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An energy transition without externalization?

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Abstract

The extended abstract presents the first results of the estimation of externalization levels of Spain through its energy transition towards 2030. . It represents a first step towards building the Calliope Spain model adapted from EuroCalliope. This first portion of the work presents the trade emissions balance for Spain for 2010 and 2015 using an Input-Output methodology. The results position Spain as a "net exporter" of emissions given that the country imports more goods and services than it exports. These insights serve as baselines to establish the country´s total internal and externalized emissions by trade partner as will be used in Calliope Spain. By examining these trends, it is possible to gain valuable insights into the correlation between international trade and greenhouse gas emissions in Spain's energy sector. This first analysis concludes with recommendations for policy.

Keywords: *Multi.Regional Input-Output; Calliope Energy Model; Trade emissions balance; Big Data*

1. Introduction

As part of its energy transition strategy, the EU has set that by 2030 member states should reduce their greenhouse gas emissions by 45% of their 1990 levels, and zero by 2050 (European Council, 2022). Policymakers rely on energy models to find what configurations of the energy system will help us reach this target. Energy system optimization models (ESOMs) process a big amount of data to reach an optimum energy system pathway according to a number of constraints. As of today, most of the ESOMs do not include environmental issues nor international trade in proper detail. One of these models is Calliope, an open-source, transparent framework for the modelling of energy systems, which also does not include environmental issues and international trade beyond the need for imports of electricity and fuel and GHG emissions.

International trade plays a double role in the energy transition. On one hand, it has traditionally increased greenhouse gas emissions through production, (often long route) transportation, and consumption of imported and exported goods and services. On the other hand, it has limited the local impacts of activities, by "externalizing" environmental impact to countries with fewer environmental regulations or lower labor standards. Thus the lack of inclusion of external trade in models that guide the energy transition seems to result in an incomplete picture of the impacts of future energy pathways.

Spain has a significant impact on global greenhouse gas emissions through the consumption of imported products. Current estimates account for a 160% economic trade deficit growth in 2022 (Ministerio de Industria Comercio y Turismo, 2023) and in 2018 imported goods were responsible for 50% of the country´s total greenhouse gas emissions (Ministerio para la Transición Ecológica y Reto Demográfico, 2020).

Spain is set to curve its emissions through the implementation of The Integrated National Energy and Climate Plan (PNIEC), which proposes the reduction of greenhouse gas emissions by 23% compared to 1990 levels by 2030 and zero by 2050 (Ministerio para la Transición Ecológica el Reto Demográfico, 2020). However, these targets refer to domestic emissions only. Neither the PNIEC nor the TIMES model used for its definition includes the externalization of environmental impacts elsewhere. Still, following the Sustainable Development Goals (SDGs), energy systems must be designed in a way that are both clean and fair. Externalization of impacts is one of the most common forms of modern colonialism (Muradian & Martinez-Alier, 2001) and must be considered in the definition of cleaner (and fairer) energy systems.

In this work, we take the energy transition scenarios in Spain for 2030 as modelled by Euro Calliope (Pickering et al., 2022) and calculate their level of externalization assuming the productive structure and terms of trade and compare it with a previous study for the year 2010 and 2015. This analysis is a first step towards building Calliope Spain, an adaptation of EuroCalliope model that will include high-level resolution externalization. Analyzing these trends, offer insights into the relationship between international trade and greenhouse gas emissions in Spain for energy and concludes with policy recommendations.

2. Literature Review

The relationship between greenhouse gas emissions and international trade has been the subject of numerous studies and academic research in recent years. Several studies have highlighted the role of international trade in driving greenhouse gas emissions. For example, researchers have found that international trade is responsible for a significant portion of global greenhouse gas emissions, with emissions embodied in trade accounting for over a quarter of global emissions (Hertwich & Peters, 2009). Another study found that emissions embodied in China's exports were responsible for 26% of the country's total carbon dioxide emissions (Peters et al., 2011).

The estimation of greenhouse gas emissions in international trade has been extensively studied, with a particular interest in accounting for embodied emissions in trade - the emissions generated in the production and transport of goods produced in one country but consumed in others. Studies have looked at the amount of carbon embodied in international trade flows from different countries to determine the magnitude of emissions from imports (Peters et al., 2012; Wyckoff & Roop, 1994). The trade emissions balance or pollution terms of trade help to understand the environmental costs that shift between countries in international trade (Duan & Jiang, 2017). The diverse methodologies on the estimation of the trade emissions balance give research a wide variety of indicators and information to choose from, including revisiting the Leontief Input-Output model (Muradian et al., 2002; Muradian & O'Connor, 2001; Sánchez-Chóliz & Duarte, 2004).

