Unequal raw material exchange between and within countries: Galicia (NW Spain) as a core-periphery economy

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Abstract

A global multi-regional input-output model with sub-national resolution for Galicia, north-west Spain, was used to study physical and value added trade balances between Galicia, the rest of Spain and the world. Within the framework of Ecologically Unequal Exchange theory, we argue that a region, such as Galicia, can play a twofold role as core and periphery in the global division of extractive activities. We show that Galicia is a sink, i.e. net importer of natural resources from middle- and low-income economies, and that the lower the income of the trade partner, the more raw material intensive the imports (measured as upstream kg per USD imported value added). However, this physical deficit is less accentuated than for the rest of Spain and Galicia's material footprint is significantly lower (~14.2 compared with ~24.5 tonnes/capita). Moreover, Galicia is a source, i.e. net exporter of raw materials compared with more thriving European Union economies and, even for some key trade partners, such as Germany, UK and the rest of Spain, it is a net importer of value added.

Key words

Unequal exchange, Material footprint, Material flow accounting, Value added, World system theory, Multi-Regional Input-Output

Highlights

- Material and value added flows between Galicia (NW Spain), the rest of Spain and the world were studied.
- Sub-national differences makes Ecologically Unequal Exchange more complex to assess.

• A region can play a twofold role as core and periphery in the global division of extractive activities.

• Galicia is a sink of natural resources from lower income countries, but it is a source compared with more thriving economies.

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1. Introduction

Orthodox trade theory states that free trade allows countries to benefit from exchanging products according to their comparative advantages, by specialising in exporting those products they can produce more efficiently. In contrast, the theory of Ecologically Unequal Exchange (EUE) states that free trade generates winners and losers, with poor countries specialising in primary and extractive activities, with low value added but high environmental and social impacts, and rich economies specialising in high value manufacturing and services provision. This situation restricts development options for poor countries and perpetuates inter-territorial inequalities (Andersson and Lindroth, 2001; Hornborg, 2009; Muradian and Martinez-Alier, 2001). EUE theory is rooted in the theories of 'unequal economic exchange' (Emmanuel, 1972), 'dependence' (Prebish, 1950) and 'world system' (Wallerstein, 1974), and emerged as an ecological interpretation of these intellectual traditions (Hornborg, 1998). In a world system economy where wealthy, developed nations represent the core and poor, underdeveloped nations constitute the periphery, EUE suggests that core nations rely on foreign natural resources to fuel their socio-economic metabolism, pushing the 'commodity frontiers' (Moore, 2000) and causing environmental cost shifting to periphery nations, which leads to the emergence of socio-environmental conflicts (Muradian et al., 2012).

From an empirical viewpoint, pioneering work by Bunker (1984) examined how core countries influenced the export and extractivist orientation of Brazil. Several studies followed, always focusing on specific countries or groups of countries. For example, EUE theory has been empirically tested for different environmental pressures and impacts of vertical flow of exports, such as greenhouse gas, sulphur dioxide or particulate matter emissions (Prell and Feng, 2016; Prell and Sun, 2015; Yu et al., 2014), ecological footprint or land use (Andersson and Lindroth, 2001; Jorgenson and Clark, 2009; Moran et al., 2013; Oppon et al., 2018; Yu et al., 2014), water use or pollution (Moran et al., 2013; Oppon et al., 2018; Shandra et al., 2009c; Yu et al., 2014), deforestation or biodiversity threats (Moran et al., 2013; Shandra et al., 2009b, 2009a) and calories in food products (Falconí et al., 2017). Most empirical analyses testing EUE theory have been conducted at the nation-state scale, which does not always properly capture inter-territorial asymmetries, especially in large countries. This lack of research obscures the analysis, since the existing disparity in geographical size and population among nations and the huge economic and environmental regional divergences within countries are not taken into account (Godar et al., 2015), which hinders a better understanding of intra-national relations.

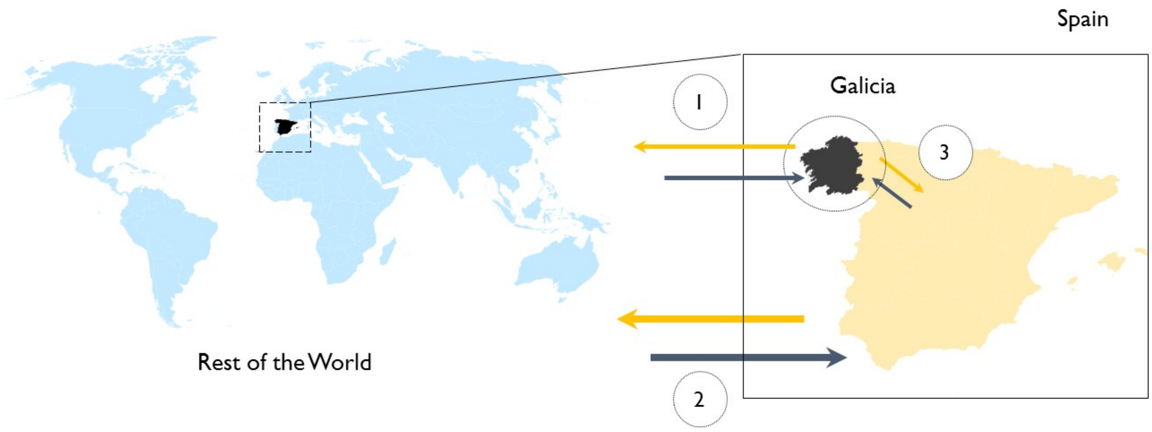
This issue has been discussed from the viewpoint of 'internal colonialism' (González Casanova, 1965) within the world system and unequal exchange literature. The concept originated to make visible political, economic and cultural colonisation processes that took place within the new-born nation states after independence, especially in Latin America. However, it has also been applied in non-Latin American contexts, including the United States and Europe, to understand relations of cultural domination (ethnic or racial) and unequal exchange dynamics within nation states (Drakakis-Smith and Wyn, 1983; Hicks, 2004). For the case of Spain, dependency scholars explored this idea in the 1970s, showing the peripheral role of poorer regions within the country such as Galicia (Beiras, 1973), Andalusia (Delgado Cabeza, 1981) and Extremadura (Naredo et al., 1978). More recently, Carpintero et al. (2015) and Sastre et al. (2015) studied the socio-economic metabolism of Spanish regions, shedding light on the intra-national differences on socio-metabolic profiles and regional raw material extraction and use patterns. Also the global greenhouse gas emissions driven by the Galician consumption were estimated (see Roibás et al. 2018). However, these studies have not entered ecological-economic dialectics, i.e. the EUE theoretical framework, which still operates solely at national level. Against this background, the present work aims to take a step in this direction, by providing empirical evidence of EUE for a Spanish region, Galicia, historically considered a periphery within the country.

Consequently, this work approached EUE at two complementary levels (Figure 1): i) at sub-national level with a regional study case, i.e. Galicia within Spain; but also ii) at global level, providing a suitable framework to analyse the sub-national case study. We hypothesised that Galicia, as an EU region, belongs to the core but, on downscaling within Spanish borders or the EU, it belongs to the periphery. We argue that, from a socio-ecological standpoint, an economy could play a twofold core-periphery role that reflects its position in the global economic hierarchy. In this regard, world system scholars acknowledge the existence of nuances within the dichotomy core/periphery, recognising its multi-scalar dimension and the difficulty of making clear and precise distinctions (for further details, see Hornborg and Crumley, 2006; Chase-Dunn and Hall, 1997). Although there is no consensus on empirical characterisation of these groups, semi-peripheries are usually described as countries with an 'intermediate position in the core/periphery hierarchy' and therefore with features of both typologies (Chase-Dunn and Hall, 1997). Again, this discussion is usually conducted at national level, but not considering the regional intra-national diversity.

Therefore, the main goal of this work was to test the existence of EUE in a subnational case by studying monetary and raw material trade patterns. In testing EUE theory, we also evaluated the following hypotheses: i) Richer territories, either countries or regions within countries, are net importers of materials and vice versa. That is to say, the material footprint of rich nations exceeds their domestic extraction; ii) Richer territories exchange their products on the global market with favourable terms of trade (USD gross trade/kg), and iii) Richer territories export materials with lower material intensity in terms of value added (kg/USD of value added) in comparison with their imports, which means lower mobilisation of domestic natural resources to generate and export value added to the global market. In this study, we defined cores and peripheries according to these premises, i.e. cores were considered sinks and peripheries sources of raw materials and, in monetary terms, cores were assumed to enjoy favourable trade conditions in comparison with non-core economies. Following previous studies (e.g. Moran et al., 2013), income per capita was the indicator used to operationalise EUE and analyse countries and regions as cores or peripheries in a simple way. Finally, it should be stressed that being a net exporter of materials does not necessarily exclude occurrence of EUE in relation to other indicators, since the apparent surplus could be related to net imports in other natural resource flows, e.g. net exports of agricultural products might occur as a result of net imports of energy products employed as inputs in farming activities (Dorninger and Hornborg, 2015).

