Greenhouse Gas Emissions from intra-national freight transport: Measurement and scenarios for greater sustainability in Spain[1]

Llano, Carlos. (carlos.llano@uam.es) (†)(+)
Pérez-Balsalobre, Santiago. (santiagoj.perez@uam.es) (*)
Pérez-García, Julián. (julian.perez@uam.es) (*)

(†) Departamento de Análisis Económico: Teoría Económica e Historia Económica. Facultad de Ciencias Económicas y Empresariales. Universidad Autónoma de Madrid. Campus Cantoblanco. 28049 Madrid.; and L. R. Klein Institute and CEPREDE, Universidad Autónoma de Madrid, 28049 Cantoblanco, Madrid.
(*) Departamento de Economía Aplicada. Facultad de Ciencias Económicas y Empresariales. Universidad Autónoma de Madrid. Campus Cantoblanco. 28049 Madrid.; and L. R. Klein Institute and CEPREDE, Universidad Autónoma de Madrid, 28049 Cantoblanco, Madrid.

(+) Corresponding author.

Abstract:

Greenhouse Gas (GHG) emission is a topic of major concern worldwide. Recently, Cristea et al, 2013, provided a methodology for estimating GHG emissions associated with international trade by transportation mode at the World level. In line with this paper, we estimate an equivalent database of GHG emissions for the interregional trade flows taking place within a country (Spain). With this aim, we build a novel database on GHG emissions due to origin-destination flows between the Spanish provinces covering the period 1995-2015. For each year, we combine the industry-specific flows by four transport modes (*road*, *train*, *ship* and *aircraft*), with the corresponding GHG emission factor for each mode by tons*km, borrowed from the specialized literature. Once that the dataset of GHG emissions is obtained, we generate and analyze the temporal, sectoral and spatial pattern of the Spanish inter-regional GHG flows. We then forecast emissions for the period 2016-2030, and address the possibility of promoting transport mode shifts in search for a more sustainable freight system within the country, substituting specific origin-destination-product flows in high-polluting modes (road) to more environmental friendly alternatives (railway).

Keywords: Greenhouse gas emissions; national freight transport emissions; interregional trade by transport mode; modal shift.

---

[1] **Acknowledgements:** This paper was developed in the context of two research projects: the C-intereg Project (www.c-intereg.es) and ECO2016-79650-P from the Spanish Ministry of Economics and Innovation.

Greenhouse Gas Emissions from intra-national freight transport: Measurement and scenarios for greater sustainability in Spain

1. Introduction

Greenhouse Gas (GHG) emission is a topic of major concern in Europe and worldwide. According to several official documents, transport is responsible of around a quarter of EU GHG emissions, following the energy industries as the most polluting sector. However, while in other sectors GHG emissions have been decreasing, in transport they have risen. Moreover, the transport modes with the sharpest increase in traffic volumes have also seen the largest increase in GHG emissions: international aviation by 93%, international shipping by 32% and road transport by 17% in 2012 compared to 1990 levels.

In order to fulfill the commitments of reducing global GHG emissions in line with the Kyoto Agreement, the European Commission's (EC) 2011 White Paper on Transport put forward several non-binding longer-term targets for the transport sector, with an overall goal to cut transport GHG emissions by at least 60% by 2050 (with respect to 1990 levels). Since 2008, some reductions have been achieved and transport GHG emissions fell by 3.3% in 2012, with the biggest reduction in road (3.6%) and aviation (1.3%). However, in 2012 the EU transport emissions still remained 20.5% above 1990 levels and will need to fall by 67% by 2050 in order to meet the targets set in the 2011 White Paper on Transport.

In 2014 the European Council agreed that the EU will reduce its GHG emissions by 40% by 2030, compared to 1990 levels. Such effort will be structured in two parts: On the one hand, sectors covered by the emissions trading system (ETS) will have to lower emissions by 43% from 2005 levels. Sectors outside the ETS, which include transport, will need to reduce them by 30% from 2005 levels. For these sectors, the Effort Sharing Decision (ESD) establishes how many tones of GHG emissions each EU Member State may emit annually, and is based on the country's relative wealth (GDP per capita).

In 2012 heavy duty vehicles (HDVs) were responsible for around 30% of road transport emissions, that is, more than 5% of EU GHG emissions and around 10% of total non-ETS emissions. That implies that less than 5% of all vehicles on the road emit around 30% of road transport CO_2 emissions. The prediction for this highly polluting mode are also negative: a 2011 AEA-Ricardo study for the EC estimated that HDV emissions would rise by 22% by 2030. Furthermore, the International Transport Forum estimates that by 2050 CO_2 emissions from Europe's surface freight will increase by 28 to 55%. According to a recent report (Transport and Environment, 2015), HDVs will be responsible for 41% of total road transport CO_2 if no additional actions are adopted.