Overall, the relationship between greenhouse gas emissions and international trade is a complex and multifaceted issue, with various factors influencing the extent of the relationship. Using the Euro Calliope model, it is possible to analyze different scenarios for the Spanish energy system, such as the impact of increasing renewable energy capacity, changing electricity demand patterns, or implementing different policy measures (Pickering et al., 2022). For example, the model can be used to evaluate the potential for increasing wind and solar capacity in Spain, and to explore the optimal mix of different energy sources to meet electricity demand while minimizing costs and greenhouse gas emissions.

3. Methodology

We revisit Serrano and Dietzenbacher´s trade emissions balance methodology for the small country case (Serrano & Dietzenbacher, 2010). The case considers a world economy consisting of two regions ($r, s = 1,2$) where the country of interest is region 1 and the Rest of the World (RoW) is region 2. Each region is composed of n sectors that produce one product that might be used by other sectors as intermediate input or consumed (either at home or abroad). The model[1] $x = Ax + y$ for the estimation of the trade emissions balance of region 1 with region 2 is solved by $x = (I - A)^{-1}y$, where $L = (I - A)^{-1}$ is the Leontief inverse. The estimation associated with the production of each region is rendered from the multiplication of the gross output with a matrix of atmospheric emission coefficients defined as W^r. Each element of the matrix indicates the domestic emission of a pollutant per unit of an industry´s output for one of the regions. An important assumption is that the production technology and emission intensities are the same for the country and the RoW. The assumption is made due to a lack of data on technology or the RoW. The other assumption for this case is that the small country´s exports are considered negligible when compared to the RoW. Under these assumptions we formulate the trade emissions balance, and using Serrano and Dietzenbacher´s simplified expression we have:

$$1) \quad eb^1 = W(I - A - M)^{-1}(exp^1 - imp^1)^2$$

The variable exp^1 gives the vector of total exports and imp^1 the vector of total imports of the country. The equation will result in the trade emissions balance per type of pollutant embodied in aggregate exports and imports of region 1.

The data sources of this paper are the 2010 and 2015 Input-Output Tables from the Spanish National Statistics Institute as well as the Accounts of emissions into the atmosphere by branches of activity (Instituto Nacional de Estadística, 2015, 2018, 2022). The Input-Output Tables are categorized into 64 sectors (NACE) and 64 products (CPA), and the emissions accounts are categorized into 63 sectors and 13 pollutant substances. The estimations in this paper will consider 9 of the 13 pollutant substances (i.e., CO_2, CH_4, N_2O, SF_6, HFCs, PFCs, SO_2, NO_x, and NH_3) and will not consider sector 64 named "Activities of extraterritorial organizations and bodies" due to lack of data in the matrices. Taking this into account, the estimation is set by a 63 × 63 symmetrical environmental input-output table. In the following section, the empirical results will be discussed.

[1] We define x as the gross output of a country, A as the matrix of input coefficients and y as the final demand.

[2] For the simplified expression, M represents the import coefficients of the country. Adding A to M results in the technical input matrix that is then used in the Leontief inverse.

4. Provisional results

Using the information from the Input-Output Tables we aggregate all the NACE sectors' exports and imports for 2010 and 2015 to obtain the net exports for both years. We notice that in general imports are larger than exports in Spain for both years, rendering a negative trade balance. The data also shows two important shifts between both years. Firstly, both exports and imports increase between 2010 and 2015. Secondly, the increase in exports is greater than the imports, which then results in a decrease in the net exports between both years. We also consider the aggregate emissions per type of pollutant using the Accounts of emissions. By adding the total emissions per pollutant per sector, we compute the total emissions per type of pollutant (expressed in thousand tons), as seen in columns (1) and (2) of Table 1. The "Aggregate emissions per type of pollutant" show that the largest proportion of emissions is CH_4 for both years, notwithstanding the significant interannual decrease. Also, most of the emissions per type of pollutant decrease, except for SO_2 and NH_3. These changes are non-trivial because they affect the results in the trade emissions balance. In columns (3) to (8) we show the results from using Equation 1) and the selected datasets for 2010 and 2015:

Table 1. Aggregate emissions per type of pollutant and Trade emission balances (2010-2015). (Thousand tonnes)

