Regional Material Flow Accounting and Environmental Pressures in Spain: exploring the Role of Physical Trade at the Regional Scale.

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Abstract. Within Economy-Wide Material Flow Accounting, the Physical Trade Balances have been widely acknowledged as a powerful tool to evaluate the allocation of environmental burdens through trade across nations. This article approaches this issue from a subnational perspective. The International (In) and Interregional (Ir) Physical Trade Balances (PTB) of seventeen Spanish regions are calculated for twelve broad types of commodities between 1996-2010. Results show that: 1) interregional trade is as relevant as international trade in terms of total volume traded. 2) The composition of the IrPTB and InPTB are qualitatively dissimilar. 3) Specialization patterns are also found at the regional scale. Our database covers only direct flows; therefore these results must be cautiously evaluated since they are just the first step in the understanding of the subnational patterns of trade. Further debate and research must include estimates on indirect flows and/or raw material equivalents in order to expand the analytical insight of this study.

1. Introduction

Economy-wide material flow analysis (EW-MFA) has been acknowledged as a key assessment tool for examining the material exchanges between human activity and the environment through a set of consistent and comparable indicators (Fischer-Kowalski et al., 2011). Some of the current environmental challenges related to resource depletion or sinks exhaustion can be framed, quantified and analyzed from an EW-MFA perspective, complementing the understanding of the environmental dimension associated with economic development. Among them, the environmental dimension of international trade (InT) has been intensely addressed (Neumayer, 2001; Muradian and Martínez Alier, 2001; Giljum and Eisenmenger, 2004; Muñoz et al., 2009).

EW-MFA provides the analyst with a biophysical perspective that further expand the insights on unequal ecological trade (Muradian and Martinez Alier, 2001), environmental burden shifting (Schütz et al, 2004), and North-South relationships (Giljum and Eisenmerger, 2004) among other issues.

EW-MFA has been mostly applied to nations and so the works focused on trade have dealt with international exchanges through the analysis of one of the core indicators, the so-called Physical Trade balances (Eurostat, 2001). Some works have successfully applied EW-MFA at the subnational and urban scale (Kovanda et al, 2009; Niza et al., 2009, Carpintero, 2015). However, lack of data is a significant drawback when the regional scale is addressed (Hammer et al, 2003). Consequently, the number of studies focused on regional MFAs is limited as compared to national studies, and practically inexistent on the subnational patterns of physical trade (Li and Zhang, 2013).

This paper’s objective is to explore and compare the physical size and patterns of interregional trade (IrT) and InT at the regional scale and its implications in terms of qualitative and quantitative environmental pressures. This is an innovative approach to environmental burden displacement through EW-MFA since to the author’s knowledge it had not been previously done in a systematic way for the whole of the regions of a country and for a reasonable time span. To this aim, the following section describes the most relevant methodological points. Next, results are showed and subsequently discussed. Finally, some concluding remarks are drawn.

2. Methodology and data

EW-MFA has reached a significant level of standardization since the publication of the first guidelines by Eurostat (2001), which harmonized the gathering and processing of data resulting in a consistent accounting framework. A database was compiled (Carpintero, 2015) following the most updated version of these guidelines (Eurostat, 2013). Based on this framework, a set of standard EW-MFA indicators was calculated for each of the seventeen Autonomous Communities (ACs) comprising Spain, of which we will focus on the physical trade balances (PTB) in in this paper. PTB is calculated by subtracting exports to imports contrarily to monetary accounts (i.e. positive values of the PTB implies net physical imports). The innovative aspect of this database is that trade flows have been normalized into twelve broad material categories[1] and next split into interregional (Ir) and international (In) exchanges. Thus IrPTB and InPTB can be independently calculated for each region.

IrT includes freight transport by road, domestic coastwise traffic, pipelines, railway trade and cargo planes. Our database accounts for the first three categories, which include more than 90% of total interregional trade following the reports of the Spanish National Statistics Institute. Data on trade by railway and cargo planes was not included for reporting because the data sources did not meet the quality criteria regarding time spans and commodity disaggregation for normalization. International trade is readily published at the ACs level following an appropriate level of disaggregation for MFA purposes.

System boundaries were set by balancing both statistical availability and its analytical relevance. NUTS2[2] regions accomplished both because on one hand statistics are reported directly at this scale except in the case of trade by pipeline, which was modeled (see Sastre et al, 2015). On the other hand, these boundaries coincide with the main Spanish administrative organizations (ACs), in turn provided with a high degree of political independence (i.e. for environmental policies) according to the Spanish Constitution[3]

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[1] These categories are biomass (raw and semi-manufactured), metallic minerals (raw and semi-manufactured), non-metallic minerals (raw and semi-manufactured), energy carriers (raw and semi-manufactured), and finished products.

[2] NUTS (Nomenclature of Territorial units for Statistics) refer to the geocode standard for referencing the subdivision of European Union members for statistical purposes (similarly to the Combined Statistical Areas of the United States). NUTS are hierarchically organized into 3 nested levels (NUTS1, NUTS2, NUTS3). Spain is divided into 19 NUTS2 regions of which 17 are known as autonomous communities and 2 as Autonomous Cities. The autonomous cities are considered in this study. See Notes at the end of the text.

Detailed information on data sources, coefficients and estimations can be found in Carpintero et al. (2015) and Sastre et al. (2015). General issues of compiling an EW-MFA database at the regional scale have been addressed elsewhere (Hammer et al, 2003).

The relevance of the upstream requirements of trade as well as indirect flows is crucial for the study of the environmental dimension of trade (Giljum, 2004; Dittrich et al, 2012). The focus of this work is on direct flows though. Given the disaggregation level of materials, key flows in terms of ecological rucksacks and raw material equivalents (Carpintero, 2005; Schoer et al, 2012) are separately analyzed. Further debate is needed within the EW-MFA community in order to consistently apply the coefficients for the calculation of indirect flows and raw material equivalents at the regional scale. Nevertheless, the main patterns can be still approached through direct flows (Perez-Rincon, 2006).

