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EU carbon emissions by multinational enterprises under control-based accounting

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ABSTRACT

The territory-based conception of environmental commitments disregards the crucial role of multinational enterprises (MNEs) in the global generation of greenhouse gases. Such a misconception discourages MNEs from pledging own emissions reduction goals as global agents and exempts their origin country of any responsibility for the emissions they generate abroad. We propose a new allocation criterion based on who has the ability to take MNEs' decisions called the control-based accounting. We apply it for the first time to the MNEs' foreign affiliates operating in the EU and estimate the CO_2 emissions responsibility of EU countries under the control-based criterion, that is, assigning emissions generated by foreign-controlled companies to the origin country of the firms (controlling country) instead of the host country (as in the territory-based approach). We found that Germany and France are the EU countries with the highest control-based responsibilities; whereas Poland, the Czech Republic and Hungary bear significantly less responsibility under this approach compared to other allocation methods. The United States is the non-EU country with the greatest responsibility for emissions physically generated within the EU's territory through foreign affiliates. Targeting climate policies towards inducing parent companies and controlling countries to calculate and reduce the carbon footprint of their affiliates would place MNEs at the forefront of the fight against climate change.

1. Introduction

According to recent research, 75% of current commitments to reducing emissions by countries are partially or totally insufficient to keep global warming below 2 to 1.5 °C and to reduce GHG emissions by 50% by 2030 (Watson et al., 2019). The European Union's pledge was deemed sufficient, through the mitigation policies adopted to reduce its domestic emissions, to yield GHG domestic emission reductions of 58% by 2030 (Watson et al., 2019). However, as the EU has reduced the emissions within its territory, the relevance of the emissions embodied in its imports increases accordingly (Wood et al., 2019a), and therefore, EU countries should take mitigation measures that progressively incorporate part of their carbon leakage, because otherwise, they will not be globally on the path to achieve the Paris Agreement goals. The European Commission acknowledges that maintaining the leading role of the EU in fighting climate change and the success of EU efforts and the Paris Agreement requires a "shift from action by the few to action by all" where "the EU must promote worldwide uptake of policies and action to reverse the currently unsustainable emissions trajectory" (European Commission, 2018).

Although there is widespread consensus on the need for greater ambition to achieve an emissions path compatible with the 1.5 °C goal (IPCC, 2018; Wiedmann and Lenzen, 2018), the emissions reported by Paris Agreement committed countries and their emission reduction targets still rely on territorial or producer criteria (Fan et al., 2016; UNFCCC, 2020a). That choice of criterion jeopardises reductions targets because it neglects the role of international trade (Kanemoto et al., 2014; Peters, 2008) and relies on unilateral and voluntary country-by-country objectives (Nieto et al., 2018). The literature on responsibility and allocation criteria by countries, especially regarding the production-based versus the consumption-based criterion (Afionis et al., 2017; Kander et al., 2015; Peters, 2008), has contributed to proposed accounting alternatives to allow mitigation of environmental and social impacts linked to international trade (Wiedmann and Lenzen, 2018). Other allocation criteria have been progressively developed, such as the shared responsibility (Gallego and Lenzen, 2005), the income-based criterion (Marques et al., 2012), technology-adjusted consumption-based accounting (Kander et al., 2015), the dynamic consumption-based model (Chen et al., 2018b), value added-based responsibility allocation (Piñero et al., 2018; Randers, 2012), historic or cumulative responsibility (Peters et al., 2015) and an ex-post emission responsibility allotment (Dietzenbacher et al., 2020). Each criterion displays

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different advantages and drawbacks (see for instance Wiedmann (2009); Afionis et al. (2017); Jakob et al. (2014) or Fan et al. (2016) for consumption-based versus production-based criteria and Dietzenbacher et al. (2020) for a wider comparison including technology-adjusted criterion). In terms of efficiency or equity in mitigating domestic environmental impacts, the best choice would depend on the specific situation faced, and no single criterion covers all the emissions that a country can affect or address through its policies (Steininger et al., 2016; Zhou and Wang, 2016). Moreover, despite the growing interest of companies in taking action against climate change (Blanco et al., 2016; Dietz et al., 2018), none of the existing criteria focus on the responsibility or exploit the possibilities of multinational enterprises (MNEs). It is necessary to assess the role and responsibility that MNEs have on the emissions generated in each country and how they can contribute to mitigating these impacts by establishing production standards and selecting their suppliers along their global production chain. This is the objective pursued with the control-based criterion proposed in this research.

The control-based criterion has the objective of involving transnational entities in the responsibility of countries and introducing such entities in the setting of mitigation targets. To this end, the criterion makes a country responsible for the virtual carbon embodied in the global production chains of companies whose capital owners belong to that country (López et al., 2014). Therefore, compared to the producer-based criterion used to allocate emissions responsibility in international agreements (Kyoto Protocol, Paris Agreement, etc.), the control-based criterion incorporates the emissions related to affiliates of MNEs from the compiling country that are located in foreign countries and subtracts the emissions corresponding to affiliates of MNEs from other countries operating in the territory of the compiling country. The important weight that MNEs have on world GDP, representing one-third of it (Cadestin et al., 2018a), the fact that trade between affiliates is very concentrated (Ramondo et al., 2016), and the capacity that MNEs have to assume leadership in their supply chains and induce their customers and suppliers to comply with sustainable practices (Jia et al., 2019) (Gosling et al., 2016) and standards (Kareiva et al., 2015) make the control criterion an adequate instrument to evaluate how these companies can spread good mitigation practices around the planet.

Applications of consumption-based accounting have been extended to study the role played by different types of households (Druckman and Jackson, 2016; López et al., 2017), to endogenise investment (Sodersten et al., 2018), to study the role of cities (Hung et al., 2019; Mi et al., 2016; Moran et al., 2018) or carbon spillovers by regions (Ning et al., 2019) and to analyze the policy implications for cities at different spatial scales (Ottelin et al., 2019). Although demand-side solutions, such as consumption-based criteria, have certain advantages in mitigating climate change (Creutzig et al., 2018), this approach has rarely been adopted by legislation (Wiedmann and Barrett, 2013). For instance, the targets to cut GHG emissions in the EU by at least 40% below 1990 levels by 2030 (European Commission, 2015) or to reach net zero carbon by 2050 (European Commission, 2019) were set regarding EU's territorial emissions. However, consumption-based measures are being introduced in several sets of official statistics and official reports as an indicator of global impact, as in the OECD Green Growth Strategy (OECD, 2011) and the 2019 UNEP Emissions Gap Report (United Nations Environment Programme, 2019), with the warning that this measure is not used within the context of the United Nations Framework Convention on Climate Change (UNFCCC). Additionally, at the EU level, Eurostat has been calculating the carbon footprint of the EU since March 2019 (Eurostat, 2019b) and The European Environment State and Outlook 2020 includes footprint measures to assess the environmental impact and resource use in the EU (European Environment Agency, 2019).

Therefore, the adoption of a consumption-based criterion as a benchmark for mitigation is not yet clear (Afionis et al., 2017; Jakob et al., 2014). One of those advantages of consumption accounting is that, irrespective of the agent under consideration, it incorporates international trade (He and Hertwich, 2019), and thus, it is an appropriate instrument for mitigating carbon leakages (Wiedmann and Lenzen, 2018) that the EU's leadership in mitigation policies might be causing. In this regard, Koch and Basse Mama (2019) found that German firms covered by the EU Emissions Trading System (ETS) have increased the number of their affiliates outside the EU by approximately 28%, on average. The consumption-based criterion extends the responsibility beyond the borders of the city, region or country in comparison to the producer criterion, since incorporating the emissions associated with the entire global production chain prevents dilution of responsibility. The same happens with the control criterion since those companies that relocate their production to other countries (through subsidiaries) would see their carbon footprint increased and, with it, their environmental responsibility. In a similar line of research, Li et al. (2019) calculate the full supply chain corporate responsibility to assess ambitious carbon mitigation scenarios, but they do not consider the heterogeneity of companies. At the enterprise level, the meta-analysis of Branger and Quirion (2014) shows how the most efficient solution to avoid emissions leakage when designing an emissions market that incorporates imports is that of border discounts (which in practice implies either using a consumer criterion or a criterion based on control, as both consider imports). Additionally, Jakob and Marschinski (2013) and Steininger et al. (2014) analyze the impact of the adoption of a consumption-based criterion on carbon leakages.

However, in the consumption-based criterion, the role of intermediate goods is blurred, as they become endogenous when based on a demand model (Kanemoto et al., 2012) and, with it, the production decisions made by the companies (Skelton, 2013). The control-based method highlights these relationships and decisions through global value chains. To this end, the control-based criterion requires a prior calculation of the carbon footprint of MNEs' subsidiaries (López et al., 2019), which provides a global instrument to improve their environmental management by identifying carbon hotspots, setting mitigation targets and assessing the measures that these agents take to reduce their carbon burden. Once corporations are aware of their direct and indirect environmental impacts, they can begin to implement the necessary sustainable management associated with any global production chain (O'Rourke, 2014). Although such a task is complicated, Kagawa et al. (2015) and Kanemoto et al. (2018) show how there is a low number of important clusters through which CO_2 emissions are transmitted, which facilitates sustainable carbon management as companies have to target only a small number of suppliers from energy-intensive sectors.