	Aggregate emissions per type of pollutant		Emissions embodied in exports		Emissions embodied in imports		Trade emission balance	
	2010	2015	2010	2015	2010	2015	2010	2015
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
CO_2	217	214	147,181,607	197,265,972	169,558,395	199,385,248	-22,376,789	-2,119,277
CH_4	1,537	1,492	678,027,460	883,919,393	781,111,517	893,415,556	-103,084,057	-9,496,163
N_2O	55	55	147,181,607	190,766,377	169,558,395	192,815,827	-22,376,789	-2,049,450
PFC	0.10	0.09	80,046	78,809	92,216	79,656	-12,170	-847
HFC	15	8	8,842,934	5,891,324	10,187,372	5,954,616	-1,344,438	-63,292
SF_6	0.23	0.22	251,621	306,624	289,876	309,918	-38,255	-3,294
NO_x	880	792	484,296,687	609,524,996	557,926,842	616,073,273	-73,630,155	-6,548,277
SO_2	249	262	172,857,204	271,909,577	199,137,588	274,830,768	-26,280,384	-2,921,191
NH_3	424	443	174,685,168	254,287,229	201,243,466	257,019,100	-26,558,299	-2,731,870

Source: Own elaboration from the 2010 and 2015 Spanish Input-Output and Accounts of emissions.

Columns (3) to (8) present the aggregate emission balances for Spain in 2010 and 2015. The data shows that, for both years, the emissions embodied in the imports are higher than those embodied in the exports. Spain has a negative trade emission balance for all gases in both years. This implies that Spain would be a "net exporter" of pollution to the RoW under the assumption that both regions use the same technology to produce commodities. The goods that are produced in the exporting region create emissions within its geographical limits and are accounted for as such. Spain shifts the environmental cost of producing domestic final or intermediate consumption goods to other countries.

The imports of goods from Spain may contribute to greater carbon emissions in the RoW due to several factors, including transportation emissions and consumer trends. One of the primary contributors to carbon emissions in international trade is transportation. Goods from Spain need to be shipped to their destination, and the emissions from this transportation can be significant. The carbon footprint of transporting goods over long distances depends on the mode of transport, the distance traveled, and the weight and volume of the goods. For example, shipping by sea is less carbon-intensive than air transportation, but it can still result in significant emissions over long distances. Also, the import of goods from Spain may lead to increased consumption and associated carbon emissions. When consumers have access to a wider range of products, they are more likely to purchase them, which can increase the demand for transportation and production. This increased demand can lead to an increase in carbon emissions, particularly if the goods are produced in a carbon-intensive way.

Similarly, the use of imported inputs to export goods generates indirect emissions. These are considered in Equation 1) following Serrano and Dietzenbacher´s analysis (Serrano & Dietzenbacher, 2010). Given that the imports a greater proportion of goods than it exports, the emissions associated with them are also greater. The production of goods often involves the use of other goods and services that may themselves generate carbon emissions. For example, the production of steel for a car may involve the use of energy and raw materials that generate carbon emissions. The emissions associated with these upstream activities are known as indirect emissions, and they can be significant, particularly for goods that require a lot of resources to produce.

The results have a similar trend to those found in Serrano and Dietzenbacher. These cannot be compared directly due to the change in methodologies in the Input-Output Tables in 2008 (Instituto Nacional de Estadística, 2011). In general, Spain is a net importer country that renders larger "exports" of emissions to other countries that produced its imported goods. However, the analysis can be expanded to the emissions created by each sector. Serrano and Dietzenbacher criticize the limits of Equation 1), which holds for aggregate and broader estimations of the emissions of the economy´s trade emissions balance. To create more detailed estimations other methodologies can be adopted (Peters et al., 2012; Sánchez-Chóliz & Duarte, 2004; Serrano & Dietzenbacher, 2010).

5. Conclusions

The results of any modeling exercise are highly dependent on the assumptions and data inputs used and should be interpreted with caution and this is the case for energy modeling. In this work, we contribute to close a dangerous gap that excludes externalization in energy system optimization models. We revisited trade emissions balance estimation methodologies for the most recent data available for Spain. The results present the country as a net exporter of emissions through its import channels but not directly attributed to the consumption of imported goods. To reduce the carbon footprint of international trade, it is essential to account for emissions generated directly and indirectly. Thus the design of Calliope Spain must consider international trade in its design with enough level of detail to offer useful insights for the implementation of emission reduction policies.

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