The EC has adopted a new strategy for curving this trends for the whole transport sector (European Commission, 2006, 2009) and more specifically with the ones affecting the road mode. In parallel, each member state, following international and European guidelines, are increasing efforts and resources towards the measurement and accomplishing of the general commitments. Spain is also taking its own measures, trying to promote inter-modality and the use of less polluting modes, the development of greener transport infrastructures (highway of the Sea and of railways) and the massive use of eco-friendly mobility alternatives (electric vehicles, bicycle, etc.).

With respect to the measurement of emissions within a country like Spain, one of the main instruments is the publication of the Country Inventory Report, following the European Environmental Agency (EEA). In the case of Spain, the Informative Inventory Report (IIR) is elaborated by the Spanish National Inventory System (SEI) within the Ministry of Agriculture and Fishing, Food and Environment (MAPAMA, 2017)[2]. According to the last IIR report for 2018, Energy emissions stand out for their relative weight for almost every pollutant assessed in the Spanish Inventory. Except for some cases, Energy sector is responsible of more than 50% of the pollutants emissions in the Inventory. Along the last two decades, emissions reductions have had a drastic effect on most of the pollutants with reduction rates higher than 50% in 2016 compared to 1990 levels. Within Energy, transportation accounts for a large share of current emissions, being road transportation the one with the largest share. This subcategory encompasses pollutant emissions from traffic of vehicles, including both road transportation of passengers or freight.

The methodological effort behind the estimation of the IIR is outstanding, involving the use of hundreds of variables at the production and consumption level. As in other vast statistical exercise such as the *National Accounts*, figures are obtained by the combination of a wide range of statistics and methods. For the case of transportation, emissions are estimated through a detailed process, mainly based on the available figures on the energy uses by different transport modes at the national level. Although the number of statistics is large, in essence, the estimation follows a *top-down approach*, where the specific origin-destination-product-mode of each flow is hardly considered. Thus, the exact allocation of the responsibility of the polluting activities is difficult to be addressed (Ferng, 2003). This can be critical when considering the sub-national entities within a highly decentralized country such as Spain, where not just the national government, but also the regions (Nuts 2), provinces (Nuts 3) and municipalities (Nuts 5), are co-responsible in terms of moderating GHG emission[3].

As it has been described by Cristea et al, 2013, this situation is similar to the one observed for the international freight flows worldwide. In their case, while the International Transportation Forum generates aggregate estimates about the emissions from international transport, following a top-down approach, Cristea et al, 2013 suggest an alternative bottom-up procedure, something that better allows allocating the responsibility of the pollution generated across countries and sectors. For this reason, they highlight the convenience of estimating the emissions following bottom-up approaches, by combining data on GHG emission indicators by mode and the *tons*km* moved in each one of the, knowing the origin-destination and type of product delivered.

In line with the methodology described in that paper for international freight flows, the aim of ours is estimating an equivalent database of GHG emissions for the intra and inter-provincial freight flows taking place within a country (Spain). To this regard, it is common finding estimates of GHG emissions of freight flows within a country using input-output frameworks and CGE modeling (Sanchez-Choliz and Duarte, 2004; Abrell, 2010; Lenzen et al., 2004; Machado et al., 2001; Mongelli et al, 2006). However, with the exception of interregional input-output tables (Alvaro-Fuentes, et al., 2014; López et al, 2015), the possibility of allocating the emissions to the specific origin-destination-product flows is not possible. The main reason is the scarcity of information with respect to origin-destination flows at the sectoral level in most of the countries, as suggested by Cristea et al, 2013. To this regard, to the best of our knowledge, no previous attempts are found in Spain of covering origin-destination emissions due to freight flows, with an equivalent coverage than the one done here.

---

[2] The 2018 IIR report was compiled in the context of the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP), and contains detailed information on annual emission estimates of air quality pollutants by source in Spain for the EMEP domain (excluding the Canary Islands) from 1990 onwards.

[3] It is interesting to consider, for example, how regions and cities are responsible on the development and control of transportation infrastructures and services going on within urban areas, that is, the densest ones in terms of congestion and pollution; Similarly, in Spain, Municipalities, the Diputaciones Provinciales as well as Comunidades Autonomas share with the National government different responsibilities with respect to the follow up of quality of fresh water for human consumption. Similar situations are applicable to the management of waste and residuals, etc.

