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CO_2 emissions embodied in international trade: A multiregional Input-output model for Spain

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Abstract

As a result of globalization and free trade agreements, international trade is enormously growing and inevitably putting more pressure on the environment over the last few decades. This has drawn the attention of both environmentalist and economist in response to the ever growing concerns of climate change and urgent need of international action for its mitigation. In this work we aim at analyzing the implication of international trade in terms of CO_2 between Spain and its important partners using a multi-regional input-output (MRIO) model. A fully integrated 13 regions MRIO model is constructed to examine the pollution responsibility of Spain both from production and consumption perspectives. The empirical results show that Spain is a net importer of CO_2 emissions which is equivalent to 29% of its emission due to production. Even though the leading partner with regard to import values are countries such as Germany, France, Italy and Great Britain, the CO_2 embodied due to trade with China takes the largest share. This is mainly due to the importation of energy intensive products from China coupled with Chinese poor energy mix which is dominated by coal-power plant. The largest portion (67%) of the global imported CO_2 emissions is due to intermediate demand requirements by production sectors. Products such as Motor vehicles, chemicals, a variety of machineries and equipments, textile and leather products, construction materials are the key imports that drive the emissions

due to their production in the respective exporting countries. Being at its peak in 2005, the *Construction* sector is the most responsible activity behind both domestic and imported emissions.

1. Introduction

Concerns on economic and social consequences of climate change are continuing to grow as there are scientific evidences on its potential impact (Stern, Peters et al. 2006; IPCC 2007). The Kyoto Protocol has been an international measure adopted since 1997 in an attempt to mitigate the potential cost of climate change by committing ratified countries to reduce their GHG emissions 5% below 1990 levels in the first commitment period of 2008-2012. However, the Protocol is often criticized for creating carbon leakage in two ways. On one hand, as it only commits a subgroup of high income countries and it does not impose mandate on developing countries that are economically emerging and dominating the global greenhouse gas emissions, there is a shifting of energy and emission intensive goods to be produced in countries that are not ratified (*strong carbon leakage*). On the other hand, the responsibility to committing countries is only from production perspective, in a way that only emissions occurred within the national territories are considered. This totally ignores embodied emissions due to imports, which is referred as *weak carbon leakage*. While the international trade is enormously growing due to free trade agreements, its indubitable effect on the environment (Antweiler, Copeland et al. 2001; Machado, Schaeffer et al. 2001; Copeland and Taylor 2005) and the constraint of already existing global measures for climate change mitigation in capturing emissions associated with trade flow (Peters and Hertwich 2006b; Peters and Hertwich 2008; Weber, Peters et al. 2008; Lin and Sun 2010) have been speculated for long time both by environmental and economic analysts. In this paper we investigate the significance of international trade between Spain and its key trading partners with respect to CO_2 emissions embodiment. The model applied is based on input-output framework (Leontief 1941; Miller and Blair 2009). Environmental Input-Output analysis (EIO) is a top-down approach which accounts for resource consumption and emission release using generic data, IO tables that present the interrelationship of all industries in an economy (Leontief 1970). EIO has been used for a long while for estimating pollution embodiment in international trade. In early 1970s, Walter (1973) applied EIO models to examine the US product profile of exports and imports and their environmental profiles. But Fielke (1975) was the first who implemented the Leontief inverse in determining the US trade deficit in embodied energy. Since then a number of studies have been carried out using EIO approach to analyze the environmental implication of international trades. Most studies have implemented the single-regional input-output approach (SRIO), which is usually based on the very simplified assumption of the same technology both for imported and domestic products (Wyckoff and Roop, 1994; Kondo, Moriguchi *et al*., 1998; Lenzen, 1998; Machado, Schaeffer et al., 2001; Sánchez-Chóliz and Duarte, 2004). However, such assumption is far from the reality, particularly when there are high discrepancies both in technology and energy mixes between the trading partners, and therefore, it may be subjected to large errors as estimated by Lenzen et al. (2004) and Peters and Hertwich (2006a). Detail review on the use of SRIO models for international trade and emissions analysis can be found elsewhere (Wiedmann, Lenzen et al. 2007; Wiedmann 2009).

On the premises of avoiding errors due to same technology assumption in SRIO analysis, the development of multi-regional input-output (MRIO) approach emerged as the best alternative in environmental analysis associated with international trade. Unlike the SRIO, a complete MRIO model differentiates the production technology and then the related energy and environmental profile of imported goods and services from domestic ones. MRIO model fully integrates the domestic requirement matrix with imports, which is derived from international trade flows to simulate the interdependency of sectors in one region with all other sectors in trading partners. Hence, it allows seeing the entire supply chain of trades and emissions flows linked with goods and services imported to or exported from domestic region. Though the application of MRIO model dates back to mid of 19s, it was only recently that different works have emerged applying MRIO models in analyzing embodied emissions due to trade, to cite but a few: (Lenzen, Pade et al. 2004; Nijdam, Wilting et al. 2005; Peters and Hertwich 2006a; Peters and Hertwich 2006b; Peters and Hertwich 2006c; Guan and Hubacek 2007; Hertwich and Peters 2009; Wiedmann 2009)

Particular to the Spanish case, there are few studies which analyze the environmental implication of international trade between Spain and rest of the world. Sánchez-Chóliz and Duarte (2004) used a SRIO model to study the potential impact of international trade in the level of CO_2 emissions generated by the economy for the year 1995. The study concluded that the pollution imported through the intermediate and final demand requirement of the Spanish economy is off-set by the pollution exported to satisfy demands outside Spain, leaving the net trade balance of only 4237 thousand ton (1.3% of the total emissions produced in Spain). More recently, Cadarso et al. (2012) analyzed the impact of international trade and the shared responsibility in the Spanish economy for the period 2000 to 2005 using SRIO model. In this study, they defined a set of criteria to share the responsibility of sectors for their direct emissions due to production as well as due to their input requirements. The responsibility was shared to all sectors along the global production chain depending on the value added on each step.

With regard to MRIO model application, in what we know, a smaller number of studies have been conducted. Serrano and Dietzenbacher (2010) is the only work found by the authors in a peer-reviewed English-language journal. They developed a two regions (Spain and rest of the world) MRIO model to examine the emissions responsibility of the Spanish economy due to international trade taking into account both the net trade balance and responsibility balance concepts. They considered the years 1995 and 2000 and evaluated the effect for nine different types of gases. They concluded that both concepts (net trade balance and responsibility balance) yield the same results. Though not yet published in any peer-reviewed English-language journal, there are few studies that apply MRIO models to the Spanish case (Arce González, Cadarso Vecina et al. 2012; Navarro 2012; Navarro and Madrid 2012).