3. Results

3.1 The Physical Size of the Interregional and International Trade in Spain

The results for the material flows of Spain must be placed in the context of an economic growth from the beginning of the nineties to 2007 and subsequent recession linked to global financial trends and the strong performance of the domestic construction sector. Figure 1 illustrates the general increase of material flows throughout the Spanish economy between 1996 and 2007. Domestic Extraction rose from 446 Mt to 770 Mt, the total volume of international exchanges (i.e. imports plus exports) grew 50% whereas interregional trade more than doubled. In absolute terms, IrT became as relevant as InT and its growth rate was greater than for InT, DE and GDP. This means that during the period of economic growth, the Spanish regions intensified their exchanges with other regions more than extraction or international trade. This can be explained by the leading role of the construction sector dynamics and the limited mobility of construction minerals.

Despite their comparable relevance in quantitative terms, the structure of IrT and InT are quite dissimilar. Figure 2 displays the accumulated volumes of IrT and InT for five broad categories. InT is far more relevant for the supply of metallic minerals and fossil fuels, which is related to the poor domestic endowment of these resources in Spain. On the other hand, finished products and non-metallic minerals are traded mostly within the Spanish borders. Biomass in turn presents a more balanced situation. The relevance of taking IrT and InT separately is particularly convenient for the case of construction minerals. Given their abundance these minerals are relatively cheap, and therefore its mobility is limited to a few kilometers: the volume of non-metallic minerals in the interregional context was 25% of total trade while it did not surpass 10% of international physical trade. Thus, a separate analysis of the IrT and the InT permits the environmental pressures exerted by construction activities to be captured.

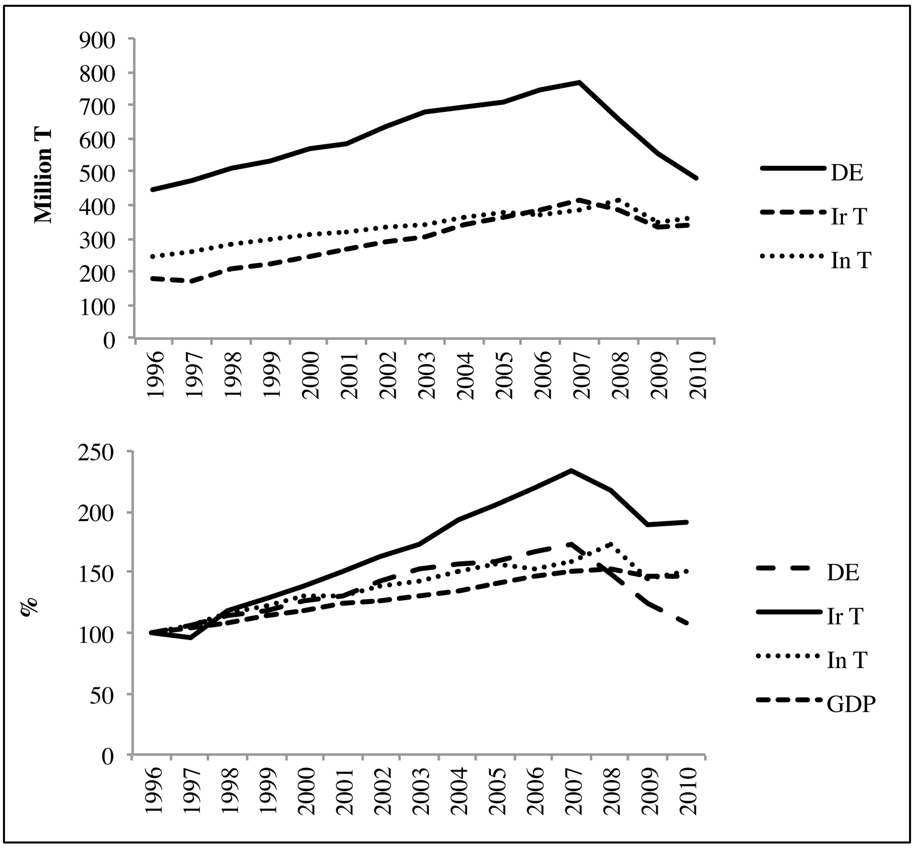

Fig 1. Absolute and relative trend of Domestic Extraction, Trade and GDP in Spain, 1996-2010. DE:Domestic Extraction,; IrT: Volume (imports+exports) of Interregional trade; InT: Volume (imports+exports) of International trade.

3.2 IrPTB and InPTB of the Spanish Regions.

At the national scale, Spain has significantly changed its physical patterns of trade in the last century (Infante-Amate et al., 2015), shifting from a biomass-based metabolism to an economy of "*appropriation*" of foreign natural resources (Carpintero, 2005). From the early sixties, the national PTB reached positive values (i.e. net importer) mostly due to the imports of fossil fuels (for a detailed review on the physical patterns of trade of the Spanish economy, see Carpintero (2005)).