Another approach that focuses on the environmental impacts of companies and captures the upstream emissions in the global chain of production is the 'Spend-based method' proposed by the GHG Protocol to assess the companies' value chain emissions (scope 3) using input-output models (GHG Protocol, 2011). In the GHG Protocol guidelines, the assessment of scope 3 emissions should be carried out by all types of companies, regardless of whether they supply the intermediate or final demand, and therefore these emissions generate double-counting when they are added up at an aggregate level (Lenzen, 2008). This creates an inconvenience when setting emission reduction targets at the country level and hinders agreements on the mitigation of emissions generated in international trade, as evidenced during the COP25 held in Madrid in 2019 (UNFCCC, 2020b). The control-based approach proposed in this paper avoids that double-counting by focusing only on final producers and it is therefore a more appropriate approach for assigning responsibilities to countries, including all emissions in global value chains, whose leaders and policymakers are the ones that sign the international mitigation agreements.

In the present research, we apply the control-based criterion to MNEs operating within EU borders; this criterion could help the EU to maintain and increase its leadership in the efforts against climate change. First, we calculate the carbon footprint of MNEs by controlling country, that is, by country of origin of the parent company of the affiliates operating inside EU borders, including those affiliates from other EU member states. Using these footprints, we quantify the role of the MNEs in each EU country regarding emissions generation and assess how countries' responsibility on emission changes when taking into account firm ownership. Finally, calculations of control-based allocation responsibility within the EU are made assuming the emergence of a regional agreement establishing the use of this methodology.

2. Methods and data

2.1. The concept of control

The meaning of control that we adopt here follows the definition given by Eurostat in the Foreign Affiliates Statistics (FATS) Recommendation Manual (Eurostat, 2012): "*control shall mean the ability to determine the general policy of an enterprise by choosing appropriate directors, if necessary. In this context, enterprise A is deemed to be controlled by an institutional unit B when B controls, whether directly or indirectly, more than half of the shareholders' voting power or more than half of the shares*". Under this definition, one may realize that in today's globalizing world, enterprises can be controlled by either a domestic or a foreign institutional unit. An enterprise A is classified as a domestic-controlled company when its controlling institutional unit is resident in the same country in which the enterprise A has its residence. On the other hand, an enterprise A is classified as a foreign-controlled company when its controlling institutional unit is resident in a different country from where the enterprise A resides. Independent enterprises that are not controlled by any other corporation or institutional unit are classified as domestic-controlled companies. To simplify, we use the term '*controlling country*' to refer to the country of residence of the controlling institutional units and '*host country*' to refer to the country where controlled companies reside. Note that for domestic-controlled companies, their controlling country and their host country coincide, while in the case of foreign-controlled companies, their controlling country and their host country are different.

As the reader may have realised, institutional units that has control over foreign companies are those corporations commonly known in the literature as multinational enterprises (MNEs) (Cadestin et al., 2019; OECD, 2018), and correspondingly, foreign-controlled companies are commonly called *foreign affiliates* (Cadestin et al., 2019; Eurostat, 2012). In this study, the concept of '*multinational enterprises*' and its acronym '*MNEs*' encompass any company that has control over at least one foreign affiliate, regardless of the size of the controlling company or the foreign affiliate. Thus, data used in this work take into account companies of every size (large, medium and small).

From the perspective of a country, one can distinguish between two types of foreign affiliates i.e., outward and inward. The outward foreign affiliates of country C are the companies residing in non-C countries and controlled by MNEs whose headquarters are in country C, whereas inward foreign affiliates of country C are those companies residing in country C that are controlled by MNEs whose headquarters are in non-C countries. Therefore, the companies controlled by country C encompass domestic-controlled companies plus outward foreign affiliates, whereas inward foreign affiliates are not controlled by country C since the control over these companies relies on MNEs residing in foreign countries. Note that the definitions from above imply that outward foreign affiliates of one country (controlling country) are simultaneously inward foreign affiliates of another country (host country).

2.2. MRIO model and the producer footprint (PF)

MRIO models have been widely used to calculate the emissions responsibility of countries with both production-based and consumption-based accounting methods (PBA and CBA, respectively). PBA identifies direct emissions generated in production and allocates them to the country where they occur, whereas CBA tracks indirect and direct emissions generated all over the world in all production stages and allocates them to the country where the final goods are consumed. The general equation of environmentally extended MRIO models with n countries and k sectors used to calculate both PBA and CBA is

$$\boldsymbol{F}=\begin{bmatrix} F^{11} & F^{12} & \dots & F^{1n} \\ F^{21} & F^{22} & \dots & F^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ F^{n1} & F^{n2} & \dots & F^{nn} \end{bmatrix} \begin{bmatrix} P^{11} & P^{12} & \dots & P^{1n} \\ P^{21} & P^{22} & \dots & P^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ P^{n1} & P^{n2} & \dots & P^{nn} \end{bmatrix} \begin{bmatrix} Y^{11} & Y^{12} & \dots & Y^{1n} \\ Y^{21} & Y^{22} & \dots & Y^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ Y^{n1} & Y^{n1} & \dots & Y^{nn} \end{bmatrix} = \boldsymbol{PY} \quad (1)$$

where $\boldsymbol{P}=\hat{\boldsymbol{f}}(\boldsymbol{I}-\boldsymbol{A})^{-1}$, of size nk x nk, is the emissions multiplier (consisting of the Leontief inverse, $(\boldsymbol{I}-\boldsymbol{A})^{-1}$, pre-multiplied by the CO_2 emission coefficients vector, $\hat{\boldsymbol{f}}$), which captures both the direct and indirect emissions needed to produce one unit of output by country and sector, and $\boldsymbol{Y}$, of size nk x n, is the final demand matrix consisting of k-element column vectors, $\boldsymbol{y}^{rs}$, which represent the monetary values of output produced in country r and consumed by final demand agents of country s. Therefore, matrix $\boldsymbol{F}$, of size nk x n, gathers all emissions directly and indirectly generated to satisfy the total final demand. Summing the $\boldsymbol{F}$ matrix horizontally results in production-based accounting by producer country (r) and sector ($PBA_r = \sum_s \boldsymbol{F}^{rs}$), which is the measure considered by the Kyoto Protocol and Paris Agreement for emissions reduction commitments, whereas the vertical sum results in consumption-based accounting by consumer country (s) ($CBA_s = \sum_r \boldsymbol{F}^{rs}$), which is also known as the carbon footprint (Cadarso et al., 2018; Davis et al., 2011; Kanemoto et al., 2012; Peters, 2008; Peters and Hertwich, 2008).

In this paper, we start from a concept that could be considered an intermediate point between the concepts of PBA and carbon footprint: the *producer footprint* (PF) (López et al., 2019; Ortiz et al., 2020) (see Fig. 1). The PF approach consists of tracking direct and indirect emissions generated all over the world in all production stages and allocating them to the country where the final goods are produced rather than the country in which the final products are consumed (as done in CBA). Therefore, the PF can be interpreted as the carbon footprint of producers and it is similar to the sales-based inventory or the final-product-based criterion proposed in Kanemoto et al. (2012) and Wiebe (2018), respectively. The value added of PF resides in its ability to identify the emissions hotspots stages of global production chains and highlights the need for firms to achieve sustainable management either directly, by incorporating low-carbon practices into the production processes that they carry out, or indirectly, by encouraging suppliers to do so or choosing new low-carbon suppliers (see Wiebe (2018) for a detailed analysis and application).

We calculate PF by modifying the final demand matrix in Eq. (1), placing the total final demand supplied by each sector and country in the main diagonal, that is, summing the $\boldsymbol{Y}$ matrix in expression (1) horizontally, obtaining an nk-element column vector of total final demand without distinction between domestic and foreign final demand, and then diagonalizing that vector, as shown in Eq. (2):

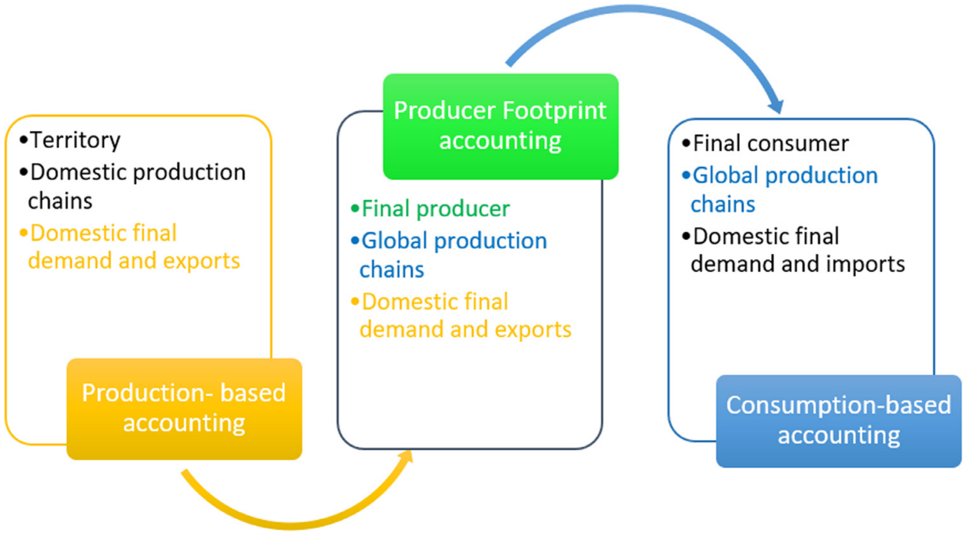

Fig. 1. The producer footprint accounting: similarities and differences with the production-based and consumption-based methods.