All the previous studies that analyze the effects of international trade on CO_2 emissions for Spain are either restricted to only two regions or interregional applications. However, a full MRIO model in the Spanish economy has not been yet constructed. Therefore there is a need to develop such a complete model that looks at a more broaden scope, from only two regions analysis to almost all trading partners. Applying 13 regions multi-directional MRIO model, our study aims at analyzing CO_2 emissions stimulated due to international trade flow of the Spanish economy. The MRIO model allows us to understand the link between demand on production of goods and services among the regions and their environmental consequences (in terms of CO_2 emissions). Therefore, this study addresses the following questions. How would the Spanish economy be seen in terms of trade balance based on its consumption and production structure? Which partners have the most significant contribution in emissions due to trading with Spain? What are the key products responsible for the most of emissions embodied in imports? How the results from MRIO model would be used in CO_2 emissions reduction strategies by policy makers?

The paper is structured as follows. Section 2 presents the methodological foundations of MRIO, data sources and the main assumption considered. The main results and their policy implications are discussed in section 3. Section 4 concludes.

2. Methodology and database

MRIO models are recognized to be a suitable tool to analyze emission embodied in trade both from consumption and production perspectives. They are able to trace the emissions linked with trades as a result of demand and supply interdependency of industries in domestic economy with foreign agents. In this section we present the construction of a 13 region environmental MRIO model for the Spanish economy based on Peters *et al.* (2009). Assuming that there are *n* regions, in which each region's production is classified into *m* sectors, the MRIO model can be formulated using the traditional IO framework as follows:

$$x = Ax + y \tag{1}$$

where *x* is a column vector of total output, $x = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix}$, in which each element x_i represents the sectoral total output vector of region *i*. *A* refers to the total inter-industry requirement matrix, which integrates both the domestic and imported inputs for each sector in each region. It can be described as, $A = \begin{bmatrix} A_{11} & \cdots & A_{1n} \\ \vdots & \ddots & \vdots \\ A_{n1} & \cdots & A_{nn} \end{bmatrix}$. Each A_{ij} in *A* is matrix of technology requirements on domestic production in region *i*, and A , mxm matrix, denotes the inter-industry technological requirement from region *i* to region *j*. The total inter-industry technology requirement of region *i* can be equated from the column sum of *A* as $\sum_{i=1}^{m} A_{ij}$. *y* is the vector of total final demands which comprises both demand on domestic production and exports. It can be represented as: $y = \begin{bmatrix} y_{11} + y_1^{ex} \\ y_{21} \\ \vdots \\ y_{n1} \end{bmatrix}$. y_{ii} is $mx1$ vector of final demand requirements on domestic production by domestic consumers and y_1^{ex} represents the demand by foreign consumers. y_{ij} stands for the final demand flow from region *i* to region *j*.

The above MRIO model can be written as:

$$x = (I - A)^{-1} y \tag{2}$$

where I is the identity matrix of the required size.

An environmental extension of the model in equation (2) can be expressed as:

$$\varepsilon = e'(I - A)^{-1} y \tag{3}$$

where ε is the total environmental emissions associated with the production of y output from all n regions. $e = \begin{bmatrix} e_1 \\ \vdots \\ e_n \end{bmatrix}$ is a vector of direct emission intensities, in which each element e_1 represents a vector of emission intensities of sectors in region i.

The MRIO model allows us to explicitly estimate the environmental impacts associated with domestic and import production for final consumption of goods and services. Emissions associated with the production of final demand in the domestic region (i = 1) can be calculated as:

$$\varepsilon_1 = e_1' A_{11} x_1 + e_1' y_{11} + e_1' \sum_{j \neq 1} (A_{1j} x_j + y_1^{ex}) \tag{4}$$

Where $\varepsilon_1 = e_1' A_{11} x_1 + e_1' y_{11}$ calculates emissions due to the production of outputs for domestic economy, both for intermediate and final demand requirements, and $e_1' \sum_{j \neq 1} (A_{1j} x_j + y_1^{ex})$ are emissions due domestic outputs production for both intermediate and final demand required by sectors and consumers abroad.

Similarly, the emissions due to imported goods and services from region $i \neq 1$ to region 1 are estimated as:

$$\varepsilon_i = e_i' [(I - A)]_{ii}^{-1} \left[\sum_{j \neq i} (A_{ij} x_j + y_{i1}) \right] \tag{5}$$

where $\sum_{j \neq i} (A_{ij} x_j + y_{i1})$ comprises both the direct exports as final demand (y_{i1}) and intermediate demand ($A_{i1} x_1$) pluse the indirect final demands ($\sum_{(l \neq i,1)} A_{il} x_l$). Here the indirect final demands refer to demands which undergo manufacturing process in any other regions before they are supplied to region *1* (eg. parts of machines manufactured in Japan and supplied to Italy where they are assembled and re-exported to Spain).

Production vs. consumption based emissions estimations

Generally there are two perspectives from which CO_2 emissions embodied in international trade could be estimated: the production and consumption perspectives. Production based emissions accounting, a method used in Kyoto protocol, considers CO_2 emissions that are emitted during the production activities of domestic economy, without regarding where the produced goods and services are consumed, i.e. domestically or abroad. It includes emissions associated with the production of goods and services which are produced and consumed domestically and those which are exported to other markets. However, it does not take into account the emissions that occurred outside the national territory during the production process of goods and services which are consumed by domestic consumers. The production emissions (ε_P) can be estimated using equation (4) as it comprises both the domestic and export demand.

Unlike the production based emissions accounting framework, the consumption based accounting is founded on the principle that consumers are responsible for all emissions associated with the production of goods and services which they are consuming regardless of the geographical location of production. It comprises emissions associated with all products which are produced and consumed domestically, products produced abroad but directly consumed within the economic boundary, and finally products which are produced abroad and supplied to industries as intermediate products and finally consumed domestically. This can be estimated as the sum of domestic emissions due to domestic final demand plus the imported emissions from all other regions to region 1:

$$\varepsilon_C = e_1' A_{11} x_1 + e_1' y_{11} + \varepsilon_{i \neq 1} \qquad (6)$$

The net emissions trade balance is a surplus or deficit emissions from the import and export, i.e it can be approximated from the difference between the consumption and production based emissions.