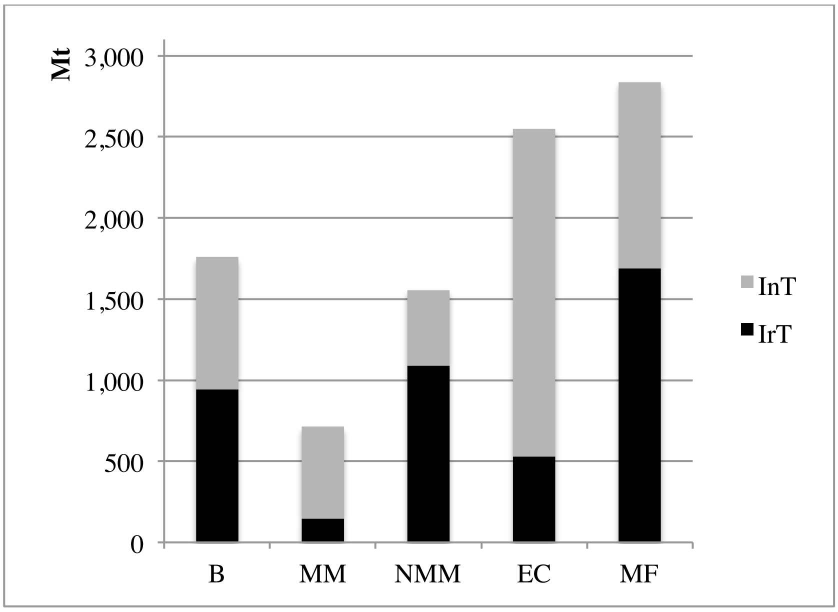

Figure 2. Structure of total volume of the Interregional and International Trade. Accumulated 1996-2010. Notes: B: Biomass; MM: Metallic minerals; NMM: Non-Metallic Minerals; EC: Energy Carriers; MF: Manufactured products; InT: Interntaional Trade; IrT Interregional Trade.

At the regional scale, the same pattern can be observed (table 1). Castile La Mancha and Extremadura are the only net exporters in the international context. Asturias and Murcia show the highest values in the InPTB while Madrid and the Basque Country lead the ranking in PTB per area. Catalonia and Andalusia present the greatest volumes of international trade across regions. Only these two regions along with Asturias and the Canary islands show greater values of InT as compared to IrT and it is strongly related to the Spanish dependency on foreign fossil fuels, as it will be shown later.

In spite of the openness toward international markets, most of the ACs still show greater volumes of IrT in physical terms. Moreover, IrPTB is negative in six of the seventeen ACs, which implies that IrT patterns are more heterogeneous than InT on the subnational level. The main Ir net exporters in per capita terms are Murcia and Castile La Mancha. Murcia is also the main net exporter regarding IrPTB per area, this time followed by the Basque Country. The greater volumes of IrT are mobilized in Madrid and Valencia.

Table 1. Interregional and International Trade in Spain at the regional level.
Note: M: Imports; X Exports; PTB: Physical Trade Balance. M,X, PTB and PTB per km^2 refers to accumulated values from 1996 to 2010. PTB per capita refers to the median value for the period.

	Interregional Trade						International Trade					
	M	X	M+X	PTB	PTB	PTB	M	X	M+X	PTB	PTB	PTB
Regions	Mt	Mt	Mt	Mt	t/cap	t/km^2	Mt	Mt	Mt	Mt	t/cap	t/km^2
Andalusia	331	453	785	-122	-1.2	-93	657	285	941	372	3.2	283
Aragon	303	269	572	34	1.5	47	64	40	104	24	1.4	33
Asturias	128	146	274	-18	-1.0	-114	262	55	317	208	13.3	1307
Balearic I	52	5	57	48	3.3	635	30	6	36	23	1.7	314
Canary I	49	19	67	30	1.0	269	130	35	165	95	3.8	850
Cantabria	110	109	219	1	0.3	9	42	26	68	16	2.2	201
C-Leon	423	405	829	18	0.7	13	58	52	109	6	0.1	4
C-La Mancha	397	499	896	-103	-3.9	-86	18	24	43	-6	-0.2	-5
Catalonia	427	508	935	-81	-0.8	-168	709	292	1001	418	4.3	867
Valencia	536	476	1012	60	0.9	172	296	222	518	74	0.9	213
Extremadura	128	66	194	62	3.5	100	16	24	40	-8	-0.4	-12
Galicia	174	179	352	-5	-0.2	-11	314	115	429	199	4.8	448
Madrid	650	419	1069	231	2.6	1920	266	106	372	160	1.6	1326
Murcia	205	324	529	-119	-6.3	-704	244	56	301	188	11.2	1108
Navarre	165	169	334	-4	-0.6	-25	31	31	61	0	0.1	1
Basque C	328	384	712	-55	-2.1	-510	343	144	487	198	6.5	1829
La Rioja	90	87	178	3	0.9	40	6	5	12	1	0.3	14

3.3 The Commercial Profile of the Spanish Regions

Biomass flows were similar in size for both IrT and InT. Figure 2 shows the regional differences in terms of quantity and commercial profile. Catalonia stands out as the largest net importer of international biomass products although it is a net exporter in the regional context, which is explained by the role of the strong agro-industrial sector in this region. Valencia is another agro-industrial center of Spain, although in contrast its regional balance is positive and the international is negative which reflects the orientation towards the international, mostly European, food markets of fruits and vegetables. The case of Galicia is qualitatively different since its imports are mainly agricultural products while its exports relate to fish and forest biomass that seems a case of complementarity. Madrid shows a striking net positive balance as compared to other regions while large and less densely populated regions such as Castile La Mancha and Castile Leon are net regional exporters.

