrying is expected as it is usually a sector that is relevant for exports but not as relevant for countries production and taxation.

Figure 7: Tax revenue by sector, most exposed countries



For some countries, such as Belarus (BLR), Moldavia (MDA), Ethiopia (ETH) and Zimbabwe (ZWE), indirect impacts are the ones that contributes the most. Because these impacts captures not only the production for domestic industries, but also the production for other countries' industries, it may indicate that the non-sunset industries of these economies are vulnerable because they depend on the demand of other economies' potential sunset industries. Therefore, although they seems to be less exposed when only total production is accounted, by using the multi-regional input-output framework one can verify that they may present high levels of exposition.

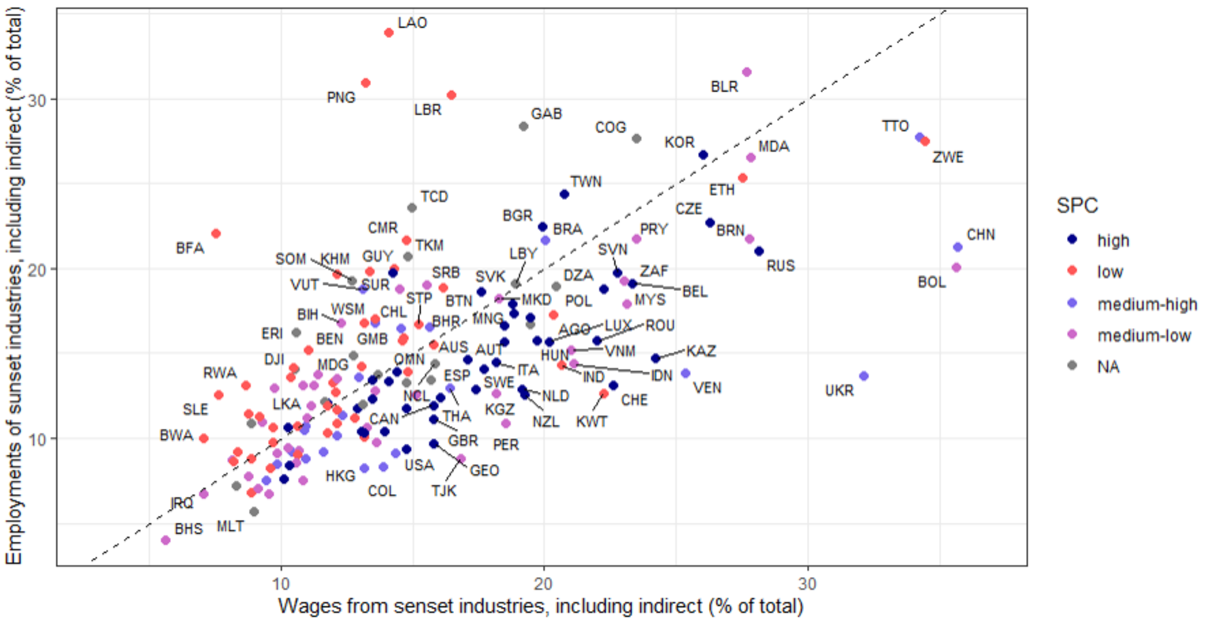
4.4. Socio-economic

Besides countries' fiscal and external exposure, it is important to analyse also the socio-economic exposure to the low-carbon transition. According to Saget et al. (2020), the low-carbon transition will destroy many jobs in highly carbonized industries, such as fossil fuel electricity and extraction, and will generate many others in low carbon activities, such as renewable energy, agriculture and plant based production. Although the worldwide net impact is positive, countries where sunset industries are responsible (directly and indirectly) for generating most of the jobs and paying large share of wages are those with the highest exposure to the low-carbon transition in the socio-economic dimension.

High exposure, however, does not necessarily mean high vulnerability. Countries with high socio-economic exposure to the low-carbon transition that also present high inequality, a large share of the population below the poverty line and low levels of social protection are much more vulnerable than countries where sunset industries are relevant but population is relatively well protected against job losses. The International Labour Organization compiles data on Social Protection Coverage (SPC) for most of the countries under consideration here (ILO, 2017). The share of the population covered by at least one social protection benefit provides a synthetic information on the resilience of countries' most impacted population.

Figure 8 presents countries' direct and indirect dependence on sunset industries to generate employment in the vertical axis and wages in the horizontal axis. The Social Protection Coverage (SPC) is presented as the point colour. Countries in the upper right part of the graph are those that depends on sunset industries to both generate employment and pay wages, those in the bottom left pay low wages in these industries but sunset industries are not responsible for generating a large number of employment. The dashed line is the 45-degree line, where share of wages and employments are the same. Therefore, those countries in the upper left, despite generating many jobs directly and indirectly in these industries, are not dependent of them in terms of wages, and those in the bottom right present high dependence in terms of wages but not so high in terms of employment.

Figure 8: Countries' socio-economic exposure and vulnerability



Considering the SPC, the most vulnerable economies are Zimbabwe (ZWE) and Ethiopia

(ETH). In these countries, besides contributing for the wage bill, sunset industries contribute significantly to generating employment, meaning that socio-economic exposure is high, and the SPC is low, which means that besides very exposed, they are also very vulnerable. Belarus (BLR), Moldavia (MDA) and Bolivia (BOL) present also a high exposure, and a low level of coverage, indicating a high socio-economic vulnerability, even though not as high as Zimbabwe and Ethiopia.

In Trinidad and Tobago (TTO) and China (CHN), despite the exposure, vulnerability is not so high, as they present a high share of the employed population covered by social protection benefits. South Korea (KOR), Czech Republic (CZE) and Russia (RUS) are interesting cases as well, once they present very high levels of SPC. Therefore, despite the higher socio-economic exposure, their vulnerability is much lower. Moreover, if one considers also the capacity of these countries to migrate from sunset industries to green products, measured by the GCP, as discussed before, one can affirm that despite the exposure, the socio-economic risks are also very low, as they rank among the most complex countries. The same rationale is valid for China (CHN) and, at a lower level, for Ukraine (UKR). China ranks first in the GCP, which means that it is the country with the higher capacity to migrate to green products. Therefore, despite the higher exposure and the SPC around the average, one cannot affirm that China is a vulnerable country. Ukraine is also among the countries with the higher GCP (it ranks 50th), despite not having the same level of productive and technological capabilities as China.

