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TRANSPORTATION AND STORAGE SECTOR AND GREENHOUSE GAS EMISSIONS: AN INPUT-OUTPUT SUBSYSTEM COMPARISON FROM SUPPLY AND DEMAND SIDE PERSPECTIVES

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SUMMARY

We develop an input–output subsystem analysis based on the Ghosh model. Our method analyzes the interrelations in terms of emissions between the different subsystem subsectors and between the subsystem and the rest of sectors of the economy through the decomposition of total emissions into four explanatory components. In contrast to previous subsystem analyses based on the Leontief model, our method considers the emissions of the whole activity of the subsystem and not only those related to its final demand. This is particularly relevant to study the responsibility for emissions of the activity of sectors that produce mainly for other sectors. We apply this method and also the subsystem analysis from the demand-side perspective to analyze the transportation and storage subsystem in Spain in 2014. The activity of the subsystem induced the rest of sectors of the economy to pollute less than the emissions it was induced to emit. There are significant differences between the outcomes from demand- and supply-side perspectives, so that the consideration of both perspectives provides more accurate policy recommendations.

Keywords: Ghosh model, greenhouse gas emissions, input–output, subsystem analysis, transportation and storage sector.

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1. INTRODUCTION

There is growing concern about the consequences of climate change at an international level. A proof of this concern is the Paris Agreement, which came into force in 2016 and which will be operational in 2020 and which aims to reduce greenhouse gas (GHG) emissions globally in order to limit Earth's warming to below 2°C.

Transportation is one of the economic activities that contributes most to global GHG emissions, since it is responsible for 20% of the emissions from fuel combustion (World Bank, 2017). In the case of the European Union-28, transport emissions account for 21% of total GHG emissions and their contribution have increased since the 1990s (Eurostat, 2016). In particular, in Spain transport activity is responsible for 25% of total GHG emissions, moreover, these have increased by 50% since 1990 (MAPAMA, 2017). In this scenario, the European Union has implemented different environmental strategies related to transport activity in order to reduce its emissions. The main goal of these measures, as revealed in the Transport White Paper 2011, is to contribute to the target of reducing total greenhouse gases. In particular, the European Union have committed to reducing its GHG transport emissions in 2050 by 60% compared to 1990 (European Commission, 2011).

The input–output Leontief model (Leontief, 1951) has been widely used in the literature as a method to study emissions of an economy given the productive structure of the economy and the relationships between the different economic sectors. In particular, a methodological extension of the model, the analysis of subsystems proposed by Sraffa (1960) and developed by Alcántara (1995) for the case of air pollution, has allowed to analyze how a sector or a group of sectors —a subsystem— induces itself and the rest of the sectors of the economy to pollute to satisfy its own final demand. Therefore, the analysis of subsystems from the demand-side perspective has been a useful instrument for analyzing direct and indirect emissions related to the activity of a productive sector or group of sectors based on its own final demand and the productive structure of the economy. Some references in this line are, for example, the works whose objective is to study the GHG emissions of all sectors of an economy. This is the case of the investigations carried out by Llop and Tol (2013), which examine the case of the Irish economy in 2005 and conclude that there are strong asymmetries both in the contribution of the different economic sectors to total emissions, as well as in the different decomposed components of this contribution; by Ge et al. (2016), who identify the role of each sector in the total emissions of Beijing in China in 2010 and determine that the main area responsible is the service sector; or Yuan et al. (2018), who investigate the case of China for the period 1997–2012 and determine that the main sectors responsible for CO_2 emissions are equipment manufacturing, construction, and service sectors. In addition, it is worth mentioning those works whose purpose is to study the emissions of a particular economic sector, thus, Alcántara and Padilla (2009) analyze CO_2 emissions of the service sector in Spain in 2000, studying the behavior shown by their different productive subsectors, and highlight the weight of transportation in direct emissions and of the other services in indirect emissions, and note the scant attention that environmental policies have paid to these other services, despite their importance as being heavily responsible for emissions; Ge and Lei (2014) study the service sector in Beijing and determine that the transportation, storage, mail, and telecommunications subsectors are the main areas responsible for the direct emissions of the service sector, while the scientific studies and technical services, hotels and restaurants, and health care, social security and social welfare subsectors contribute significantly to the indirect emissions of this sector; and Piaggio et al. (2015) inquire about the role of CO_2 emissions of the service sector in Uruguay in 2004, and point out that the direct emissions of this sector are mainly due to the transportation subsector, although the emissions that the service sector induces in the rest of the sectors of the economy are considerable and are due to those service subsectors not related to transport activities. Finally, the works focused on the study of the emissions of other specific pollutants are equally relevant, such as the investigations by Navarro and Alcántara (2010), which present an analysis of the methane emissions of the processed food sector in Catalonia in 2001 and emphasize that the implemented policies in this sector should take into account the importance of intrasectoral relations between the different subsectors of the processed food sector; and Alcántara et al. (2017), who investigate the nitrogen oxide emissions of the different productive sectors in Spain in 2007, studying all sectors as subsystems of the economy, and offering guidance on the policies to be applied in the different sectors to mitigate these emissions.

To sum up, all these previous studies used the analysis of input–output subsystems under a demand-side approach. Nevertheless, in the particular case of the transportation sector, its intermediate demand is crucial, since its activity and emissions are mainly explained by the inputs it produces for the other sectors of the economy. Therefore, both the intermediate demand and the final demand are significant for explaining the activity and emissions of transportation. Then, in order to study this sector, it seems appropiate to consider a complementary analysis to the subsystem analysis from the demand-side perspective so that, regardless of the end use of its production, the interrelations in terms of emissions that its activity establishes with the rest of the sectors of the economy are analyzed. The knowledge of these linkages together with those established in the subsystem analysis from the demand-side perspective can help to determine the correct design of environmental policies whose aim is the abatement of GHG emissions of the transportation sector. Taking into account the above, we base our methodology on the Ghosh model (Ghosh, 1958), or *output approach*, as it allows us to address the problem of transport emissions through the analysis of the forward linkages (direct and indirect) that this sector establishes with the other economic sectors and thus shows the dependence of this sector as a supplier on the other economic sectors as demanders of its output. Unlike the Leontief model —or *input approach*—, which is based on a theoretical model[1] widely accepted in the economic literature in which the technology used in the production of a good is fixed, that is, the proportion of inputs required in the production of a good is constant, the Ghosh model is a controversial one that is the object of debate.[2] The Ghosh model is based on the assumption of fixed distribution of output, an assumption that is not based on any economic theory (Cronin, 1984), and which implies that the proportion of output allocated to different consumers is constant (for a more detailed analysis see, for example, Oosterhaven, 1988, 1996, 2012; Gruver, 1989; Dietzenbacher, 1989, 1997; Lenzen, 2003; De Mesnard, 2009; Guerra and Sancho, 2011). However, the employment of this model at a given time, where prices are fixed, is valid as a descriptive and ex-post device from a forward perspective of the intersectoral linkages given a productive structure (Dietzenbacher 1992, 2002; Lenzen, 2003). In conclusion, despite the criticisms it has received, there is consensus when it comes to justifying its use as an instrument to carry out comparative studies at the international level and for the identification of key sectors and intersectoral relations (Oosterhaven, 1988; Lenzen, 2003). In short, the Ghosh model is suitable for complementing the study of the total emissions generated by the transportation sector activity from a demand-side perspective, given that this perspective does not take into account the sector activity as an input supplier of other sectors of the economy, as it only analyzes the emissions associated to the satisfaction of its final demand. Whereas, the supply-side analysis overcomes this problem by considering the whole activity of the sector via the use of its primary inputs, whatever the final use of its output is (final demand or intermediate demand). It is important to emphasize that the Ghosh model as a descriptive analysis tool does not allow to extrapolate the results here obtained to other economies or other

[1] However, it is not free of criticism. For a brief summary of such criticisms, see Lenzen (2003).

[2] The main criticisms related to the Ghosh model lie in the discussion of what is its correct economic interpretation and, consequently, the misuse of it that some authors have made in practice. For example, Oostherhaven (1988) emphasizes the fact that it is not credible that the increase in the value added of one sector has no effect on the value added of the other sectors. In a similar way, Gruver (1989) focuses his criticism on the perfect substitutability between the inputs of the production function of each sector, according to which no input is essential in the production process given that any input can be substituted by the rest of inputs. Finally, De Mesnard (2009) focuses on criticizing the fact that the demand is infinitely elastic, that is, that demand absorbs any increase in the supply of a good, i.e., buyers buy as much output as is produced.

periods, which would be possible in the case of Leontief's demand-side perspective (*backward linkages* perspective).