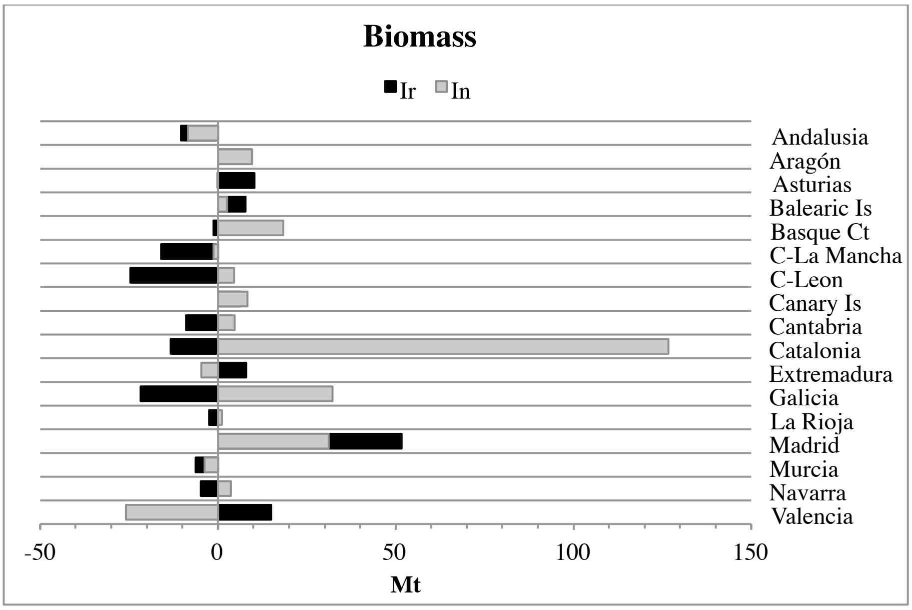

Fig 3. Interregional and International Physical Trade Balances of biomass. Accumulated 1996-2010. Notes: Ir: Interregional; In International.

The poor natural endowment of metallic minerals in Spain and its downward trend of extraction have led to a high and positive InPTB for all ACs (figure 4). In the regional context, metallic minerals are mostly mobilized in their semi-manufactured forms. Asturias, the Basque country and Galicia own the most powerful metallic industries in the country. Among the main regional exporters only Andalusia, Castile Leon and Galicia extract significant quantities of metal ores domestically. In the case of Valencia, only semi-manufactured metallic products are exported.

The overall picture points to a sharp dependency of the Spanish regions on foreign sources of strategic metallic minerals. Although it represents a low share of the traded volumes in both IrT and InT, the largest share of the ecological rucksack of trade are usually related to these products Bringezu et al, 2004; Muñoz et al, 2009).

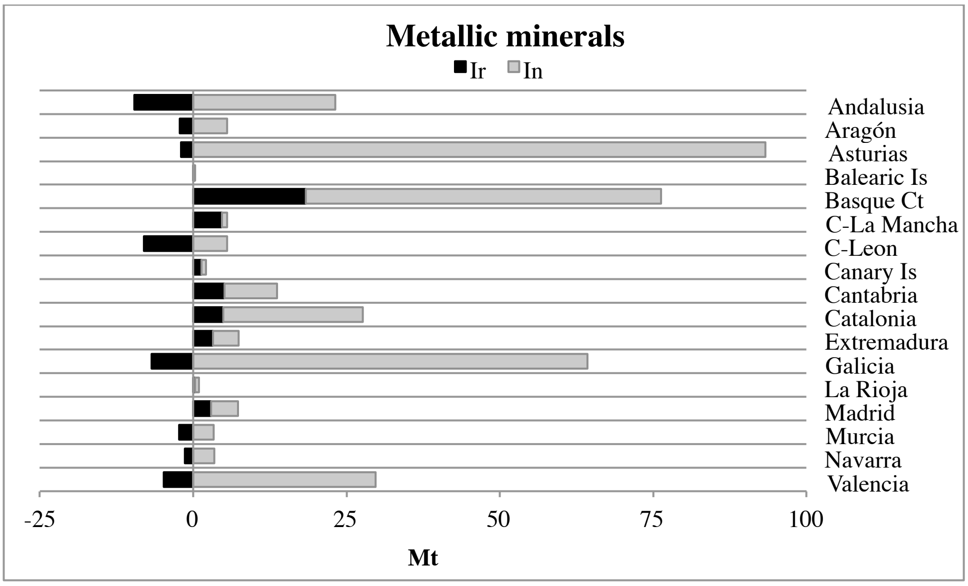

Fig 4. Interregional and International Physical Trade Balances of biomass. Accumulated 1996-2010. Notes: Ir: Interregional; In International.

Fossil fuels and semi-manufactured energy carriers determined a great share of the international and international trade flows given that Spain do not count on significant fossil resources as compared to its consumption (Sastre et al, 2015). Thus coastal regions where refineries are located import fossil fuels, which are processed and exported to other regions in the form of semimanufactured energy carriers. Therefore, all AC's heavily rely on foreign imports, be it in its raw or processed form through the internal redistribution.

In order for this picture to be complete, electricity flows must be also considered since in some of the ACs a large part of fossil fuels imports are set aside for electricity production (Figure 6). This is the case for Castile Leon, Extremadura, Castile La Mancha, Asturias, Aragon and Galicia. These regions are burdened with CO_2 emissions from electricity consumed in other regions, namely Madrid, the Basque Country and Andalusia. For example, Castile Leon's production of electricity from renewable sources currently covers its demand.