Taking advantage of a previous investigation (Llano et al, 2017), where a detailed inter-provincial trade dataset was developed and used to analyze transport-mode competition within Spain for a given year (2007), we now build an extended database on intra and inter-provincial freight flows, which serve then as a base to obtain GHG emissions due to origin-destination flows between the Spanish provinces covering the period 1995-2015. The flow data is based on a permanent dataset collected and prepared within the c-intereg Project (www.c-intereg.es). Departing from this dataset, which relies on the most detailed data available in the country on origin-destination-product statistics about freight flows by transport mode (*road*, *train*, *ship* and *aircraft*), we forecast the origin-destination-product-mode flows for the period 2015-2030 by means of gravity models, using intra and inter-provincial origin-destination distance by mode, as well as our own predictions about the evolution of the provincial GDP within Spain for the same period.

In addition, we built the corresponding dataset for GHG emission for each transport mode and year, measured in terms of GHG emission factors measured in gCO_2 *per tons*km*. These indicators are obtained for the period 1995-2015 departing from estimates already published by official institutions and other sound academic publications in the field. Then, forecast for the period 2015-2030 are obtained for each mode, by extrapolating their observed time trends.

Then, for each year, we combine the industry-specific flows by four transport modes with the corresponding GHG emissions factors. Once that the dataset of GHG emissions is built, we generate and analyze the temporal, sectoral and spatial pattern of the Spanish inter-provincial GHG flows. We then address the possibility of promoting transport mode shifts in search for a more sustainable freight system within the country, substituting specific origin-destination-product flows in high-polluting modes (road) to more environmental friendly alternatives (railway).

Our results suggest that Spain has reduced GHG emissions in -10% between 1995-2015. However, our baseline scenario suggests that, to a large extent, this reduction in recent years is a *mirage* caused by the crisis, which induced great reductions in GDP and freight traffic. Even considering strong efficiency gains in the GHG emission factor for each mode, the positive expectative for the GDP for the forecasting period will induce similar intensities of freight flows than the ones observed before the crisis. Even in our alternative scenario, which assumes hypothetical modal shift in long-distance road trips to railway, the GHG emissions for 2030 still remain over the ones observed today.

The rest of the paper is structured as follows: Section 2 reviews recent literature on the measurement and reduction of GHG emissions due to freight flows both at the international, European and country level, with a final focus in Spain. Section 3 describes the empirical strategy followed on the estimation of the GHG emissions within Spain. This section is subdivided into different sub-sections dealing with the two parallel datasets considered (origin-destination freight flows vs GHG emission indicators) and the two periods considered (1995-2015 vs 2016-2030). Section 4 comprises our empirical analysis of the patterns of trade and emissions obtained for each region, product type and transportation mode, and concludes describing the main results for the suggested scenarios.

2. GHG emissions and freight flows

As it is explained in McKinnon and Piecyk, 2009, there are several alternative ways to estimate CO_2 emissions from freight transport flows. They claim that despite the interest of alternative method of estimation, the variability of figures, from official sources to academic approaches, can erode the confidence of industry stakeholders in the validity of the estimates. In their case, using UK data and focusing on the road mode, they evaluate various methods of obtaining such estimates for the road freight transport at the national level in a given year. More specifically, these authors consider 4 alternative methodologies used in the UK to estimate emissions due to road freight transportation in 2006: Two are taken directly from official government sources, while the others were calculated by the authors: i) National Environmental Accounts estimate for the 'road transport of freight'; ii) HGV-activity of British-registered haulers on UK roads using survey-based fuel efficiency estimates ; iii) All HGV-activity using survey-based fuel efficiency estimates; iv) All HGV-activity in Great Britain using test-cycle fuel efficiency estimates. Differences between these 4 approaches are due mainly to differences in the scope of the calculation, methodology and alignment of vehicle classifications. The two lowest estimates relate solely to British-registered operators and therefore provide only a partial view of road freight activity in the UK.

As commented in the introduction, another interesting reference to our paper is Cristae et al, 2013, among the short literature analyzing the GHG emissions associated to international trade using origin-destination flows by mode. These authors, collected an extensive data on worldwide trade by transportation mode and use this to provide detailed comparisons of the GHG emissions associated with output versus international transportation of traded goods. Their analysis emphasize that international transport is responsible for 33 percent of world-wide trade-related emissions, and over 75 percent of emissions for major manufacturing categories. Their analysis covered both emissions associated with production and transportation of goods delivered abroad. This wide approach allowed them to distinguish between the emissions in terms of production (output) of the products to be exported, as well as the one induced by their transportation to the final destination (transport); moreover, regarding the later, they also consider the *scale effect* (i.e. changes in emissions due to changes in demand for international transportation) and the *composition effect* (i.e. due to changes in the mode mix). They conclude that including transport dramatically changes the ranking of countries by emissions per dollar of trade. Then, they investigate whether trade inclusive of transport can lower emissions. In one quarter of cases, the difference in output emissions is more than enough to compensate for the emissions cost of transport. More interestingly for our paper, they also tested how likely patterns of global trade growth will affect modal use and emissions. According to their results, full liberalization of tariffs and GDP growth concentrated in China and India lead to transport emissions growing much faster than the value of trade, due to trade shifting toward distant trading partners.