This work presents two novelties regarding previous research in the literature that analyzes the environmental responsibility of the activity of a sector or group of sectors in the economy, given its productive structure and its sectoral interrelations. Firstly, we develop the method of subsystem analysis from the supply-side perspective, which, in turn, we extend in order to study the responsibility for pollutant substances. Secondly, we carry out an empirical analysis of the responsibility of transportation and storage subsystem for GHG emissions of the whole economy by applying the model to the Spanish economy in 2014 and compare the results with those obtained using the usual subsystem method from the demand-side perspective. The analysis allows us to examine in detail and under two different perspectives the relationships established in terms of emissions between the different productive subsectors of the subsystem, and between them and the rest of the productive sectors of the economy. The knowledge of these relationships will help the adequate design of environmental policies aimed at reducing emissions in the transportation and storage subsystem. The environmental policy implications that stem from both perspectives are discussed. Lastly, it is also worth mentioning that we perform the study of total emissions of transportation and storage activites of productive sectors (intermediate and final demands) and, therefore, we leave out of the analysis private transportation and storage activities.

We organize the rest of this research as follows. In Section 2 we describe the methodology. In Section 3 we present the data, along with the results and discussion. In Section 4 we summarize and conclude the investigation.

2. METHODOLOGY

In what follows we present our method of input–output subsystem analysis based on the Ghosh model. For the construction of subsystems from a demand-side perspective employed in this research, see Alcántara and Padilla (2009), and Navarro and Alcántara (2010).

2.1. The Ghosh model

Let us assume that the economy can be classified into *n* productive sectors. From the information contained in an input–output table we may write:

(1) $$\mathbf{x}' = \mathbf{u}'\mathbf{Z} + \mathbf{v}'$$

where $\mathbf{x}$ is a (n x 1) vector that denotes total output and its characteristic element x_i depicts the gross output of sector i; $\mathbf{Z}$ is a (n x n) matrix that represents the intermediate inputs and its characteristic element Z_{ij} represents the sector's j use of sector i production; and $\mathbf{v}$ is a (n x 1) vector that designates primary inputs used by the different productive sectors and its characteristic element v_i is the value of primary inputs available for sector i. All three variables are expressed in monetary terms. Moreover, $\mathbf{u}$ is a summation vector of appropriate dimension[3].

If the allocation coefficients are defined as:

(2) $$b_{ij} = \frac{z_{ij}}{x_i}$$

b_{ij} denotes the share of sector's i output used by sector j.

Then, for the whole economy and in compact form, we can write:

(3) $$\mathbf{B} = \hat{\mathbf{x}}^{-1}\mathbf{Z}$$

Given the allocation coefficients and operating, we can rewrite equation (1) as follows:

(4) $$\mathbf{x}' = \mathbf{v}'(\mathbf{I} - \mathbf{B})^{-1} = \mathbf{v}'\mathbf{G}$$

where $\mathbf{G}$ is the Ghosh inverse matrix, and its characteristic element G_{ij} denotes the total, direct and indirect, value of sector's j output per unit of primary input of sector i.

2.2. Input–output subsystem analysis from a supply-driven perspective

It is possible to construct subsystems, in the vein of Sraffa (1960), from a supply-side perspective in an analogous way to the subsystems built from the demand-side perspective.

We split matrix **B** into two groups, s and r, so that s depicts the productive sectors from 1 to k that belong to the subsystem, and r depicts the rest of productive sectors from k+1 to n of the economy, such as:

$$\mathbf{B} = \begin{pmatrix} \mathbf{B}_{\mathrm{ss}} & \mathbf{B}_{\mathrm{sr}} \\ \mathbf{B}_{\mathrm{rs}} & \mathbf{B}_{\mathrm{rr}} \end{pmatrix}$$

Then, we can rewrite equation (1) as:

(5) $$(\mathbf{x}'_{\mathrm{s}} \quad \mathbf{x}'_{\mathrm{r}}) = (\mathbf{x}'_{\mathrm{s}} \quad \mathbf{x}'_{\mathrm{r}}) \begin{pmatrix} \mathbf{B}_{\mathrm{ss}} & \mathbf{B}_{\mathrm{sr}} \\ \mathbf{B}_{\mathrm{rs}} & \mathbf{B}_{\mathrm{rr}} \end{pmatrix} + (\mathbf{v}'_{\mathrm{s}} \quad \mathbf{v}'_{\mathrm{r}})$$

[3] (′) indicates the transposition of a vector or a matrix; vectors and matrices are written in bold, vectors with a lowercase letter and matrices with capital letters, and scalars in italics; (^) denotes the diagonalization of a vector.

Then:

(6) $$\mathbf{G} = (\mathbf{I} - \mathbf{B})^{-1} = \left[\begin{pmatrix} \mathbf{I}_{\mathrm{ss}} & \mathbf{0} \\ \mathbf{0} & \mathbf{I}_{\mathrm{rr}} \end{pmatrix} - \begin{pmatrix} \mathbf{B}_{\mathrm{ss}} & \mathbf{B}_{\mathrm{sr}} \\ \mathbf{B}_{\mathrm{rs}} & \mathbf{B}_{\mathrm{rr}} \end{pmatrix}\right]^{-1} = \begin{pmatrix} \mathbf{G}_{\mathrm{ss}} & \mathbf{G}_{\mathrm{sr}} \\ \mathbf{G}_{\mathrm{rs}} & \mathbf{G}_{\mathrm{rr}} \end{pmatrix}$$

where $\mathbf{I}_{\mathrm{ss}}$ and $\mathbf{I}_{\mathrm{rr}}$ are identity matrices. Likewise, we can rewrite equation (4) as follows:

(7) $$(\mathbf{x}'_{\mathrm{s}} \quad \mathbf{x}'_{\mathrm{r}}) = (\mathbf{v}'_{\mathrm{s}} \quad \mathbf{v}'_{\mathrm{r}}) \begin{pmatrix} \mathbf{G}_{\mathrm{ss}} & \mathbf{G}_{\mathrm{sr}} \\ \mathbf{G}_{\mathrm{rs}} & \mathbf{G}_{\mathrm{rr}} \end{pmatrix}$$

In our subsystem analysis from a supply-driven perspective, the relevant issue is the relationships between the different economic sectors when the subsystem uses its primary inputs, that is, $\mathbf{v}_{\mathrm{s}}$. In order to isolate the interrelations of the subsystem, i.e., the relations between the sectors of the subsystem and between the subsystem and the rest of sectors of the economy, we establish $\mathbf{v}_{\mathrm{r}} = 0$ in equation (7), so that:

(8) $$(\mathbf{x}^{\mathbf{s}\prime}_{\mathrm{s}} \quad \mathbf{x}^{\mathbf{s}\prime}_{\mathrm{r}}) = (\mathbf{v}'_{\mathrm{s}} \quad \mathbf{0}') \begin{pmatrix} \mathbf{G}_{\mathrm{ss}} & \mathbf{G}_{\mathrm{sr}} \\ \mathbf{G}_{\mathrm{rs}} & \mathbf{G}_{\mathrm{rr}} \end{pmatrix} = (\mathbf{v}'_{\mathrm{s}}\mathbf{G}_{\mathrm{ss}} \quad \mathbf{v}'_{\mathrm{s}}\mathbf{G}_{\mathrm{sr}})$$

where the superscript s in the left part of the equation indicates that the subsystem is the only recipient of the output vectors obtained.

This expression can help to understand the nature of the subsystems analysis from a supply-side perspective. Thus, $\mathbf{v}'_{\mathrm{s}}\mathbf{G}_{\mathrm{ss}}$ is a row vector that shows the output that each one of the sectors of the subsystem had to produce induced by the sectors of the subsystem when they used their primary inputs. We can also interpret the result in another way if we transform the previous expression in $\hat{\mathbf{v}}\,\mathbf{G}_{\mathrm{ss}}\mathbf{u}$, a column vector that shows the total, direct and indirect, output that the subsystem sectors had to produce in relation to the primary inputs used by each one of them. Regardless of whether we analyze it by rows or columns, from now on, this component collects what we define as the internal component. The matrix $\hat{\mathbf{v}}\,\mathbf{G}_{\mathrm{ss}}$ refers to the output of the subsystem according to its primary inputs.