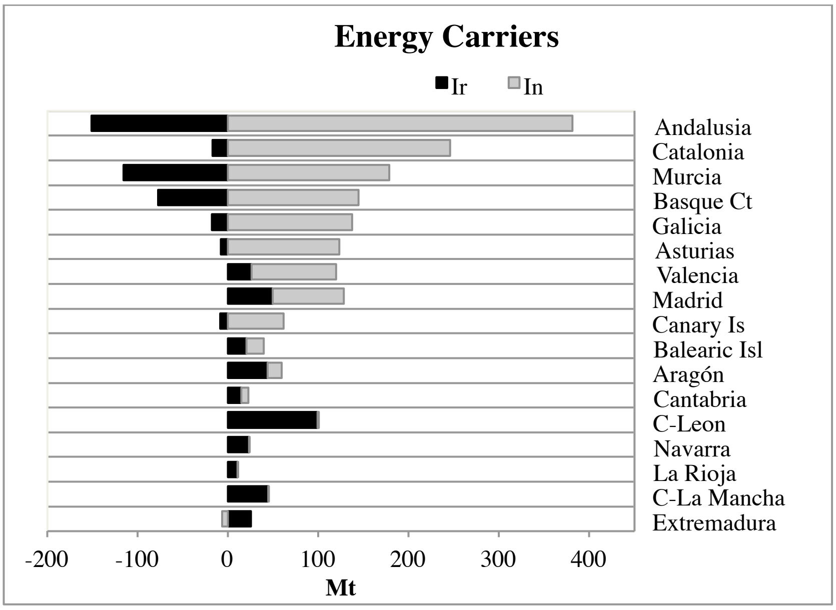

Fig 5. Interregional and international PTB of Energy Carriers. Accumulated 1996-2010. Notes: Ir: Interregional; In: international.

Non-metallic minerals have been a key flow in the last period of growth within Spain given the strong dynamics of the construction sector from 1996 to 2007 (Sastre et al. 2015). Provided that these materials are in general abundant, accessible and often cheap, they do not usually represent a significant flow in the international figures. Figure 7 shows how the InPTB are relatively less important than InPTB across region. The regional exchanges seem to be far more active though. The regional supply of construction minerals seems to be affordable for some regions such as Madrid, the Basque Country and Galicia. On the other hand, the surrounding ACs, namely Castile La Mancha and Castile Leon seem to be the providers.

Figure 8 includes manufactured products. The Basque Country shows the clearest profile as exporter of finished products in both the international and the national markets. Catalonia presents the highest values in the IrPTB but also significant net imports of international products and in Andalusia occurs exactly the opposite. In contrast Madrid stands out again as a net importer in both regional and international terms.

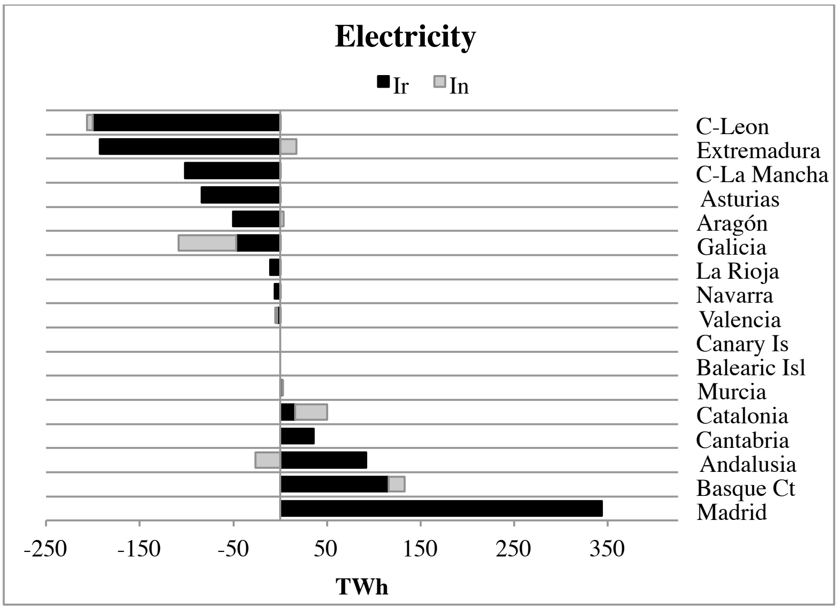

Fig 6. Interregional and international Electricity Trade Balance. Accumulated 1996-2010. Notes: Ir: Interregional; In: international.

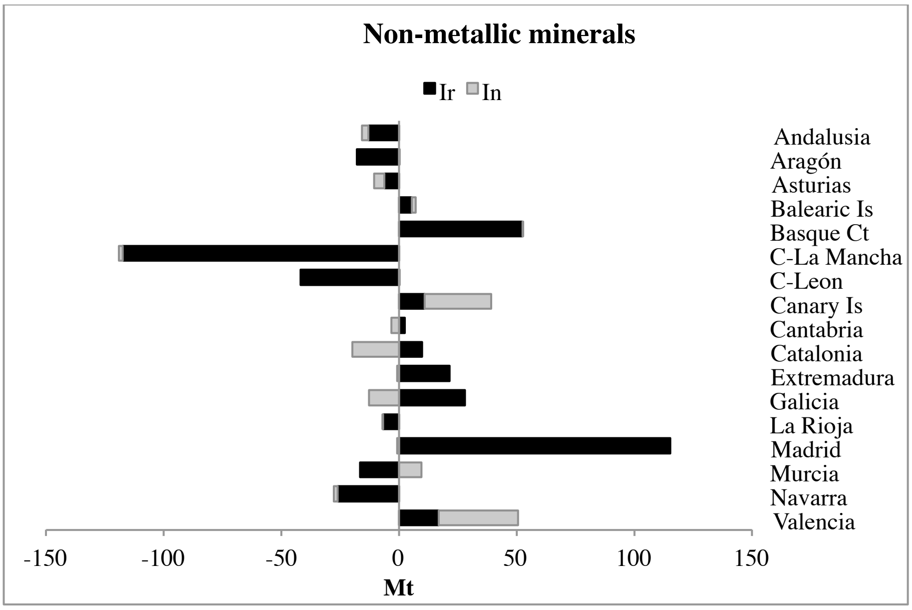

Fig 7. Interregional and international PTB of Non-metallic minerals. Accumulated 1996-2010**.** Notes: Ir: Interregional; In: international.