Data

The 13 region MRIO tables are constructed through linking both the IO tables and bilateral trade data provided by OECD. The OECD is one supplier of consistent and harmonized IO tables that can be used for international trade and environmental analysis. The latest OECD IO data set covers inter-industrial transactions of goods and services of 48 countries (all OECD countries but Iceland and 15 non-member countries). It provides both the domestic and import tables separately for the years 1995, 2000 and 2005. The IO tables and the bilateral trade data are in accordance with a harmonized industry structure of the ISIC[1] Rev. 3. The OECD bilateral trade database provides monetary values of imports and exports of goods and services broken down by industrial sectors and by end-use categories (Zhu, Yamano et al. 2011). Each off-diagonal block matrix A_{ij}, which represents the import requirements from region i to region j are derived from the bilateral trade data and total output vector of region j. The bilateral data from OECD is only for intermediate goods and services; it doesn't include imports directly consumed by individuals. Therefore, the vector of imported final goods, y_{ij} elements of total final demand vector y in equation (1), are derived based on the assumption that imported final demands are in the same proportion as imported intermediate demands from the trading partners using the following equation:[2]

$$y_{i1} = \widehat{M_{ij}} y_{import} \tag{7}$$

where y_{import} is imported final demand to Spain and M_{ij} is the share of import of each goods, which is calculated as:

$$\{M_{ij}\}_c = \frac{\{m_{ij}\}_c}{\{\Sigma_i m_{ij}\}_c} \tag{8}$$

where $\{m_{ij}\}_c$ is the total import of intermediate good c from region i to domestic region 1 (Spain).

The data on CO_2 emissions were obtained from the World Input-Output Database (WIOD). WIOD is a project funded by the European Commissions, Research Directorate General as part of the 7th Framework Programme. It provides a set of harmonized supply and use tables and extensive satellite accounts for 27 EU countries and 13 non-EU major world countries for the period from 1995 to 2009 (WIOD, 2012). The CO_2 emissions data of WIOD includes both energy related and non-energy emissions and they are separately reported, which allows to simulate the environmental

[1] ISIC stands for International Standard Industrial Classification of all Economic Activities.

[2] The symbol ^ accompanying a vector denotes the diagonalisation of the corresponding vector.

implication of switching from one energy source to another (from gas to coal in energy sectors). In line with the OECD IO tables, the CO_2 emissions data of WIOD are classified based on ISIC Rev. 3. The CO_2 data are used to derive the emission intensity vector in equation (3).

A multidirectional industry-by-industry MRIO model of the Spanish economy with its 12 important trading partners is constructed for the year 2005. Figure 1 illustrates the import and export structure of Spain with its trade partners for the year 2005. According to the data from INE (2008), around 66% of the total imported goods are from the EU and 76% of the total exports are to the EU. Germany (DE), France (FR), Great Britain (GB), Italy (IT), Netherlands (NL), Portugal (PT) and Belgium (BE) are among the most dominant partners of Spain both in imports and exports. All together represent around 55% and 63% of the total imports and exports, respectively. The Asian market represents 17% of imports and 7% of exports of the Spanish international trade. China (CN) and Japan (JP) are important partners of Spain, which together account for 8% of the total Spanish imports. Around 9% of the total imports and 10% of exports from Spain are represented by America. United States (US) and Brazil (BR) are among the important partners.

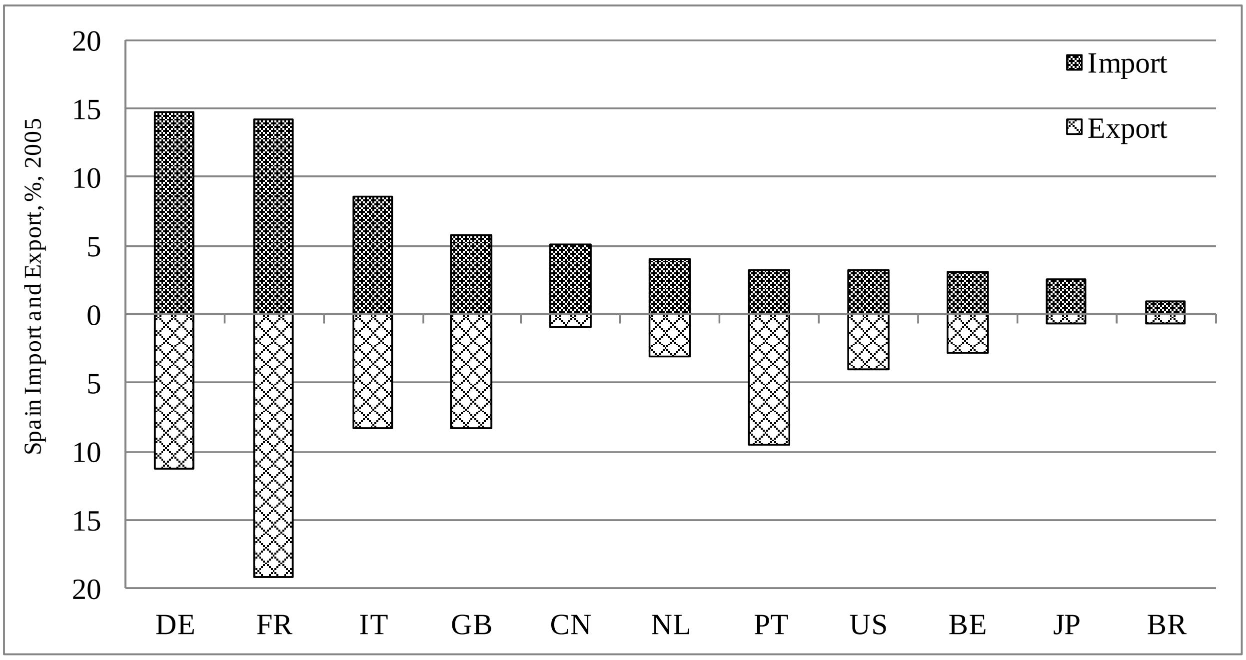

Figure 1 Import and export structure of Spain with its important trading partners (own elaboration based on data from INE data)