In the same way, we proceed with respect to the other component of equation (8). $\mathbf{v}'_{\mathrm{s}}\mathbf{G}_{\mathrm{sr}}$ is a row vector that collects the output that each sector that do not belong to the subsystem had to produce based on the primary inputs used by the subsystem sectors. $\hat{\mathbf{v}}\,\mathbf{G}_{\mathrm{sr}}\mathbf{u}$ is a column vector that depicts the output that the sectors that do not belong to the subsystem had to produce given the level of primary inputs used by each sector of the subsystem. The matrix $\hat{\mathbf{v}}\,\mathbf{G}_{\mathrm{sr}}$ denotes the output of the rest of the sectors of the economy as a consequence of the activity of the subsystem. It is worth pointing out that this is a spillover component, but from a forward linkages perspective.

2.3. Supply-driven input–output subsystems analysis and environmental pressures

We can extend the previous method in order to analyze the environmental behavior regarding some pollutants, energy consumption, or the use of natural sources, etc., analogously to the development of the subsystem analysis from a demand-side perspective (or input approach) based on the Leontief model.

Let $\mathbf{e}$ be a (n x 1) vector of sectoral emissions, then $\hat{\mathbf{x}}^{-1}\mathbf{e} = \mathbf{c}$, where $\mathbf{c}$ is a (n x 1) vector that depicts the emission per unit of sectoral output, which we can divide into two subsets, the subsystem and the rest of sectors of the economy, such as: $\mathbf{c} = \begin{pmatrix} \mathbf{c}^{\mathrm{s}} \\ \mathbf{c}^{\mathrm{r}} \end{pmatrix}$.

If we diagonalize the value added of the subsystem in equation (8) and post-multiply it by $\mathbf{c}$, we have:

(9) $\mathbf{f}^{\mathrm{s}} = \hat{\mathbf{v}}_{\mathrm{s}}\, \mathbf{G}_{\mathrm{ss}}\mathbf{c}^{\mathrm{s}} + \hat{\mathbf{v}}_{\mathrm{s}}\, \mathbf{G}_{\mathrm{sr}}\mathbf{c}^{\mathrm{r}}$

where $\mathbf{f}^{\mathrm{s}}$ are the total, direct and indirect, emissions of the subsystem from a forward linkages perspective. From this perspective, total emissions are easily differentiable into two components. First, the component corresponding to the first summand on the right-hand-side,$\hat{\mathbf{v}}_{\mathrm{s}}\, \mathbf{G}_{\mathrm{ss}}\mathbf{c}^{\mathrm{s}}$, corresponds to the internal component, as mentioned above, but now extended to the study of environmental pressures. Second, the component corresponding to the second summand on the right-hand-side,$\hat{\mathbf{v}}_{\mathrm{s}}\, \mathbf{G}_{\mathrm{sr}}\mathbf{c}^{\mathrm{r}}$, corresponds to the spillover component extended to analyze environmental pressures but from a forward linkages perspective. In order to obtain further relevant information related to the nature of the emissions of a given subsystem, we disaggregate $\hat{\mathbf{v}}_{\mathrm{s}}\, \mathbf{G}_{\mathrm{ss}}\mathbf{c}^{\mathrm{s}}$ even more. Then, considering the inverse of a partitioned matrix, we can write:

(10) $\mathbf{G}_{\mathrm{ss}}\mathbf{c}^{\mathrm{s}} = (\mathbf{I}_{\mathrm{ss}} - \mathbf{B}_{\mathrm{ss}})^{-1}\mathbf{c}^{\mathrm{s}} + (\mathbf{I}_{\mathrm{ss}} - \mathbf{B}_{\mathrm{ss}})^{-1}\mathbf{B}_{\mathrm{sr}}\mathbf{G}_{\mathrm{rs}}\mathbf{c}^{\mathrm{s}}$

which decomposes the internal component into two new components: the first summand on the right-hand-side of equation (10) shows the own internal component of the subsystem, and the second summand on the right-hand-side of the equation depicts the feedback component that corresponds to the relations between the subsystem and the rest of sectors of the economy. The interpretation of these two components is relatively simple, but not as straight as it would be in the case of a model generated from a demand-side perspective. Given the expression of the own internal component, after the diagonalization of the vector $\mathbf{c}^{\mathrm{s}}$, we obtain a matrix whose characteristic element $[(\mathbf{I}_{\mathrm{ss}} - \mathbf{B}_{\mathrm{ss}})^{-1}\hat{\mathbf{c}}^{\mathrm{s}}]_{ij}$, where $i, j \in s$, shows the pollution generated by the *j* sector due to the output it had to produce per unit of value added of *i*. As regards the feedback component, we use a similar transformation to the previous one in order to obtain a matrix whose characteristic element $[(\mathbf{I}_{\mathrm{ss}}-\mathbf{B}_{\mathrm{ss}})^{-1}\mathbf{B}_{\mathrm{sr}}\mathbf{G}_{\mathrm{rs}}\hat{\mathbf{c}}^{\mathrm{s}}]_{ij}$ shows the pollution generated by the *j* sector due to the increase of its output as a consequence of the increase in the output of the sectors that do not belong to the subsystem per unit of value added of the sector *i*.

Substituting in equation (9) the values found in equation (10), we have:

(11) $$\mathbf{f}^{\mathrm{s}}=\hat{\mathbf{v}}_{\mathrm{s}}(\mathbf{I}_{\mathrm{ss}}-\mathbf{B}_{\mathrm{ss}})^{-1}\mathbf{c}^{\mathrm{s}}+\hat{\mathbf{v}}_{\mathrm{s}}(\mathbf{I}_{\mathrm{ss}}-\mathbf{B}_{\mathrm{ss}})^{-1}\mathbf{B}_{\mathrm{sr}}\mathbf{G}_{\mathrm{rs}}\mathbf{c}^{\mathrm{s}}+\hat{\mathbf{v}}_{\mathrm{s}}\mathbf{G}_{\mathrm{sr}}\mathbf{c}^{\mathrm{r}}$$

Given that the most relevant, from the perspective of our research, is to quantify intersectoral relations, we can rewrite equation (11) as follows:

(12) $$\mathbf{f}^{\mathrm{s}}=\hat{\mathbf{v}}_{\mathrm{s}}[(\mathbf{I}_{\mathrm{ss}}-\mathbf{B}_{\mathrm{ss}})^{-1}-\mathbf{I}_{\mathrm{ss}}]\mathbf{c}^{\mathrm{s}}+\hat{\mathbf{v}}_{\mathrm{s}}(\mathbf{I}_{\mathrm{ss}}-\mathbf{B}_{\mathrm{ss}})^{-1}\mathbf{B}_{\mathrm{sr}}\mathbf{G}_{\mathrm{rs}}\mathbf{c}^{\mathrm{s}}+\hat{\mathbf{v}}_{\mathrm{s}}\mathbf{G}_{\mathrm{sr}}\mathbf{c}^{\mathrm{r}}+\hat{\mathbf{v}}_{\mathrm{s}}\mathbf{c}^{\mathrm{s}}$$

In equation (12), the direct emissions of the different sectors of the subsystem corresponding to its value added are isolated. Consequently, we divide the total responsibility for emissions of the subsystem in terms of emissions into four explanatory components.

Net own internal component:

(13) $$\mathrm{NOIC}=\hat{\mathbf{v}}_{\mathrm{s}}[(\mathbf{I}_{\mathrm{ss}}-\mathbf{B}_{\mathrm{ss}})^{-1}-\mathbf{I}_{\mathrm{ss}}]\mathbf{c}^{\mathrm{s}}$$

This depicts the direct and indirect emissions in net terms generated by each one of the subsystem sectors due to the productive activity of the other sectors of the subsystem.

Feedback component:

(14) $$\mathrm{FBC}=\hat{\mathbf{v}}_{\mathrm{s}}(\mathbf{I}_{\mathrm{ss}}-\mathbf{B}_{\mathrm{ss}})^{-1}\mathbf{B}_{\mathrm{sr}}\mathbf{G}_{\mathrm{rs}}\mathbf{c}^{\mathrm{s}}$$

This accounts for the direct and indirect emissions generated by the subsystem sectors due to the increase of the output of the sectors that do not belong to the subsystem that, in turn, had been induced by the productive activity of the subsystem.