We focused on the study of raw material extraction and use for the following reasons. First, trade currently drives one-third of global extractions of raw materials and this share is increasing (Schandl et al., 2016). Second, extractions often occur in poor countries with fragile governments, e.g. extraction of coltan (Moran et al., 2015) or oil (Wenar, 2015). Third, environmental damage caused by extractions is mainly local, in contrast to other threats such as climate change. This complicates social awareness and action in sink countries due to lower exposure to degradation (Givens and Jorgenson, 2011), and can thus indirectly promote 'not in my backyard' attitudes. We relied on a global multi-regional input-output model with sub-national resolution for Galicia. As far as we know, material flow accounting indicators have been calculated at subnational level for only three countries: Spain (Carpintero et al., 2015; Sastre et al., 2015), Austria (Schoder et al., 2006) and Belgium (Christis et al., 2016). Among these, only the Belgian study estimates raw material flows as we did here, i.e. by quantifying upstream raw material extractions for producing trade products (for further details, see section 3).

Figure 1. Material exchanges quantified in this study for a total of 188 world countries with Galicia (1) and the rest of Spain (2), and intra-national trade flows (3).



2. Case study

Some specific socio-economic and environmental characteristics make Galicia a relevant case. Galicia is a Spanish 'autonomous community'[1], located in the north-west of the Iberian Peninsula, and is considered under Spanish law to be an 'historical nationality', due to its cultural and language singularity in comparison with the rest of Spain. In 2011, Galicia had around 2.7 million inhabitants (95 per km^2) and its income was still far below the EU average (81%) and unemployment was markedly higher, 17.3% compared with an EU average of 9.7%[2]. The ageing rate of the Galician population is one of the highest in Europe, due to low

[1] Equivalent to the NUTS2 (Nomenclature of Territorial units for Statistics) level used by the EU and similar to the Combined Statistical Areas of the United States.

[2] Income as a percentage of the EU average for 2011 from Eurostat's regional economic accounts, measured as GDP at current market prices by NUTS 2 regions, purchasing power standard (PPS) per inhabitant. Unemployment rate by sex, age and NUTS 2

fertility and strong historical emigration and, as a consequence, depopulation of large rural areas is difficult to reverse (Martínez-Filgueira et al., 2017). Relative to its small population and GDP (5.9 and 5.2% of the country total, respectively)[3], it has relevant extractive industries, especially fish, wood and construction minerals. It represents half the fish biomass caught in Spanish waters, 44% of the forest biomass harvested in Spain in 2010 (mainly eucalyptus destined for the pulp industry) and between 48-78% of granite and 32-59% of annual slate extractions during the first decade of this century (Carpintero et al., 2015). Further, Galicia was also the main Spanish region in volume of coal mining until 2008, when reserves were depleted, with 350 millions of tonnes of brown lignite extracted between 1975 and 2007 (Rodríguez et al., 2018). Despite the absence of bauxite ores in the region, there was important development of the aluminium sector in Galicia during the 1970s, which is explained by two factors: i) the availability of a large coal mine and a thermal power station, which provided a secure supply of electricity at a subsidised price under the Spanish tariff system at the time; and ii) the extensive Galician coastline close to main commercial maritime routes to Europe, providing easy entry of raw materials and exit of manufacturing products to European markets (Doldán-García, 2009). Moreover, there have been some recent attempts to develop metal mining mega-projects with significant potential impacts on the environment, landscape and local economy, which have faced equally important civil resistance (Doldán, 2013; Rubinos et al., 2010). Finally, Galicia has one of the few Spanish oil refineries and petrochemical products are produced primarily to satisfy demand in the rest of Spain, and it imports high volumes of natural gas, mainly used in combined-cycle power plants to strengthen the capacity for exporting electricity to the Spanish market.

3. Material and methods

3.1. Framework and indicators

In this work, EUE was assessed through two dimensions; the biophysical, informing about environmental pressure exerted on ecosystems, and the economic, informing about exchange value, and their interaction. Here, raw material extraction and use following principles of 'material flow accounting' or 'economy-wide material flow analysis' (Eurostat, 2018; OECD, 2008) was used as a proxy for environmental pressure. Material flow accounting is a consistent framework for measuring the physical basis of socio-economic systems (Fischer-Kowalski et al., 2011). It accounts for biomass removals by agriculture, forestry and fishing activities, along with abiotic extractions of metals, other minerals and energy carriers by mining and quarrying. The three key physical indicators considered here were material footprint (as a proxy for pressure driven by final consumption), domestic extraction (as a proxy for pressure occurring within the country borders) and raw material trade balance (as an indication of sink or source of natural resources at global level).

regions from Eurostat's regional labour market statistics.

[3] Population and GDP from the Spanish Statistics Institute. GDP from Spanish regional accounts, functional approach by autonomous communities and autonomous cities. Base 2010 series. Population from the municipal register (January, 1st).

Material footprint, also called raw material consumption, is calculated by adding up all raw material extractions occurring within the domestic environment plus the upstream raw material extractions needed for producing imports (i.e. raw material equivalents of imports using standardised terminology) and deducting upstream raw material extractions inherent to export production (i.e. raw material equivalents of exports). Thus material footprint equals domestic extraction plus the raw material trade balance, which is defined as raw material equivalents of imports minus exports. If the material footprint is higher than domestic extraction, this means that the economy has a physical deficit and can be considered a net exporter of environmental pressure. When appropriate, domestic extraction was normalised by area in this study, because it could be argued that higher extractions in a reduced space exert greater pressure on natural ecosystems than lower extractions in an extended space (Schaffartzik et al., 2016). In addition, domestic extraction and material footprint were normalised by population, because previous research has shown that population density is an important variable explaining biophysical asymmetries between countries, especially for wealthier countries (e.g. Bruckner et al., 2012; Krausmann et al., 2008; Wiedmann et al., 2015).

There are two accounting principles for computing and allocating raw material embodiments in trade products, depending on whether intermediate trade products are handled exogenously or endogenously (Cadarso et al., 2018; Kanemoto et al., 2012; Peters, 2008; Su and Ang, 2011). Endogenous accounting of intermediate trade products means that raw material embodiments of intermediates are always allocated from place of extraction to final consumers, irrespective of existing intermediary steps in the supply chain. In contrast, in exogenous accounting, material requirements are always assigned to direct trade partners, irrespective of where final consumption occurs. The former is more appropriate to assess unequal material exchange at final consumer level, while the latter is better suited to most common notions of trade balance and, more specifically, to the concept of terms of trade frequently used in the EUE literature. Since the approaches have different policy interpretations, both were used in this analysis[4]. Material footprint was estimated considering intermediate trade endogenously, as done previously (e.g. Giljum et al., 2015; Wiedmann et al., 2015), whereas raw material trade balances were estimated by considering intermediate trade exogenously (see Cadarso et al. (2018) for further explanations). However, we also tested our hypotheses considering intermediate trade endogenously for estimating trade balances.

We used two indicators for exchange value; prices per product as a proxy for terms of trade (ToT), as done in most previous studies (e.g. Infante-Amate and Krausmann, 2019; Moran et al., 2013; Samaniego et al., 2017), and gross value added embodied in international trade (e.g. Yu et al., 2014). The fraction of value added exported, i.e. value added domestically produced but absorbed elsewhere, is a key driver of economic growth. However, EUE suggests that a peripheral economy exports a high volume of raw materials with low value added, and thus lower prices, while high-value products associated to those physical flows are produced elsewhere. Following this reasoning, ToT (USD/kg) and material intensity (kg/USD value added)

[4] There is a third approach in which intermediate trade is also exogenous, but the foreign share of extractions is included (e.g. Seppälä et al., 2011; Weinzettel and Kovanda, 2009). This third approach, while relevant from a single country viewpoint, causes double counting of material trade flows when multiple regions are analysed and was not considered in this work.

would be more advantageous for core economies. Balances were estimated as inflows minus outflows, because physical and monetary flows have opposite directions: upstream raw materials in exports (virtually) leave the country to the importer nation, while money enters the economy when products are dispatched. Consequently, correspondence between physical and financial flows implies a change in sign. Lastly, value added was used mainly for estimating trade balances and material intensities and, accordingly, intermediate trade was modelled exogenously.

3.2. Data

Estimation of domestic extraction from agricultural and mining statistics is straightforward, while raw material embodied in trade products requires complex modelling (Eisenmenger et al., 2016; Lutter et al., 2016; Schoer et al., 2013). In this study, an environmentally extended global multi-regional input-output (MRIO) model was employed, as is common practice (e.g. Arto et al., 2012; Tukker et al., 2014). In building the model, we followed the approach proposed by Christis et al. (2016) for Flanders and the rest of Belgium and developed a MRIO model with sub-national resolution for Galicia and the rest of Spain. It is worth noting that this model is not a fully sub-national MRIO (e.g. Bachmann et al., 2015; Cazcarro et al., 2013) and flows between regions within Spain cannot be individually assessed. MRIO databases with different sectoral, temporal and geographical resolution are available (Tukker et al., 2018; Tukker and Dietzenbacher, 2013). The Eora database (Lenzen et al., 2013, 2012) was used here because of its high country and sector resolution and because, at the time the calculations were performed, it included data for 2011, which was the chosen reference year. Sub-national input-output data were obtained from the official statistics office (Galician Statistics Institute) and complemented with trade data from the Spanish Ministry of Commerce. Global raw material extraction data were taken from the UN Environment International Resource Panel Global Material Flows database (Schandl et al., 2016), while extraction data for Galicia and the rest of Spain were taken from national and regional statistics. In short, model development involved: i) designing correspondence classifications between Eora data for Spain and input-output data for Galicia; ii) conversion to common currency; and iii) subtraction of Galician data from Spanish data in Eora. In a very few cases, Galician data were higher than those for Spain in Eora and the resulting values for the rest of Spain were set to zero. Nevertheless, we tested the impact of this assumption by running a version of our model without suppressing any quantity. Eora includes 188 world countries and, after splitting Spain into two, our model considered 189 entities, which were classified by income following the World Bank classification[5]. Further method and data explanations, along with some results of tests performed, are offered in Supporting Information (SI) to this paper.