We also find relevant papers conducting country specific analysis. To this regard, Steenhof et al., 2006 analyzed the case of Canada, where, under the Kyoto Protocol, it has committed to an average annual reduction of greenhouse gases of 6% below 1990 levels between 2008 and 2012. By that time, freight transportation contributed to 9% of Canada's emissions. Their paper showed that since 1990, increasing cross-border trade and a concurrent modal shift towards trucks were the most important determinants in increasing freight sector emissions. Then, in an attempt to predict future scenarios, looking toward 2012, they focused on the impact that different events might have in the freight contribution to control Canadian emission such as the increasing trade with Asia by railway, or advances in technology affecting trade between US and Canada.

In addition to the one commented before for the entire UK (McKinnon and Piecyk, 2009), Zanni and Bristow, 2010 analyzed the CO_2 emissions due to freight flows in London, using historical and projected road freight CO_2 emissions. They also explored the potential mitigation effect of a set of freight transport policies and logistics solutions in the period up to 2050. In spite of the effectiveness of such measures, this reduction seems only be capable of partly counterbalancing the projected increase in freight traffic, suggesting that profound behavioral measures are need if London wants to reach the CO_2 emissions reduction targets.

There are also a number of interesting papers focusing on Spain. For example, Sanchez-Choliz and Duarte, 2004, analyzed the sectoral impacts that Spanish international trade had on the levels of atmospheric pollution using an input–output model. They analyzed the direct and indirect CO_2 emissions generated in Spain and abroad due to Spanish exports and imports. Their results showed how the sectors of transport material, mining and energy, non-metallic industries, chemical and metals are the most relevant CO_2 exporters; while other services, construction, transport material and food were the biggest CO_2 importers.

Another obliged reference for the Spanish case is Cadarso et al, 2010, where these authors, interested in the growing offshoring process as a result of the fragmentation of production chains, wants to measure the CO_2 emissions due to increases in final and intermediate imports. Their main contribution is the generation of a new methodology for quantifying the impact of international freight transport by sector, which serves to assign responsibility to consumers. This methodology considers the distance and the means of transport as key elements and uses input– output methodology. It was then applied to the Spanish economy combining data from input–output tables, import data, and CO_2 emission data. The results show that the proportion of total CO_2 emissions accounted for by emissions from international freight transportation increase up to 4.16% between 1995 and 2000. As expected, the industries where this offshoring process is more intense show the greatest increases in carbon emissions related to international transport. These emissions are significantly higher than emissions embodied in domestic inputs in some of those industries where international fragmentation of production is relevant and increasing.

More recently, Alvaro-Fuentes, et al., 2014, developed a multiregional input-output model to evaluate the importance of international trade of agricultural products as well as their food-miles emissions on the proposed extended carbon footprint (ECF) measure of Spanish agriculture in the period 2000-2008. This measure of ECF incorporates the virtual carbon embodied (domestic, imported and international transport) in the consumption of Spanish products of agriculture plus the direct emissions or producer responsibility of the Spanish agriculture sector. Their results suggest that Spanish agriculture ECF in 2008 is 18.5 Mt CO_2, more than doubles the usual measure of carbon footprint. The importance of these emissions lead them to compute a carbon border tax, on both embodied emissions and international freight transport in agriculture products.

Finally, we find some additional papers discussing some potential measures to curve GHG emissions within Spain. On the one hand, López-Navarro, 2014, in the context of the EC actions towards promoting greater use of intermodal transport through, for example, by means of promoting the *'motorways of the sea'*, reviews the existing literature to examine the extent to which environmental aspects are relevant in the modal choice in the case of short se shipping and motorways of the sea. He also uses the values the EC provides to calculate external costs for the Marco Polo freight transport project proposals to estimate the environmental costs for several routes, comparing the use of road haulage with the intermodal option that incorporates the Spanish motorways of the sea. The results of this comparative analysis show that inter-modality is not always the best choice in environmental terms. The same topic is also analyzed by Pérez-Mesa et al, 2010. Furthermore, additional relevant references correspond to two technical analysis conducted by consulting groups on behalf of the Ministery of Public Works, with the aim of analysis the potential shift of freight flows from heavy trucks to railway and short-sea-shipping (SSS) (Ministerio de Fomento, 2015; 2011). Such studies will be considered later on when describing potential scenarios for reducing emissions through modal shifts.