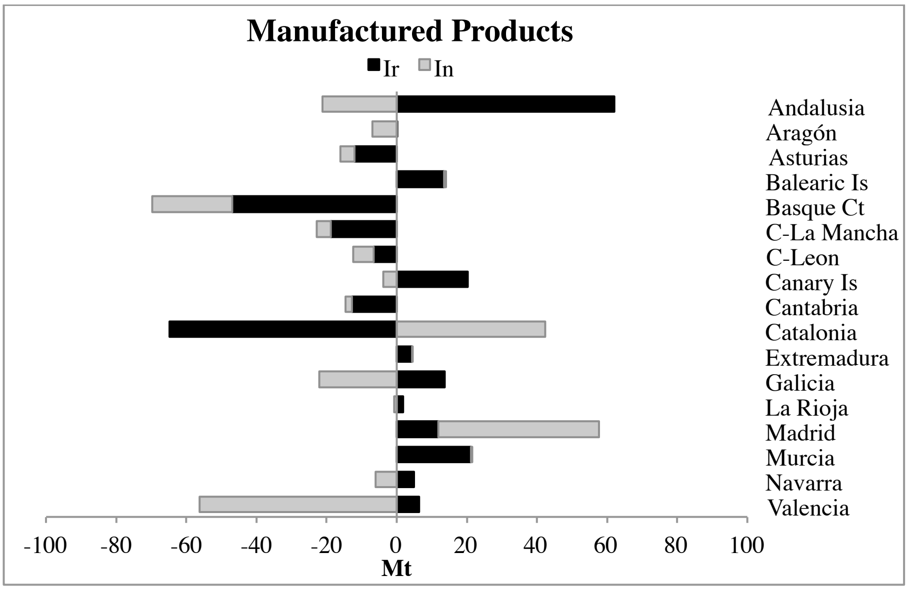

Fig 8. Interregional and international PTB of manufactured products. Accumulated 1996-2010. Notes: Ir: Interregional; In: international.

3.4 Environmental Burden Shifting Through International Trade

Through the assessment of PTB of raw natural resources, a first approach to environmental burden shifting through trade can be made. A positive PTB (i.e. net imports) implies that a share of the raw materials required for the economic system of one region are outsourced along with their associated environmental impacts. This phenomenon has been consistently documented in the last decades for international trade relations (Bringezu et al., 2004). In this sense, our database permits regions to be profiled according to their PTB in both quantitative (mass) and qualitative (type of material) terms. Thus the understanding of how some territories are connected to others is further expanded.

Figure 10 shows the net accumulated flows of InT for the Spanish regions. Most of the net international flows are raw materials coming from Africa, Asia, non-EU and South American countries. In turn Andalusia, Catalonia and the Basque Country accumulate 50% of the Spanish InPTB.

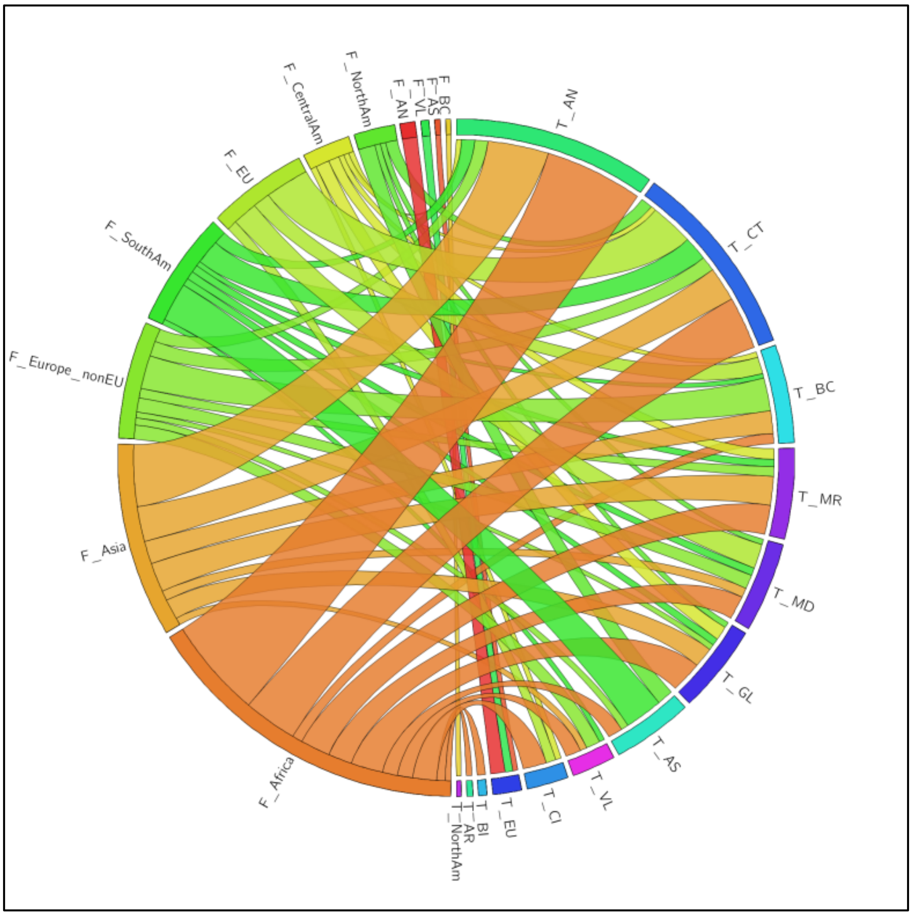

Fig 9. Accumulated International Physical Trade balances of the Spanish Regions, 1996-2010. Note: F: From. T: To. Region codes: AN, Andalusia; AR, Aragon; AS, Asturias; BI, Balearic Islands; CI, Canary Islands; CN, Cantabria; CL, Castile-Leon; CM, Castile-La Mancha; CT, Catalonia; VL, Valencia; EX, Extremadura; GL, Galicia; MD, Madrid; MR; Murcia; NV, Navarre; BC, Basque Community; RJ; La Rioja.