4. Results

4.1. Material footprint of rich countries exceeds domestic extraction

[5] Defined as GNI per capita in 2017: Low-income economies are those with 995 USD or less, lower middle-income economies have between 996 USD and 3,895 USD, upper middle-income economies have between 3,896 USD and 12,055 USD and high-income economies have 12,056 USD or more.

Figure 2 displays domestic extraction and material footprint in tonnes per capita for the world, the OECD, the EU, four income groups (high income (HI), upper-middle income (UMI), lower-middle income (LMI) and low income (LI)), Spain, the rest of Spain and Galicia by material type in 2011. As can be seen, the material footprint of HI economies, including OECD countries and the EU, is higher than that of UMI, LMI and LI economies. Specifically, in 2011 the material footprint of HI countries was 1.7, 5.8 and 15.2 times higher than that of UMI, LMI and LI economies, respectively. The material footprint of the OECD was 1.5 times its domestic extraction, while for the EU this value rose to 1.9. Similar material dependence from abroad was identified for Spain, the rest of Spain and Galicia, although for the latter to a lesser degree. The Spanish footprint was 2.8 times its domestic extraction, whereas for Galicia this amount halved to 1.4, showing a material footprint closer to the UMI group. Furthermore, Galician biomass footprint was lower than domestic extraction and equivalent for non-metallic materials, while in the Spanish case the material footprint was clearly higher than domestic extraction in all cases. Lower biomass footprint in comparison with domestic extraction, and to some extent with non-metallic minerals, is only apparent for LMI and LI economies. Figure 2 shows that richer economies, including our study case, are net importers of materials, but it does not provide information about where environmental pressure takes place. This information is presented in Tables 1 and 2.

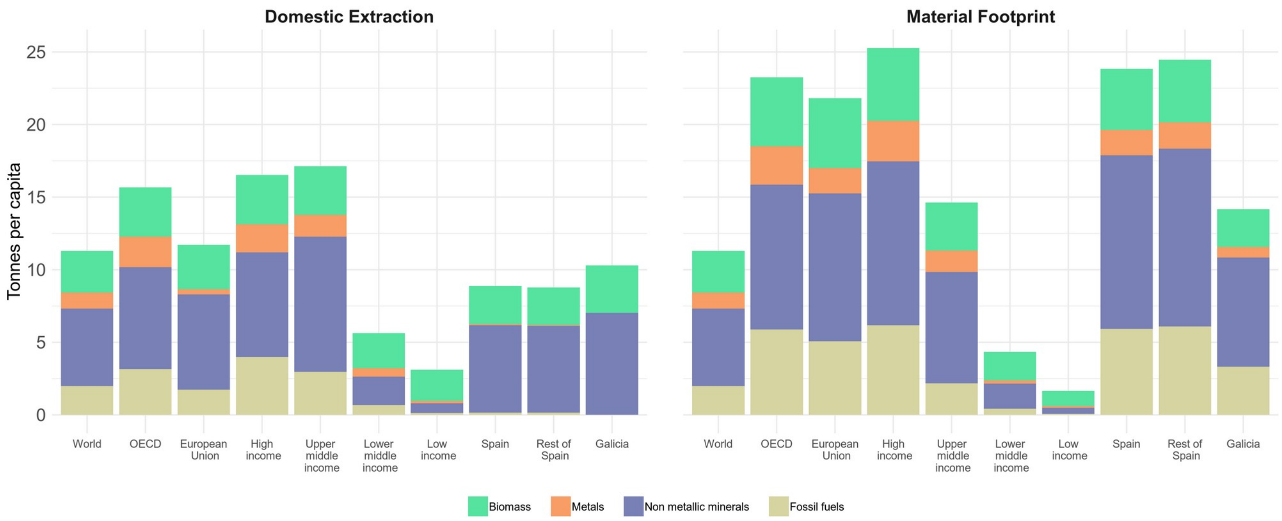


Figure 2. (Left) Domestic extraction and (right) material footprint for the world, the OECD, the European Union, four income groups, Spain, the rest of Spain and Galicia for the year 2011 by material category (biomass, metals, non-metallic minerals and fossil fuels).

Table 1 and 2 depict domestic extractions and material footprint and shows the origin and destination of raw materials for each income group. In the reference year (2011), 47% of the 19,834 Mt of material consumption in HI economies came from other groups, and of this 32% was extracted from UMI environments (i.e. 3,001 Mt), 13% from LMI (i.e. 749 Mt) and 2% from LI (i.e. 54 Mt). This outsourced share of HI economies was notably larger than for other groups, which obtained 14-24% of their material footprint from outside their category. In absolute terms, UMI countries were the main material providers to

HI economies in 2011, but in per capita terms consumers from HI countries as a group required overall twelve times more materials from LMI economies than the reverse flow, and around seven times more from the other two categories (Table 2). Thus from an individual consumer viewpoint, exchanges between HI and LMI countries were notably more unbalanced. For domestic extraction per km^2, more pronounced pressures from HI economies, thirty four times higher than the opposite flow, occurred in LI environments (Table 1). In brief, there were patent material imbalances between HI economies but, depending on the normalisation, the most affected corresponding income group varied, i.e. it was UMI in absolute terms, LMI in per capita terms and LI in per km^2 terms.

Table 1. Domestic extraction by destination of materials in 2011.

	Domestic Extraction							
Destination	**High income (HI)**		**Upper middle income (UMI)**		**Lower middle income (LMI)**		**Low income (LI)**	
	(Mt)	**(t/km^2)**	**(Mt)**	**(t/km^2)**	**(Mt)**	**(t/km^2)**	**(Mt)**	**(t/km^2)**
HI	16,029	403.24	9,639	169.29	3,959	177.91	716	46.91
UMI	3,001	75.49	30,930	543.24	1,718	77.20	304	19.93
LMI	749	18.85	1,403	24.64	9,554	429.94	134	8.77
LI	54	1.37	108	1.89	87	3.92	793	51.93
Total	**19,834**	**498.95**	**42,080**	**739.06**	**15,318**	**688.32**	**1,947**	**127.54**

Area: high income = 39,751,387 km^2, upper middle income = 56,935,855 km^2, lower middle income = 22,254,268 km^2, low income = 15,264,610 km^2. Mt = million tonnes.

Table 2. Material footprint by origin of materials in 2011.

	Material Footprint							
Origin	**High income (HI)**		**Upper middle income (UMI)**		**Lower middle income (LMI)**		**Low income (LI)**	
	(Mt)	**(t/cap)**	**(Mt)**	**(t/cap)**	**(Mt)**	**(t/cap)**	**(Mt)**	**(t/cap)**
HI	16,029	13.35	3,001	1.22	749	0.28	54	0.09
UMI	9,639	8.03	30,930	12.59	1,403	0.52	108	0.17
LMI	3,959	3.30	1,718	0.70	9,554	3.51	87	0.14
LI	716	0.60	304	0.12	134	0.05	793	1.27
Total	**30,344**	**25.27**	**36,053**	**14.63**	**11,840**	**4.35**	**1,042**	**1.66**

Population: high income = 1,200,665,343 inhabitants, upper middle income = 2,457,488,305 inhabitants, lower middle income = 2,722,562,002 inhabitants, low income = 626,201,940 inhabitants. Mt = million tonnes, t/cap = tonnes per capita.

Table 3 and 4 show domestic extraction by destination of materials and material footprint by their origin for Galicia and the rest of Spain in 2011. Extractions in Galicia for producing exports to the rest of Spain were almost three times higher than imports and represented 22% of the total (i.e. 6.31 Mt), which is not surprising considering the population and economic activity scale differences. However, both systems extracted a similar share to be exported to the rest of the EU. In terms of domestic extraction per unit area, the value was slightly higher for Galicia (973 t/km^2) than for the rest of Spain (819 t/km^2). Results for material footprint were more interesting. The rest of Spain appeared to be a more open and more dependent economy, with 83% of its material consumption coming from Galicia or other countries (i.e. 904.82 Mt). The corresponding figure for Galicia decreased to 70% (i.e. 27.65 Mt), pointing to more modest integration in global value chains, although still far from the degree of closeness mentioned earlier for non-HI economies. Further, material dependence from intra-national extractions of the average Galician consumer was higher, 800 kg/person in contrast with 140 kg/person for the rest of Spain. This indicates that, in per capita terms, Galician consumption exerts higher pressure on the environment of the rest of Spain than the other way around. However, these figures need to be evaluated relative to the corresponding monetary flows by product, which is done in the next sections.