3. Empirical strategy

Let us begin by considering a country with I provinces (for Spain, $I = 52$, given the presence of 50 provinces and 2 autonomous cities in Africa). Intra and inter-provincial transport (freight) flows are registered in volume (tons) separately for each transport mode (m), $\{F_{ij}^R;\ F_{ij}^T;\ F_{ij}^S;\ F_{ij}^A\}$, namely: road ($R$), train ($T$), ship ($S$) and aircraft ($A$). In the absence of intermediation (re-exportation schemes), the aggregate of all deliveries is obtained by adding together the corresponding mode specific flows, $F_{ij} = F_{ij}^R + F_{ij}^T + F_{ij}^S + F_{ij}^A$. The same can be said regarding product k specific flows using each of these m modes. An additional t suffix for time serves to consider the panel data configuration of our dataset.

Now, following (Cristae et al 2013), **Eq. 1** defines the general expression for estimating the GHG emission associated with each freight flows within a country:

$$E_{ijt} = \sum_k \sum_m F_{ijt}^{mk} * Dist_{ij}^{mk} * e_t^{mk} \qquad [1]$$

Where, E_{ijt} denotes the GHG emissions associated with all the freight flows from origin i to destination *j* in year *t*. Such emissions are obtained by adding across modes *m* and products *k*, for every given *i-j* trip within the country, considering the weight of the corresponding flows by mode (F_{ijt}^{mk}), the distance measured in km traveled by each mode in each delivery ($Dist_{ij}^{m}$), and a set of vectors e_t^{mk}, with the GHG emission factors produced by mode *m* for product *k* when providing one $ton*km$ of transportation services. Note that this final element also has subscript *t*, as an attempt to incorporate efficiency gains in terms of the emission factors for each mode by year. Moreover, a suffix *k* is also added, indicating that, in some cases, it will be possible to introduce certain heterogeneity within each transport mode, due to the use of specific types of vehicles, which indeed might induce different emission levels. Although our paper will not put much emphasis on this component [suffix *k* will drop from term e_t^m onwards], it is interesting to include it here for further extensions[4]. For the case of distance, we assume to be constant along time between any *i-j* dyad for each mode.

3.1. Estimating GHG emissions by mode for the period 1995-2015

Departing from **Eq. [1]** and considering the case of Spain, the estimation of the GHG emissions for each mode in the period 1995-2015 will be done by the combination of two parallel datasets: i) first, the one containing the intra and inter-provincial freight flows by year, product and mode, which contributes with the elements (F_{ijt}^{mk}) and $Dist_{ij}^{m}$, ii) second, the one containing the GHG indicators by mode (e_t^m).

The inter-provincial freight flows by mode

The flow data used in this paper are based on the most accurate data on Spanish bilateral transport flows of goods by transport mode (road, train, ship, aircraft). This rich dataset was collected and filtered in accord with the methodology described in Llano et al. (2010) and published as part of the C-intereg project (www.c-intereg.es). This data includes refinements and extensions with respect to the one published in previous papers (Llano et al, 2011; Gallego et al, 2015; Llano et al 2017). It is analyzed at the provinces level (Nuts 3), using the largest possible sectoral detail (29 products) compatible with the four transport modes.

The construction of this dataset relies on a number origin-destination transport statistics, such as: roads (Permanent Survey on Road Transport of Goods by the Ministerio de Fomento), railways (Complete Wagon and Containers flows, RENFE), ship (Spanish Ports Statistics, Puertos del Estado) and aircraft (O/D Matrices of Domestic flows of goods by airport of Origin and Destination, AENA). Since the final goal of this dataset is to serve as a base for obtaining

---

[4] Demir et al. 2014, review a number of variables determining the emission just in the road mode. These factors can be divided into five categories: vehicle, environment, traffic, driver and operations, and includes variables such as speed, acceleration, congestion, road gradient, pavement type, ambient temperature, altitude, wind conditions, fuel type, vehicle weight, vehicle shape, engine size, transmission, fuel type, oil viscosity… Similar variability can be also described for railway, ship and airplane, which suggest that the average vectors here will just be able to describe the most likely general trends.

monetary flows between regions in the country, flows not associated with economic transactions were eliminated (*i.e.:* it does not include empty trips, removals, military or fair materials moved along the country, etc.). This fact introduces differences in the levels of *tons* and *tons*km* for each mode with respect to the general statistics used by the official top-down estimates. Such feature can be seen as a drawback with respect to the final level of emission, but is also a virtue since it is more directly connected with the real economic activity capture in the National Accounts, which is usually an obliged reference to any environmental analysis. In addition, our dataset has put emphasis on cleaning intra-national freight flows from the presence of ambushed international deliveries (see Gallego et al, 2015), something that avoid double counting of transit flows, mainly by road and railway, from the *hinterlands* to the ports before/after their loading/unloading for exporting/importing to/from foreign markets.