$$\bar{F}=\begin{bmatrix}\bar{F}^{11} & \bar{F}^{12} & \dots & \bar{F}^{1n}\\ \bar{F}^{21} & \bar{F}^{22} & \dots & \bar{F}^{2n}\\ \vdots & \vdots & \ddots & \vdots\\ \bar{F}^{n1} & \bar{F}^{n1} & \dots & \bar{F}^{nn}\end{bmatrix} \begin{bmatrix}P^{11} & P^{12} & \dots & P^{1n}\\ P^{21} & P^{22} & \dots & P^{2n}\\ \vdots & \vdots & \ddots & \vdots\\ P^{n1} & P^{n2} & \dots & P^{nn}\end{bmatrix}\begin{bmatrix}\hat{Y}^{11} & 0 & \dots & 0\\ 0 & \hat{Y}^{2\cdot} & \dots & 0\\ \vdots & \vdots & \ddots & \vdots\\ 0 & 0 & \dots & \hat{Y}^{n}\end{bmatrix}= P\hat{Y} \tag{2}$$

where the k-element diagonalized vector $\hat{y}^{r\cdot} = \sum_s y^{rs}$ stands for the monetary value of total final demand satisfied by country r with no distinction of the countries that ultimately consume country r's final production. Then, the horizontal sum of matrix $\bar{F}$ (of size nk x nk) results in the PBA by producer country (r) and sector ($PBA_r = \sum_s \bar{F}^{rs}$), whereas the vertical sum results in the PF by final-producer country (s) and sector ($PF_s = \sum_r \bar{F}^{rs}$), that is, all the CO_2 emitted all over the world in all production stages and embodied in the finished goods produced within the boundaries of country s. All those emissions are allocated to country s, regardless of whether those goods are subsequently exported or consumed domestically.

Then, the PF accounting coincides with the usual measure of carbon footprint (CBA) on the endogenous tracking of emissions generated in intermediate production. However, the methods differ in the allocation of emissions embodied in exports of finished products as PF attributes those emissions to the producer country, while the CBA allocates those emissions to the country of destination (where the finished products are consumed). At the same time, the PF approach coincides with PBA on the allocation of emissions generated in final production to the country where that production physically happens, but while PBA allocates emissions embodied in intermediate imports to the country where the intermediate products were physically produced, the PF allocates those emissions to the country that transforms imported inputs into final products. In brief, PF is an accounting method that tracks emissions along the whole production chain until the final producers and allocate those emissions to the country where the final producer resides (see Table S1 for a detailed comparison between PF, PBA and CBA).

2.3. The control-based allocation of CO2 emissions

The conjunction of the PF approach and the concepts of controlling/host countries derives in the control-based allocation method. This method makes controlling countries responsible for the emissions that their controlled companies generate to satisfy final demand. In other words, the control-based responsibility of country C includes the emissions directly and indirectly generated by both its domestic-controlled companies and its outward foreign affiliates and excludes the emissions generated by the inward foreign affiliates controlled by foreign MNEs. For example, under the control-based method, France is responsible for the emissions generated by all companies operating in France plus the emissions generated by French MNEs abroad, less emissions generated by affiliates from non-French MNEs operating within French borders.

We must take the following steps to obtain the control-based responsibility of country C: **1.** Use Eq. (2) to estimate the total PF of country C as host country, which gathers the PF of domestic-controlled companies and inward foreign affiliates. **2.** Estimate the PF of country C's outward foreign affiliates. **3.** Estimate the PF of country C's inward affiliates. Finally, **4.** Aggregate the results of steps 1 and 2 and then subtract the result of step 3. Note that the control-based allocation method is an application of the PF accounting approach, so it holds final producers responsible for emissions generated along the whole production chains.

Step 1 consists of applying Eq. (2) and summing the columns of matrix $\bar{F}$ corresponding to country C ($PF_c = \sum_r \bar{F}^{rc}$). This estimation and its implications have already been explained above and results in the aggregated PF of domestic-controlled companies and inward foreign affiliates residing in country C.

In *step 2*, we intend to isolate the PF of outward affiliates of country C's MNEs. However, this step is conditional on the lack of information about technology and trade flows of intermediate and final products from and to MNEs around the world. This lack of data leads us to use, as a first estimation, the simplest procedure, that is to allocate emissions to MNEs depending on the presence of those MNEs in each sector of every country. The implicit assumption is that MNEs' foreign affiliates and the national sectors share the same technical structure and the same proportions of imports and exports (see details on this assumption in Section 2.4).

Thus, for *step 2*, we replicate the methodology applied by López et al. (2019) for calculating the carbon footprint of the United States' outward foreign affiliates. They introduce a diagonal matrix of percentages ($\hat{\boldsymbol{m}}_O^c$) into Eq. (2) to capture the participation in production of country C's outward foreign affiliates in each sector of every host country ($\boldsymbol{OPF_c} = \boldsymbol{P}\hat{\boldsymbol{m}}_O^c\hat{\boldsymbol{Y}}$), as shown in Eq. (3):

$$\boldsymbol{OPF_c} = \begin{bmatrix} \bar{O}_c^{11} & \bar{O}_c^{12} & \dots & \bar{O}_c^{1n} \\ \bar{O}_c^{21} & \bar{O}_c^{22} & \dots & \bar{O}_c^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \bar{O}_c^{n1} & \bar{O}_c^{n2} & \dots & \bar{O}_c^{nn} \end{bmatrix} = \begin{bmatrix} P^{11} & P^{12} & \dots & P^{1n} \\ P^{21} & P^{22} & \dots & P^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ P^{n1} & P^{n2} & \dots & P^{nn} \end{bmatrix} \begin{bmatrix} \hat{m}_O^{c1} & 0 & \dots & 0 \\ 0 & \hat{m}_O^{c2} & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \hat{m}_O^{cn} \end{bmatrix} \begin{bmatrix} \hat{y}^{1\cdot} & 0 & \dots & 0 \\ 0 & \hat{y}^{2\cdot} & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \hat{y}^{n\cdot} \end{bmatrix} \tag{3}$$

where $\hat{\boldsymbol{m}}_{\boldsymbol{o}}^{\boldsymbol{cs}}$ is a k-element diagonalized vector with the percentage participation of outward foreign affiliates controlled by country C in the total value added generated in every sector of country s (being C, s = 1...n). Thus, matrix $\hat{\boldsymbol{m}}_{\boldsymbol{O}}^{\boldsymbol{c}}$, of size nk x nk, acts as a proxy for the percentage participation of foreign MNEs in the PF of every country and sector. Therefore, the matrix $\boldsymbol{OPF_c}$, of size nk x nk, captures direct and indirect emissions generated all over the world and embodied in the final goods and services produced by outward foreign affiliates controlled by country C's MNEs (*step 2*). The vertical sum of matrix $\boldsymbol{OPF_c}$ results in the PF of country C's outward foreign affiliates by host country (s) and sector ($OPF_{cs} = \sum_r \bar{O}_c^{rs}$). Note that the definition of outward foreign affiliates implies that the elements contained in sub-matrixes $\hat{m}_O^{cc}$ and $\bar{O}_c^{rc}$ are equal to zero (this simply means that, by definition, there cannot be country C's outward foreign affiliates in country C itself).

We follow a similar procedure for *step 3*. In this step, we do not use the percentages matrix of outward affiliates, $\hat{\boldsymbol{m}}_{\boldsymbol{O}}^{\boldsymbol{c}}$ (indicated by the subscript O), but we replace it by a percentages matrix of inward foreign affiliates, $\hat{\boldsymbol{m}}_{\boldsymbol{I}}^{\boldsymbol{c}}$ (indicated by the subscript I). Then, the PF of inward foreign affiliates located in country C ($\boldsymbol{IPF_c} = \boldsymbol{P}\hat{\boldsymbol{m}}_{\boldsymbol{I}}^{\boldsymbol{c}}\hat{\boldsymbol{Y}}$) is estimated through Eq. (4):

$$\boldsymbol{IPF_c} = \begin{bmatrix} \bar{I}_c^{11} & \bar{I}_c^{12} & \dots & \bar{I}_c^{1n} \\ \bar{I}_c^{21} & \bar{I}_c^{22} & \dots & \bar{I}_c^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \bar{I}_c^{n1} & \bar{I}_c^{n2} & \dots & \bar{I}_c^{nn} \end{bmatrix} = \begin{bmatrix} P^{11} & P^{12} & \dots & P^{1n} \\ P^{21} & P^{22} & \dots & P^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ P^{n1} & P^{n2} & \dots & P^{nn} \end{bmatrix} \begin{bmatrix} \hat{m}_I^{c1} & 0 & \dots & 0 \\ 0 & \hat{m}_I^{c2} & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \hat{m}_I^{cn} \end{bmatrix} \begin{bmatrix} \hat{y}^{1\cdot} & 0 & \dots & 0 \\ 0 & \hat{y}^{2\cdot} & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \hat{y}^{n\cdot} \end{bmatrix} \tag{4}$$

where $\hat{\boldsymbol{m}}_{\boldsymbol{I}}^{\boldsymbol{cs}}$ is a k-element diagonalized vector with the percentage participation of inward foreign affiliates located in country C and controlled by country s in the total value added generated in every sector of country C (being C, s = 1...n). Therefore, matrix $\boldsymbol{IPF_c}$, of size nk x nk, captures all direct and indirect emissions generated all over the world and embodied in the final goods and services produced by inward foreign affiliates located in country C (*step 3*). The vertical sum of matrix $\boldsymbol{IPF_c}$ results in the PF of country C's inward foreign affiliates by controlling country (s) and by sector ($IPF_{cs} = \sum_r \bar{I}_c^{rs}$). Again, the elements contained in sub-matrix $\hat{m}_I^{cc}$ and column $\bar{I}_c^{rs}$ are equal to zero. We remark that there are as many $\hat{\boldsymbol{m}}_{\boldsymbol{O}}^{\boldsymbol{c}}$ matrices as controlling countries in the analysis and as many $\hat{\boldsymbol{m}}_{\boldsymbol{I}}^{\boldsymbol{c}}$ matrices as host countries.