3.5 Environmental burden shifting through interregional trade

Given the significant flows mobilized via IrT, it seems interesting to explore how raw materials, and particularly biomass and non-metallic minerals are exchanged. Figure 11 shows the aggregated InPTB of biomass products (agricultural biomass, wood, livestock and fish) between regions. A certain degree of commercial specialization on raw agricultural, forest, fish and livestock products can be identified in Castile Leon, Castile La Mancha, Galicia and Andalusia. The case of Catalonia is different, since its InPTB of these products was much higher than their Ir exports. Madrid is by far the most relevant net importer, as it occurred in the rest of categories.

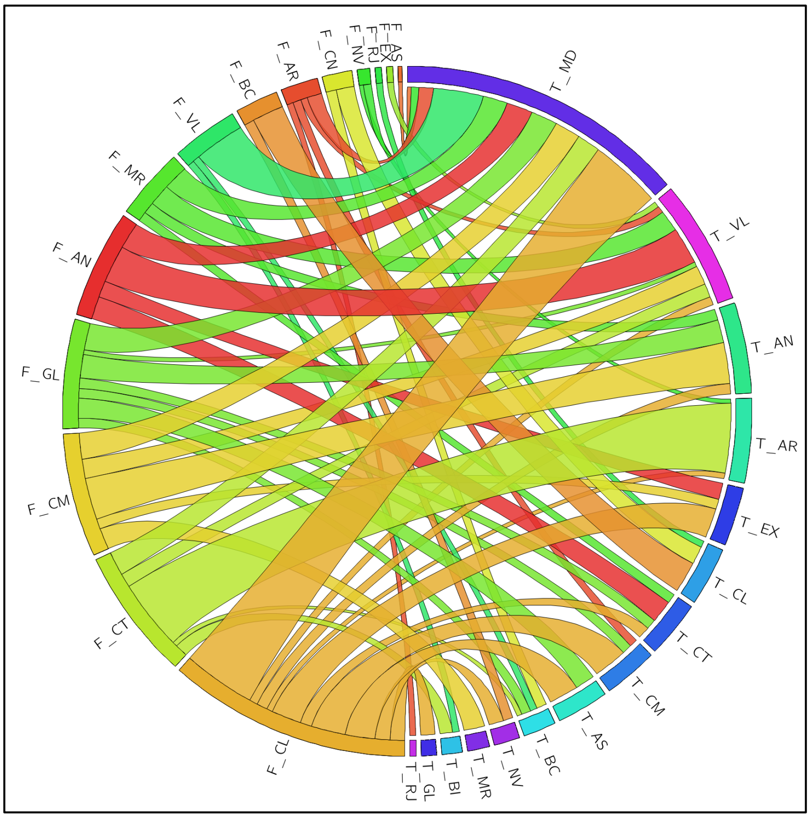

Fig 10. Accumulated Interregional Physical Trade balances of Biomass, Accumulated 1996-2010. Note: F: From. T: To. Region codes: AN, Andalusia; AR, Aragon; AS, Asturias; BI, Balearic Islands; CI, Canary Islands; CN, Cantabria; CL, Castile-Leon; CM, Castile-La Mancha; CT, Catalonia; VL, Valencia; EX, Extremadura; GL, Galicia; MD, Madrid; MR; Murcia; NV, Navarre; BC, Basque Community; RJ; La Rioja.

In Figure 12, interregional flows of non-metallic minerals are displayed. Trade of non-metallic minerals (and the associated burden shifting) is more relevant at the regional scale since these materials present a limited mobility given its low prices. During the period 1996-2007, known as the "housing bubble", the Spanish construction sector held one of the highest shares of value added as compared to other European countries (Sastre et al, 2015). During this period Madrid increased its PTB of non-metallic minerals sixty times. Interregional imports of these materials were barely 2% of the values for domestic extraction in 2000. In 2007, IrPTB of construction minerals were 33% of domestic extraction. This means that Madrid shifted the environmental pressures linked to extractive activities, mainly to Castile La Mancha and Castile Leon. The same happened between Valencia and Murcia or the Basque Country and Castile Leon.