The GHG emission indicator by mode

In addition, a dataset on GHG emission indicator per transport mode has been built upon the information offered by the specialized literature. On the one hand, there are a number of official documents offering interesting information on different environmental indicators that are useful to our goals:

The Spanish Ministry of Public Works (SMoPW = Ministerio de Fomento) regularly publishes different indicators on the overall GHG emissions produced by the transport sector. Although none of them fully fulfil the requirements of our analysis, they offer a good base for its estimation. To this regard, the SMoPW publish the following indicators:

- Total GHG emissions generated by the Spanish transport sector due to passengers and freight movements by modes. More specifically, they publish the ktCO2 equivalent produced by each of the following transport modes (road; railway; air) in a year for a long period: 1990-2015. Ship is omitted. Such figures are produced in the context of the National Inventory of GHG Emissions, where the SMoPW works in coordination with the MAPAMA, following the international methodology stablished by the European Environmental Agency (EEA). Such estimates follow a top-down approach, and are based on consumption data.
- In connection to the former, the SMoPW also publish the GHG emissions factors generated by just three transport modes (road; railway; air), measured in gCO2 equivalent per *tons*km*, due to freight deliveries within Spain. These figures are reported for the period 2005-2015. The emission factor for railway does not include indirect emissions due to electric power.
- The SMoPW also publishes aggregate figures about the traffic (measure in terms of *tons*km*) by each transport mode (road, railway, ship and air) corresponding to the internal freight flows in Spain. The largest statistical series for this indicator corresponds to 1996-2015, but it is not always fully compatible with the emission indicators commented before.

In addition to this official data, we have found interesting references for building up a set of alternative scenarios regarding the on-average GHG emission factors per transport mode and year within Spain. The main sources considered are Cristea 2013, Ministerio de Fomento (several years http://observatoriotransporte.fomento.es/OTLE/LANG_CASTELLANO/BASEDATOS/), and Monzón et al, 2009. **Table 1** summarize alternative GHG emission indexes by mode revised in the literature. For each mode, the three main references considered in our analysis appear market in pale grey. Note that in general, our estimates are prudent, compared to higher factor considered in the literature, mainly for the case of Aircraft.

In our case, the GHG emission factors finally used in the Baseline scenario are the following:

- For *road* (79.88 gCO2 per *tons*km* in 2005) and *aircraft* (149.64 gCO2 per *tons*km* in 2005). The emission factors are taken from the SMoPW for the period in which they are available (2005-2015). For the rest of the years, 2005-1995, the time series are obtained by combining our information on *tons*km* and the total emissions by mode published by the SMoPW.

- For *ship* (22.15 gCO2 per *tons*km* in 2005), since the SMoPW does not publish emission factors due to internal freight flows by ship, we estimated them considering the relative intensity of this mode with respect to the other three as reported by Monzón et al 2009, ECMT (2007), TRENDS (2003).
- For *railway*, in order to include direct plus indirect emissions due to electric power (the SMoPW does not include them in their estimates), we consider the level of emission reported by Monzón et al 2009, ECMT (2007), TRENDS (2003) for the year 2000 (22.8 gCO2 per *tons*km*). The evolution of this level during the rest of the period is obtained in the same way than for *road* and *aircraft*, by combining our information in *tons*km* for this mode, and the total emissions published by the SMoPW for *railway* (just considering direct emissions).

<< Table 1 about here>>

3.2. Predicting GHG emissions by mode for the period 2016-2030.

As in the previous section, estimating the GHG emissions for each mode in the period 2016-2030 requires the combination of different forecast exercises able to produce the equivalent elements F_{ijt}^{mk} and e_t^m. Next we describe the approach followed for each step:

- We start by estimating F_{ijt}^{mk}, the intra and inter-provincial trade flows for the period 2016-2030. This step relies on the use of the gravity equation, which implies estimating the corresponding GDPs for each of the Spanish provinces in this period, assuming a time invariant vector for the distance $Dist_{ij}^m$ and a set of control dummy variables.
- Next we obtain the corresponding predictions for the GHG emission factor e_t^m.

Forecasting the provincial GDPs for the period 2016-2030.

The aim of this section is obtaining *GDP* predictions for each Spanish province in the forecasting period. On the outset, it should be said that the Spanish Institute of Statistic (INE) publishes *GDP* and Value Added (*VA*) figures on yearly basis, both for regions (Nuts 2) and provinces (Nus 3). However, the level of disaggregation is lower for provinces, our reference spatial unit. For this reason, it is convenient to predict the evolution of *GDPs* at the regional and provincial level simultaneously, as a way to enjoy the richer information available in Spain at the Nuts 2 level.