Scale component:

(15) $$\mathrm{SC}=\hat{\mathbf{v}}_{\mathrm{s}}\mathbf{c}^{\mathrm{s}}$$

It measures the direct emissions of a subsystem sector generated when it used its primary inputs.

Spillover component:

(16) $$\mathrm{SOC}=\hat{\mathbf{v}}_{\mathrm{s}}\mathbf{G}_{\mathrm{sr}}\mathbf{c}^{\mathrm{r}}$$

It shows the emissions corresponding to the output that the sectors that do not belong to the subsystem had to produce once the subsystem initiated its productive activity.

It is not difficult to consider the importance that the activity of the sectors that do not belong to the subsystem had on the emissions of the subsystem. If in equation (7) we establish $\mathbf{v}'_{\mathrm{s}} = 0$, then, we obtain:

$$(17)\quad (\mathbf{x}^{r\prime}{}_{\mathrm{s}} \quad \mathbf{x}^{r\prime}{}_{\mathrm{r}}) = (\mathbf{0}' \quad \mathbf{v}'_{\mathrm{r}}) \begin{pmatrix} \mathbf{G}_{\mathrm{ss}} & \mathbf{G}_{\mathrm{sr}} \\ \mathbf{G}_{\mathrm{rs}} & \mathbf{G}_{\mathrm{rr}} \end{pmatrix} = (\mathbf{v}'_{r}\mathbf{G}_{\mathrm{rs}} \quad \mathbf{v}'_{\mathrm{r}}\mathbf{G}_{\mathrm{rr}})$$

It is worth noting that now the vector $\mathbf{v}'_{\mathrm{r}}\mathbf{G}_{\mathrm{rs}}\hat{\mathbf{c}}^{\mathrm{s}}$ denotes the emissions of each one of the sectors of the subsystem as a function of the production of the rest of the sectors of the economy, i.e., the sectors that do not belong to the subsystem. In the same way, $\hat{\mathbf{v}}_{\mathrm{r}}\mathbf{G}_{\mathrm{rs}}\mathbf{c}^{\mathrm{s}}$ depicts the emissions of the subsystem as a whole related to the primary inputs of the sectors of the rest of the economy.

3. DATA, RESULTS AND DISCUSSION

3 .1 Data

We define the transportation and storage subsystem, which is the object of study of this research, as the subsystem composed of the different subsectors of transportation and storage sector according to the NACE classification of 2009 (INE, 2017). In particular, these subsectors are "Land transport and transport via pipelines", "Air transport", "Water transport", "Warehousing and support activities for transportation" and "Postal and courier activities".

This research obtains the input–output table of the Spanish economy for 2014 from the World Input–Output Database (WIOD, 2017). The database provides input–output tables for the 28 countries of the European Union and 15 other major countries worldwide (WIOT) for the period 2000–2014. Likewise, the input–output table of each country is divided into 55 sectors and its units are expressed in millions of dollars at current prices (Timmer et al., 2015).

In addition, we obtain the GHG emissions data by economic sectors for Spain in 2014 from the Air Emissions Accounts published by the National Institute of Statistics (INE, 2018). This database contains information for a total of 66 economic sectors. In order to make the input–output table compatible with the sectoral emissions data, we aggregate the GHG emissions of the Air Emissions Accounts, which present a higher degree of disaggregation, of the following sectors: "Administrative and support service activities"; "Human health and social work activities"; "Arts, entertainment, and recreation”; and “Other service activities".

It is worth mentioning that a more detailed analysis could have been done if the data of the "Land transport and transport via pipelines" subsector had been disaggregated. These would have allowed taking into account the activity related to the additional intrarelationships between the different subsectors of the subsystem and between them and the rest of the sectors of the economy. Nevertheless, in the absence of such data, it is not possible to carry out this potential analysis. Likewise, the outcomes of this work only consider transport activities supplied externally, therefore, the conclusions are somewhat limited given that the emissions corresponding to transport activities carried out directly by sectors are not taken into account.

Lastly, it is important to point out that the World Input–Output Data Base (WIOD) shows that the Spanish transportation and storage subsystem allocated 64.1% of its production to the other productive sectors of the economy in the form of intermediate goods, while the remaining 35.9% went to satisfy its final demand.

3. 2. Results and discussion

3.2.1. GHG emissions of the transportation and storage subsystem in Spain in 2014

In 2014, direct GHG emissions of the transportation and storage subsystem in Spain were 45,380.0 thousand tons of CO_2 equivalent ($CO_{2\text{-eq}}$) explaining 13.5% of total GHG emissions of the whole economy. Meanwhile, the input–output analysis from a supply-side perspective indicates that total, direct and indirect, GHG emissions of the transportation and storage subsystem activity reached 38,442.7 thousand tons of $CO_{2\text{-eq}}$ accounting for 11.5% of total GHG emissions. In turn, the analysis from a demand-side perspective points to 27,143.2 thousand tons of $CO_{2\text{-eq}}$ of direct and indirect GHG emissions being responsible for 8.1% of total GHG emissions of the whole economy (Table 1).

The outcomes point to significant differences between both perspectives. Notwithstanding, it is worth remembering that demand- and supply-side perspectives provide different information. Specifically, the analysis from a supply-side perspective informs about the greenhouse gases that were induced by the use of the primary inputs of the subsystem, namely, the productive activity of the subsystem pushed the subsystem and the other sectors of the economy to emit. On the contrary, the analyisis performed from a demand-side perspective denotes the emissions resulting from satisfying the final demand of the subsystem; or, in other words, the satisfaction of the final demand of the subsystem pulled the subsystem and the other sectors of the economy to emit. Table 1 displays that the input–output analysis from a supply-side perspective assigns higher levels of greenhouse gases to the subsystem than the analysis from the demand-side perspective. This outcome holds for the subsystem as a whole and for subsectors with the exception of “Water transport” and “Air transport” subsectors, precisely those subsectors whose final demand is higher than their intermediate demand. The reason is that the analysis of total subsystem emissions from a demand-side perspective does not include the considerable emissions related to the subsectors activity of the subsystem as input suppliers of other sectors of the economy.

Additionally, Table 1 also shows that total subsystem emissions were lower than its direct emissions under both perspectives, and not only for the subsystem as a whole, but also for its subsectors[4]. Therefore, the transportation and storage subsystem contributed less to emitting greenhouse gases than direct emissions initially indicate. From the above, we can assert that, both from a demand- and a supply-side perspective, the productive activity of the rest of the sectors of the economy is to a great extent responsible for GHG emissions of the subsectors of the subsystem whose direct emissions exceed their total emissions. This result corroborates that obtained in the investigations of Tarancón and del Río (2007) and Alcántara and Padilla (2009) for Spain, and Piaggo et al. (2015) for Uruguay. However, it differs from the works of Butnar and Llop (2011) for Spain, and Ge et al. (2016) for Beijing. This discrepancy in the results could be explained because in the first three investigations the transportation and storage sector is the object of analysis, either aggregated or disaggregated by subsectors; meanwhile, in the last two investigations, the object of analysis is the aggregated transportation, storage, and communications sector.

[4] With the exception of the subsector “Warehousing and support activities for transportation” in the analysis of total emissions from both perspectives and of the subsector “Postal and courier activities” in the analysis of total emissions from the supply-side perspective.

Table 1. Total and direct GHG emissions of transportation and storage subsystem. Spain, 2014.

	Total GHG emissions				Direct GHG emissions	
	Supply-side perspective		Demand-side perspective		Thousands of tons of $CO_{2\text{-eq}}$	%
	Thousands of tons of $CO_{2\text{-eq}}$	%	Thousands of tons of $CO_{2\text{-eq}}$	%		
Land transport and transport via pipelines	24,025.9	7.2%	14,713.3	4.4%	31,712.7	9.5%
Water transport	549.5	0.2%	1,003.4	0.3%	1,061.6	0.3%
Air transport	5,685.1	1.7%	9,586.1	2.9%	11,980.8	3.6%
Warehousing and support activities for transportation	7,661.6	2.3%	1,791.9	0.5%	564.6	0.2%
Postal and courier activities	520.4	0.2%	48.5	0.0%	60.3	0.0%
Transportation and storage subsystem	38,442.7	11.5%	27,143.2	8.1%	45,380.0	13.5%
Total economy	335,564.3	100.0%	335,564.3	100.0%	335,564.3	100.0%

Note: The direct emissions of households amounted to 67,793.5 thousand tons of $CO_{2\text{-eq}}$ while the total sectors emitted 267,771.1 thousand tons of CO_{2-eq}.
Source: Prepared by the authors with the data from INE (2017), and WIOD (2017).