RAS method

In linking IO domestic table with the bilateral trade data, we have used the RAS procedure, an iterative method that updates IO tables. Due to unavoidable asymmetry problems, which may result from different trade systems definition, characterization of specific goods or transaction types, different valuation of imports and exports between countries, consideration of transit trades, re-exports and re-imports, and so on, there are some discrepancies between the values of imported goods by a given country and the corresponding exports from the other trade partner. As a result the total intermediate output of each sector does not match with the sum of its domestic and import outputs. Therefore, a balancing of the total intermediate requirement matrix (Z) which is derived from the OECD domestic IO tables and bilateral trade data is required. Assuming that Z* is the unknown target matrix, with the same dimension and structure of Z, but only the column and row sum are known (from the total intermediate outputs and inputs of each country), the balanced matrix Z**, which has both similar dimensional and structural property of Z, but the same margin as Z* is obtained from the implementation of RAS method. RAS approach uses the margins of Z* and the structure of Z to bi-proportionally adjust Z matrix and generate a balanced Z** in such a way that it reflects both the property of Z with approximately similar margins of Z* (Miller and Blair, 2009).

3. Results and discussion

This section presents the main findings of the MRIO analysis. When the production base accounting framework is considered, a total of 292.5 Mton of CO_2 emissions occurred on the Spanish territory, 73.5% of which are emissions associated with the production of final demanded for domestic consumer and the 26.5% is due to demand by foreign market. Figure 2 shows the contribution of each sector to the total domestic CO_2 emissions linked with the production of both domestic and export final demand. When the sectoral emissions intensities are analyzed, *Electricity, gas and water supply*; *Other non-metallic mineral*; and *Coke, refined petroleum products and nuclear fuel* are the most important sectors that together are responsible for around 68% of the total direct emissions occurred in Spain to provide other sectors energy and materials to produce final demand for both domestic and export consumptions. In line with Alcántara and Padilla (2006), these are the key sectors that concentrate most of the emissions caused from the production perspective of the Spanish economy. As shown in the Figure 2 the emission intensity of the energy sector is by far higher than other key sectors. This shows how the outputs from this sector have great impact on the total CO_2 emissions generated in Spain. Emissions reduction measures in the sector such as increasing the share of renewable energy source in the national energy production mix, increasing the efficiency of energy generating plant by introducing more advanced technologies, switching from coal-powered turbine to natural gas or from single-cycle turbine to combined-cycle turbine and so on, will contribute to a decrease of total Spanish domestic emissions.

Different figure emerges when instead of emission intensities the total emissions, as a sum of direct and indirect, are considered. The total emissions express the emissions generated by the whole productive system in response to the production of final demand by the corresponding sector. When analyzed from the domestic demand side, the emissions concentrated in the key sectors are distributed among different sectors according to the final demand on each activity and their dependence on the key sectors to produce the demanded outputs. In this regard the construction sector of the Spanish economy is the most important, which relies on the other sectors in carrying out its activities. This implies that the sector buys pollution from other sectors through its input requirements to produce its final domestic demand for consumption. During at its peak, in 2005, the production of energy and material needed to satisfy the demand from the construction sector alone generated around 28% of the total emissions in Spain. Despite its burst after the crisis, from 2008, the sector is thought to be the significant contributor of the Spanish economy and was the most important factor linked with the economic boom in the country for almost a decade. Its high contribution to the total CO_2 emissions is resulted from its tremendous economic growth. Next to Construction sector are Electricity, gas and water supply; Wholesale and retail trade, repairs; Hotels and restaurants; and Food products, beverages and tobacco, which together contribute to 37% of the total indirect CO2 emissions. When analyzed from the exports demand side, *Transport and storage*, *Other non-metallic mineral* and *Chemical and chemical products* show important domestic pollution generated to supply exports.