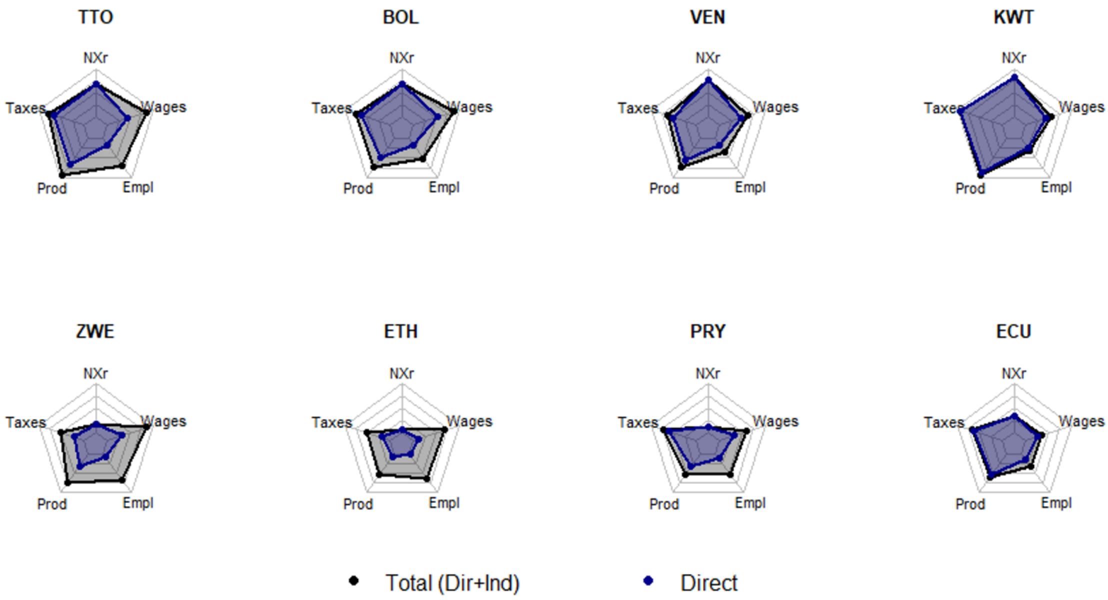
5. Multidimensional exposure

The analysis of countries' exposure and vulnerabilities need to account for different dimensions. Although having a lower external exposure is important, for example, it does not compensate for high fiscal exposure or socio-economic exposure. Thereby, the different dimensions cannot be aggregated into one single indicator.

With the aim of showing how these different exposures vary across countries, Figure 9 presents some countries' exposure degrees for five indicators discussed before: Net raise of foreign currency (NXr), Tax revenue (Taxes), Production (Prod), Employment (Empl) and Wages. These countries were selected to illustrate the importance of the multidimensional analysis once they present high levels of exposition for different reasons. The blue part of the radar graph is the direct exposure, which accounts only for sunset industries; the grey part is the total exposure, which accounts both for the direct and indirect exposure.

The four countries in the top (Trinidad and Tobago, Bolivia, Venezuela and Kuwait) present high dependence of sunset industries in all the three dimensions analysed. Except for employment in Kuwait, all variables are close to the maximum across all economies (including Wages), indicating that these economies are exposed for all dimensions. In the case of Trinidad and Tobago and Bolivia, indirect impacts are relevant to explain the socio-economic exposure (measured by wages and employment dependence), while in the case of Venezuela and Kwuait the indirect impacts are almost nonexistent. Despite these differences, the low-carbon transition may constraint growth in all these economies by exposing

Figure 9: Selected countries' multidimensional exposure



Min-max: NXr[0-100%], Taxes[0-70%], Prod[0-50%], Empl[0-40%], Wages[0-40%]

them to both balance-of-payments crisis and fiscal and socio-economic constraints.

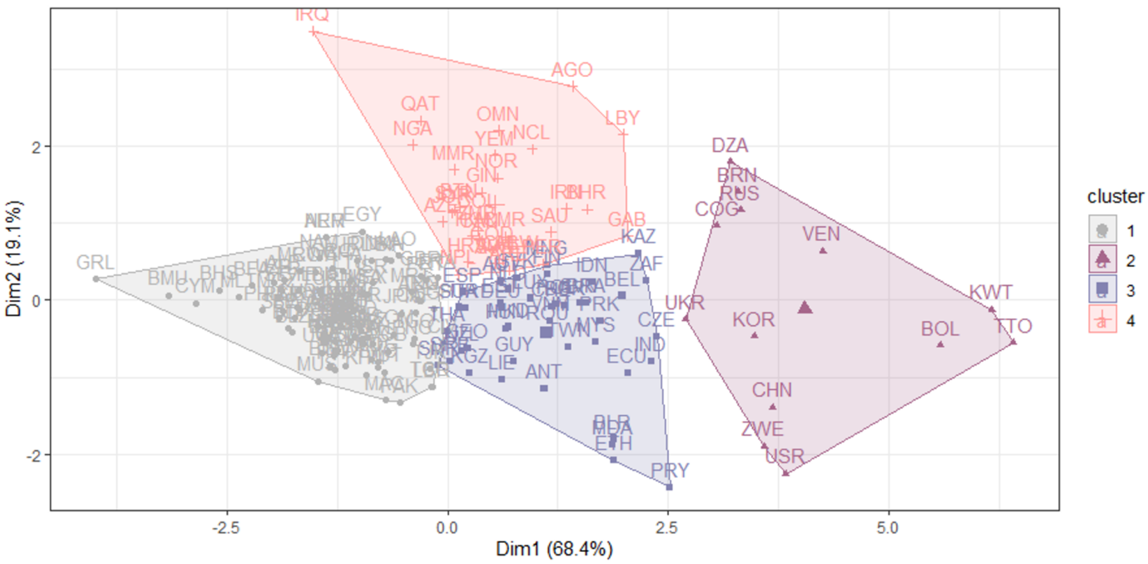
The four economies in the bottom (Zimbabwe, Ethiopia, Paraguay and Ecuador) present a lower external dependence, but are exposed in the other two dimensions (fiscal and socio-economic). In these economies, sunset industries are not responsible for raising foreign currency, but they are important directly (in Paraguay and Ecuador) or indirectly (in Zimbabwe and Ethiopia) for government fiscal balance and for generating employments and paying wages. Therefore, even though the external dimension is not a main concern, by analysing other dimensions we see that these economies are also highly exposed.

5.1. Clustering

We ran clustering algorithms on the different dimensions mentioned before in order to determine similarities across countries. Clustering analysis is an important tool to group together countries with similar characteristics, allowing us to identify different groups of countries depending on their exposition to transitional risk. We use hierarchical cluster analysis due to the fact that it does not require a prior knowledge of the number of clusters, as for example is the case with partitioning algorithms. Hierarchical clustering only requires a dissimilarity measurement between groups of observations, based on the pairwise dissimilarities among observations (Hastie et al. 2017, p. 520). In particular, we construct a dissimilarity matrix based on Euclidean distances and apply a set of agglomerative (bottom-up) strategies. Such strategies start at the bottom, where every country is a separate cluster, and then they recursively merge countries into larger clusters based on the smallest intergroup dissimilarity. We utilise Ward's minimum variance method, which minimises the within-cluster inertia, or error sum of squares. The result is a dendrogram, with each hierarchy level representing disjoint clusters of countries. From the resulting dendrogram structure, however, it is hard to pinpoint the optimal number of clusters. For this reason, we use a combination of statistical heuristics as well as economic intuition, in order to identify the potential clusters [1].

Figure 10 presents the four clusters in the first two main components, after reducing the dimension of the dataset via Principal Component Analysis (PCA). Since the dissimilarity matrix cannot contain empty elements, we drop employment from the cluster analysis, as data is not available for many countries. Note that as discussed above, this is not a major limitation due to the relatively high correlation of Employment with Wages.