Tables 2 and 3 present the outcomes of the decomposition of total GHG emissions related to the activity of the transportation and storage subsystem in Spain in 2014, following both our methodology of subsystem analysis from the supply-side perspective and the analysis from the demand-side perspective, respectively. The results point that the feedback component (the subsystem emissions because of the activity of sectors of the economy that do not belong to the subsystem for which the subsystem is responsible) plays a minor role for explaining the subsystem emissions. On the other hand, the level of significance of the other three components changes according to the perspective analyzed. Thus, from a supply-side perspective, the scale component (direct emissions of each subsector of the subsystem corresponding to the use of its primary inputs) accounted for more than three fifths of total emissions, followed by the spillover component (emissions of the sectors not belonging to the subsystem induced by the productive activity of the subsystem) with a little more than a fifth part, and the net own internal component (emission of each subsector of the subsystem because of the productive activity of the other subsectors of the subsystem) with almost a sixth part. Whereas, from a demand-side perspective, it is the scale component (direct emissions of each subsector of the subsystem when satisfying its final demand), with four-fifths, that is virtually responsible for total emissions, which implies that the spillover component (emissions of the sectors that do not belong to the subsystem to provide inputs to the subsystem to satisfy its final demand) and the net own internal (emissions of each subsector of the subsystem when producing inputs to satisfy the final demand of the rest of the subsystem subsectors) component barely explain one tenth and one twelfth of total emissions, respectively. The analysis by subsectors unveils the reason for these differences in the results of the decomposition according to the perspective used. In particular, from the supply-side perspective, both the "Warehousing and support activities for transportation" subsector, with 19.9% of total emissions, and the "Air transport" subsector, with 14.8%, accompany the "Land transport and transport via pipelines" subsector, with 62.5%, as the most significant GHG emitting subsectors of the subsystem. On the contrary, from the demand-side perspective, it is the "Land transport and transport via pipelines" subsector, accounting for 54.2% of total emissions, together with the "Air transport" subsector, with 35.3%, the main subsectors responsible for total subsystem emissions. That is, when the productive activity considered is that aimed at satisfying the final demand of the subsystem, i.e the demand-side perspective, the subsectors "Land transport and transport via pipelines" and, specially, the "Warehousing and support activities for transportation" lose significance as responsible for the subsystem emissions, while the "Air transport" subsector becomes more important. However, when the productive activity corresponds to satisfy both, the intermediate demand and the final demand, namely the supply-side perspective, occurs just the opposite. An in-deph analysis of the results of the decomposition for these three subsectors allows us to obtain new findings. First, the scale component diminish its importance as an explanatory component of the subsystem emissions in the particular case of "Air transport" subsector from the supply-side perspective (13.4%) in relation to the demand-side perspective (30.3%), in line with the fact that its final demand exceeds its intermediate demand. Second, the higher spillover component from the supply-side perspective (12.5%) with respect to the demand-side perspective (5.0%) explains the highest responsability of the "Land transport and transport via pipelines" subsector as emitting subsector from the supply-side perspective. Finally, the different share of the "Warehousing and support activities for transportation" subsector as responsible for the subsystem emissions in both perspectives is explained by the net own internal and spillover components that stand for 18.8% of total subsystem emissions from the supply-side perspective but only for 5.9% from the demand-side perspective.

Table 2. Decomposition of total GHG emissions (thousands of tons of $CO_{2\text{-eq}}$) of the transportation and storage subsystem from a supply-side perspective. Spain, 2014

	Net own internal component	%	Feedback component	%	Scale component	%	Spillover component	%	Total GHG emissions	%
Land transport and transport via pipelines	1,043.7	17.8%	219,8	46.6%	17,940.0	75.3%	4,822.5	58.3%	24,025.9	62.5%
Water transport	19.3	0.3%	9,5	2.0%	442.9	1.9%	77.8	0.9%	549.5	1.4%
Air transport	339.4	5.8%	28,8	6.1%	5,137.4	21.6%	179.5	2.2%	5,685.1	14.8%
Warehousing and support activities for transportation	4,433.9	75.5%	177,2	37.5%	270.4	1.1%	2,780.1	33.6%	7,661.6	19.9%
Postal and courier activities	32.9	0.6%	36,6	7.8%	34.5	0.1%	416.4	5.0%	520.4	1.4%
Transportation and storage subsystem	5,869.2	100.0%	472.0	100.0%	23,825.3	100.0%	8,276.2	100.0%	38,442.7	100.0%
%	15.3%		1.2%		62.0%		21.5%		100.0%	

Source: Prepared by the authors with data from INE (2017), and WIOD (2017).

Table 3. Decomposition of total GHG emissions (thousands of tons of $CO_{2\text{-eq}}$) of the transportation and storage subsystem from a demand-side perspective. Spain, 2014

	Land transport and transport via pipelines	Water transport	Air transport	Warehousing and support activities for transportation	Postal and courier activities	Transportation and storage subsystem	%
Net own internal component	679.8	61.8	625.3	912.1	16.1	2,295.0	8.5%
%	29.6%	2.7%	27.2%	39.7%	0.7%	100.0%	
Feedback component	142.3	18.3	57.4	62.7	2.1	282.8	1.0%
%	50.3%	6.5%	20.3%	22.2%	0.8%	100.0%	
Scale component	12,542.4	721.4	8,234.4	134.1	6.4	21,638.7	79.7%
%	58.0%	3.3%	38.1%	0.6%	0.0%	100.0%	
Spillover component	1,348.8	201.9	669.0	683.0	23.9	2,926.7	10.8%
%	46.1%	6.9%	22.9%	23.3%	0.8%	100.0%	
Total GHG emissions	14,713.3	1,003.4	9,586.1	1,791.9	48.5	27,143.2	100.0%
%	54.2%	3.7%	35.3%	6.6%	0.2%	100.0%	

Source: Prepared by the authors with data from INE (2017), and WIOD (2017).

3.2.2. The transportation and storage subsystem emissions induced by the rest of the sectors of the economy

Table 6 in the Appendix presents, from the supply-side perspective, the GHG emissions of the transportation and storage subsystem due to the output it had to produce because of the productive activity of the sectors that do not belong to the subsystem. Table 7 shows, from the demand-side perspective, the GHG emissions of the subsystem attributable to the inputs it produces to satisfy the final demand of the sectors not belonging to the subsystem. These emissions reached 15,213.5 thousand tons of $CO_{2\text{-eq}}$ from the supply-side perspective and 21,163.5 thousand tons of $CO_{2\text{-eq}}$ from the demand-side perspective. The analysis shows that the sectors of the economy that induced the subsystem to emit more were the service sectors not related to transport and storage activities —62.5% and 47.4% of these emissions from the supply- and demand-side perspectives, respectively— and the "Manufacturing" sector —27.6% from the supply-side perspective and 38.2% from the demand-side perspective of these emissions. It is worth noting that the service sectors, excluding the subsystem, are to a great extent responsible for the subsystem emissions and this outcome holds for both perspectives. This outcome shows that the productive activity of the subsystem in response to the productive activity of service sectors —whether activated by the final demand or by the use of its primary inputs— largely explains the subsystem emissions. This result is in line with the results obtained from a final demand perspective by Alcántara and Padilla (2009) and Piaggio et al. (2015) for the Spanish and the Uruguayan economy, respectively.

On the other hand, it is worth pointing out that the outcomes related to the “Manufacturing” sector present significant dissimilarities between both perspectives. The satifaction of its final demand pulls the subsystem emissions, especially those from the “Land transport and transport via pipelines” subsector, so that from the demand-side perspective these emissions are significantly higher than those from the supply-side perspective. Precisely, the analysis from the supply-side perspective gives less importance to the “Manufacturing” sector as responsible for the subsystem emissions. Its productive activity pushes the subsystem emissions to a lesser extent, particularly, those of the “Land transport and transport via pipelines”subsector.