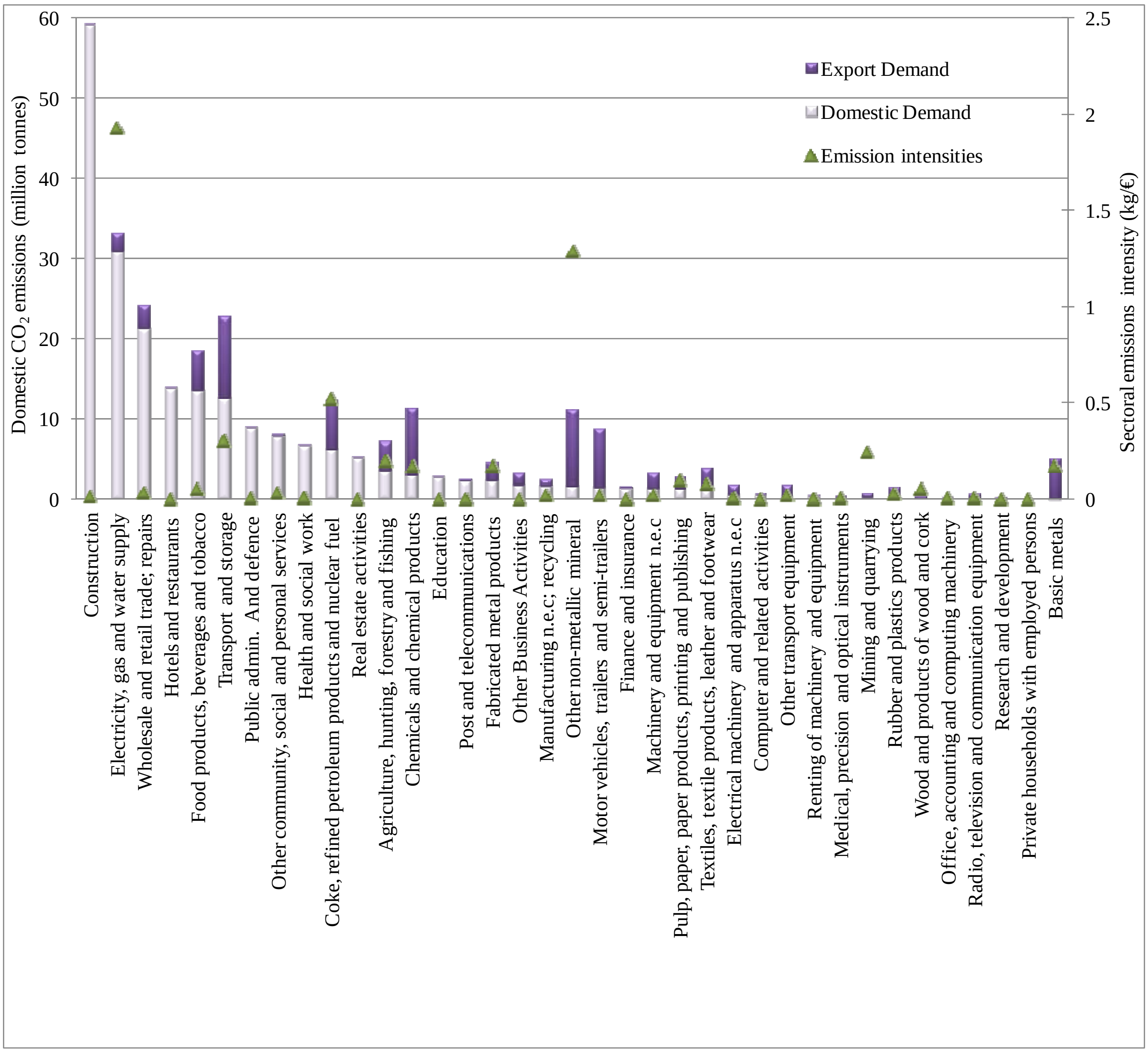

Figure 2 CO_2 emissions produced in Spain to supply both domestic and export demand, 2005

The consumption based emissions, all the emissions which are directly or indirectly produced elsewhere in order to provide goods and services consumed in Spain, are presented in Figure 3. According to the analysis, the Spanish economy is responsible for 378 Mton CO_2 emissions. The difference between the consumption and production based emissions reveals that Spain was a net importer of emissions with a trade balance of 85.4 Mton of CO_2 emissions, which is approximately 29% of its production emissions. This reflects the significance of international trade in the context of CO_2 emissions and its implication for policy considerations. As can be seen from figure 3, the largest portion of the emissions occurred in Spain is mainly to produce final goods or services for domestic consumption.

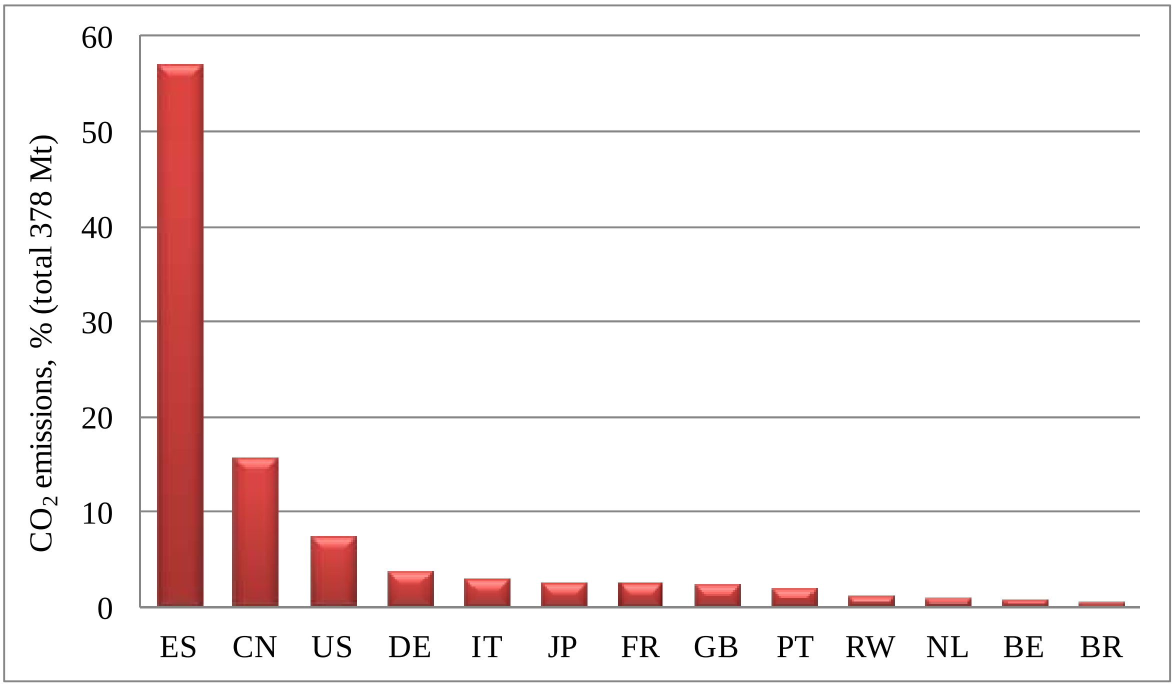

Figure 3 Consumption based emission by country where goods and services are produced, 2005

An important amount of CO_2 is released in China due to its export to Spain, of which 45% is due the supply of intermediate goods for the Spanish sectors and 40% is due to direct supply of final goods to consumers in Spain. The remaining 15% are due to the supply of intermediate goods for the most important trading partners of Spain, in order for them to produce export for Spain.

CO_2 emissions occurred in US due to consumption in Spain is also comparatively high. 52% of these emissions are due to supply of intermediate inputs for Spanish sectors to produce output for domestic consumption. Around 33% percent of the emissions are due to the production of final goods which are directly consumed by the Spanish consumers. The rest is due to import requirements of other regions to produce both intermediate and final goods for the Spanish economy. Though not as high as US and China, considerable amounts of CO_2 are also generated in Germany, France, UK, Italy and Japan.

A closer look to the import structure and emissions embodied in imported goods gives more insight on the key trading partners and their contribution to the global emissions derived from their exports to Spain. Figure 4 presents the CO_2 emissions embodied in imported goods by country of origin. As shown, emissions associated with imported goods from China dominate to a great extent, which contributes to 36% of the total emissions due to imports. It is followed by US that accounts for 17%. Around 38% of the total embodied emissions are due to imports from the EU. When analyzed by end-use, the emissions due to the production of intermediate products that are reprocessed by domestic sectors before being supplied to domestic final demand account for 41% of total emissions. Imported goods that are directly supplied to domestic final consumer represent 33%. Additionally, the Spanish economy re-exports around 26% of the total imported emissions to other countries.