Table 3. Domestic extraction by destination of materials for Galicia and the rest of Spain in 2011.

Destination	Domestic Extraction					
	Galicia			Rest of Spain		
	(Mt)	(t/km^2)	%	(Mt)	(t/km^2)	%
Domestic final demand	11.95	404.02	42	180.74	379.68	46
Intra-national final demand	6.31	213.52	22	2.23	4.69	1
Rest of European Union	5.17	174.73	18	73.33	154.05	19
Rest of high income	2.96	100.09	10	62.50	131.29	16
Upper middle income	1.67	56.36	6	47.48	99.73	12
Middle lower income	0.69	23.35	2	21.96	46.13	6
Low income	0.04	1.28	0	1.67	3.51	0
Total	**28.79**	**973.35**	**100**	**389.90**	**819.08**	**100**

Area: Galicia = 29,575 km^2, rest of Spain = 476,025 km^2. Mt = million tonnes.

Table 4. Material footprint by origin of materials for Galicia and the rest of Spain in 2011.

Origin	Material Footprint					
	Galicia			Rest of Spain		
	(Mt)	(t/cap)	%	(Mt)	(t/cap)	%
Domestic environment	11.95	4.27	30	180.74	4.07	17
Intra-national environment	2.23	0.80	6	6.31	0.14	1
Rest of European Union	2.81	1.01	7	105.92	2.39	10
Rest of High income	4.82	1.72	12	162.82	3.67	15
Upper middle income	10.14	3.63	26	398.74	8.98	37
Middle lower income	6.65	2.38	17	196.79	4.43	18
Low income	1.01	0.36	3	34.25	0.77	3
Total	**39.60**	**14.17**	**100**	**1,085.56**	**24.45**	**100**

Population: Galicia = 2,795,422 inhabitants, rest of Spain = 44,395,071 inhabitants. Mt = million tonnes.

3.2. Richer territories are net importers of raw materials and trade their products under more advantageous conditions

While doubts about material dependencies between HI economies and the rest of the world are resolved, an assessment of monetary flows must be performed. Table 5 lists trade in raw materials, gross trade and trade in value added by income group for 2011. Trade in raw materials was ~33 Gigatonnes, which represented 42% of global material extraction and accounted for ~21 billion USD in the global economy. Of that figure, around 60% was value added. HI economies exported 34% of all raw materials in trade but 70% of all value added, while their population was 17% of the world total in 2011. The other economies exported the remaining 66% of raw materials, but only 30% of traded value added. The gap between terms of trade for imports and exports expanded markedly when descending the income level. For UMI economies, there was some agreement between material and payments, i.e. the sign reversed, but this did not happen for the two lower income groups. Regarding value added, most of that in 2011 was absorbed by HI economies (75%) and UMI countries (20%), and differences in material intensities between income groups were manifest. Material intensity of exports of HI economies was half that of imports and, to generate one USD of value added, they required 1.22 kg of raw materials, in comparison with 7.71 kg of LMI economies or an extreme value of 30.45 kg for LI economies. LI economies are net exporters of materials, but net importers in value added and gross terms.

Table 5. Total trade in raw materials, gross trade, terms of trade (ToT), trade in value added and material intensity by income group in 2011.

Income Group	**Trade in raw materials (10^9 kg)**			**Gross trade (10^9 USD)**			**ToT (USD/kg)**		**Trade in value added (10^9 USD va)**			**Intensity (kg/USD va)**	
	M (a)	X (b)	Balance (a-b)	M (c)	X (d)	Balance (d-c)	M (c/a)	X (d/b)	M (e)	X (f)	Balance (f-d)	M (a/e)	X (b/f)
HI	23,398	11,463	11,935	16,281	15,710	-572	0.70	1.37	10,021	9,429	-591	2.33	1.22
UMI	7,222	14,480	-7,257	4,235	4,299	64	0.59	0.30	2,654	3,171	517	2.72	4.57
LMI	2,460	6,258	-3,797	1,194	1,076	-119	0.49	0.17	715	811	96	3.44	7.71
LI	246	1,126	-880	93	50	-44	0.38	0.04	60	37	-23	4.09	30.45
Total	**33,326**	**33,326**	**0**	**21,804**	**21,134**	**-670**	**0.65**	**0.63**	**13,449**	**13,449**	**0**	**2.48**	**2.48**

M = imports, X = exports. USD va = US dollars of value added. Differences at aggregated levels for gross trade due to statistical discrepancies.

Figure 3 shows total trade (sum of imports and exports for each country) in raw materials and value added for the highest raw material traders (and Galicia) in 2011. The size of dots indicates the magnitude of the trade balance in absolute values, i.e. without considering its sign, while the y-axis displays population density. A completely balanced economy would be on the blue line, whereas a net exporter(importer) would be in the left(right) side of the graph. In Figure 3A, material dependencies between HI economies and the rest of the world are clearly visible, but degree of imbalance varies significantly depending on the economy. For instance, Japan has a much more pronounced unbalance situation than USA, while Germany is in the middle of the two (Figure 3A). Similar imbalances, although less intense, can be seen to the left of the blue line, e.g. when comparing India and Russia. In addition, in the case of HI countries, a certain correspondence between population density and physical deficits can be seen, with highly populated HI countries (i.e. population density above 250 inhabitants/sq.km) generally showing a more accentuated imbalance (i.e. ratio above 0.5), although there are some exceptions (e.g. Slovakia, Latvia and the rest of Spain). Galicia, with a similar population density (95 inhabitants per km^2) to the rest of Spain (93 inhabitants per km^2) has a notably less marked imbalance (ratio equal to 0.37). A few UMI economies appear on the right-hand side in Figure 3A, although only Romania's raw material imports are twice exports. Lastly, only LMI economies have high population density and an intense negative trade balance (e.g. Vietnam, Pakistan, Nigeria), while HI economies in the left side are mainly mineral or oil exporters. In Figure 3B, the pattern observed for raw materials vanishes and in general, there is a much more unclear distribution in terms of value added.

Moreover, in some cases certain countries remain in the same part of the graph, i.e. the sign of their balance remains the same, which indicates that these nations have a position in global value chains as value added exporters but natural resources sinks. This is the case for e.g. Germany, France, Italy and Japan. It is not the case for Galicia (ratio -0.12) or the rest of Spain, although for the latter the unbalance situation is remarkably attenuated (Figure 3B).

Figure 3. Total trade balance in A) raw materials (RM) and B) value added (VA) in 2011 (countries below 110 million tonnes trade flow, with the exception of Galicia, and with population density above 600 inhabitants per km^2 are not shown).

3.3. Galicia as core and periphery

To understand more thoroughly our study case, Table 6 reproduces Table 5, but focusing on Galicia. The region emerges as a net importer of raw materials from middle and low income economies, but at the same time a net supplier of natural resources to HI countries. Further, while there is certain correspondence between physical and gross trade flows, terms of trade are more advantageous for Galicia when the income of the trade partner is lower, since prices per tonne of Galician imports from UMI, LMI and LI countries are, respectively, 6.8, 8.3 and 78.9 times lower than the prices of exports. Moreover, Galicia is a net importer of value added from all income groups considered and thus, in relation to HI countries, also acts as a sink of value added and source of natural resources. Accordingly, material intensity of exports to HI is 52% higher than that of imports, i.e. overall generating and exporting value added from Galicia requires 1.5 times more material extractions than the opposite flow (Table 6). In contrast, material intensity of imports to Galicia from LMI and LI economies are significantly higher than aggregated values of exports for those groups in Table 5, i.e. they are above the global average. Finally, aggregated material intensity of Galician exports is notably below that for middle and low income economies, and 12% less than the aggregated material intensity for HI economies shown in Table 5. This indicates that in general terms, the region's material intensity is low in comparison with that of other rich economies.

Table 6. Trade in raw materials, gross trade, terms of trade (ToT), trade in value added and material intensity by income group for Galicia in 2011.

Income Group	Trade in raw materials (10^6 kg)			Gross trade (10^6 USD)			ToT (USD/kg)		Trade in value added (10^6 USD va)			Intensity (kg/USD va)	
	M (a)	X (b)	Balance (a-b)	M (c)	X (d)	Balance (d-c)	M (c/a)	X (d/b)	M (e)	X (f)	Balance (f-d)	M (a/e)	X (b/f)
HI	10,572	15,366	-4,794	24,803	27,674	2,872	2.35	1.80	15,218	14,513	-705	0.69	1.06
UMI	11,865	851	11,014	3,241	1,574	-1,667	0.27	1.85	2,664	761	-1,903	4.45	1.12
LMI	9,491	597	8,894	870	452	-418	0.09	0.76	697	252	-445	13.62	2.37
LI	4,544	10	4,534	132	24	-108	0.03	2.30	83	16	-67	54.59	0.64
Total	**36,473**	**16,825**	**19,648**	**29,724**	**29,045**	**679**	**0,80**	**1,77**	**18,663**	**15,543**	**-3,120**	**1.95**	**1.08**

M = imports, X= exports. USD va = US dollars of value added.