Thus, our point of departure is the forecasts provided by CEPREDE (www.ceprede.es) at the national and regional level (Nuts 2) in Spain, with a breakdown of 23 activity branches covering the needed forecasting horizon. These forecasts have been obtained through different linked models developed by the "Lawrence R. Klein" Institute at the University Autonomous of Madrid, whose general structure is described in **Figure 1**. A more detailed description of the main macro-econometric model (Wharton-UAM) can be found in Pulido y Perez (2001), whereas the detailed methodology for design the long term international scenario is found in Moral y Pérez (2015). The Wharton-UAM model is the one providing the forecasting trends for the Spanish economy within the Project Link, an international collaborative research group for econometric modelling, coordinated jointly by the Development Policy and Analysis Division of United Nations/DESA and the University of Toronto (https://www.un.org/development/desa/dpad/project-link.html).

<< Figure 1 about here>>

The scheme for regional disaggregation of *GDP* is quite similar to the one described below for provinces, and it is based on the sectoral structure of each region in terms of *VA*, and the corresponding elasticities between the regional and national performance by sectors.

Departing from the regional figures provided by the Wharton-UAM model, the predictions for each province will be obtained considering their sectoral mix and the evolution of the regions where they belong to. With this aim, we depart from the data available in the Spanish Regional Accounts published by National Statistical Institute (INE), where provincial *GDP* and *VA* figures are published for the period 2000-2015, broken into 7 activity branches. For each province *i*, total GDP in each period *t* can be obtained by the aggregation of the *VA* for the seventh activity branches *b*, plus net production taxes *I*.

$$GDP_{i,t} = \sum_{b=1}^{7} VA_{b,i,t} + I_{i,t} \qquad [2]$$

For each branch and province (Nuts 3), the historical elasticity between the growth rate of the *VA* in volume terms (Chained Linked Volume Index, IVA) of provinces *i* (Nuts 3) and regions *r* (Nuts 2) are computed.

$$\varepsilon_{b,i}^{z} = \frac{1}{T}\sum_{t}\frac{\Delta IVA_{b,i,t}}{\Delta IVA_{b,r,t}}, \quad \forall\, 2016 < z < 2030 \qquad [3]$$

Where $VA_{b,r,t}$ is de volume index of *VA* in branch *b* from region *r* whom province *i* belongs to. These initial elasticities are harmonized to guarantee the stability of predictions, making unitary the weighted average of the elasticities in the different provinces belonging to each region.

$$\varepsilon_{b,i} = \varepsilon_{b,i}^{z} * \frac{1}{\sum_{i}\omega_{b,i} * \varepsilon_{b,i}^{z}}, \quad \forall\, 2016 < z < 2030 \qquad [4]$$

Where $\omega_{b,i}$ is the weight of province *i* over the regional VA in branch *b*.

Once these elasticities have been computed, we can obtain an initial GDP for each province *i* by multiplying them by regional forecasts in each branch[5]

$$GDP^{0}{}_{i,t+z} = \sum_{b=1}^{7} VA_{b,i,t+z-1} * \left(1 + \varepsilon_{z,i} * \Delta IVA_{b,r,t+z}\right), \quad \forall\, 2016 < z < 2030 \qquad [5]$$

Afterwards, these initial values are corrected in order to match the regional GDP with the aggregation of the provincial ones.

$$GDP_{i,t+z} = GDP^{0}{}_{i,t+z} * \frac{GDP_{r,t+z}}{\sum_{p} GDP^{0}{}_{i,t+z}}, \qquad \forall\, 2016 < z < 2030 \qquad [6]$$

Thus, the corresponding GDP figures are obtained for each province in the forecasting period, which match the regional and national predictions produced by CEPREDE. Although provincial GDP, can be decompose in the VA of 7 branches, in this paper we just use aggregate provincial GDP figures.

Forecasting inter-provincial flows in period 2016-2030.

Departing from the predictions obtained in the previous section for the *GDPs* at the province level in the period 2016-2030, we now estimate, for the same period, the corresponding intra and inter-provincial flows, split by the 4 modes, and each of the 29 types of products considered in our historical sample. This is done by means of the gravity equation, the most standard methodology

---

[5] Net taxes are treated as an additional activity branch.

to model international and interregional trade flows (Head and Mayer, 2014; LeSage and Llano, 2014). Our approach is rooted in previous articles modeling equivalent flows in Spain (Gallego et al., 2015; Llano et al, 2017; Garmendia et al, 2012; Llano et al., 2010). In our case, a baseline model is described by **Eq. [7]**:

$$F_{ijt}^{mk} = \beta_0 + \beta_1 lnY_{it} + \beta_2 lnY_{jt} + \beta_3 Own\_pro + \beta_4 lnDist_{ij}^{m} + \beta_5 Contig + X_i + X_j + \mu_{i,mk} + \mu_{j,mk} + \varepsilon_{ijmkt} \tag{7}$$