Finally, *in step 4*, we obtain the control-based responsibility of country C ($CTRL_c$) through the following Eq. (5):

$$CTRL_c = \sum_r \bar{F}^{rc} + \sum_{r,s} \bar{O}_c^{rs} - \sum_{r,s} \bar{I}_c^{rs} \tag{5}$$

Once the control-based approach is defined, mathematically and conceptually, it is worth to highlight the differences between this allocation method and the CBA, which is the most widely used method in the literature when it comes to assessing direct and indirect emissions released along global supply chains.

The main difference between these two approaches was already mentioned above i.e. whilst CBA method tracks emissions until final consumers, the control-based method tracks them to an earlier stage, until final producers. Then, emissions allocation across countries is also different in the two methods: the CBA allocates the emissions responsibility to the countries where final consumers reside, while the control-based approach allocates it to the countries where the controlling companies reside (controlling country). Allocating responsibilities to consumer countries implies an emphasis on what final consumers are able to do to enhance reductions in the carbon footprint of their country, for example by changing their consumption patterns. On the other hand, the control-based approach intends to emphasize what the companies with great decision-making power can do to reduce the carbon emissions released by themselves, their suppliers and their affiliates operating all over the world.

Consumers can replace the consumption of one product by another with lower carbon footprint, but they cannot modify the way the products are produced, they cannot reduce the carbon footprint of a product, yet, companies can. Firms have the ability to not only innovate but also use and choose low-carbon inputs and suppliers and perform greener production processes with cleaner energy sources. And when it comes to MNEs, the low-carbon practices that they introduce in their production processes and along their supply chain will enhance the emission reductions of countless companies (both upstream and downstream value chains) and consumers worldwide. Therefore, compared to CBA, the control-based approach and its focus on multinationals increase ambition in emission reduction targets at both global and national levels.

2.4. Limitations

This section delves into the implications behind the assumption of MNEs' foreign affiliates producing with the same technology and supply chain than domestic companies. In reality, technology and supply chains of foreign MNEs are widely heterogeneous across sectors and countries (Cadestin et al., 2018a; Chen et al., 2018a). They are affected simultaneously by the institutional framework of the host country and the techniques and capital provided from the MNEs' headquarters (located in the controlling country), showing similarities and differences compared to domestic firms in host countries. However, the lack of data on MNE's technology at multi-regional level takes us to introduce the assumption in question which seems to be reasonable for achieving the purposes of the paper, considering the information available. Thus, following the input-output framework, our methodological proposal assumes that the production structure of both domestic companies and MNEs' foreign affiliates in a particular host country is an average of the technologies used by the different firms operating in each particular sector, average that includes the inward foreign affiliates. This makes our results highly dependent on the structure of foreign investment across sectors, rather than coming from actual differences in the production structure and efficiency. For instance, according to our estimates, the US affiliates operating in the EU show a lower PF per thousand US$ of VA than Japanese affiliates. This does not mean that US affiliates produce with cleaner technology and supply chain than Japanese affiliates; the differences are explained by the fact that the US affiliates operate in sectors and host countries with lower average carbon intensities than those where Japanese affiliates operate. On the other hand, comparisons between US and Japanese affiliates in the same sector and host country, e.g. motor vehicles in Spain, would not show significant differences in the PF/VA ratio, since they both are supposed to produce using the average technology of Spain's automobile industry. Considering this limitations, our estimates have focused on a regional analysis by controlling- and host-countries rather than on an intra-sector analysis.

Although using the sector average could be perceived as a heavy assumption, its impact on final results is not as strong as it might seem

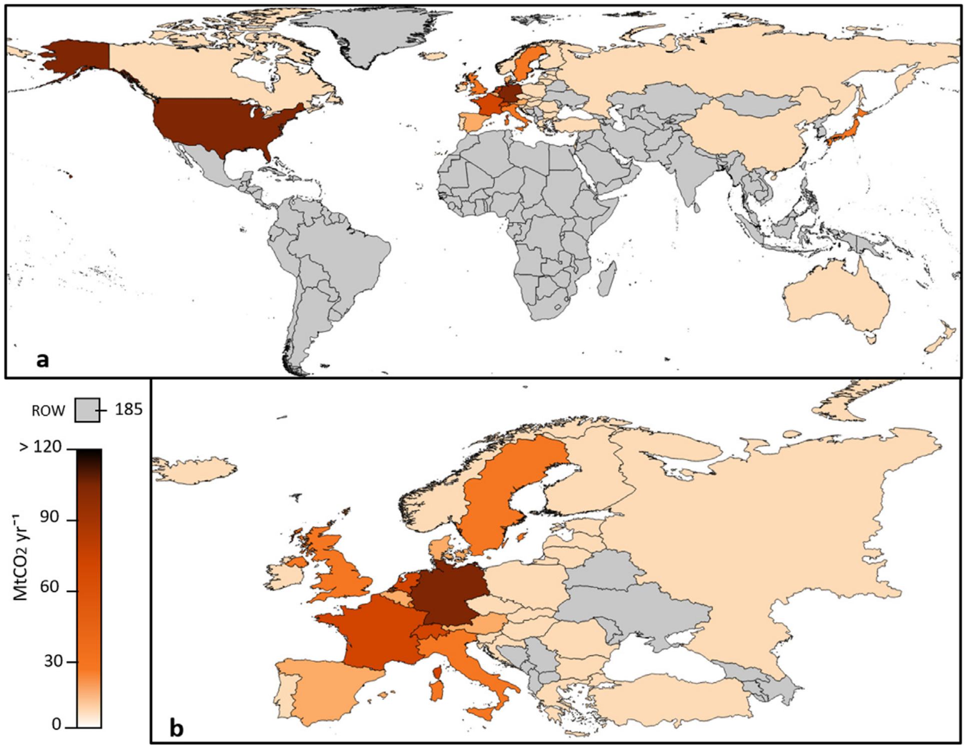

Fig. 2. PF of EU's inward foreign affiliates by controlling country. **a.** World countries. **b.** Zoom for European countries.

at first sight, since both domestic companies and foreign affiliates take electricity from the electricity grid of the same (host) country, which is the main source of CO_2 emissions in the carbon footprint of almost all production activities (IEA, 2020; IPCC, 2014; Wood et al., 2019b). Moreover, our results on foreign affiliates' PF are mainly affected by the affiliates with high levels of production which, at the same time, have significant influence on the average technology of their respective sector; therefore, the sector average is a plausible reflection of inward affiliates' technology in those sectors with high activity of foreign MNEs. In other words, the larger the size of the inward affiliates over the total sector, the better the average technology reflects the way they operate (and the stronger their influence on the results).

2.5. Data

We obtain data from two databases: the Eora Global Supply Chain Database (Eora) and Eurostat. Among the different available MRIO databases, we use Eora (Lenzen et al., 2012, 2013) because its advantages in terms of up-to-date data, regional disaggregation and the availability of suitable CO_2 emissions data (for an analysis of uncertainties linked to the different MRIO databases, see Moran and Wood (2014), Owen et al. (2016) or Peters et al. (2012)). Eora provides symmetric MRIO tables at basic prices and disaggregated to 189 regions and 26 sectors. We use the tables from the latest available year, 2015. The vector of CO_2 coefficients is also provided by Eora according to the same geographical and sectoral classification. The monetary units of the tables are thousand $US, and the CO_2 emissions come in gigagrams (Gg), which are equal to mega-tonnes (Mt).

Eurostat (2019a) provides the data on the value added at factors cost generated by inward foreign affiliates classified by host country, sector and controlling country. Data are disaggregated to 67 industries, following NACE Rev.2 classification (2-digit), and the units are million euros. To make the Eora and Eurostat data consistent, we harmonized the sectoral classifications of both datasets to 26 industries (following the Eora classification), the regional classification to 43 regions (according to Eurostat controlling countries classification) and the monetary units to thousand US$ (see Table S2 for details on the harmonization of the two databases).