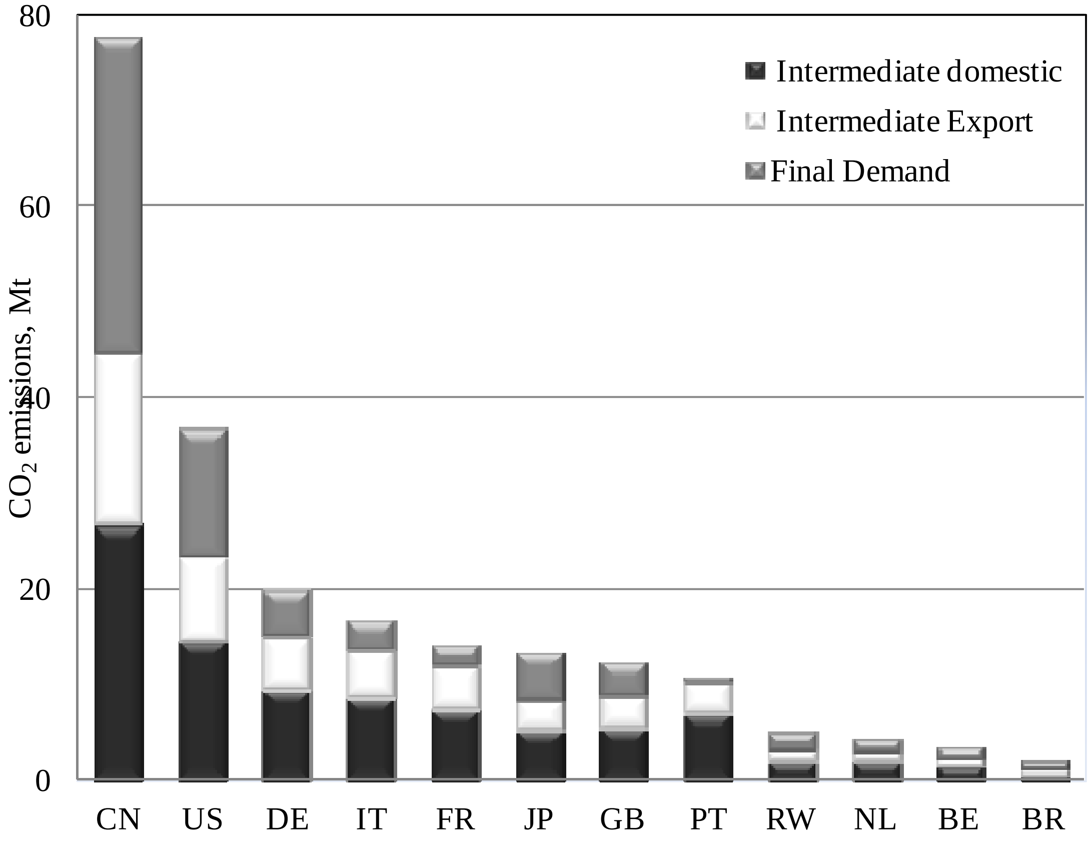

Figure 4 CO_2 emissions embodied in imported goods and services, 2005

The imported goods and services that dominate the total imported emissions from the selected countries are presented in Figure 5. As can be seen, sectors such as Motor vehicles, chemicals, a variety of machineries and equipments, textile and leather products, construction materials are the key imports that drive the emissions due to their production in the respective exporting countries.

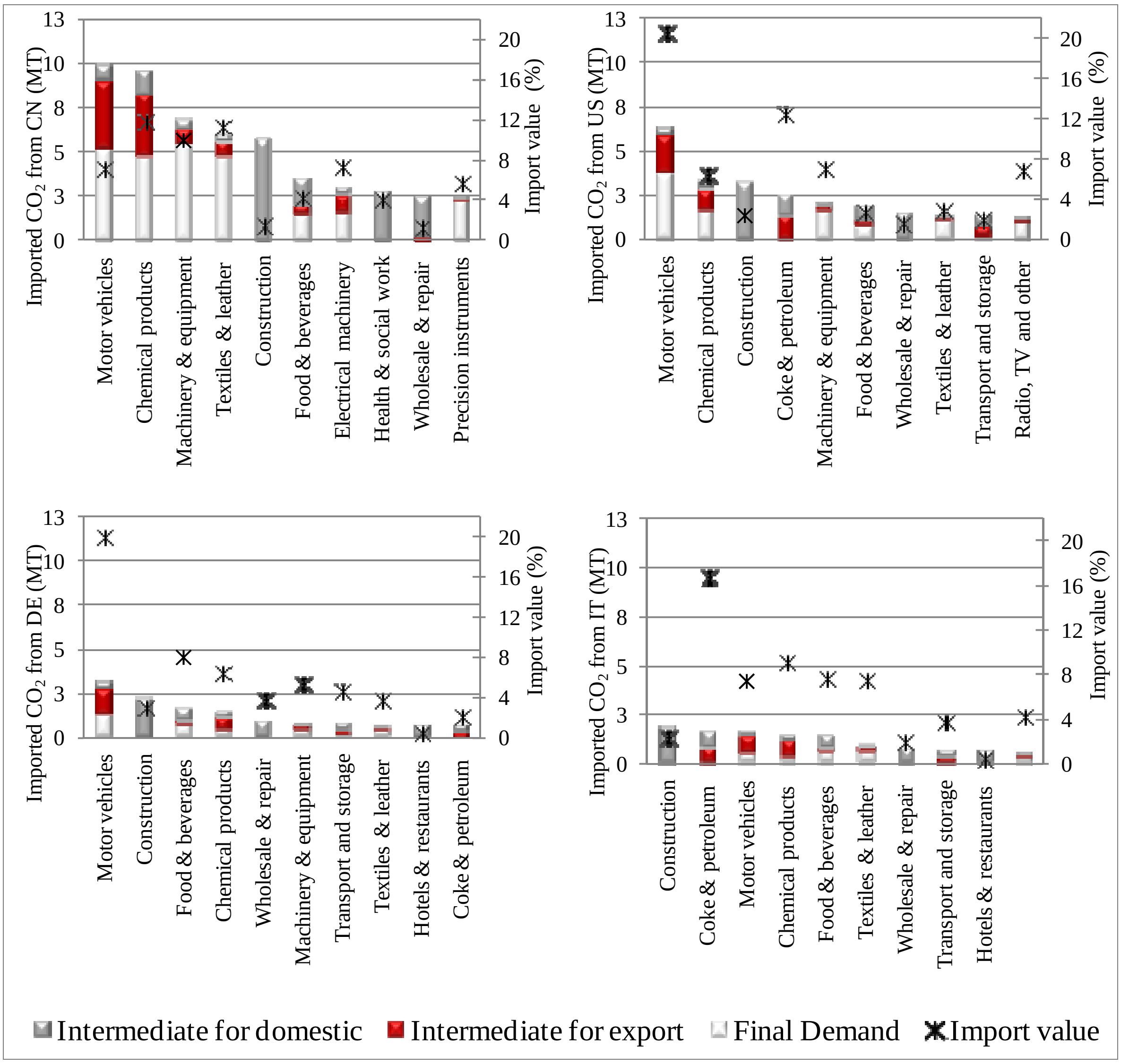

Figure 5 CO_2 emissions and import values of top 10 sectors from selected countries, 2005