Figure 10: Cluster of countries according to their exposition

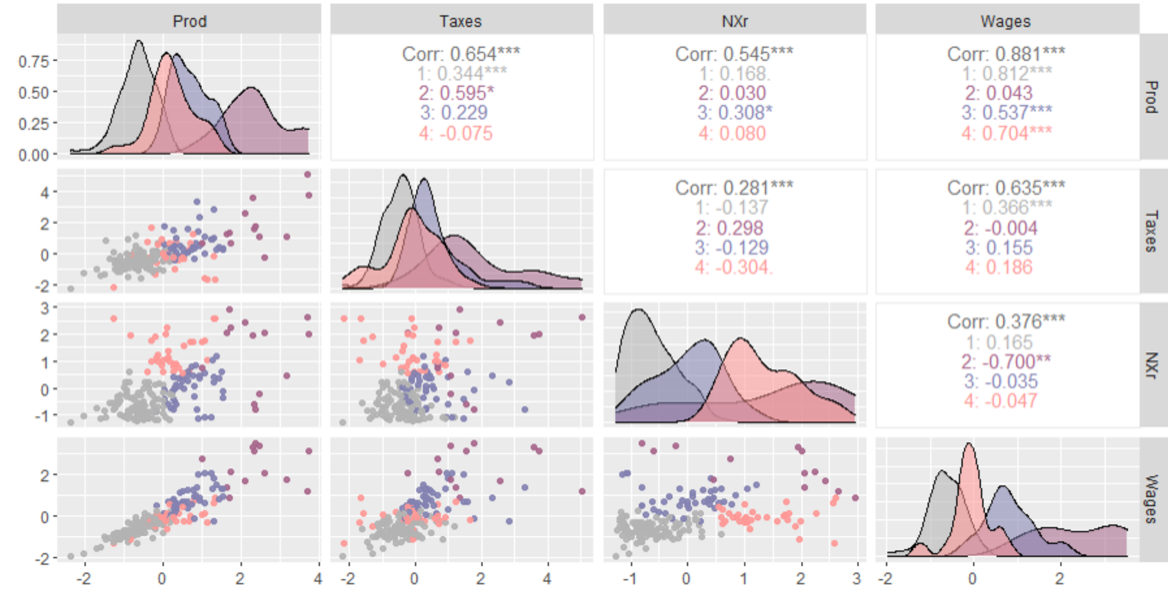


The grey cluster (left-hand side) is composed of countries with lower levels of exposition in general, and hence can be categorised as "low exposition economies". The purple cluster (right-hand side) is composed of countries with the highest exposition. The height countries discussed in the previous section lie in this group, even though their exposition are due to different dimensions. This group is also composed of countries with low green complexity such as Algeria, Bolivia and Venezuela, hence displaying high vulnerability and risk, and countries with higher green complexity such as Russia, South Korea and China, hence displaying more resilience. Therefore, although included in the group of high exposition, countries do not present necessarily uniformly high vulnerabilities and risks to the low-carbon transition. Note that this partly occurs due to our choice to focus on 4 clusters. Considering for example a higher number of clusters, Bolivia, Kuwait and Trinidad and Tobago are classified in a separate cluster.

Economies lying in the two clusters in the center of the space display moderate to high exposition in some dimensions but not all of them, requiring a more detailed analysis along the different dimensions. Figure 11 presents the distributions of the different dimensions we are considering in our analysis, within each different cluster.

[1] For more details on the choice of method and several robustness checks see the Appendix

Figure 11: Distributions of exposure dimensions per cluster



The two center clusters are well-defined in terms of the countries' exposition. Countries in grey and purple groups have respectively the lowest and highest average exposition in all dimensions[2]. The red and the blue clusters, however, present a much less clear degree of exposition. These group of countries are in the middle in all the four variables we are taking into consideration, but the position of these groups is changing across dimension. In terms of production and tax revenues, these two groups are very similar. Nevertheless, whilst the red cluster presents, in general, a high external exposure, the blue cluster presents a high exposure in the socio-economic dimension.

Even though some countries in green present higher external exposure than countries in blue (and vice-versa), as countries in the same group present similarities across all dimensions, we can sum up the relative exposure of each clusters of countries as follows:

- in grey, countries with low exposure;
- in purple, countries with high exposure in general;
- in red, countries that tend to have higher external exposure;
- and in blue, countries that tend to have high socio-economic exposure.

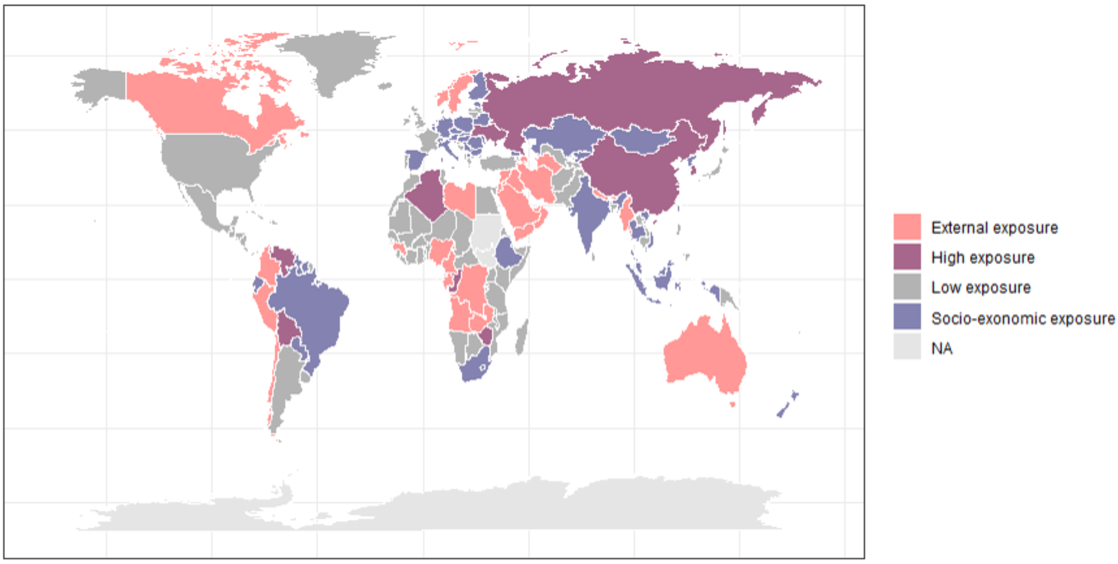
Figure 12 presents a world map where countries are divided in these clusters.

6. Discussion

Analysing developing countries' exposure and vulnerabilities to the low-carbon transition is crucial to identify the different policies that could be applied in different contexts. Because

[2]Note that there is overlapping across clusters indicating that we can observe countries belonging in other clusters with lower or higher exposition than those of the countries belonging to the low- or high- exposition clusters.

Figure 12: Countries' exposure by clusters



the transition will demand large public investments in green infrastructure, subsidies for emerging industries and technologies, investments in social protection among other fiscal expenses, countries with high fiscal vulnerabilities will hardly succeed in the low-carbon transition if policies do not consider this constraint. Analogously, countries will need to import inputs and machines to move from emission intensive technologies to green ones. Therefore, countries' external vulnerabilities may also constrain the low-carbon transition if green policies do not account for that.

6.1. Contributions

With the aim of contributing to the emerging literature on countries' systemic and macroeconomic exposure and vulnerabilities to the low-carbon transition, this paper develops a methodology, based on hybrid multi-regional input-output matrices, to evaluate the sectoral importance to raise foreign currency and to generate fiscal revenues. In the case of foreign currency, we consider both exports and its imported content. In the case of fiscal revenues, we consider both the direct relevance of the sector to raise taxes, as well as sectors that supplies inputs for sunset industries and, consequently, are indirectly impacted. These two dimensions are relevant as they may constraint the low-carbon transition if adequate green policies are not designed considering countries' specificities. Moreover, we also analysed countries' socio-economic exposure by estimating the sectoral importance to generate both wages and employment. This is important because although the net impact of the low-carbon transition is expected to be positive in terms of employment, this might not be true for all countries and sectors. Countries that depend on sunset industries to generate employment and pay wages will face negative impacts.