3.2.3. The emissions exchange between the transportation and storage subsystem and the rest of sectors of the economy

We have just seen in previous sections that from the supply-side perspective the transportation and storage subsystem induced the rest of the productive sectors of the economy to emit 8,276.2 thousand tons of $CO_{2\text{-eq}}$. Meanwhile, the rest of the sectors of the economy induced the subsystem to emit 15,213.5 thousand tons of $CO_{2\text{-eq}}$. Nevertheless, from the demand-side perspective, the subsystem induced the rest of sector of the economy to emit 2,926.7 thousand tons of $CO_{2\text{-eq}}$, while the sectors of the economy that do not belong to the subsystem induced it to emit 21,163.5 thousand tons of $CO_{2\text{-eq}}$. Therefore, regardless of the perspective used we can affirm that the rest of the sectors of the economy induced in net terms the transportation and storage subsystem to emit more greenhouse gases than the opposite. This outcome explains the lower relative share of the subsystem in relation to the total emissions of the economy if direct and indirect emissions are taken into account than if only direct emissions are considered. On the other hand, the huge difference between the emissions assigned to the subsystem under the different perspectives makes clear that if we only focused on a demand-side perspective we would be ignoring a great part of the transport activity and emissions associated to its intermediate demand. It is worth noting that the main divergence in the results provided by both perspectives in relation to total emissions is due to the “Manufacturing” sector. Thus, the analysis from the demand-side perspective attributes lower responsibility to the subsystem as emitting sector than that from the supply-side perspective by assigning higher responsibility to the “Manufacturing” sector as a sector that induces the subsystem emissions.

Tables 8 and 9 in the Appendix show the detailed results of this analysis from the supply-side and the demand-side perspective, respectively. Table 8 outcomes reveal that almost all the sectors that do not belong to the subsystem pushed the subsystem to emit more than the opposite when carrying out their productive activity, with the exception of, in order of importance, "Agriculture, forestry and fishing"; "Electricity, gas, steam and air conditioning supply"; "Mining and quarrying"; and "Water supply; sewerage, waste management and remediation activities”. Whereas, from the demand-side perspective, Table 9 indicates that the final demand of all the sectors not belonging to the subsystem, with the exception of "Electricity, gas, steam and air conditioning supply”, pulled and was responsible for the emissions generated by the subsystem more than the opposite. Consequently, we can affirm that, regardless of the perspective used, the service sectors not related to transportation and storage activities are significantly responsible for the subsystem emissions. This outcome corroborates the analysis of the previous section.

Likewise, it is worth mentioning that all the subsectors of the subsystem are more induced to emit than vice versa, with the exception of the "Warehousing and support activities for transportation" subsector[5]. Precisely, it is the supply-side perspective that highlights the importance of this subsector as responsible for the GHG emissions of the subsystem, thanks, in part, to the significance of the spillover component; significance that is not collected in the demand-side perspective.

3.2.4. The environmental policy implications of both perspectives

The identification of the main activities responsible for transportation and storage subsystem emissions should be key in the design of environmental measures aimed at reducing or, at least, mitigating the growth of emissions from the transportation and storage subsystem. It is also worth noting that the different information provided by the outcomes of both perspectives allow to infer different (and complementary) environmental policy recommendations. Thus, from the demand-side perspective the main subsectors responsible for the scale component coincided to the most polluting subsystem subsectors in terms of direct emissions; specifically, "Land transport and transport via pipelines" and "Air transport" subsectors. This outcome indicates that the productive activity of these two subsectors significantly explained the GHG emissions of the subsystem. Moreover, if we consider that the direct emissions of the "Land transport and transport via pipelines"[6] subsector basically correspond to the activities of "Road transport" and "Transport via pipelines", the following suggestions can be surmised. Firstly, the authorities should promote the replacement of "Road transport" and "Air transport" with "Rail transport" and/or "Water transport", through measures such as, for example, more investments to ameliorate intermodal transportation hubs that favors the interoperability of the nodes and the logistic platforms in order to foster rail and/or water freight transport. Secondly, "Road transport" and "Air transport" activites should be more energy efficient; therefore, the authorities should encourage measures such as technological improvements in vehicles, the use of cleaner fuels, and infrastructure through, for instance, state aids for R+D+I related to more efficient engines and/or fuels and the introduction of new recharging infraestructures such as charging points for electric cars in road networks. Thirdly, the authorities should stimulate the use of less harmful sources of energy in environmental terms, for example, through subsidies for the use of second- and third-generation biofuels, reduction in port fees for ships powered by alternative fuels, or exemption for registration tax for less polluting vehicles. Likewise,

[5] And also the exception of Postal and courier activities in the supply-side perspective.
[6] Rail transport does not directly emit greenhouse gases, since its main source of energy is electricity.

from the demand-side perspective, as regards the spillover component, the activity corresponding to satisfy the final demand of the subsector "Land transport and transport via pipelines" explains, largely, these indirect emissions. In particular, this subsector pulls on the emissions of the sectors “Electricity, gas, steam and air conditioning supply” and “Manufacturing”, specially, those of the sector “Manufacture of coke and refined petroleum products”. All of them are sectors related to sources of energy that is why the environmental measures, again, should focus on higher energy efficiency and less polluting sources of energy.

From the supply-side perspective, the outcomes suggest additional reccommendations in terms of environmental policies. The spillover component discloses the subsector "Warehousing and support activities for transportation" as significantly responsible for emissions. Moreover, the productive activity of this subsector together with that of the “Land transport and transport via pipelines” pushes, particularly, the sectors “Electricity, gas, steam and air conditioning supply”, “Manufacturing”, and “Agriculture, forestry and fishing” to emit. As regards to “Manufacturing” sector, the main sectors that are pushed to emit are the sectors “Manufacture of other non-metallic mineral products”, “Manufacture of basic metals”, and “Manufacture of chemicals and chemical products”, sectors related to transport infraestructures. Therefore, the rational use of materials in transport infrastructures, that, also, are friendly to the environment, should be promoted, for instance, with an adequate design of transport infraestructures at national and European level through higher coordination among different levels of government, or requiring the use of ecofriendly materials in the contracts of the public administrations related to the construction or maintenance of the infrastructures. In turn, the dissaggretation of the net own internal component by subsectors shows that "Warehousing and support activities for transportation" was the most important productive subsector in explaining this component. In terms of environmental policies, the significance of the “Warehousing and support activities for transportation” subsector should lead the authorities to encourage the continuous introduction of new improvements in transport logistics, such as e.g. minimizing empty running or improving transport efficiency (tons carried per vehicle), which could result in significant reductions of GHG transport emissions (Andrés and Padilla, 2015), through measures such as promoting backload and the increase of diesel tax.

It should be noted that our outcomes, using the analysis of subsystems from both the supply- and demand-side perpectives, have some similiarities in qualitative but not quantitative terms to those obtained by Alcántara and Padilla (2009). Their analysis is focused on the services sector subsystem, where transportation and storage subsector is just one more subsector of the subsystem, and it is performed from the demand-side perspective, so that their results only reflect the impact on emissions related to the final demand of the services sector. Furthermore, it is important to highlight that the environmental policy measures aimed at reducing GHG emissions on the transportation and storage subsystem suggested in this study are aligned with the proposals of previous research that, even with different objectives and using different methodologies, obtained some comparable results to ours (see, for example, the works of Timilsina and Shresta, 2009; and Andrés and Padilla, 2018; for the environmental policy measures related to the scale component, such as the use of cleaner fuels, less polluting modes of transportation, or more energy efficient vehicles; and McKinnon, 2015; for environmental policy measures related to the net own internal component, where improvements in the logistics of freight transport and its storage is a relevant issue). However, it is worth noting that, unlike the previous investigations, our work allows measuring the contribution of all the activity of each subsector of the subsystem to total GHG emissions of the whole economy and our outcomes provide significant information on which environmental measures should be prioritized.

4. Conclusions

We have developed an input–output subsystem analysis from a supply-side perspective based on the Ghosh model and have extended it to the analysis of the polluting behavior of a subsystem. The input–output subsystem analysis allows the study of the interrelations in terms of emissions between the different subsystem subsectors and between the subsystem and the rest of the sectors of the economy. In contrast to the subsystem analysis from a demand-side perspective, our supply-side method allows us to consider the emissions of the whole activity of the subsystem and not only those related to its final demand. This is particularly useful for studying the whole responsibility for emissions of the activity of sectors, such as the transportation and storage sector, whose production is to a great extent an input for other sectors.