Figure 4 presents trade in raw materials and value added for Galicia's 25 most important raw material trade partners in 2011, with the y-axis showing trade balances in absolute values, i.e. without considering trade sign, to make the diagram more compact. First, it can be seen that Galicia is a heavily unbalanced net importer of raw materials from middle and low income economies (e.g. Egypt, Guinea, Mexico), but also from some HI economies (e.g. USA, Saudi Arabia). In general, there is some correspondence between raw material and value added flows, although less so for Algeria, Saudi Arabia and India. In contrast, more thriving EU economies (e.g. Germany, UK, France) act as sinks of materials from the Galician environment, while the region's imports of value added from those regions exceed exports. This is also the case for the rest of Spain. The exchange between Galicia and the rest of Spain is further explored in Table 7, where trade in raw materials, value added and gross trade are disaggregated by industry. In terms of value added, Galicia is a net importer from the rest of Spain, mainly due to imports of business activities (17% of value added imported in 2011), metal industry (14%) and basic chemistry (4%). Main sectors making Galicia a net exporter of raw materials are mining (25% of raw material exports), forestry (18%), wood and paper (8%) and cement production (11%). Together, these accounted for 63% of the raw material extractions for exports in 2011, while their contribution to value added exports was 9%. Food industry and agriculture are also relevant sectors, being responsible, respectively, for 13% and 10% of raw material exports, and 20% and 6% of value added exported in 2011. However, important subnational flows of food and agricultural products enter the Galician economy and offset the outflows. Overall, material intensity of value added in 2011 was more than double for Galicia than for the rest of Spain (Table 7), i.e. exporting value added to the rest of Spain requires twice as much raw material extraction and processing as the opposite flow. However, it remained below 1 kg per USD of value added traded in 2011 and was therefore still far from the more pronounced intensities shown for middle and low income economies in Table 5.

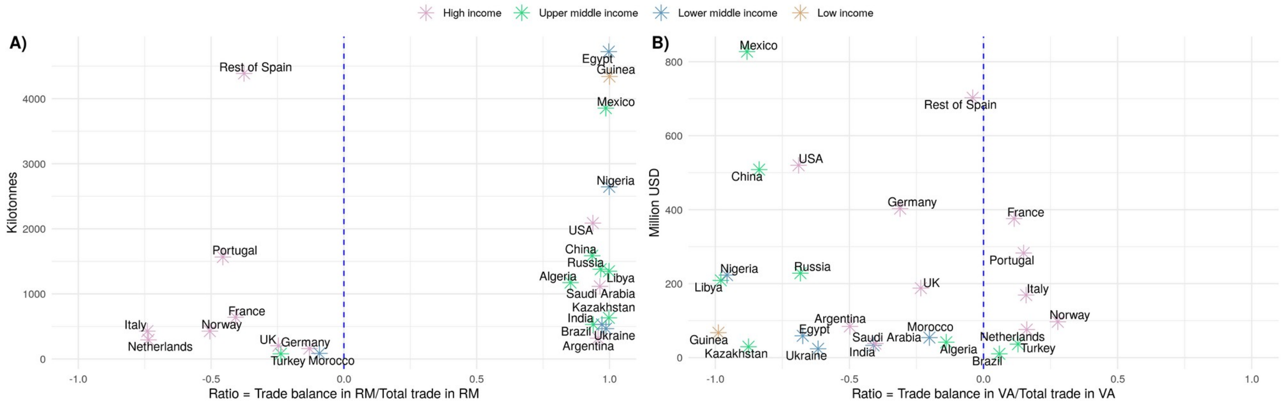


Figure 4. Trade balance in A) raw materials (RM) and B) value added (VA) for Galicia and its 25 most important raw material trade partners in 2011. Trade balances are in absolute values on the y-axis.

Table 7. Trade in raw materials, trade in value added, gross trade, terms of trade (ToT), trade in value added and material intensity between Galicia and the rest of Spain in 2011.

Product Group	Trade in raw materials (10^6 kg)			Gross trade (10^6 USD)			ToT (USD /kg)		Trade in value added (10^6 USD va)			Intensity (kg/ USD va)	
	M (a)	X (b)	M-X. (a-b)	M (f)	X (e)	X-M (e-f)	M (f/a)	X (e/b)	M (d)	X (c)	X-M (c-d)	M (a/d)	X (b/c)
Agriculture	706	829	-124	458	655	197	0.65	0.79	360	468	109	1.96	1.77
Forestry	3	1,460	-1,457	2	146	144	0.58	0.10	2	130	128	1.82	11.28
Fishing	6	78	-72	33	160	127	5.15	2.04	26	158	132	0.25	0.50
Mining	284	1,997	-1,713	18	44	26	0.06	0.02	14	32	19	20.85	61.82
Food	1,011	1,072	-61	2,491	3,427	936	2.46	3.20	1,678	1,678	0	0.60	0.64
Textile & clothes	40	19	21	696	654	-42	17.38	34.71	405	295	-110	0.10	0.06
Wood & paper	59	648	-589	478	658	180	8.06	1.02	279	423	144	0.21	1.53
Basic chemistry	221	39	182	1,803	1,449	-354	8.15	36.69	763	348	-416	0.29	0.11
Cement	447	920	-473	436	208	-229	0.98	0.23	326	131	-195	1.37	7.01
Metal	589	339	250	1,964	1,397	-567	3.33	4.12	1,273	698	-576	0.46	0.49
Machinery	31	28	3	386	341	-44	12.38	11.99	252	201	-51	0.12	0.14
Equipment	16	27	-11	193	235	41	12.21	8.78	114	126	12	0.14	0.21
Motor vehicles	18	27	-9	316	1,027	711	17.90	38.48	122	336	214	0.14	0.08
Vessels	1	31	-30	27	354	328	34.66	11.46	14	229	215	0.05	0.13
Other transport	2	2	0	83	34	-49	33.86	15.78	45	17	-29	0.05	0.13
Other manuf.	20	43	-23	324	200	-124	15.91	4.61	210	135	-75	0.10	0.32
Electricity	0	140	-140	0	1,295	1,295	0.00	9.25	0	792	792	0.00	0.18
Sales & Accomm.	21	135	-114	366	577	211	17.65	4.27	305	506	201	0.07	0.27
Transport services	37	40	-3	1,299	1,126	-173	35.22	28.29	969	745	-224	0.04	0.05
Business act.	88	131	-43	1,921	772	-1,149	21.77	5.88	1,575	697	-879	0.06	0.19
Other services	40	20	20	392	260	-132	9.90	13.05	309	193	-116	0.13	0.10
Total	**3,640**	**8,028**	**-4,388**	**13,686**	**15,017**	**1,332**	**3.76**	**1.87**	**9,042**	**8,339**	**-703**	**0.40**	**0.89**

M = imports, X = exports. USD va = US dollars of value added.

4. Discussion

4.1. Global division of extractive activities

The geospatial separation between production and consumption centres has increased in recent decades, causing displacement of social and environmental impacts (Wiedmann and Lenzen, 2018). According to EUE theory, the metabolic profile of HI economies depends on importing natural resources from abroad, which are transferred from peripheries to cores via international trade. There is ample evidence that rich countries are usually net material importers, measured only as mass of trade products flow (e.g. Dittrich and Bringezu, 2010; Gonzalez-Martinez and Schandl, 2008; Pérez-Rincón, 2006; Russi et al., 2008; Weisz et al., 2006) or including the upstream raw material requirements (e.g. Giljum et al., 2015; Muñoz et al., 2009; Wiebe et al., 2012; Wiedmann et al., 2015). Nevertheless, Moran et al. (2013) recently challenged this evidence. Based on MRIO data, they concluded that, in absolute terms, HI economies are net exporters of resources, and not importers, and attributed this to higher technological efficiency. However, Dorninger and Hornborg (2015) revisited this issue using a more up-to-date version of the same MRIO database and found the opposite, i.e. that HI countries are significantly more dependent on non-HI countries than the other way around, to the extent that they are net importers of materials. The results of the present analysis, again using the same MRIO database, but an updated version for a different year, support the latter findings. We found that in the study year (2011), raw material trade mobilised 42% of domestic extractions and that HI economies were responsible for 70% of total imports, while all other economies were responsible for the remaining 30%. Therefore, only HI economies have a positive balance.