The results show that there is a significant variation among countries in terms of the dependence to sunset industries. While some countries are more exposed in the fiscal dimension, others are more exposed in the external or in the socio-economic dimensions. It means that one cannot look only into aggregate measures of expositions once they have different meanings and may have different consequences for the economy. This multidimensional perspective becomes explicit when we analyse countries' sectoral exposition: even though external exposition is mainly explained by mining activities, petroleum, chemicals and non-mineral metals are the main responsible for fiscal exposure, and the socio-economic exposure is explained mainly by the indirect impacts.

The analysis of the exposure is complemented by the analysis of the capabilities of countries to adapt to the constraints posed by the low-carbon transition. We use the Green Complexity Potential to measure the countries' capacity to migrate to green industries and the Human Development Index to measure their capacity to provide resilience to socio-economic vulnerabilities. The combination of the high fiscal and external exposure and low productive and technological capabilities indicates that the country is vulnerable to the low-carbon transition. Furthermore, if it has a high socio-economic exposure and low Social Protection Coverage, one can characterize the country as highly vulnerable in socio-economic terms to the transition.

6.2. Extensions

The sectoral aggregation in the EORA-26 does not allow us to perfectly identify what are the sunset industries in each country. The country case studies presented in the Appendix propose complementary analysis for two countries: Jordan and Gabon. For example, Jordan could be considered a country with some degree of exposure because medicament and fertilizers are in the same sector as refined petroleum, a sunset industry, the country is competitive in these industries, hence leading us to mitigate Jordan's data-driven exposition. One possibility of refining these results is using more disaggregated Input-output tables. Shapirp (2021), for example, uses the Exiobase, which disaggregates 48 countries into 163 industries to measure CO2 intensity for each international and intra-national trade flow in the global economy. This dataset, as well as all other multiregional tables available cover only a few developing economies. Therefore, an extension of this analysis can be made using either country tables or MRIO that covers less countries but have more detailed sectoral coverage.

Besides extending the work developed here for more disaggregated data, it would be interesting to analyse countries' exposures in different dimensions, such as the exposition of countries' financial system to the low-carbon transition. Sectoral financial data allow us to identify the financial exposure and sensitivity of different sectors to low-carbon transition shocks. Godin and Hadji-Lazaro (2021) developed a methodology to identify the demand-induced transition vulnerabilities and applied to South Africa, where data on sectoral assets, equities and liabilities are available for 2018 on the Annual Financial Statistics Survey for 190 industries. Using an input-output approach, the authors identify not only those industries with the highest financial fragility, but also how it may propagate through the industrial network using Cahen-Fourot et al. (2020)'s approach. Based on this, it is possible to analyse the financial exposition of industries within different countries based on their position in the surrounding industrial network and on the overall structure of expenses in this network.

The analysis of the external exposure in this paper is based only on real flows. The dependence on sunset industries considers only their importance to raise foreign currency through exports. Nevertheless, Foreign Direct Investments (FDI) are also an important source of foreign currency for some countries, sometimes preventing balance-of-payment constraints and sometimes reinforcing real flows. Again, the lack of sectoral data is the main constraint for this analysis. FDI inflows are available for developed economies for 12 sectors at the OECD Stat, and some developing countries, such as Colombia, have these data with similar disaggregation. Nevertheless, data are not available for most of the developing economies, and hence one cannot account yet for this aspect when analysing external exposure.

Another possible extension is related to the fiscal exposure. One of the assumptions of the paper is that wage and profit taxation is the same across sectors for a given country, and the sectoral fiscal dependence is given either by differences in product taxation (sales and VAT) or by differences in the composition of income distribution, (wages, profits and other incomes). There might be, however, countries where profits and wages are less taxed in some sectors, and it is not accounted for here. In some countries, however, this data is available disaggregated by sector, which allows us to identify more precisely the fiscal exposure. The Federal Revenue of Brazil (RFB, in Portuguese), for example, provides data for each tax disaggregated into 87 industries. These data allow us to identify what is the actual contribution of each sector for the fiscal revenue and, using the input-output framework, one can also account for the indirect dependence on each of these industries. Once more detailed data for other countries are also available, one can estimate more precisely both the direct and indirect sectoral tax contribution of sunset industries, and hence countries' fiscal exposure.

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A. Appendix

A.1. Country analysis: Gabon and Jordan

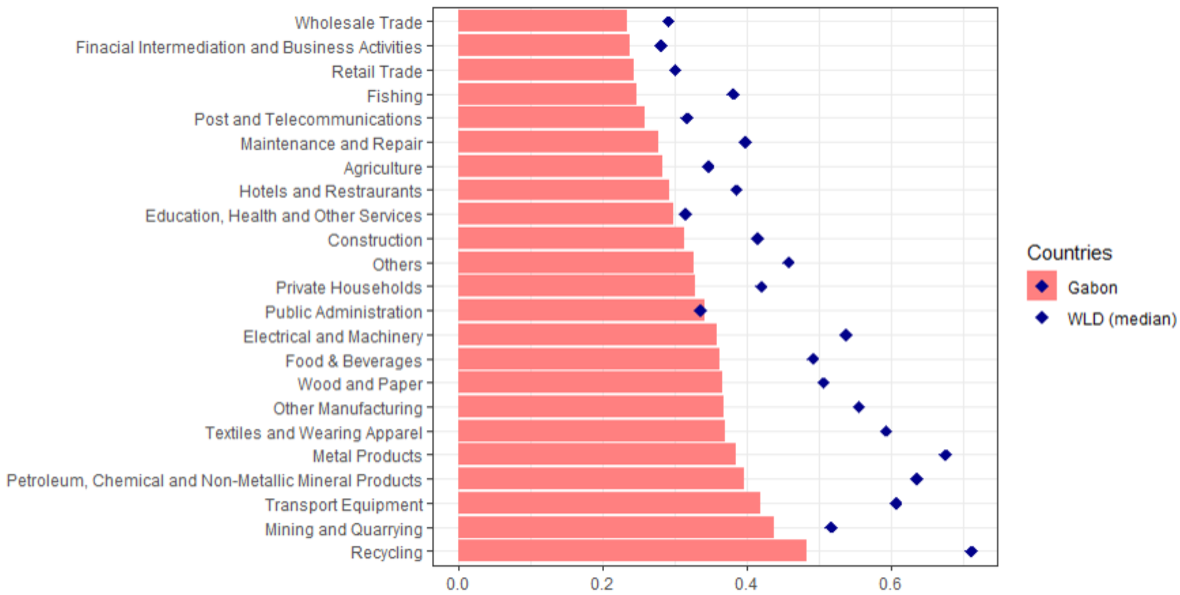
Based on the methodology presented in Section 2, one can also evaluate the sectors responsible for macroeconomic exposure, and, based on this analysis more deeply the consequences of the low-carbon transition for all countries that data is available.

We took here two countries to analyse as examples of the possibilities: Jordan and Gabon. These economies were chosen because they have very different productive structures and they are located in different regions, despite presenting similar levels of income (both are developing economies).

A.1.1. Emission-intensity by sector

Before analysing countries' exposure level, however, it is important to evaluate whether sunset industries in these economies are the same as those defined for the world economy in general. This is important because based on this, one can exclude and include sunset industries according to the specificity of these economies. Figures 8 and 9 presents the CO2 emission-intensity by sector for these economies considering direct and indirect upstream emissions.