At the regional level, Eurostat's data are available for 30 host countries (28 EU members, Norway and Bosnia-Herzegovina, of which we only take into account the data from the 28 EU members) and 42 controlling countries (28 EU members plus 14 other major economies) plus a ROW aggregate of own elaboration. From these data, we can obtain the complete information needed to build $\hat{m}_I^c$ matrices for the 28 EU members as host countries; however, we find incomplete information to estimate the $\hat{m}_O^c$ matrix values as there is no data on the outward foreign affiliates controlled by EU members and located in extra-EU countries. For example, Eurostat (2019a) does provide information about the outward affiliates controlled by Germany that reside in any of the other 27 EU member states, but it does not provide data on the outward foreign affiliates controlled by Germany that reside in the United States, Japan, China or any other country outside the EU. Hence, the estimation of emissions generated by EU countries' outward foreign affiliates that we make here is limited to the EU's territory, and the analysis of control-based emissions responsibility is done under an intra-regional perspective; that is, EU countries are assigned responsibility for their outward foreign affiliates, but only for those located within the EU (see Tables S3 and S4 for details on the data used to build matrixes $\hat{\boldsymbol{m}}_I^c$ and $\hat{\boldsymbol{m}}_O^c$).

3. Results

3.1. Controlling countries of the producer footprint of the EU's inward foreign affiliates

The PF of the whole EU economy in 2015 is estimated at 4187 $MtCO_2$, of which 714 $MtCO_2$ (17.1%) are related to MNEs' foreign affiliates (Ortiz et al., 2020). What are the countries to which these subsidiaries belong and, therefore, the countries that control and make the decisions that affect these companies and host countries? The control criterion makes it possible to answer this question. Under the control criterion approach, almost half of the footprint of those affiliates is controlled by 4 countries (Fig. 2): the United States (US), which accounts for 16% of the total PF of the EU's inward foreign affiliates (114 $MtCO_2$), followed by Germany, with 97 $MtCO_2$ (14%), France and the Netherlands, whose controlled emissions reach 63 $MtCO_2$ (9%) and 42 $MtCO_2$ (6%), respectively.

At global level, high control responsibilities over the emissions of inward affiliates located in the EU (intense orange areas in Fig. 2a) are concentrated in only three developed regions: the US, Europe and Japan. Although Japan's responsibility is not too large (2.8% of total), it is the second highest among non-European countries, after the US. Regarding ROW, its controlled emissions in the EU reach 185 Mt CO_2, which make up 26% of the total (gray areas in Fig. 2a). China's small responsibility under the control-based approach is noticeable (2.8 $MtCO_2$), which contrasts with its main role in assessments under most usual allocation methods such as production and consumption-based approaches (Liu et al., 2016). This is due mainly to the scarcity of Chinese MNEs operating as final producers within the EU, as the strategy of internationalization of Chinese companies has been directed to Asia as main destination, followed by America and Africa, which add up to more than 75% of the stock of Chinese foreign direct investment, while only around a 3% corresponds to Europe in 2010 (Zhang et al., 2012) (see also Table S5).

Despite the large responsibilities of the ROW and US, most of the emissions associated with MNEs' foreign affiliates are controlled by EU members through intra-EU movements of subsidiaries. EU members control 48% of all foreign affiliates PF, led by Germany and France, as said before (Fig. 2b). Here, the relatively high values of Luxembourg (18 $MtCO_2$) and Switzerland (34 $MtCO_2$) are remarkable. The Swiss share is larger than that of large EU economies such as Spain and Italy and the UK, also. Most likely, Luxembourg's and Switzerland's high control responsibilities are explained by the tax-flexible conditions in both countries, which invite MNEs to settle their headquarters in their territory and shift profits to them (Torslov et al., 2018).

The emissions embodied in foreign affiliates' production operating in the EU is a negative outcome collateral to the generation of VA. It is worth noting that although the US is responsible for a high amount of the EU's carbon footprint, it is also the country that controls the highest quantity of VA generated by foreign affiliates within the EU, US $342,446 million (19% of foreign affiliates VA), more than large European economies such as Germany, France or the UK (see Table S5). Moreover, foreign affiliates from the US show a relatively low PF per unit of value added (PF intensity). According to our estimations, on average, they generate 0.29 tCO_2 per thousand US$ of VA. Their PF intensity is the second lowest among companies coming from the top 10 controlling countries, only bested by affiliates from the UK (0.26 tCO_2 per thousand US$ of VA) (see Table S5). The countries whose controlled affiliates display the lowest average PF intensity are Malta (0.11 tCO_2 per thousand US$ of VA), Australia (0.20), Liechtenstein and New Zealand (0.21). In contrast, the highest PF intensities are found in foreign affiliates controlled by the Czech Republic (1.14), Russia (1.13), and Latvia (0.94).

Where are these foreign affiliates operating? What are the host countries? The high concentration found regarding the country of origin (controlling country) of MNEs' foreign affiliates emissions in the EU has its reflection in the host countries. Fig. 3. displays interactions between host and controlling countries by plotting emission from the top four controlling regions (US, Germany, France and ROW), that concentrate 64% of all emissions embodied in foreign affiliates' final production within the EU, to their five respective primary destinations in the EU (host countries). The details on the flows' magnitude, origin and destination provide valuable information to comprehend the interconnections between host and controlling countries and make it easier to identify MNE emissions hotspots. We highlight the case of Poland, as it is among the top 5 destinations of Germany, France and ROW (lilac arrows), but its economic context is quite different from the other main recipients (UK, Germany or Spain). Carbon-intense production in Poland, along with massive inflows of foreign affiliates attracted by low energy prices and salaries (Markandya et al., 2016) (Bruno et al., 2012), might be the primary causes of Poland's role as one of the European hotspots in the MNEs' carbon footprint.

In addition, results show the presence of sectoral hotspots, because emissions of the inward foreign affiliates' PF are clearly concentrated in 4 sectors (transport equipment, petroleum and chemical products, machinery and electricity, and gas and water) that gather manufacturing and energy activities (Fig. 4). These are energy-intensive sectors with a considerable carbon footprint burden embodied in their production chains, which largely explain the high PF of foreign affiliates in these sectors. Looking at the PF of services sectors, we find significant contributions by foreign affiliates operating in transport, wholesale trade and business activities. The share of MNEs' control over the emissions generated in the top 5 sectors varies from 13% to 40% (indicated by fuchsia circles). The participation of MNEs in the sector's footprints is particularly high (above 30%) in 5 sectors: transport equipment, petroleum and chemical products, machinery, wholesale trade and telecommunications.

In general, the ROW and United States stand out as the main controllers in almost every sector. Both have especially high participation in the emissions of foreign affiliates operating in transport equipment, petroleum and chemical products and machinery. The participation of the ROW is also important in the transport sector. Germany plays a significant role in the 4 aforementioned sectors as well, while the participation of France in the emissions in electricity, gas and water is remarkable (20% of total, the second highest after the ROW).

Bar length indicates the total PF of EU's inward foreign affiliates operating in the corresponding sector ($MtCO_2$, top axis). The contributions of the main controlling countries in each sector are indicated by coloured segments ($MtCO_2$, top axis). The percentage weight of inward foreign affiliates over the total PF of each sector in the EU is indicated by pink circles (bottom axis).

3.2. A control-based allocation of emissions for the EU countries

In this section, we want to evaluate how the emission responsibilities of EU countries would be affected and distributed assuming that the 28 members agreed to allocate emissions generated by domestic companies and intra-regional foreign affiliates under the control-based criterion. In this agreement, for example, Germany would be responsible for the PF generated by German domestic companies plus the PF from German outward foreign affiliates residing in other EU countries, less the PF from Germany's inward foreign affiliates controlled by other EU countries. Note that, within this agreement, emissions generated by foreign affiliates coming from and going to extra-EU countries are not assigned to their controlling country since we are assuming it is a regional agreement that binds only EU countries and companies; therefore, those affiliates are considered domestic companies of their respective host countries.