Furthermore, the discussion of EUE needs to go beyond the classical North-South division, offering more detailed assessments identifying social, political and power determinants between trade partners (Jorgenson et al., 2009). For instance, recent studies show that population density is an important explanatory variable, especially in the case of HI countries (Bruckner et al., 2012; Krausmann et al., 2008; Wiedmann et al., 2015). Our analysis confirmed that population density plays a relevant role: within the HI group, highly populated countries are more material-dependent (e.g. Japan and most EU countries) than less densely populated countries (e.g. USA, Canada). On the other hand, there are some HI economies which are net material exporters and are sparsely populated, with very heterogeneous profiles but in all cases endowed with valuable natural resources, including: oil countries (e.g. Kuwait, Oman, Saudi Arabia), mining exporters (e.g. Chile, Australia) and small European countries (e.g. Sweden, Norway). Other studies use regional or historical relations among nations to explain EUE. For example, Samaniego et al. (2017) demonstrate that despite prices (USD/kg) increasing during the 2000s with the commodities boom, South American countries had monetary deficits, which they tried to compensate for by increasing their physical exports, fuelling social conflicts and environmental deterioration. For the specific case of Colombia, an abrupt fall in prices of exports in the 1980s separated import and export flows, which were at similar levels one decade earlier (Pérez-Rincón, 2006). Further, Infante-Amate and Krausmann (2019) show that France benefited from advantageous terms of trade with its former colonies during the colonial and post-colonial period, until new power cores emerged. Generally, prices in kg/USD for exports have been falling for all income levels since 1990, although large differences remain between higher and lower income groups (Moran et al., 2013). In value added terms, Yu et al. (2014) show that some countries in South-East Asia, South Asia and Africa export large amounts of products with high embodied environmental impacts, but at the same time capture small quantities of value. Our findings align with this previous research by pointing out that: i) the trade balance of HI economies is favourable because it is the only group selling more expensive products than it buys; and ii) value added is unequally distributed among groups, being exported to a large extent by HI countries (70%, with 17% of world population) and UMI countries (24%, with 35% of world population).

4.2. Intra-national Ecologically Unequal Exchange

Most world system and EUE studies focus on the nation state, and thus knowledge about intra-national relations is limited. This knowledge gap leads to interpretative shortcomings, since countries are categorised as core, periphery or semi-periphery, but without considering internal divergences. Using the notion of internal colonialism, although not always explicitly, the theory of dependence highlights the role of regions or poorer population groups within core countries. Accordingly, some authors have identified features which could be considered peripheral or semi-peripheral in the global north. For example, Hechter (1975) reflected on the cultural grievances or status of the Irish, Scottish and Welsh populations in comparison with the English, although in that case freedom and civil rights were found not to be affected, as was, for instance, the situation of indigenous people in Latin America. This reveals the complexity of the concept when applied to heterogeneous historical-structural realities. In the Spanish context, studies in the 1970s pointed out that some regions were playing a peripheral role within the country, after specialising in extractive/low-value activities for supplying rich cores (Beiras, 1973; Naredo, 1978; Delgado Cabeza, 1981), but also from a cultural/ethnolinguistic perspective. More recently, Carpintero et al. (2015) and Sastre et al. (2015) used a socio-metabolic approach to study the direct material use of Spanish regions and revealed the location of biomass and mineral sources, including Galicia, which supply processing centres within the country. Similar imbalances between regions have been reported for Austria and for the Alpine regions of France, Germany, Italy, Liechtenstein, Switzerland and Slovenia, and their connection to the different regional economic activities (Schoder et al., 2006).

Our results show that Galicia plays a twofold role, as a core and a periphery. Therefore, it might be considered a semi-periphery in a world system, as a result of being spatially located within a rich nation and playing the role of intermediary between core and margin world regions. Net imports of raw materials from lower income economies are mainly in the form of intermediate products, which feed the metal manufacturing (aluminium) and power sectors. There are no bauxite deposits in Galicia and thus it must all be imported from abroad, mainly from Guinea. Nowadays, depletion of coal deposits and price increases in the tariff system have plunged the aluminium sector into a deep crisis, with falling activity and offshoring, which reveals the peripheral character of the region. In addition, the end of coal mining explains Galicia's increasing imports of coal (from Indonesia, USA and Russia), but a significant share of the electricity generated, along with regional primary energy from other sources, goes to sustain consumption in the rest of Spain. The only exception is the relationship between the electricity and aluminium sectors.

Two other important imported products are oil, mainly from Mexico and Egypt, and natural gas, from Nigeria. Thus, Galicia is a gateway for natural resources and energy carriers used for supporting Spanish and EU consumption, which explains its high material imports, but also its comparatively lower material footprint. When this core feature is isolated, it can be seen that Galicia also has some peripheral characteristics, such as lower value added in trade and high share of exports of primary activities, such as mining or forestry.

Beyond the particularities of Galicia, our study demonstrates the limitations of analyses on the nation-state scale. Most studies about material flows adopt either of the two extreme scales: national (or world regions) or local. Initial developments in material flow accounting (Adriaanse et al., 1997; Matthews et al., 2000) focused on the national scale, showing material consumption and trade data for a small group of Western economies. Nowadays, estimates are available for most countries (e.g., Schandl et al., 2016), and there are even long-term series (e.g. Krausmann et al., 2009). At local level, since the pioneering work of Wolman (1965) on the metabolism of cities, dozens of studies about consumption and material exchange at that scale have been performed (e.g. Kennedy et al., 2007; Metabolism of Cities, 2019). However, knowledge at a territorial meso-scale is still modest and empirical studies are scarce (Carpintero et al., 2015; Christis et al., 2016; Sastre et al., 2015; Schoder et al., 2006), possibly partly because of data limitations. This situation will likely improve with innovative methodological developments such as virtual laboratories (Geschke and Hadjikakou, 2017; Lenzen et al., 2014), spatially explicit input-output approaches (Sun et al., 2018) and similar initiatives. Finally, there is a need for better dialogue between culturalist and/or decolonialist perspectives, which analyse the consequences of colonial structures within nations and their territories and populations, with those focusing on the political economy (Grosfoguel, 2011) and the EUE.

5. Data and methodological limitations

There are several limitations associated with MRIO modelling, such as homogeneity in prices (Lenzen, 2000; Wiedmann, 2009) and geographical and sectoral aggregation errors (de Koning et al., 2015; Piñero et al., 2015; Su and Ang, 2011). Three specific uncertainty sources were explored in this work. First, we tested our hypothesis with trade balances calculated by comparing countries of origin for extractions with end-consumer countries (see Figure S2 and S3 in SI), i.e. using exclusively the MRIO approach for their estimation and treating intermediate trade product endogenously (e.g. comparing country of extraction A with country of consumption C, irrespective of whether there is an intermediary country B). No significant variations were noted at country level (Figure S2), perhaps with the exception of very open economies (e.g. the Netherlands). As expected, more pronounced variations were observed for Galicia (Figure S3), e.g. due to a port effect, raw material deficits dropped in the MRIO approach. Second, we tested the impact of setting to zero those uses coming from sub-national sources which exceeded original Eora values. We did this by running a version of our model without suppressing any quantity and found no perceptible deviations, suggesting that, at the level of analysis of the study, this assumption had no significant impact on the results. Third, regarding material flows modelled with MRIO, recent research shows that a few sectors at the beginning of the supply chain, i.e., primary sectors and basic processing, explain most of the differences between existing databases (Giljum et al., 2019). We found that our model did not estimate certain upstream material flows accurately, in particular coal coming from Indonesia. Figure S4 in SI reproduces the information in Figure 4, but employing direct flows, i.e. accounting only for mass of products crossing borders. As can be seen, direct flows from Indonesia are high, while according to our model total upstream flows are inconsistently lower. This shows that results for country pairs are more uncertain and need to be interpreted with caution. Combining MRIO with other tools, such as life cycle assessment, could be explored to overcome this limitation when estimating raw material requirements of trade products (Piñero et al., 2018).

6. Conclusions and future work

Ecologically Unequal Exchange (EUE) theory states that high-income countries and regions sustain their consumption and production because they are net importers of natural resources and outsource environmental pressures and impacts, while at the same time selling their resources at higher prices on the global market. We approached EUE on the basis of material flow accounting for a wide range of countries and in greater detail for Galicia, a Spanish region, in comparison with the rest of Spain. In particular, we compared domestic extraction, material footprint, raw material trade balances (i.e. upstream raw material supply for producing imports minus exports), terms of trade measured as price paid per kg traded and material intensity of value added flows (i.e. kg of upstream raw materials per USD of value added traded). At global level, our results align with an extensive body of previous research suggesting that in general, there are asymmetrical biophysical relationships between higher and lower income economies. This arises as a result of dissimilar terms of trade and the poorer the trade partner, the greater the asymmetry. A completely different picture emerges when tracing value added flows, since a high extractive exporting profile may not be accompanied by an equally important GDP increase due to exports. For some economies (e.g. Germany, France, Italy or Japan), the exact opposite is true, i.e. they are net importers of raw materials but exporters of value added. Therefore, in the global division of extractive activities, certain countries specialise in resource provision, others in high value-adding activities.

Following the notions of 'internal colonialism' and 'world system' theory, we tested the EUE hypothesis at sub-national scale for the case of Galicia. We found that Galicia, a high income region, is a net importer of foreign resources. This situation is exacerbated for less industrialised trade partners and in this sense Galicia presents a core profile. However, comparing material and monetary flows between Galicia, the rest of European Union and other high-income economies revealed that the region is a supplier of materials and, depending on the trade partner, a sink of value added, which are peripheral features under EUE principles. Thus, our results confirm that the dual core-periphery profile is not a dichotomy and that a region can play a twofold role depending on the exchange partner. However, for Galicia the non-core profile was less accentuated when compared with other lower income economies, which suggests a smaller inequality or a semi-peripheral role more like an upper-middle income economy. In conclusion, our findings confirm there is a global division of extractive activities. High income economies are positioned at the core, but sub-national differences in population density, natural resources endowment and division of labour bring new nuances, making EUE more complex to assess.