Figure 13: Gabon's sectoral direct and upstream CO2 emission-intensity (Kg of CO2/USD)



From Figure 13, which presents these data for Gabon, one can see that in general Gabon's sectoral emission-intensity is lower than world' median. In the case of Mining and Quarrying, the distance is not enough to exclude from being considered a non-polluting sector. Moreover, the main issue with Mining and Quarrying is not the upstream emissions, but downstream, as discussed in Section 3.1. In the case of Metal products and Petroleum, Chemicals and Non-mineral metals, the distance from the world median is higher but they are still among the most polluting industries. Although it indicates that Gabon's production is clearer than the world median, one cannot affirm that these are not sunset industries.

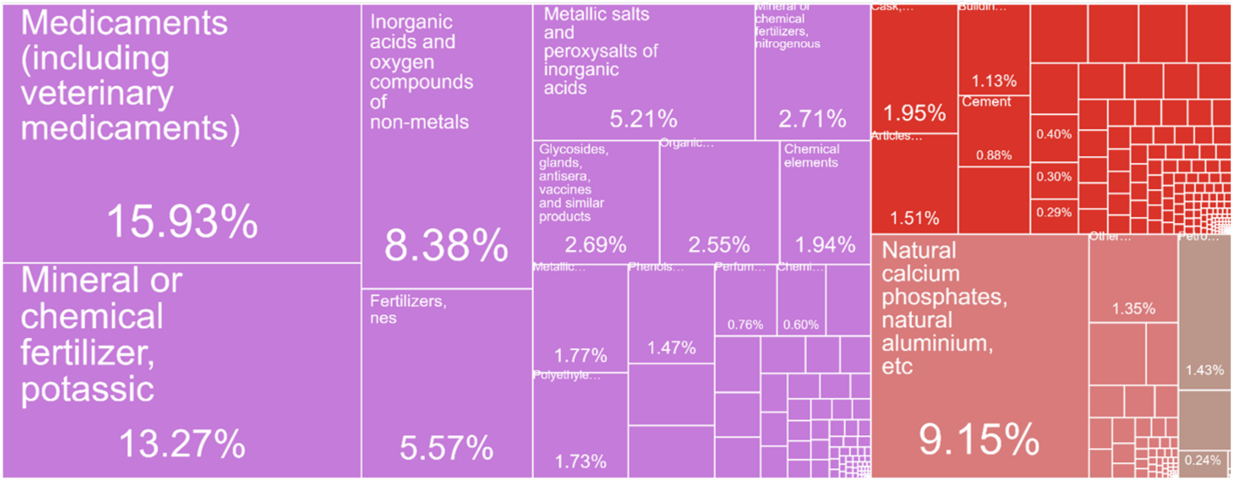
The only sector that could be considered a non-sunset industries among the potential sunset industries defined before is Wood and Paper. This sector in Gabon emits less carbon than the world median and it is not among the sectors that emit the most for this economy. Therefore, when accounting for the relative importance of sectors and the country's dependence, one need to consider that Wood and Paper is relatively less carbon intensive for Gabon, and maybe it could not be considered a sunset industry for this specific case.

In the case of Jordan, as shown in Figure 14, all sectors present higher CO2 emission intensity than the world median. Agriculture and Food & beverages are those that emit the most, and they emit more than twice the world median. Most products of these industries, however, are relevant for the low carbon transition, but the higher level of CO2 emission in Jordan indicates that the country will need to reduce emissions within industries (not only promoting structural changes) to reduce the overall emissions. In the case of the above-mentioned potential sunset industries, because they pollute more in Jordan than the world in general, one can expect that they are indeed sunset industries in Jordan, even though one need to considered the product mix discussed before.

Figure 14: Jordan's sectoral direct and upstream CO2 emission-intensity (Kg of CO2/USD)

With the aim of analysing the product mix of Jordan one can consider the export basket of the country. The Atlas of Economic Complexity presents these data for a very disaggregated sectoral classification, allowing us to analyse what are the products within the sunset industries. As one can see from Figure 15, the product mix in Jordan is very diverse, specially in the Petroleum, Chemical and Non-mineral metals sector. Medicaments, fertilizers and other important inputs for agriculture represent together more half of Jordan's exports in potential sunset industries. Because these industries are relevant for the low-carbon transition, one cannot consider that Jordan is a country dependant of sunset industries. Conversely, the product mix within potential sunset industries shows that Jordan is well-positioned relatively to most of developing countries.

Figure 15: Jordan's potential sunset industries export basket, 2018



Source: The Atlas of Economic Complexity

A.1.2. Exposition by sector: Gabon

Despite having a low-level of emissions compared with other developing economies, as seen before, some industries in Gabon's economy present relatively higher levels of emissions per unit of production, and hence they may be more impacted by the low-carbon transition. With the aim of evaluating Gabon's exposure, therefore, it is interesting to evaluate the importance of these industries in raising foreign currency (to avoid balance-of-payment constraints), in total government revenue (to avoid fiscal constraints) and in wages and employment (to reduce socio-economic conflicts).

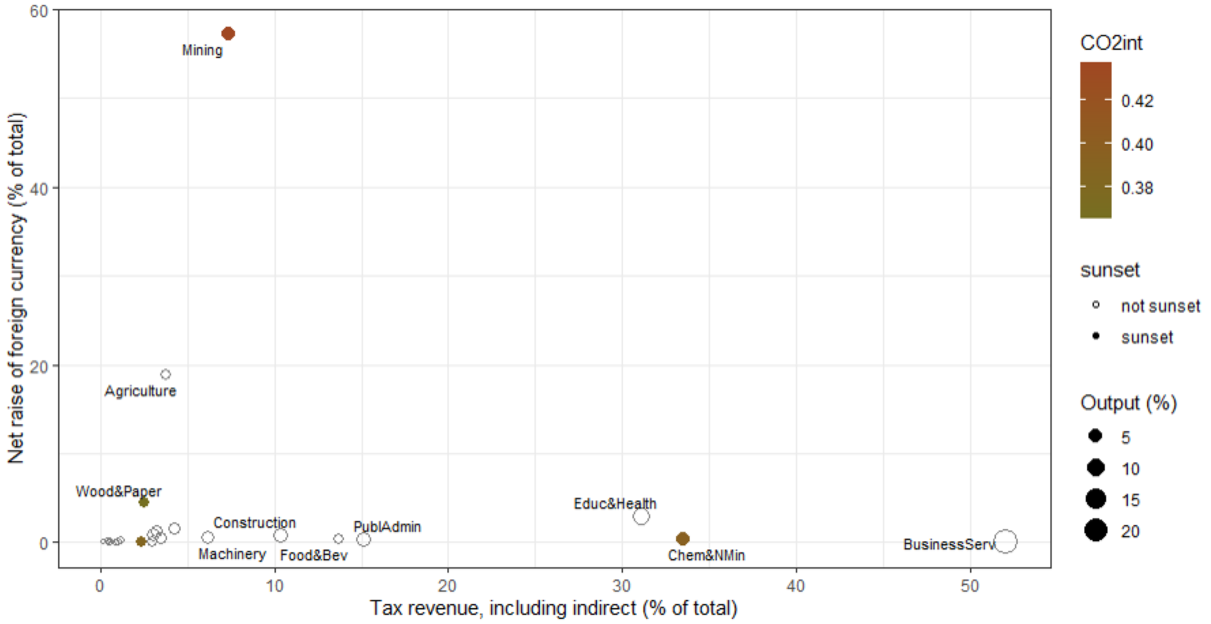
Figure 16 presents the importance of each industry to raise foreign currency (considering the imported inputs) in the vertical axis, and the importance to raise tax revenues (considering their indirect impact) in the horizontal axis. Moreover, the color of the circles indicates the CO2 intensity of the sector and its size represents the share in output.