We first evaluate intra-EU PF flows via foreign affiliates (Fig. 5): the presence of foreign MNEs in the country (as host country) increases its emissions burden (inflows) while the country's MNEs abroad (as controlling country) reduce its burden (outflows). The difference between them identify net hosts and net controllers among the EU members (cyan circles). Twelve out of the 28 members are net controllers of PF, while 16 are net hosts. In a rough classification, we may say that the group of net controllers is composed of high-developed and wealthy countries, while middle and low-developed countries are in the net hosts group. In fact, countries in Fig. 5 are sorted in descending order by GDP per capita to display more clearly the contrast between both groups. The 10 countries with the highest income levels (located at the top of the chart) are net PF controllers. Germany, France and the Netherlands are the three net controllers with the highest balance: 38, 33 and 32 $MtCO_2$, respectively. Although Germany's reception of PF is large, it is totally offset by its outflows, making the German net balance

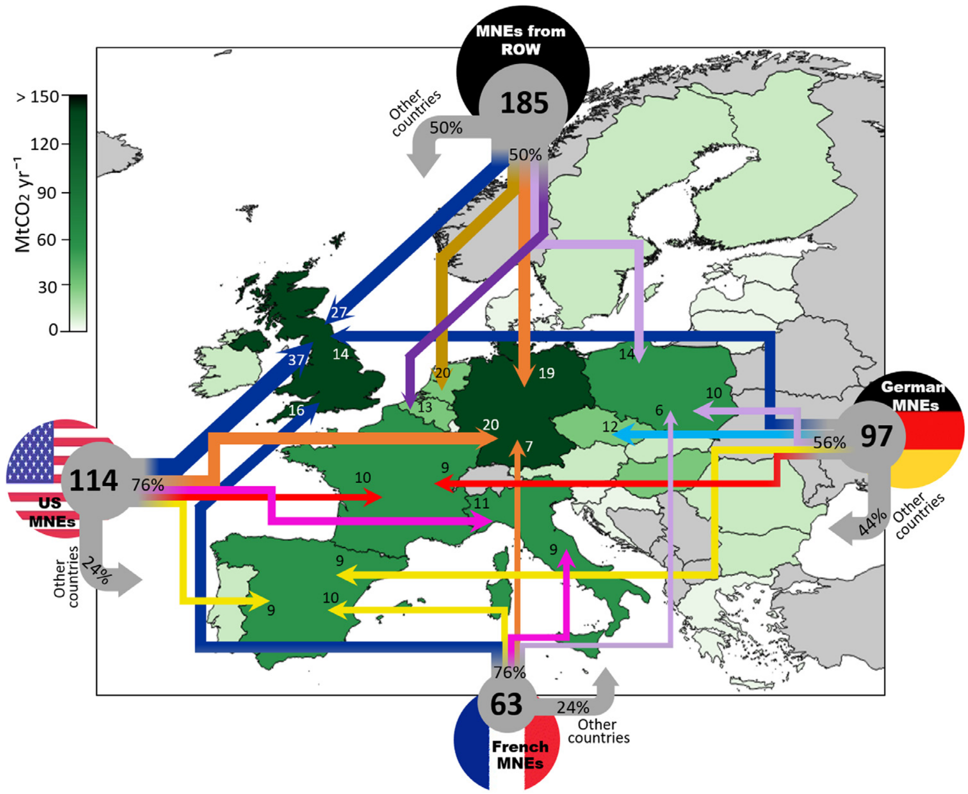

Fig. 3. PF of inward foreign affiliates by host countries and flows from main controlling regions to their primary destinations.
The intensity of green color on the map indicates the quantity of CO_2 emissions received by a country ($MtCO_2$). Flows plotted show PF controlled by foreign MNEs coming from the top 4 controlling regions (US, Germany, France and ROW), which together control 459 $MtCO_2$, accounting for 65% of total PF of inward foreign affiliates within the EU. Coloured arrows show footprint flows from each of the main controlling regions to their top 5 destination countries; each color is associated with a destination country. Numbers on the tips of the arrows indicate the quantity of emissions embodied in each flow ($MtCO_2$). Gray circles show total emissions controlled by each region, and the share that goes to their top 5 destinations is in front of the circles, whereas the gray arrow shows the share that goes to the rest of the EU countries.

the highest of the EU. Looking at the left side of the chart, we identify the UK and Poland as the greatest net hosts, with net balances of −34 and −25 $MtCO_2$, respectively. Although the UK's balance is higher than Poland's, it receives only 2 times the footprint it controls abroad; in contrast, this ratio for Poland is 31 to 1. This imbalance for Poland is a tendency among less developed countries as their outflows are too low (less than 1 $MtCO_2$ in many cases); Bulgaria, Romania, Hungary, Croatia and Poland are the countries whose ratios of PF inflows to PF outflows are the highest in the EU: 518, 111, 93, 55 and 31, respectively. These countries not only act as “low salary factories” within the EU (Bruno et al., 2012), but also assume a heavier emission burden because of the presence of foreign MNEs and the dependence on coal for energy generation. Considering that EU members control almost half of foreign affiliates’ PF within the EU (48%), it would be very feasible to find regional policies to reduce such disparities among EU members regarding carbon footprint movements via foreign affiliates.

3.3. Control criterion vs. other allocation methods

Based on the balance of PF flows above, we obtain the intra-EU control-based responsibility of the 28 members adding to the PF generated by domestic companies in each country the emisisons from the country affiliates outside its borders and subtracting the emissions of foreign affilaites within their territory. Thus, control-based allocation implies a burden shift from MNE subsidiary host country to the controlling country and, consequently, countries with more polluting MNEs’ affiliates outside their borders and less in their territory will see their responsibility increased to a greater extent. We estimated the EU's total PBA and CBA at 3470 and 4237 $MtCO_2$, respectively, while the total emissions assigned under a hypothetical intra-EU control-based agreement reach 4187 $MtCO_2$.

In comparison with PBA (Fig. 6a), control-based allocation increases emissions responsibility for 22 EU countries and decreases it for 6 countries. As expected, large economies show the greatest increases in their emissions in absolute numbers. France and Germany experience striking boosts as their control-based emissions are 141 and 132 $MtCO_2$ higher than their PBA, respectively, accounting for respective rises of 43% and 17% in their carbon responsibility (the average variation of the 28 EU members is 30%). Such rises are explained to some extent by the large outflows from these two countries (see Figs. 3 and 4), which are not included in the traditional PBA allocation, but mainly by the emissions generated in global value chains and embodied in intermediate imports that PBA does not capture but the control-based (as the consumption-based) method does.

Luxembourg stands out for the tremendous increase in its emissions responsibility in relative terms since its control-based emissions almost triple its PBA (a variation of 196%). Other large percentage deviations are found in Sweden (104%) and Denmark (72%). On the other hand, among countries that experience the largest drops in their emissions, we find Poland, Bulgaria and the Czech Republic. The net host condition of these countries largely explains such drops in their emissions, along with a re-assignation of emissions generated in intermediate production, which the control method allocates to the countries that turn those intermediate products into final ones. In relative terms Bulgaria shows the most significant drop; its control-based emissions are 36% smaller than its PBA.

The comparison with CBA brings smaller deviations (lower than 20 $MtCO_2$ in absolute value for 22 EU members), since both the control-based method and CBA include global value chains in their assignments of responsibilities (Fig. 6b). Germany, the Netherlands and Belgium show the largest positive deviations, estimated at 109, 54 and 34 $MtCO_2$, respectively, while the largest negative variations are found in the UK (−177 $MtCO_2$), Poland (−34 $MtCO_2$) and Spain (−22 $MtCO_2$). In the case of Germany, Belgium and the UK, the differences are mainly explained by the net commercial balance of final products; that is, emissions embodied in German and Belgian final exports (included by control-based accounting and excluded by CBA) are considerably higher than emissions embodied in their final imports (excluded by control-based accounting and included by CBA). The opposite is found in the case of the UK: emissions embodied in final imports are much