There were some limitations in the present analysis that need to be addressed in future research. First, adopting a dynamic approach could reveal the presence or extent of certain global convergences or show whether imbalances are increasing or stagnating. Second, we focused solely on raw material extraction and our results only show unequal material exchange, so for a more complete assessment of EUE other environmental variables should be included. Finally, applying a global MRIO model with full sub-national resolution would open the black box of the rest of Spain and allow asymmetries in material and monetary flows among all regions to be assessed. These new paths in EUE-based research are necessary in order to challenge more widespread trade theories and uncover the increasing globalised and intricate exchange networks between consumers, world regions and ecosystems.

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Supporting Information

Unequal raw material exchange between and within countries: Galicia (NW Spain) as a core-periphery economy

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1. Method description

Two approaches for estimating raw material and value added flows and trade balances were used: i) the Multi-Regional Input-Output (MRIO) model (explained in sub-section 1.1) and ii) the Material Embodied in Bilateral Trade (MEBT) model (explained in sub-section 1.2). The MRIO approach was used for calculating the material footprint, while MEBT for estimating material and value added trade balances. However, trade balances estimated following the MRIO approach are also offered for comparison (sub-section 2.1). The model built combines global MRIO data with subnational IO data (details in sub-section 1.3). Data sources are provided in Annex 1.

1.1. The Multi-Regional Input-Output (MRIO) model

The general expression in the MRIO approach for a simplified system with two regions r and s is summarized in equation 1,

$$\phi_r = \begin{pmatrix} \delta_r & \delta_s \end{pmatrix} \begin{pmatrix} L_{rr} & L_{rs} \\ L_{sr} & L_{ss} \end{pmatrix} \begin{pmatrix} y_{rr} \\ y_{sr} \end{pmatrix} = \delta' L y \tag{1}$$

where each element has a i sub-index denoting origin, while for L and y also a i sub-index for destination. ϕ_r denotes the raw material attributed to the final consumption of region r, which is composed by the final consumption of domestic products y_{rr} and imported y_{sr}. The δ_i is the raw material extraction per sectoral output in each region, which is obtained following $\delta_i = r_i \hat{q}_i^{-1}$ where r_i is the total raw material extraction by each industry and q_i refers to total sectoral output. Further, $L = (I - A)^{-1}$ is the global Leontief inverse, whose element L_{ij} indicates total input requirements of region i per unit of final demand of products from region j, and A is the global technical coefficients matrix, whose A_{ij} are estimated following $A_{ij} = Z_{ij}\hat{q}_i^{-1}$ where Z_{ij} is the intermediates matrix (further details about input output in Miller and Blair, (2009) and European Commission, et al., 2017). In the MRIO-based approach, intermediate trade among regions r and s is treated endogenously and L is estimated using domestic intermediates $A_{i=j}$ along as trade ones $A_{i\neq j}$. This feature makes possible to relate global final consumptions with indirect material requirements of intermediate trade.

1.2. The Material Embodied in Bilateral Trade (MEBT) model

In MEBT, intermediate trade among regions r and s is treated exogenously, as described in equation 2,

$$\phi_r^* = \delta_r' L_{rr}^d \hat{y}_{rr} + \delta_s' L_{ss}^d \hat{m}_{sr} - \delta_r' L_{rr}^d \hat{m}_{rs} \tag{2}$$

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where ϕ_r^* denotes the raw material attributed to consumption in region r. It is calculated adding up domestic extractions due to final demand of domestic products $\delta_r' L_{rr}^d \hat{y}_{rr}$ plus material embodied in total imports $\delta_s' L_{ss}^d \hat{m}_{sr}$ minus material embodied in total exports $\delta_r' L_{rr}^d \hat{m}_{rs}$, where m_{ij} are imports from i to j. In this case, L^d is the local Leontief inverse and uses domestic intermediates only, i.e. $A_{i=j}$, while off diagonal elements are zero, i.e. $A_{i \neq j} = 0$ (for further details see Cadarso et al., 2018). This allocates domestic extractions to both intermediate and final trade products.

In this study, equation 2 is only used for deriving the raw material trade balance between regions r and s following equation 3,

$$\rho_{rs} = \delta_s' L_{ss}^d \hat{m}_{sr} - \delta_r' L_{rr}^d \hat{m}_{rs} \tag{3}$$

If $\rho_{rs} > 0$, it can be stated that region r is a net importer of raw materials, while it is a net exporter if the opposite occurs. For comparing these flows with financial ones, two monetary variables were used: trade in value added and gross trade. Trade in value added was estimated similarly to equation 3, as equation 4 describes,

$$\beta_{rs} = \upsilon_r' L_{rr}^d \hat{m}_{rs} - \upsilon_s' L_{ss}^d \hat{m}_{sr} \tag{4}$$

but instead of δ_i, value added generated per sectoral output υ_i was defined, which was obtained following $\upsilon_i = p_i \hat{q}_i^{-1}$ where p_i is the total value added generated by each industry. Also terms are reversed and thus, if $\beta_{rs} > 0$ region r is a net exporter of value added. Results are also presented in relative terms or 'intensities' of material use per unit of value added traded. On the other hand, gross trade is measured simply using m_{ij}, that is, gross trade balance for region r is defined as $m_{rs} - m_{sr}$. Terms of trade refer to the gross monetary value per unit of material embodied in mass units.

1.3. Model construction

In figure S1, the procedure for combining global and sub-national IO data is explaining using a two to three regions model, in which Z, Y, P, x, and E, denote respectively, intermediate consumption, final demand, primary inputs, total outputs and domestic extractions. First, Galicia's input-output data were converted from euros to USD using IMF conversion rates for year 2011 (approx. 0.88 euros/USD). Next, the procedure consisted in six steps:

i) Domestic supply, use and final demand tables for Galicia were subtracted from the domestic supply, use and final demand tables of Spain available in Eora (i.e. $Z_{Gal,Gal}$ and $Y_{Gal,Gal}$ were subtracted from $Z_{SP,SP}$ and $Y_{SP,SP}$), using an *ad-hoc* correspondence scheme between both systems to a common 86 products by 61 industries scheme for the supply and use tables, and to a 86 products by 4 final demand categories for the final demand tables. It worth noting that the correspondence was done between CPC (Central Product Classification) Ver.2 followed in Galicia's IO matrices and CPC Ver.1 of Eora.

ii) Final demand and intermediate consumption tables of inter-regional flows (between Galicia and the rest of Spain) were obtained using the exports-vector from Galicia to the rest of Spain and the imports-vector from the rest of Spain to Galicia available in the Galician IO framework. For the exports from Galicia to the rest of Spain ($Z_{Gal,RoSP}$ and $Y_{Gal,RoSP}$) the domestic use shares for Spain in Eora ($Z_{SP,SP}$ and $Y_{SP,SP}$) were assumed. In contrast, for the imports to Galicia from the rest of Spain ($Z_{RoSP,Gal}$ and $Y_{RoSP,Gal}$), the import use shares of the Galician official imports use table were utilized.

iii) Subtracting inter-regional flows and domestic transactions in Galician tables from the domestic Spanish tables in Eora, the domestic intermediate consumption and final demand tables for the rest of Spain were obtained. That is, following $Z_{RoSP,RoSP} = Z_{SP,SP} - (Z_{Gal,Gal} + Z_{Gal,RoSP} + Z_{RoSP,Gal})$, and $Y_{RoSP,RoSP} = Y_{SP,SP} - (Y_{Gal,Gal} + Y_{Gal,RoSP} + Y_{RoSP,Gal})$.

iv) For imports from the rest of the world to Galicia ($Z_{RoW,Gal}$ and $Y_{RoW,Gal}$), the table of use of imports was split for each country using trade data about country of origin of imports. For exports from Galicia to the rest of the world ($Z_{Gal,RoW}$ and $Y_{Gal,RoW}$), the exports-vector for each country following custom data was distributed among industries and final demand categories, using the shares for Spain in Eora ($Z_{SP,RoW}$ and $Y_{SP,RoW}$). The utilization of specific trade data for Galicia is one difference between the model for Flanders developed by Christis et al. (2016) and this one.

v) Subtracting trade between Galicia and the rest of the world, intermediate consumption and final demand tables between the rest of the world and the rest of Spain were obtained. That is, for exports from the rest of Spain to the rest of the world $Z_{RoSP,RoW} = Z_{SP,RoW} - Z_{Gal,RoW}$ and $Y_{RoSP,RoW} = Y_{SP,RoW} - Y_{Gal,RoW}$ were followed, while for imports from the rest of the world to the rest of Spain $Z_{RoW,RoSP} = Z_{RoW,SP} - Z_{RoW,Gal}$ and $Y_{RoW,RoSP} = Y_{RoW,SP} - Y_{RoW,Gal}$ were applied.

vi) An *ad-hoc* correspondence table between primary inputs categorizations in Eora and the official Galician framework was developed. Next, the primary inputs from Galicia $P_{Gal,Gal}$ were subtracted from the Spain's primary input table in Eora $P_{SP,SP}$, and the primary inputs for the rest of Spain were obtained $P_{RoSP,RoSP}$.