To study the responsibility for GHG emissions of the whole economy of the activity of the transportation and storage sector for the case of Spain in 2014 we have applied the subsystem analysis from both the supply- and demand-side perspectives. We have analyzed the polluting behavior in terms of GHG emissions of the transportation and storage subsystem through an in-depth study of the existing linkages between the activity of its different subsectors and the interrelations that these establish with the rest of the sectors of the economy. The outcomes from both perspectives and their discussion provide relevant information for the design of environmental policies aimed at reducing GHG emissions in this sector.

The results of the input–output analysis show that the responsibility of the subsystem as greenhouse gas emitting sector is lower than that revealed by direct emissions of the subsystem, namely, the subsystem emissions are to a large extend induced by the productive activity of the rest of the sectors of the economy. In particular, the service sectors not related to transportation and storage activities are the main responsible for total emissions of the subsystem being lower than its direct emissions. Moreover, the analysis from the supply-side perspective —that focus on the emissions that the use of the primary inputs of the subsystem push to emit to the subsystem and the other sectors— attributes higher responsibility to the subsystem as a greenhouse gas emitting sector than the analysis from the demand-side perspective —that focus on the emissions that the satisfaction of the final demand of the subsystem pulls to emit to the subsystem and the rest of sectors of the economy. This outcome is in line with the fact that the intermediate demand of the subsystem exceeds the final demand. Moreover, the result is maintained for those subsectors of the subsystem with higher intermediate demand than final demand for which the applicaton of the supply-side methodology is clearly justified. Likewise, the fact that total emissions are higher from the supply-side perspective than from the demand-side perspective can be explained by the high significance that from the demand-side perspective is assigned to the “Manufacturing” sector as responsible for the subsystem emissions, which implies that the demand-side perspective is not able to consider the importance of the whole activity of the subsystem in GHG emissions. Furthermore, the subsector “Land transport and transport via pipelines” is the main responsible for the subsystem emissions, regardless of the perspective used in the analysis. Lastly, from the demand-side perspective, the high significance of the scale component attributes higher responsability to the subsector “Air transport” as emitting sector. Consequently, the demand-side perspective does not account the importance of the other components in explaining the subsystem emissions associated to its whole productive activity that is revealed from the supply-side perspective. This perspective, in turn, shows the importance of the “Warehousing and support activities for transportation” as responsible for the subsystem emissions, as the higher relevance of this subsector is due to the net own internal component and to the spillover component. Then, we obtain complementary implications in terms of environmental policy from the different perspectives, so that, from the demand-side perspective, the environmental measures should be mainly focused on the economic activity stemmed from the satisfaction of the final demand of the subsectors “Land transport and transport via pipelines" and "Air transport", whereas, from the supply-side perspective, these should also be addressed to the economic activity that comes from the use of the primary inputs of the two previous sectors and "Warehousing and support activities for transportation" subsector.

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APPENDIX

Table 4. GHG emissions (thousands of tons of $CO_{2\text{-eq}}$) of the rest of the sectors of the economy induced by the transportation and storage subsystem from a supply-side perspective. Spain, 2014

	Agriculture, forestry and fishing	Mining and quarrying	Manufacturing	Electricity, gas, steam and air conditioning supply	Water supply; sewerage, waste management and remediation activities	Construction	Wholesale and retail trade; repair of motor vehicles and motorcycles	Accommodation and food service activities	Information and communication	Financial and insurance activities	Real estate activities	Professional, scientific and technical activities	Administrative and support service activities	Public administration and defense; compulsory social security	Education	Human health and social work activities	Arts, entertainment and recreation and Other service activities	Total of the rest of the productive sectors of the economy	%
Land transport and transport via pipelines	662.2	136.3	2,557.9	1,030.1	177.5	10.5	189.9	8.9	5.0	1.0	0.1	2.7	2.9	22.0	1.2	8.1	6.3	4,822.5	58.3%
Water transport	11.6	1.1	35.1	16.5	6.2	0.2	4.7	0.2	0.2	0.0	0.0	0.2	0.6	0.7	0.0	0.3	0.2	77.8	0.9%
Air transport	27.0	3.4	73.1	44.9	10.2	0.5	9.5	0.3	0.5	1.0	0.0	0.5	1.9	3.3	0.1	1.5	1.7	179.5	2.2%
Warehousing and support activities for transportation	565.7	79.4	1,345.5	450.8	116.3	6.0	176.9	5.2	3.1	0.9	0.1	2.1	1.9	16.2	0.6	5.8	3.6	2,780.1	33.6%
Postal and courier activities	49.7	3.8	136.3	166.1	23.3	1.9	19.2	1.4	3.0	1.0	0.1	1.5	0.8	4.8	0.4	2.0	1.1	416.4	5.0%
Transportation and storage subsystem	1,316.1	224.1	4,147.8	1,708.4	333.6	19.1	400.1	16.0	11.8	4.0	0.2	7.1	8.1	47.0	2.4	17.6	12.9	8,276.2	100.0%
%	15.9%	2.7%	50.1%	20.6%	4.0%	0.2%	4.8%	0.2%	0.1%	0.0%	0.0%	0.1%	0.1%	0.6%	0.0%	0.2%	0.2%	100.0%	

Source: Prepared by the authors with data from INE (2017), and WIOD (2017).

Table 5. GHG emissions (thousands of tons of $CO_{2\text{-eq}}$) of the rest of the sectors of the economy induced by the transportation and storage subsystem from a demand-side perspective. Spain, 2014

	Land transport and transport via pipelines	Water transport	Air transport	Warehousing and support activities for transportation	Postal and courier activities	Transportation and storage subsystem	%
Agriculture, forestry and fishing	54.9	8.8	22.1	31.3	1.1	118.2	4.0%
Mining and quarrying	2.5	0.5	2.0	1.1	0.0	6.1	0.2%
Manufacturing	368.0	106.0	404.4	194.8	5.8	1,079.0	36.9%
Electricity, gas, steam and air conditioning supply	771.5	71.7	200.4	403.1	14.8	1,461.4	49.9%
Water supply; sewerage, waste management and remediation activities	23.9	6.4	16.3	13.3	1.0	60.8	2.1%
Construction	1.4	0.3	0.6	1.9	0.0	4.2	0.1%
Wholesale and retail trade; repair of motor vehicles and motorcycles	90.4	3.2	7.1	15.6	0.5	116.9	4.0%
Accommodation and food service activities	0.9	0.2	0.5	0.5	0.0	2.1	0.1%
Information and communication	4.8	0.3	2.8	2.0	0.2	10.1	0.3%
Financial and insurance activities	2.5	0.3	0.7	1.0	0.0	4.6	0.2%
Real estate activities	0.3	0.1	0.1	0.2	0.0	0.8	0.0%
Professional, scientific and technical activities	2.7	0.5	1.2	1.5	0.1	6.1	0.2%
Administrative and support service activities	3.4	0.9	2.9	2.2	0.1	9.6	0.3%
Public administration and defense; compulsory social security	18.1	2.3	6.7	12.6	0.1	39.8	1.4%
Education	0.4	0.0	0.3	0.1	0.0	0.9	0.0%
Human health and social work activities	0.8	0.1	0.2	0.2	0.0	1.3	0.0%
Arts, entertainment and recreation and Other service activities	2.3	0.3	0.8	1.2	0.1	4.8	0.2%
Total of the rest of the productive sectors of the economy	1,348.8	201.9	669.0	683.0	23.9	2,926.7	100.0%
%	46.1%	6.9%	22.9%	23.3%	0.8%	100.0%	

Source: Prepared by the authors with data from INE (2017), and WIOD (2017).