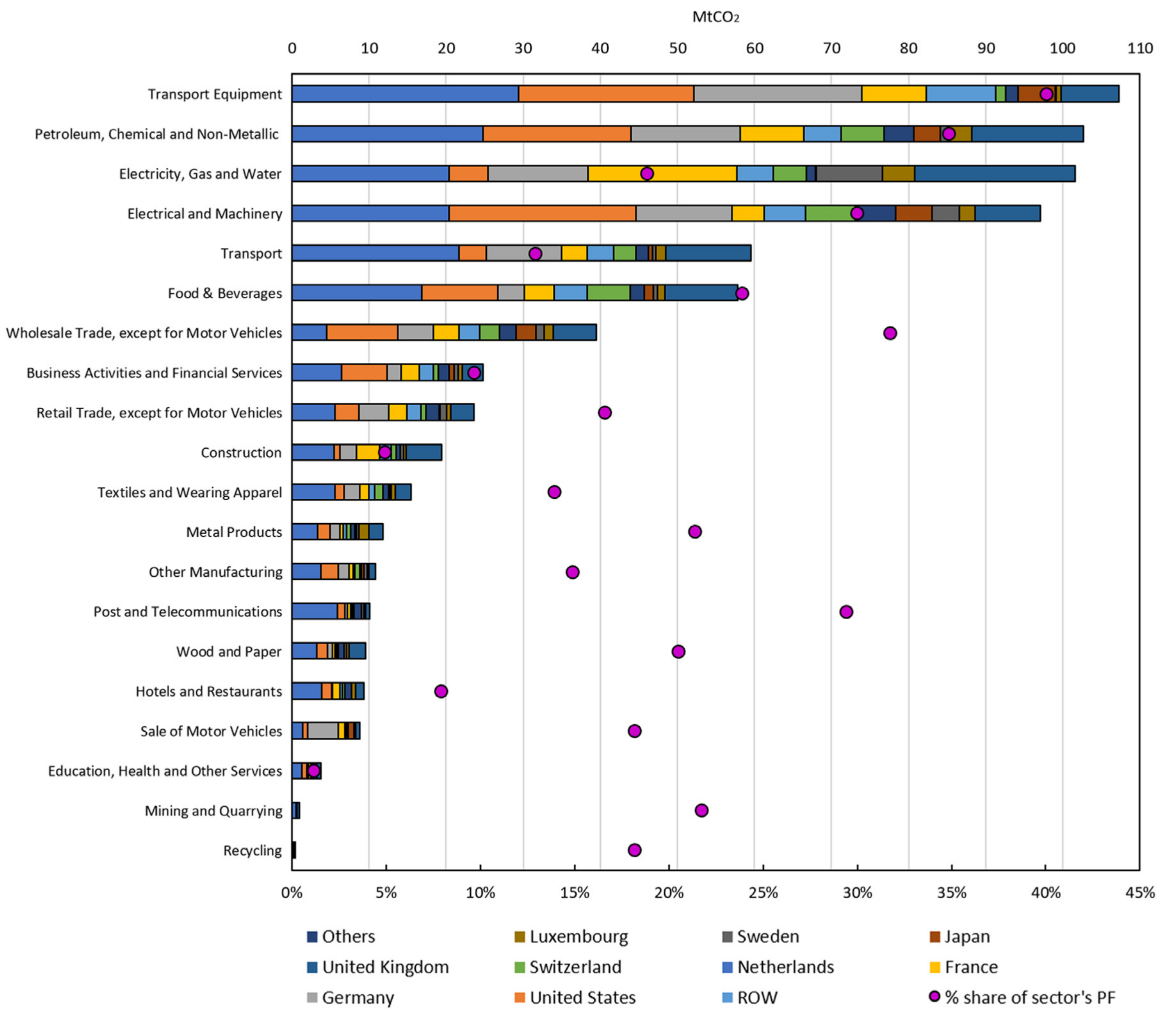

Fig. 4. PF of EU's inward foreign affiliates by sector and controlling country.

higher than emissions embodied in final exports. The cases of the Netherlands, Poland and Spain are also affected by the commercial balance of final products but to a lesser extent; instead, the differences between control-based emissions and CBA in those countries are mainly explained by MNEs' emissions flows via foreign affiliates (see net balance of outflows/inflows plotted in Fig. 5).

Percentage differences bring to the forefront 5 countries whose control responsibility varies considerably from their CBA (greater than 20%), namely, Luxembourg (a variation of 64%), Belgium (34%), the Netherlands (28%), Ireland (22%) and the UK (−28%). Here, Luxembourg appears again, along with Ireland, because of its tax flexibility (Torslov et al., 2018), which increases the registration of MNE headquarters in its territory and, ergo, increases its control-based emissions compared to its CBA (and PBA as well).

3.4. Intra- and extra-EU impacts of EU's controlled emissions

Under the control-based criterion, 67% of the total EU's emissions are generated within the EU territory, while the remaining 33% are imported from extra-EU countries (this distribution is very similar to the distribution of the EU's CBA, in which 66% of the emissions are generated in the EU and 34% are imported from outside). Thus, 2/3 of the CO_2 generated along the whole production chain by final producers located in the EU is emitted in the territory of EU countries, which respond to common environmental regulation standards. These territorial emissions are the object of the current global commitments as well as the regional emissions trading system ETS; however, allocating them under the perspective of the control criterion has substantial advantages over the territorial PBA method used in current regulations. The control-based perspective reduces the risks of carbon leakages and helps companies to be aware of their upstream emissions and to make efforts to reduce them. In doing so, it increases incentives for technology transfers not only from the parent company to the affiliates but also along the supply chain. Therefore, in the case of the EU countries, reduction targets set under the control approach would apply not only to the emissions occurring within the borders of each country and within the EU territory (67%) but also to the emissions occurring outside the EU (33%) (see Fig. 7). Moreover, at the country level, allocating MNEs' emissions to controlling countries redistributes responsibility among EU members. It relieves low-income EU countries of responsibility for a significant portion of their territorial emissions that are generated by foreign MNEs and by the production of intermediate goods demanded by the most affluent economies.

Looking at the share of emissions physically generated in the EU by controlling country, one can see a wide range of values that vary between 48% and 81%. Among the countries with the highest share of intra-EU controlled emissions, we find Poland (81%), Portugal (79%), Cyprus (79%) and Croatia (78%), while the lowest shares are found in Lithuania (48%), Slovakia (49%), Belgium (54%) and Hungary (54%). This distinction on emissions origin is useful in identifying the best opportunities and policies for reducing controlled emissions in each EU country. For instance, firms located in countries with higher shares of extra-EU controlled emissions seem to have clearer opportunities for reducing their carbon burden through source shifting, and therefore,

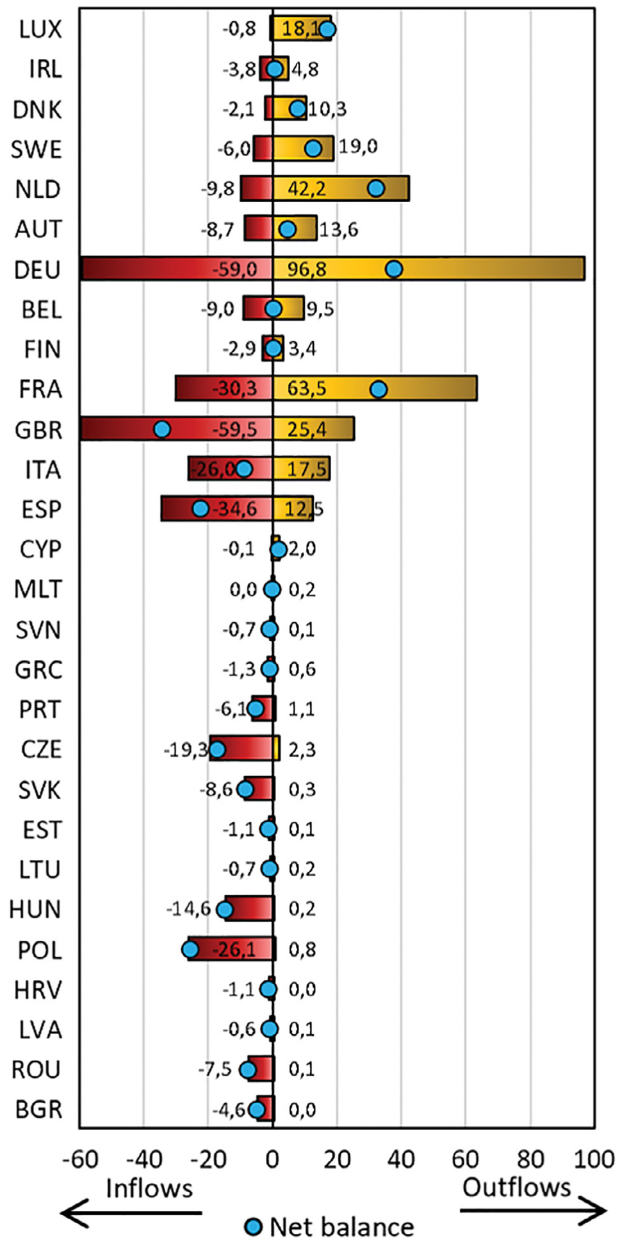

Fig. 5. Balance of intra-EU PF flows by country.
CO_2 emissions outflows (yellow bars), CO_2 emissions inflows (red bars) and the net balance (cyan circles). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

policies should be designed to create the correct incentives to carry out such shifting of upstream production stages to cleaner sources, e.g., a carbon border tax for imports from extra-EU countries.

4. Discussion and conclusions

This paper aimed to present a new approach to allocating emissions based on the control criterion of companies and offer a first application by estimating the control-based responsibility of the EU as a whole region and by country. The application of a control-based criterion can be seen disruptive in the sense that, under this criterion, foreign affiliates would adopt the emission reduction targets under the requirements of their headquarters country, e.g. affiliates from Germany, France or the Netherlands operating in Poland would follow the environmental standards of their origin country. We identify three general aspects that make the control-based approach a valuable instrument for improving equity in the assignation of responsibilities and broadening ambition in the design and achievement of global emissions reduction targets: **1.** Consideration of all emissions along global value chains and the effects of international trade, that is, direct and indirect emissions generated all over the world and embodied in the final demand products. **2.** Identification of emissions generated by MNEs' foreign affiliates and their allocation to the controlling countries, which are responsible for regulating those emissions and creating the proper incentives for the MNEs to reduce them. In other words, controlling countries could apply local regulations for reducing global emissions. **3.** Assignment to final producers' headquarters of the duty to design strategies and take actions to reduce the emissions embodied in products and lessening pressure on consumers and host countries, which is especially relevant when the host country shows a lower development level than the controlling country.

The control-based footprint helps to explain the reluctance of some countries, especially Poland, to agree with the European Green Deal demanding concretion of the Just Transition mechanism beyond the €100-billion budget (European Commission, 2019). Poland hosts foreign affiliates controlled by high-developed EU countries (such as Germany, France and the Netherlands) and, under the control-based criterion, the emissions from these affiliates would be the responsibility of the controlling countries. Our results show that adopting this criterion would alleviate the burden on Poland up to 26.1 $MtCO_2$. At the same time, control-based responsibility would indicate the extent to which each country generates emissions in other EU countries and would, therefore, be an indicator of its participation in that transition fund regarding this aspect.