After including two new regions in Eora (Galicia and the rest of Spain), the original Eora classification system is expanded from 14,839 to 14,938 industries. Maintaining an equivalence between the Spanish values in Eora and the two new regions was a priority and when official data for Galicia exceeded Eora values, these were excluded. Thus, original Spanish tables in Eora can be obtained when adding up the tables for the rest of Spain and Galicia. The potential impact in the results of those exclusions was assessed without noting any perceptible deviation.

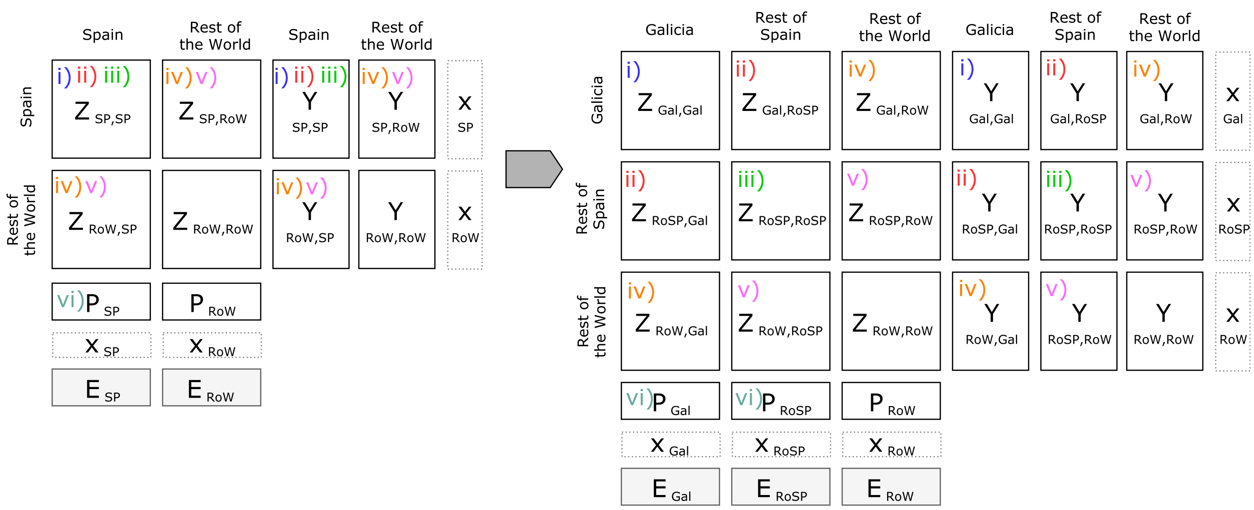

Figure S1. Construction of MRIO model with sub-national resolution for Galicia.

2. Method and data limitations

2.1 Trade balances following the MRIO approach (i.e. intermediate products considered endogenously)

Figure S2. Total trade balance in A) raw materials (RM) and B) value added (VA) in 2011 using the MRIO approach (countries below 110 million tonnes trade flow, with the exception of Galicia, and with population density above 600 inhabitants per km2 are not shown).

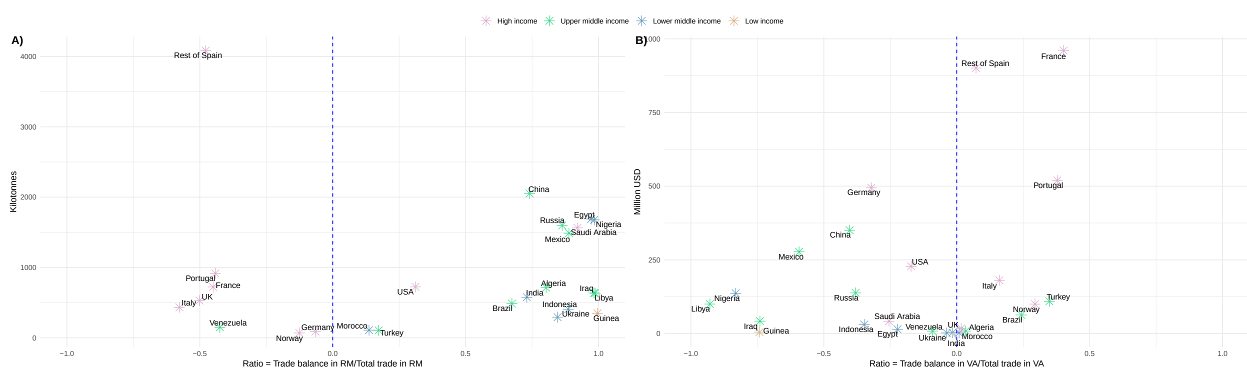

Figure S3. Trade balance in A) raw materials (RM) and B) value added (VA) for Galicia and its 25 most important raw material trade partners in 2011 using the MRIO approach. Trade balances are in absolute values on the y-axis.

2.2 Comparison between direct and embodied raw material flows

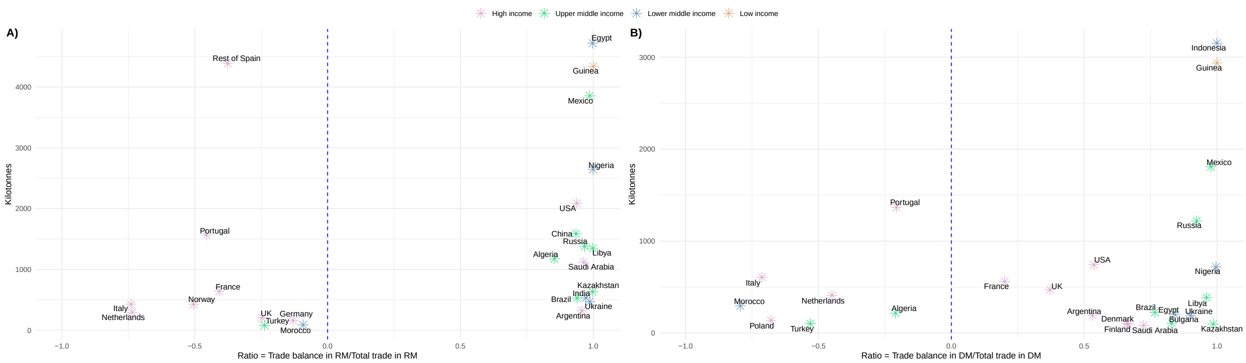

Figure S4. Trade balance in A) raw materials (RM) and B) direct materials (DM) for Galicia and its 25 most important raw material trade partners. Trade balances are in absolute values on the y-axis.

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Christis, M., Geerken, T., Vercalsteren, A., Vrancken, K.C., 2016. Improving footprint calculations of small open economies: combining local with multi-regional input–output tables. Econ. Syst. Res. 5314, 1–23. https://doi.org/10.1080/09535314.2016.1245653

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Miller, R.E., Blair, P.D., 2009. Input–Output Analysis: Foundations and extensions, Second. ed. Cambridge University Press, Cambridge.

Annex 1. Data sources

Food and Agriculture Yearbook
Spanish Ministry of Agriculture and Fishing, Food and Environment (MAPAMA)
http://www.mapama.gob.es/es/estadistica/temas/publicaciones/anuario-de-estadistica/2011/default.aspx (Accessed 23.1.2018)

Forestry Yearbook
Spanish Ministry of Agriculture and Fishing, Food and Environment (MAPAMA)
http://www.mapama.gob.es/es/biodiversidad/estadisticas/forestal_anuario_2011.aspx (Accessed 23.1.2018)

Maritime fishing captures and discharges statistics
Spanish Ministry of Agriculture and Fishing, Food and Environment (MAPAMA)
http://www.mapama.gob.es/es/estadistica/temas/estadisticas-pesqueras/pesca-maritima/estadistica-capturas-desembarcos/ (Accessed 23.1.2018)

Port statistics of the Galician Statistical Office
Galician Statistical Office (IGE)
https://www.ige.eu/web/mostrar_actividade_estatistica.jsp?idioma=gl&codigo=0307007003 (Accessed 23.1.2018)

National mining statistics
Spanish Geological Survey (IGME)
http://www.minetad.gob.es/energia/mineria/Estadistica/Paginas/Consulta.aspx (Accessed 23.1.2018)

Official Material Flow Accounts
Spanish National Statistics Institute (INE)
http://www.ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t26/p086/serie/&file=pcaxis&L=0 (Accessed 23.1.2018)

Global MRIO database Eora
Developed by the University of Sydney and own by KGM associates (http://kgm-associates.com/)
http://www.worldmrio.com/ (Accessed 23.1.2018)

Input-Output Framework Galicia 2011
Galician Statistical Office (IGE)
https://www.ige.eu/web/mostrar_actividade_estatistica.jsp?idioma=es&codigo=0307007003 (Accessed 23.1.2018)

DataComex (Trade Statistics)
Spanish Ministry of Economy, Industry and Competitiveness
http://datacomex.comercio.es/ (Accessed 23.1.2018)