Some of these products are directly supplied as final goods to be consumed directly by the consumers, while others are imported as raw materials or intermediate products to undergo the Spanish production system before they are supplied to final consumers both for domestic and export destinations. As can be seen, a considerable amount of emissions from the importation of motor vehicles and chemicals are re-exported to other countries. Additionally, emissions from the import of building and construction sector are finally consumed by the Spanish economy.

Figure 5 also illustrates that most goods and services imported from China have relatively low import value but high CO_2 emissions compared with other countries such as Germany, Italy and US. This could be explained as follows. Low price products might be resulted from the cheap labor market in China. Obviously, this could be one of the main reasons, but not the only one for having such a big divergence in import values and the associated emissions; there are also other facts behind. The relatively poor energy mix of the Chinese economy plays a crucial role in this regard. Coal covers much of the demand in Chinese energy production and the share of other less CO_2 intensive energy sources is limited, as a result the CO_2 intensity of the Chinese energy sectors were noticeably high, especially compared with countries like Norway where hydroelectricity comprises the largest share (Peters and Hertwich, 2006a). This makes the Chinese energy sector to be the largest responsible sector which accounts for around 54% of the total direct emissions embodied in goods and services exported to Spain. The predominance of energy intensive sectors in China, which may lead to high energy demand, also highlights this fact. It is obvious that on one or another way, emissions associated with the production of goods and services from a given country are dependent on the national energy mix and the production technology. Most energy intensive product from counties like Germany, France, where the relative share of renewable energy source in the national mix is high, generally show less emissions as they incorporate low CO_2 per US$ output as can be referred from Table 1. As expected, the emissions intensities of most of Chinese sectors exhibit huge differences compared with Spain, unlike sectors in other trading partners. More importantly, the energy sectors in China exhibit a considerable variation compared with the corresponding sector in Spain. Sectors which heavily relay on energy sectors also disclose high intensities, as presented in Table 1. Therefore, the import and emissions profile of different products illustrated in Figure 5 reveals the fact that Spain is importing more energy intensive products from China than from other trading partners.

Figure 5 also demonstrates how the developed world avoids emissions by shifting the production of energy and emissions intensive products to economically emerging countries such as China. A good example for this could be the emissions associated with motor vehicles imports. Representing only 7% of the total import value, 2,255 M$, vehicles from China are responsible for around 10 Mt of embodied CO_2 emissions, whereas by far larger volume of the same product group imported from Germany shows quite smaller emissions values. Germany is one of the leading exporters of motor vehicles to Spain, which satisfies around 28% of the Spanish total demand on motor vehicles. Despite the fact that large value of motor vehicles are imported from Germany, small amount of direct emissions are associated with them. This implies that the Germany economy imports energy intensive products such as different parts of vehicles for example from China, which are assembled and shipped to Spain.

Table 1 Emission intensity, as the amount of CO_2 emitted to produce a unit output for final demand, kg per $

Industry	ES	BE	BR	CN	DE	FR	GB	IT	JP	NL	PT	US	RW
Agriculture, hunting, forestry and fishing	0.44	0.66	0.52	1.01	0.41	0.38	0.45	0.36	0.37	0.76	0.41	0.61	1.31
Mining and quarrying	0.73	0.58	0.61	2.69	0.86	0.57	0.51	0.44	2.64	0.46	0.97	0.61	0.88
Food products, beverages and tobacco	0.47	0.46	0.41	1.23	0.37	0.37	0.39	0.44	0.31	0.48	0.43	0.54	1.10
Textiles, textile products, leather and footwear	0.46	0.46	0.34	1.47	0.44	0.31	0.41	0.45	0.47	0.43	0.44	0.55	0.89
Wood and products of wood and cork	0.43	0.40	0.32	1.69	0.36	0.29	0.46	0.37	0.46	0.33	0.44	0.53	1.11
Pulp, paper, paper products, printing and publishing	0.47	0.47	0.43	1.91	0.35	0.32	0.33	0.45	0.35	0.34	0.53	0.42	1.00
Coke, refined petroleum products and nuclear fuel	1.15	0.80	0.79	2.50	0.95	0.95	1.13	1.16	0.98	1.10	1.21	1.44	2.55
Chemicals and chemical products	0.76	0.79	0.72	2.63	0.52	0.54	0.57	0.76	0.82	0.89	1.33	0.79	2.18
Rubber and plastics products	0.51	0.44	0.50	3.04	0.39	0.40	0.54	0.52	0.46	0.50	0.60	0.56	1.06
Other non-metallic mineral products	1.89	1.81	1.83	9.24	1.30	1.19	1.08	1.46	1.67	0.77	2.35	1.76	2.93
Basic metals	0.72	0.97	0.91	3.46	0.83	0.64	0.97	0.72	1.15	0.80	0.63	0.91	2.70
Fabricated metal products except machinery and equipment	0.63	0.83	0.85	3.45	0.66	0.52	0.75	0.51	0.82	0.72	0.48	0.77	1.60
Machinery and equipment n.e.c	0.42	0.39	0.48	2.01	0.28	0.28	0.41	0.39	0.37	0.33	0.43	0.48	0.95
Office, accounting and computing machinery	0.35	0.29	0.33	1.46	0.23	0.28	0.30	0.33	0.48	0.43	0.26	0.42	0.79
Electrical machinery and apparatus n.e.c	0.54	0.38	0.44	1.69	0.29	0.33	0.41	0.41	0.46	0.48	0.42	0.42	0.90
Radio, television and communication equipment	0.39	0.27	0.40	1.30	0.22	0.25	0.33	0.26	0.36	0.36	0.29	0.22	0.74
Medical, precision and optical instruments	0.33	0.32	0.33	1.42	0.21	0.23	0.25	0.35	0.37	0.26	0.28	0.22	0.61
Motor vehicles, trailers and semi-trailers	0.48	0.47	0.45	1.80	0.35	0.37	0.48	0.46	0.38	0.40	0.43	0.55	0.71