The allocation of emissions responsibility under the control-based criterion for the EU has been made considering a hypothetical unilateral agreement. EU has taken the lead in the fight against climate change and launched unilaterally mitigation policies, like the release in 2005 of the first and large carbon trading scheme. Although empirical findings are ambiguous and sometimes contradictory on the causal relationship between strict domestic regulation and outward flows of direct investment (the so-called pollution haven hypothesis), some studies find a positive effect on the number of new subsidiaries abroad for both Italian and German multinationals and a larger impact on the production in foreign affiliates for the Italian ones (Borghesi et al., 2019; Koch and Basse Mama, 2019). The control-based criterion would allow limiting the carbon leakage and pollution haven hypothesis linked to unilateral stringent measures like the carbon trading scheme, by allocating the responsibility of the foreign affiliates' emissions to the controlling country; considering not only the direct emissions but all the emissions incorporated through global production chains.

In the way forward to increase ambition in the mitigation of climate change, a relevant issue is to what extent the perspective of control would help in improving the equity and effectiveness of emissions mitigation targets. Our findings show that the control criterion is fairer at the country level, since the countries with higher income per capita are those with more MNEs and foreign affiliates and, as a result, their responsibility is higher under this criterion. Equity is also promoted at the company level because the control perspective focuses on the role of MNEs in leverage mitigation strategies considering the higher economic and innovative power of these firms compared to medium and small companies. In addition, the identification of emissions generated by MNEs' affiliates allows for easier management than if we only take into account the emissions of all imported goods, since MNEs have direct control over their subsidiaries and know their production processes.

As a matter of fact, MNEs are progressively adapting their production processes to the new environmental and legislative standards by, for instance, setting internal carbon prices (CDP, 2017; NAZCA, 2019) and, in response to society's demands, firms are increasingly reporting and disclosing the environmental, social and labor conditions of their production chain and suppliers, showing significant achievements. This proves that MNEs are willing to accept huge challenges within their

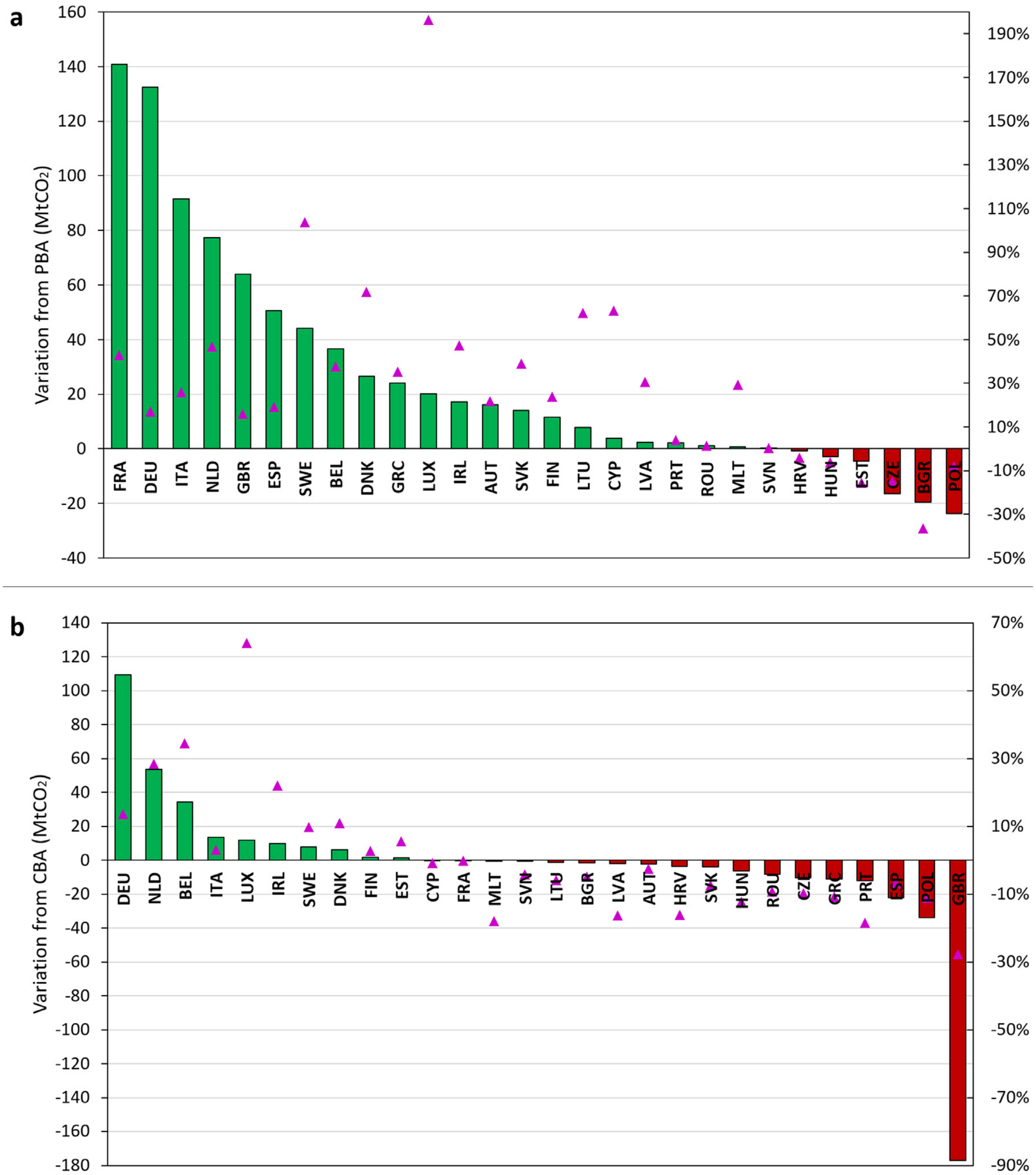

Fig. 6. Control-based responsibility by country as the variation from PBA (**a**) and from CBA (**b**). Bars represent the deviations in absolute numbers (left axis), while the deviations in percentages are represented by the fuchsia triangles (right axis). Note that the axes' ranges differ from panel a to panel b, so for comparisons between panels, one should pay attention to the values indicated by the bars instead of the bar size.

social responsibility commitments and control-based approach is a step forward to link those corporate efforts to national governments' strategies. Synergies between country-level policymakers and MNEs' environmental initiatives could set a regulatory framework led by national governments but with the potential to reduce carbon emissions in multiple foreign countries, enhancing carbon emissions reduction at global level. This is a very desirable (and feasible) scenario from the perspective of the EU since European companies and institutions have attained remarkable achievements in reducing territorial emissions, but they now should widen the scope of climate policies and pursue emission reductions beyond EU's borders. In short, the control-based approach could be the basis to create suitable opportunities for MNEs to become green transnational agents through which low-carbon practices can be deployed.

Our proposal and findings open new research lines to track companies' responsibility for emissions and climate change regarding not only where and how they operate but also how they make offshoring decisions and who the owners of the capital are in a globalised world where MNEs act as relevant lobbies for fiscal and environmental policies. The release of the OECD AMNE database (Cadestin et al., 2018b) opens new opportunities for research in this line and widens the applicability of control-based accounting. New applications can be broadened to other environmental footprints (such as water or materials) or social footprints (employment, qualifications, or work conditions) aiming to assess the role of MNEs in how countries participate in global value chains.

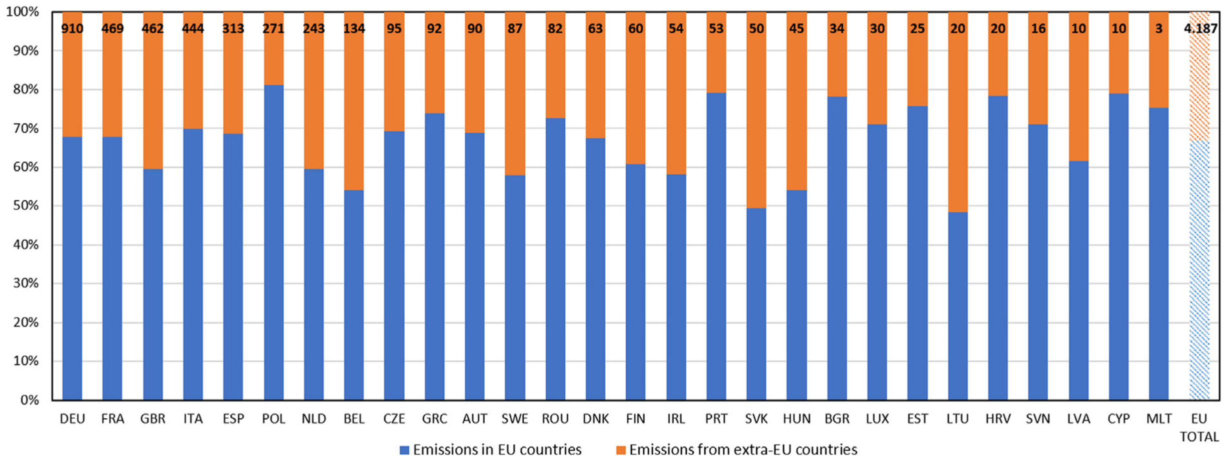

Fig. 7. Shares of controlled emissions physically generated inside and outside the EU.
Values at the top of the bars indicate the intra-EU CTRL responsibility of EU members in absolute numbers (MtCO_2).

CRediT authorship contribution statement

Mateo Ortiz: Methodology, Data curation, Software, Formal analysis, Writing - original draft, Writing - review & editing. **Luis-Antonio López:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **María-Ángeles Cadarso:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.resconrec.2020.105104.

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