The case of Gabon illustrates the importance of the multi-dimensional analysis. Mining and Quarrying is very important to avoid external constraints, as it is responsible for almost 60% of the net raise of foreign currency. Because this is considered as a sunset industry, given its high emissions per unit of production, one can affirm that Gabon presents a high level of external exposure due to its dependence of Mining and Quarrying industry.

If one looks into fiscal exposure, however, results are different. Mining and Quarrying is directly and indirectly responsible for about 7% of the fiscal revenue. On the other hand, Petroleum, Chemicals and Non-metallic Minerals is a very important industry to avoid fiscal constraints. More than 30% of the fiscal revenue depends on this industry directly and indirectly.[3]

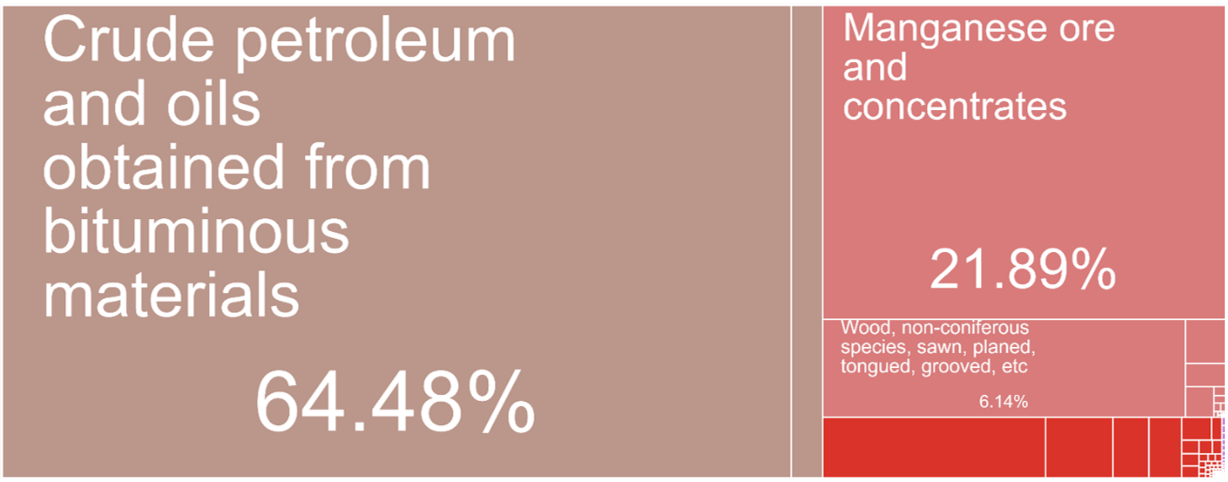
[3] It is important to note that one cannot sum up the importance of sectors as data accounts for indirect impacts,

Figure 16: External and fiscal exposure, Gabon, 2015



Different from Jordan, the product mix of Gabon export is very concentrated in few products that are considered among the most threatened by the low-carbon transition. The most important product exported by Gabon, as one can see in Figure 17, is crude petroleum, which represents about two-thirds of the potential sunset industries in the country. Manganese ores are also important for the country, representing about one-fifth of the exports of potential sunset industries. However, because it is a relevant product in the transition process, there is the possibility to Gabon to use it to reduce its external exposure to the low-carbon transition.

Figure 17: Gabon's potential sunset industries export basket, 2018



Source: The Atlas of Economic Complexity

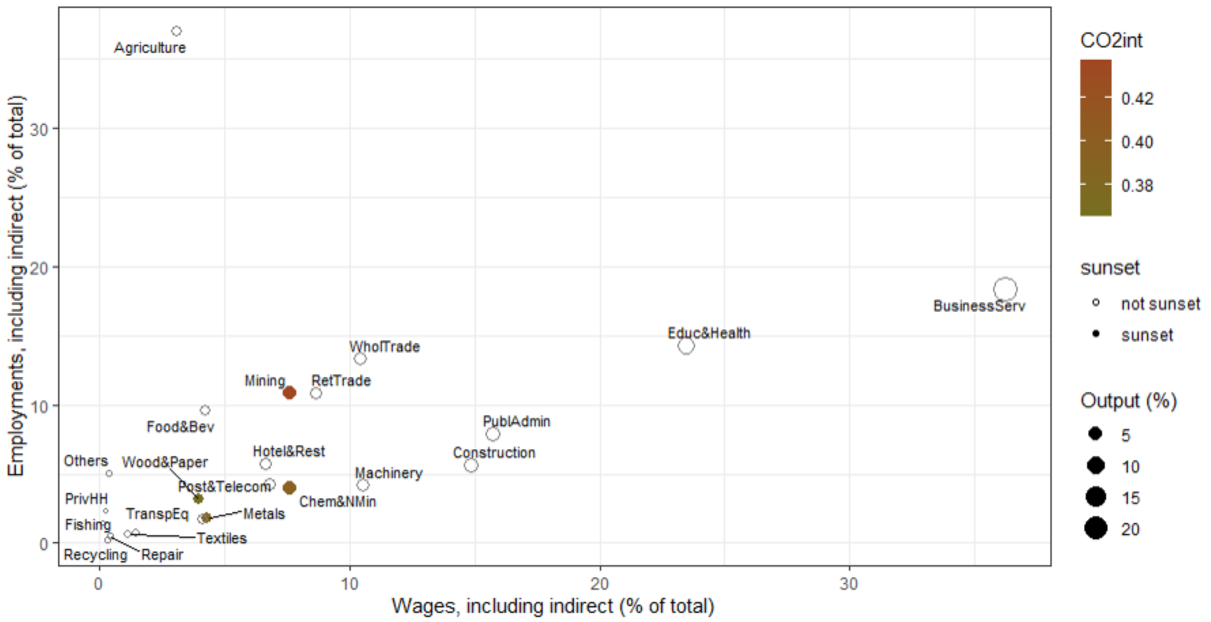
When we account also for the capacity of Gabon to migrate from sunset industries to green

and hence there is a superposition of sectoral production.

products, we verify that Gabon, besides being a country with high level of exposure to the low-carbon transition, is also a country with high vulnerability. The country ranks 210th in the Green Complexity Potential Ranking (among 226 countries), which means that it does not have the productive and technological capabilities to promote a structural change towards green products in the short and medium-term.

Besides the analysis of the fiscal and external exposure and vulnerability, it is also important to analyse the socio-economic dimension, as it shows to what extent the low-carbon transition will impact on employment and wages. Figure 18 presents the direct and indirect importance of each sector to generate employment in the vertical axis and to pay wages in the horizontal axis. Moreover, as before, the colour of the circle indicates the CO2 emission-intensity and the size the sectoral share on total output.

Figure 18: Socio-economic exposure, Gabon, 2015



Although the importance of sunset industries in the socio-economic dimension is smaller than in the other dimensions, as other sectors, such as Agriculture and Business Services, are more relevant to generate employment and pay wages, one cannot infer that there is no socio-economic exposure. More than 10% of the employment is either directly or indirectly related to the Mining and Quarrying industry, and about 7% of the wage bill is related to this industry. Moreover, Petroleum, Chemicals and Non-metallic Minerals also account for about 7% of the wage bill, and Metal Products and Wood and Paper accounts each one for about 4% (these values cannot be summed up).