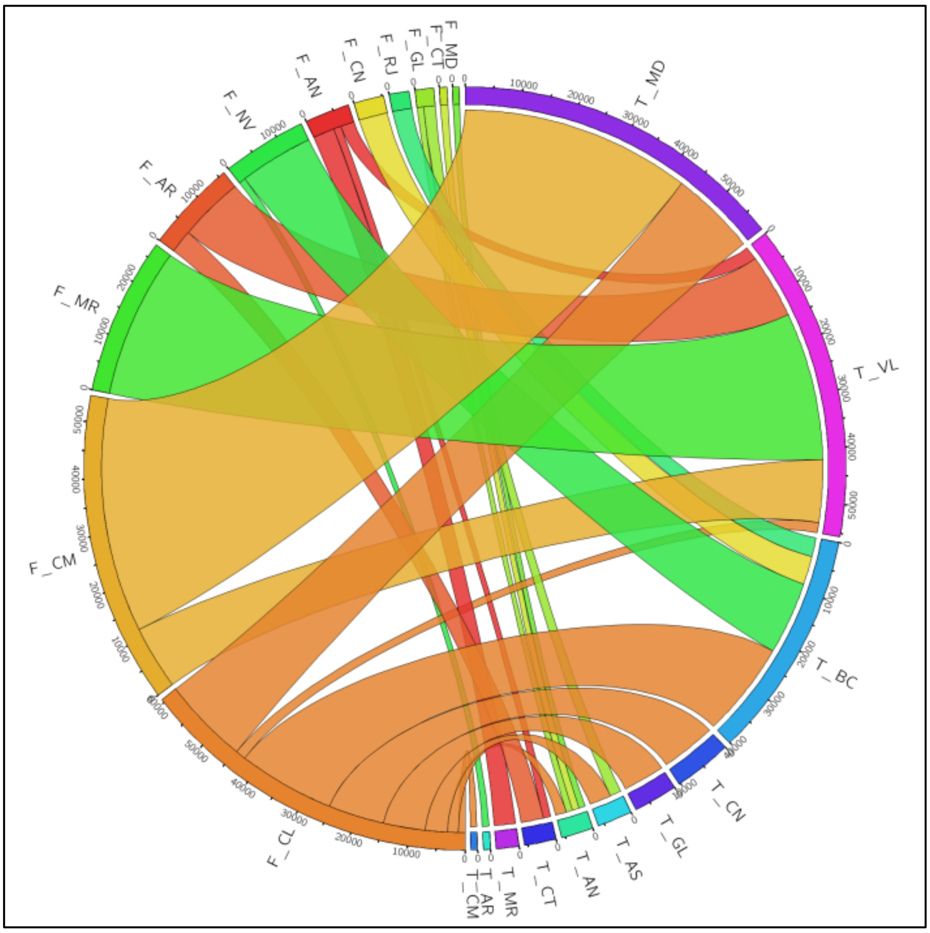

Fig 11. Accumulated Interregional Physical Trade balances of Non-Metallic Minerals, Accumulated 1996-2010. Note: F: From. T: To. Region codes: AN, Andalusia; AR, Aragon; AS, Asturias; BI, Balearic Islands; CI, Canary Islands; CN, Cantabria; CL, Castile-Leon; CM, Castile-La Mancha; CT, Catalonia; VL, Valencia; EX, Extremadura; GL, Galicia; MD, Madrid; MR; Murcia; NV, Navarre; BC, Basque

Community; RJ; La Rioja.

4. Concluding remarks

Several points emerge from our research:

- When Ir exchanges are compared to InT, its volume is similar although its composition is different. Thus environmental pressure shifting through trade might be also expected to occur across regions.
- In the international context, fossil fuels contributed to the greater share of imports. Metals ores are also mostly imported from abroad since Spain's endowment of these resources is poor as compared to its demand. Biomass presents a more balanced situation whereas manufactured products and non-metallic minerals are mostly traded between regions.
- Construction minerals have experienced a sharp increase in extraction and trade in the period between 1996 and 2007 linked to the so-called "housing bubble". The environmental pressures linked to this phenomenon have been shifted from densely populated areas (i.e. Madrid, Basque Country) towards neighbor regions devoted to raw material extraction and trade such as Castile La Mancha and Castile Leon where population density is much lower.
- Research on raw material equivalents and/or indirect flows should complete these results. Given the lack of similar works so far, it can be considered a first step in the understanding of the performance of interregional and international trade at the subnational scale.

Notes:

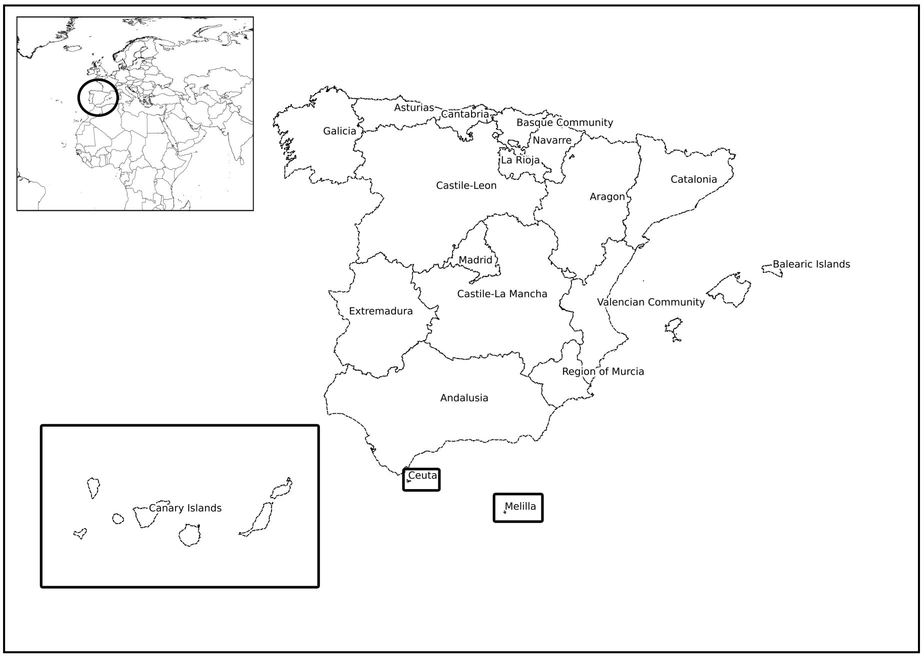

Fig. Spanish Regions at the NUTS 2 scale (autonomous communities and autonomous cities). Notes: Spain is a medium-sized country (506,000 km2) located in the Iberian Peninsula on the northwest side of the Mediterranean Sea and in the southwest of the European continent. It is made up of 19 NUTS 2 units. There are seventeen autonomous communities located within the Iberian Peninsula plus two archipelagos and two autonomous cities. The Balearic Islands are located in the northwestern Mediterranean Sea and the Canary Islands are located off the northwest coast of Morocco and the Western Sahara. Ceuta and Melilla, located on the north and northeast coast of Morocco, respectively, are so-called autonomous cities; they are included for calculation purposes (namely interregional trade), but their results are not included in the paper.

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