Other transport equipment	0.42	0.34	0.39	1.77	0.31	0.29	0.41	0.42	0.44	0.34	0.32	0.38	0.80
Manufacturing n.e.c; recycling	0.40	0.48	0.35	1.34	0.27	0.42	0.41	0.35	0.49	0.27	0.39	0.34	1.07
Electricity, gas and water supply	2.74	2.13	0.60	12.38	3.36	0.88	2.47	2.16	2.09	2.77	3.09	5.85	8.07
Construction	0.42	0.43	0.39	2.38	0.31	0.27	0.25	0.33	0.40	0.32	0.63	0.36	0.78
Wholesale and retail trade; repairs	0.26	0.27	0.15	0.85	0.18	0.14	0.21	0.24	0.14	0.20	0.26	0.22	0.52
Hotels and restaurants	0.18	0.28	0.25	1.46	0.21	0.19	0.21	0.25	0.26	0.31	0.31	0.40	0.77
Transport and storage	0.65	0.72	0.80	1.95	0.53	0.47	0.72	0.47	0.58	0.80	0.81	0.98	1.21
Post and telecommunications	0.22	0.21	0.15	1.12	0.19	0.10	0.17	0.17	0.11	0.12	0.13	0.22	0.38
Finance and insurance	0.08	0.11	0.07	0.64	0.08	0.07	0.10	0.07	0.07	0.08	0.08	0.11	0.30
Real estate activities	0.08	0.09	0.02	0.44	0.06	0.03	0.05	0.04	0.04	0.07	0.08	0.24	1.39
Renting of machinery and equipment	0.19	0.21	0.07	0.08	0.05	0.09	0.15	0.25	0.11	0.16	0.14	0.25	0.42
Computer and related activities	0.11	0.17	0.07	0.08	0.08	0.08	0.11	0.17	0.10	0.12	0.16	0.19	0.29
Research and development	0.19	0.24	0.07	1.27	0.16	0.17	0.16	0.16	0.20	0.22	0.14	0.22	0.59
Other Business Activities	0.18	0.18	0.17	1.20	0.09	0.09	0.11	0.17	0.11	0.16	0.18	0.19	0.49
Public admin. and defence; compulsory social security	0.16	0.11	0.14	0.92	0.12	0.10	0.18	0.12	0.25	0.19	0.22	0.37	0.40
Education	0.07	0.07	0.13	1.22	0.11	0.10	0.10	0.04	0.12	0.11	0.09	0.26	0.44
Health and social work	0.17	0.17	0.23	1.72	0.13	0.10	0.17	0.14	0.25	0.14	0.32	0.25	0.53
Other community, social and personal services	0.25	0.30	0.33	1.22	0.14	0.24	0.16	0.24	0.26	0.47	0.34	0.24	0.66
Private households with employed persons	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.22	0.00	0.00	0.00	0.19

4. Conclusions

In this study we analyze the CO_2 emissions generated as a result of international trade between Spain and its trading partners. For this purpose, we developed a 13 region multi-directional MRIO model that enables us to examine the pollution responsibility of Spain as the net emissions trade balance, by differentiating between the emissions resulted from domestic consumption and production.

The emissions balance shows that Spain is a net importer of emissions, which is estimated to be 29% of its domestic emissions. This implies that a large amount of emissions are embodied in Spanish imports than the emissions embodied in its exports. In line with other related studies in Spain, the findings in the paper reveal that the trade between Spain and China take the largest share of CO_2 emissions. The poor energy production mix of Chinese economy could also highlight the emissions embodied in each product that are imported from China, despite the most important partners in terms of values are Germany, France, Italy and Great Britain. The embodied emission from countries with similar production structure and environmental profile are mainly driven by the total volumes imported. Regarding to their import and export flow, the largest portion of embodied emissions is due to the demand by production sectors, which accounts to the 67% to the total imported emissions. The Construction sector is the most responsible sector behind these emissions. The year 2005 was the peak for the remarkable growth of this sector in Spain. Deliveries of the service from the sector demands large amount of input materials and, accordingly, emissions. Emissions from the import of large values of products such as motor vehicles and spare parts, machineries and equipments, textile and textile products, leather and footwear, chemical products are also considerably high. High value but relatively low emission intensive products such as computers, office machineries and other electronic devices have very little contribution.

The international trade between Spain and rest of the world has important policy implications from a global perspective. The following policy implication could be drawn from the empirical results obtained. As it is clearly observed, countries that are economically highly emerging and dominating the global trade but not legally bounded under international emissions reduction agreements are the main derivers of embodied emissions due to their looser environmental regulation. This has been a reason for many developed and major contributor to global GHG emissions to refuse to ratify the Kyoto Protocol; the US and Canada could be a good example. They consider that such unbalanced treatment favours the production of goods in non-Annex I countries while unfairly affects the competitiveness of producers that face restrictions on their emissions. Such inequity issue of international CO_2 regulations could be avoided by implementing boarder taxes. Boarder taxes or border adjustments taxes are levies imposed on imported products from countries that are not yet involved in any international CO_2 reduction protocols. Environmental tax or tradable permit price are believed by many economists and environmentalists to be the most effective and efficient way to reduce human related CO_2 emissions. They provide incentives to polluting industries for reducing their emissions through market signals. As the EU already established permit price on "cap and trade" principle with the target of reducing GHG emissions to at least 20% below the 1990 level by the year 2020, most companies are under this restriction. The boarder tax on CO_2 therefore charges companies that import goods and services from countries outside the EU the same price as current CO_2 price based on their life cycle emissions embodied in their production. The MRIO approach presented here could be used as a useful tool to analyze the global emissions flow linked with imports and exports between Spain and its important trade partners and the key sectors or product groups that are behind the embodied emissions. Such analysis could allow assessing the environmental profile of imported goods in a move to establish a general emissions taxation system.

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