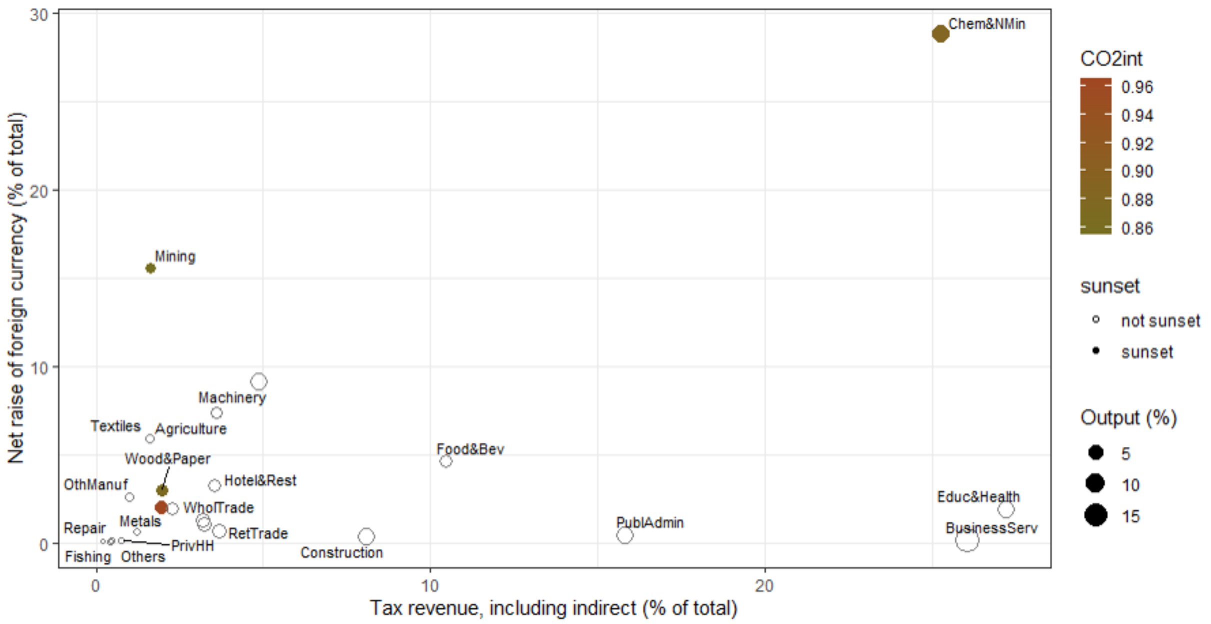
Therefore, despite not being among the most exposed economies, the dependence of Mining and Quarrying explains why this economy is highly exposed in the external and socio-economic dimensions, and considering the low productive and technological capabilities (measured by the GCP) and the low level of human development (measured by the HDI), one can affirm that Gabon is vulnerable to the low-carbon transition in terms of external and socio-economic dimensions. Moreover, because tax revenues also depend substantially on the Petroleum, Chemical and Non-mineral Metal industry, which is a sunset industry, one can affirm that Gabon is also vulnerable in the fiscal dimension.

A.1.3. Exposition by sector: Jordan

Jordan has an export basket much more diversified than Gabon. While more than 50 % of Gabon exports is Crude Oil (59.44%, according to the Atlas of Economic Complexity), excluding tourism and transport, Jordan has no products that represent more than 4% of their exports. Chemicals, Textiles, Agriculture, Machinery are all important sectors for Jordan, and hence one can expect a less external vulnerability.

Figure 19 presents the external and fiscal exposure of Jordan by sector. In the horizontal axis we have the direct and indirect importance of sectors to generate revenue for the government, and in the vertical axis their importance to raise foreign currency.

Figure 19: External and fiscal exposure, Jordan, 2015



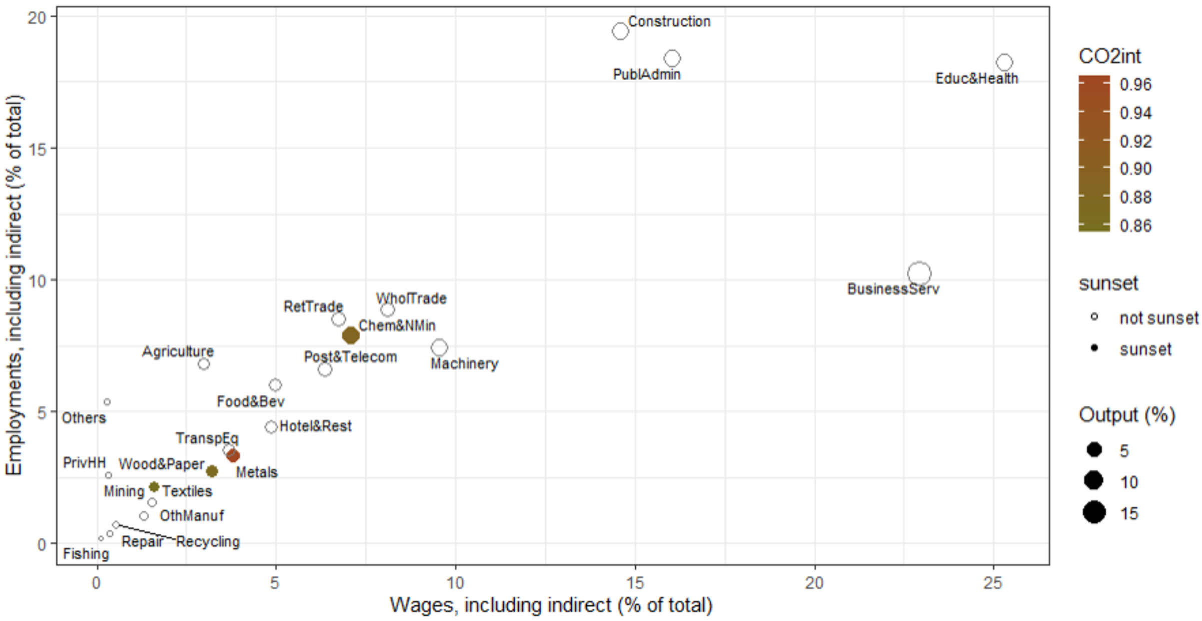
Different from Gabon, in the case of Jordan, the same sector responsible for the external exposure is also responsible for tax revenues (Petroleum, Chemicals and Non-metallic minerals). About 30 % of the net raise of foreign currency is due to this sector, and it is also responsible (directly and indirectly) to generate one-fourth of fiscal revenues.

Once this sector is considered a potential sunset industry, one could affirm that Jordan is a country with high exposition both in external and fiscal dimensions. Nevertheless, if one analyses what is within these sectors, results may be slightly different. According to the Atlas of Economic Complexity, the chemicals exported by Jordan are very diversified and most of them cannot be considered as a sunset industry. Potassic fertilizers, which are very important for agriculture, represent 17.9% of Jordan's exports in this sector, and Medicaments represent 21.5%. Based on this, Jordan cannot be considered a country with a high exposure level, despite the importance of a potential sunset industry both to generate tax revenues and to raise foreign currency.

Moreover, Jordan ranks 57th in the Green Complexity Potential rank, which indicates that the country has the productive and technological capabilities to migrate to green products. Therefore, even if the country were exposed to the low-carbon transition, it would not be vulnerable, as it could migrate to green products more easily than about three-fourth of the other economies.

The analysis of the exposition by sector can be complemented by the evaluation of the socio-economic exposure, which is based on the sectoral importance in paying wages and generating employment, as presented in Figure 20.