Table 6. GHG emissions (thousands of tons of $CO_{2\text{-}eq}$) of the transportation and storage subsystem induced by the rest of the sectors of the economy from a supply-side perspective. Spain, 2014

	Land transport and transport via pipelines	Water transport	Air transport	Warehousing and support activities for transportation	Postal and courier activities	Transportation and storage subsystem	%
Agriculture, forestry and fishing	56.2	2.7	23.8	1.2	0.1	84.0	0.6%
Mining and quarrying	4.7	0.3	4.0	0.1	0.0	9.2	0.1%
Manufacturing	1,843.8	153.1	2,161.4	33.3	2.2	4,193.7	27.6%
Electricity, gas, steam and air conditioning supply	741.7	20.6	203.1	13.8	1.1	980.2	6.4%
Water supply; sewerage, waste management and remediation activities	79.7	4.8	35.1	1.6	0.1	121.3	0.8%
Construction	204.6	11.1	86.6	9.8	0.5	312.5	2.1%
Wholesale and retail trade; repair of motor vehicles and motorcycles	2,005.6	24.2	192.0	13.7	1.0	2,236.4	14.7%
Accommodation and food service activities	136.1	7.5	83.6	2.8	0.3	230.2	1.5%
Information and communication	557.0	12.6	387.3	9.0	1.4	967.3	6.4%
Financial and insurance activities	766.2	29.0	257.7	11.9	1.1	1,065.9	7.0%
Real estate activities	696.8	80.2	249.4	20.9	2.3	1,049.6	6.9%
Professional, scientific and technical activities	529.9	35.6	229.5	10.6	1.4	807.0	5.3%
Administrative and support service activities	708.9	57.4	640.7	16.4	1.5	1,424.9	9.4%
Public administration and defense; compulsory social security	899.2	34.0	349.0	22.2	0.4	1,304.7	8.6%
Education	68.0	1.9	57.6	0.9	0.1	128.5	0.8%
Human health and social work activities	58.5	1.3	13.3	0.6	0.2	73.8	0.5%
Arts, entertainment and recreation and Other service activities	157.2	6.4	57.2	3.0	0.5	224.4	1.5%
Total of the rest of the productive sectors of the economy	9,514.1	482.4	5,031.4	171.5	14.1	15,213.5	100.0%
%	62.5%	3.2%	33.1%	1.1%	0.1%	100.0%	

Source: Prepared by the authors with data from INE (2017), and WIOD (2017).

Table 7. GHG emissions (thousands of tons of $CO_{2\text{-}eq}$) of the transportation and storage subsystem induced by the rest of the sectors of the economy from a demand-side perspective. Spain, 2014

	Agriculture, forestry and fishing	Mining and quarrying	Manufacturing	Electricity, gas, steam and air conditioning supply	Water supply; sewerage, waste management and remediation activities	Construction	Wholesale and retail trade; repair of motor vehicles and motorcycles	Accommodation and food service activities	Information and communication	Financial and insurance activities	Real estate activities	Professional, scientific and technical activities	Administrative and support service activities	Public administration and defense; compulsory social security	Education	Human health and social work activities	Arts, entertainment and recreation and Other service activities	Total of the rest of the productive sectors of the economy	%
Land transport and transport via pipelines	311.1	307.5	7,152.5	341.3	169.2	1,536.8	3,416.4	1,355.4	425.4	94.2	98.3	179.5	189.4	841.1	149.5	509.8	334.9	17,412.4	82.3%
Water transport	3.8	1.7	102.0	3.8	4.3	22.5	60.8	16.9	9.5	2.6	2.9	9.2	29.4	19.9	4.2	11.1	6.1	310.7	1.5%
Air transport	30.3	18.7	684.9	35.9	28.3	186.9	424.2	124.6	92.0	210.5	54.7	92.0	307.7	305.9	37.8	221.1	224.2	3,079.7	14.6%
Warehousing and support activities for transportation	6.5	4.5	124.7	3.8	2.8	22.1	76.4	20.1	6.6	2.0	1.9	3.7	3.2	15.6	2.1	9.1	4.8	310.0	1.5%
Postal and courier activities	0.5	0.2	10.4	1.1	0.6	5.6	7.6	4.2	5.3	1.9	2.0	2.0	1.0	3.7	1.1	2.5	1.2	50.7	0.2%
Transportation and storage subsystem	352.3	332.5	8,074.5	385.9	205.2	1,773.8	3,985.4	1,521.2	538.8	311.2	159.7	286.4	530.8	1,186.2	194.6	753.7	571.2	21,163.5	100.0%
%	1.7%	1.6%	38.2%	1.8%	1.0%	8.4%	18.8%	7.2%	2.5%	1.5%	0.8%	1.4%	2.5%	5.6%	0.9%	3.6%	2.7%	100.0%	

Source: Prepared by the authors with data from INE (2017), and WIOD (2017).

Table 8. The exchange of GHG emissions (thousands of tons of $CO_{2\text{-eq}}$) between the transportation and storage subsystem and the rest of the sectors of the economy from a supply-side perspective. Spain, 2014

	Agriculture, forestry and fishing	Mining and quarrying	Manufacturing	Electricity, gas, steam and air conditioning supply	Water supply; sewerage, waste management and remediation	Construction	Wholesale and retail trade; repair of motor vehicles and motorcycles	Accommodation and food service activities	Information and communication	Financial and insurance activities	Real estate activities	Professional, scientific and technical activities	Administrative and support service activities	Public administration and defense; compulsory social security	Education	Human health and social work activities	Arts, entertainment and recreation and Other service activities	Total of the rest of the productive sectors of the economy
Land transport and transport via pipelines	605.9	131.6	714.1	288.5	97.8	-194.1	-1,815.7	-127.3	-552.0	-765.2	-696.8	-527.2	-706.0	-877.2	-66.8	-50.4	-151.0	-4,691.6
Water transport	9.0	0.7	-118.0	-4.1	1.5	-10.8	-19.5	-7.3	-12.5	-28.9	-80.2	-35.4	-56.7	-33.2	-1.9	-1.0	-6.3	-404.7
Air transport	3.2	-0.6	-2,088.3	-158.2	-24.9	-86.0	-182.5	-83.2	-386.9	-256.7	-249.4	-229.0	-638.8	-345.7	-57.5	-11.8	-55.5	-4,851.9
Warehousing and support activities for transportation	564.5	79.4	1,312.3	437.0	114.7	-3.8	163.2	2.5	-5.8	-11.0	-20.8	-8.4	-14.5	-6.0	-0.2	5.2	0.6	2,608.7
Postal and courier activities	49.6	3.8	134.0	165.0	23.2	1.4	18.2	1.1	1.6	-0.1	-2.2	0.2	-0.7	4.4	0.3	1.8	0.6	402.3
Transportation and storage subsystem	1,232.1	214.9	-45.9	728.2	212.2	-293.4	-1,836.3	-214.2	-955.6	-1,061.9	-1,049.4	-799.8	-1,416.8	-1,257.7	-126.1	-56.2	-211.5	-6,937.3

Source: Prepared by the authors with data from INE (2017), and WIOD (2017).

Table 9. The exchange of GHG emissions (thousands of tons of $CO_{2\text{-eq}}$) between the transportation and storage subsystem and the rest of the sectors of the economy from a demand-side perspective. Spain, 2014

	Land transport and transport via pipelines	Water transport	Air transport	Warehousing and support activities for transportation	Postal and courier activities	Transportation and storage subsystem
Agriculture, forestry and fishing	-256.2	4.9	-8.2	24.8	0.6	-234.1
Mining and quarrying	-305.0	-1.1	-16.7	-3.4	-0.1	-326.4
Manufacturing	-6,784.4	4.0	-280.5	70.1	-4.6	-6,995.4
Electricity, gas, steam and air conditioning supply	430.1	67.8	164.4	399.4	13.7	1,075.5
Water supply; sewerage, waste management and remediation activities	-145.3	2.1	-12.0	10.4	0.4	-144.4
Construction	-1,535.3	-22.3	-186.3	-20.2	-5.5	-1,769.6
Wholesale and retail trade; repair of motor vehicles and motorcycles	-3,326.0	-57.6	-417.1	-60.8	-7.1	-3,868.6
Accommodation and food service activities	-1,354.5	-16.8	-124.1	-19.6	-4.2	-1,519.1
Information and communication	-420.6	-9.1	-89.3	-4.6	-5.1	-528.7
Financial and insurance activities	-91.7	-2.3	-209.8	-1.0	-1.8	-306.6
Real estate activities	-98.0	-2.8	-54.6	-1.6	-1.9	-158.9
Professional, scientific and technical activities	-176.8	-8.6	-90.8	-2.1	-1.9	-280.3
Administrative and support service activities	-186.0	-28.4	-304.8	-1.0	-0.9	-521.1
Public administration and defense; compulsory social security	-822.9	-17.6	-299.3	-3.0	-3.6	-1,146.4
Education	-149.1	-4.2	-37.5	-2.0	-1.1	-193.8
Human health and social work activities	-509.0	-11.1	-220.9	-8.9	-2.5	-752.4
Arts, entertainment and recreation and Other service activities	-332.6	-5.8	-223.4	-3.6	-1.1	-566.4
Total of the rest of the productive sectors of the economy	-16,063.5	-108.8	-2,410.7	373.0	-26.8	-18,236.8

Source: Prepared by the authors with data from INE (2017), and WIOD (2017).

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