Figure 20: Socio-economic exposure, Jordan, 2015



In the horizontal axis we have the importance of sectors in terms of wages, and we can see that none of the potential sunset industries are very relevant. Petroleum, Chemicals and Non-mineral Metals is directly and indirectly responsible for less than 7.5% of the wages, and, as discussed before, it not even can be considered a sunset industry when we analyse its composition. Metal Products, which is the second most important among the potential sunset industries, is responsible only for 4% of the wages, which indicates that, despite not being irrelevant, this is not a key industry in socio-economic terms for Jordan.

In terms of employment (presented in the vertical axis), results are very similar: Petroleum, Chemicals and Non-Metallic Minerals is an industry that is relevant (about 8% of the employment are related to it directly and indirectly), but this is a very diversified industry. On the other hand, Wood and Paper, Metal Products and Mining and Quarrying are not very relevant, and hence the country does not depend on sunset industries to generate employment, which means that it has a low socio-economic exposure.

A.2. Details on Clustering

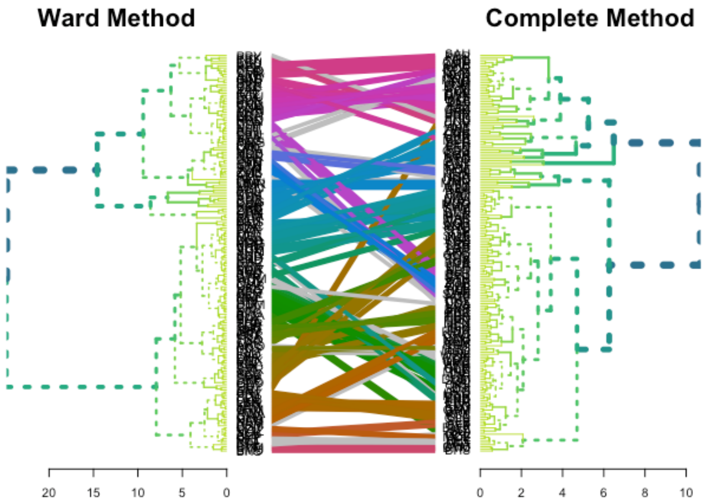
The set of agglomerative methods that we consider are the single linkage, complete linkage, average linkage, centroid linkage and Ward's minimum variance. We decided to use Ward's minimum variance based on the agglomerative coefficients. Ward's method corresponding coefficient is very high, highlighting its suitability for our analysis.

Table A.1: Agglomerative coefficients

Average	0.92
Single	0.81
Complete	0.95
Centroid	0.88
Ward	0.98

Moreover, all methods generated relatively similar clusters. The following tanglegram (Figure 21 compares the clusters formed by the complete and the Ward's methods. The highlighted linkages indicate the countries that appear in common clusters among the two methods. The continous, coloured lines in each dendrogram highlight the common clusters that appear at higher levels of hierarchy across the two methods.

Figure 21: Tanglegram: Complete vs. Ward similarity



More formally, we test for the similarity across the different methods via their pairwise cophenetic correlations, which measure the correlation between the cophenetic dissimilarities derived from two dendrograms. As evident from the cophenetic correlation matrix below, all methods give relatively similar clusters.

Table A.2: Cophenetic correlation matrix

	Complete	Single	Average	Centroid	Ward
Complete	1.0				
Single	0.81	1.0			
Average	0.95	0.9	1.0		
Centroid	0.88	0.9	0.97	1.0	
Ward	0.77	0.56	0.74	0.64	1.0

As a further robustness check we compute Baker's gamma correlation coefficient (Baker 1974) for Ward's method vis a vis the other methods, which measures the association between two dendrograms. Again, we find high similarities across dendrograms, with the exception of the centroid method.

Table A.3: Baker's gamma correlation matrix, Ward vs.

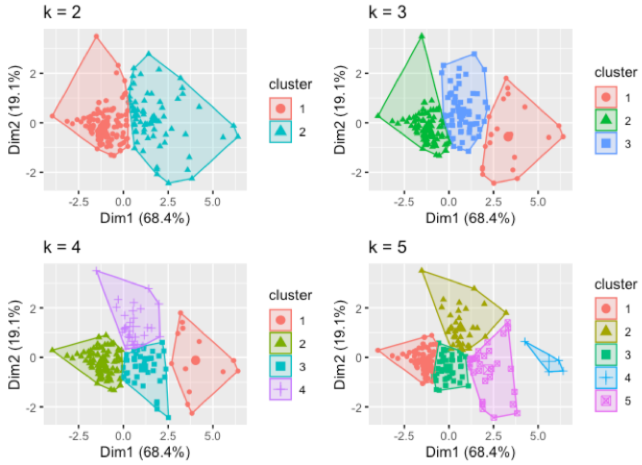
Average	0.83
Single	0.67
Complete	0.80
Centroid	0.15
Ward	1.0

Note that almost all values in the cophenetic and Baker's gamma correlation matrices are above 0.5 hence are typically considered significant. We further proceed to an exact p-value analysis of the significance of the two indexes by implementing a permutation test between Ward and the complete method. We choose to compare Ward vs the complete method as the latter has the second highest agglomerative coefficient. We perform a bootstrap analysis (500 samples) to estimate the distributions of the cophenetic and Baker's gamma correlations. We then test the null hypothesis that the correlations of the Ward vs the complete method are 0, i.e. that the two dendrograms are not similar. Under the assumption of asymptotic normality, we reject the hypothesis of non-similarity between the two clusters at the 0.99 confidence interval, for both the cophenetic and Baker's gamma.

To chose the appropriate number of clusters we use a combination of statistical heuristics and economic intuition. In particular, we utilised the NbClust statistical package (Charrad et al. 2015), which provides 30 different indices for the determination of the number of clusters. We then calculated a weighted average of the proposed number of clusters, assuming equal weights for each index. From this analysis the optimal number of clusters obtained is k =3 (rounded down). Nevertheless, we decided to use k=4 as it defines the group of high-risk countries more clearly, without distorting the general structure of high, mid and low risk grouping that we also retrieve from 3 clusters (see also Figure 22 below).

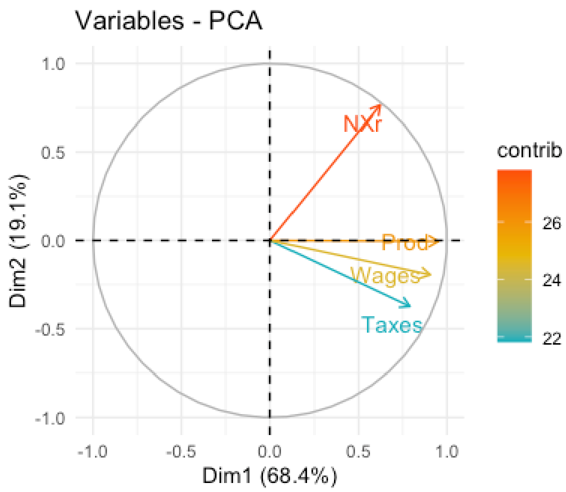
Figure 22 presents how the clusters change for different numbers of k.

Figure 22: k-means clusters



Lastly, as is common in such clustering exercises, we perform Principal Components Analysis (PCA) and apply k-means clustering on the first two main components. The main benefit of PCA is that a small number of principal components can pick up the largest variance in the data. Hence, visualising the data on the two main components allows us to identify the variables that contribute the most to the (dis)similarities across countries. We use k-means as it uses the same objective function as the Ward method and since we fix the number of clusters (k=4), we can now implement partitioning methods. This serves as a further robustness check of our hierarchical clustering results. The PCA results are presented below. Figure 23 presents the contribution of each variable in the first two principal components.

Figure 23: PCA components



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