F_{ijt}^{mk} is the volume (*tons*) of freight flows delivered from province i to province j of product k in year t, transported by mode m. Note that i and j are two of the 52 Spanish provinces, so any flow where if $i = j$ is intra-provincial, while any flow with $i \neq j$ would be inter-provincial. Suffix m indicates the transport mode used in the delivery, which can take four values (R=road; S=ship; A= aircraft; T=railway). Suffix k can take 29 values, corresponding to the 29 types of products described in **Table A.4.** in the Annex. Note that as a robustness check, equivalent flows have been obtained for the intra an inter-provincial trade flows measure in current euros.

The variables lnY_{it} and lnY_{jt} are the logarithms of the nominal GDP of the exporting and importing provinces, respectively. Note that the GDP in the historical period corresponds to the official ones published by the INE, while for the forecasting period they correspond to the ones obtained in the previous section, which are compatible with the national and regional predictions offered by CEPREDE. This is the only set of time-variant variables specific to each *i-j* pair that will be taken into account when forecasting the intra and inter-provincial flows for the period 2016-2030.

In addition to these time-variant variables for the forecasting period, a number of time-invariant ones are also considered. First, as it is standard in this type of modeling, a dummy variable, *Own_Prov*, is included to control for the different nature of flows within a province and between provinces within Spain. This dummy variable takes the value one if the flow's origin and destination are the same province and zero otherwise. The anti-log of this dummy is the *own-province effect* or *home bias* extensively discussed in the literature of international trade.

The variable $lnDist^{m}_{ij}$ is the logarithm of the distance between province i and province j for each mode m. Note that, in line with Gallego et al. (2015), we have used alternative distance measures per transport mode. Each of these alternative distance is obtained as follows:

$Dist^{R}_{ij}$, which represents the most likely bilateral distance (in *km*) for deliveries by road:

(i) For all bilateral deliveries within the peninsula (47 inner provinces), we follow Zofío et al. (2014), where GIS software determines the shortest trip distance between any two places on the basis of the actual network of roads and highways (including such parameters as slope, quality and maximum legal speed). We thus obtain raw bilateral distances for a detailed picture of the Iberian Peninsula, split into more than 800 areas. These raw distances are aggregated, with averages weighted by the various populations of these areas, to produce a province-to-province matrix of inter-provincial distances.

(ii) For the three island provinces, we obtain bilateral distances between them and the inner provinces by adding the official distance traveled by ship between the islands and the main maritime ports (Cádiz for the Canary Islands, Barcelona for the Balearic Islands) to the road distance from these two main ports to each inner province. This road distance exactly corresponds to the distance described above. This treatment is justified because deliveries between inner regions and the islands are in fact made by *Ro-and-Ro* and similar strategies, with trucks loaded onto ships.

We have checked the results against alternative *distance* measures, such as actual distances reported by trucks upon their deliveries, and found them to be robust. However, we have decided to use GIS distances, as they avoid problems related to computations of intra-provincial distances traveled by trucks within each province. GIS distances are simply not affected by the huge number of short trips entailed by capillary distribution from wholesalers to retailers (see Diaz-Lanchas et al., 2013).

$Dist^{T}_{ij}$, which represents the bilateral distance (in *km*) traveled by *railway*, as reported by RENFE (the former Spanish rail monopoly). RENFE expresses data on bilateral flows between any two provinces in tons*km and tons. By dividing the first measure by the second, we obtain a fairly precise average distance traveled by trains in a given year (2007) for the main inter-provincial pairs. When a specific bilateral distance is not available, we substitute road distance.

$Dist^{S}_{ij}$,, which represents bilateral distance (in *km*) by *ship*. The distance between ports (coastal and islands provinces) is reported by the official Spanish port authority, Puertos del Estado. Again, to fill gaps in the data and in the unlikely event that an island reports flows by ship with inner regions (multimodal), we substitute road distance.[6]

$Dist^{A}_{ij}$, which represents the most likely bilateral distance (in *km*) for air transport. This is the straight-line distance computed by GIS between airport locations in Spain. For provinces with no airports, we substitute road distance.

To capture the positive effect of adjacency between provinces, we introduce the dummy variable *Contig*, which takes the value one when trading province i and j are contiguous and zero otherwise. This variable conveniently controls for higher inter-provincial trade flows between contiguous Spanish provinces. ε_{ijmkt} denotes the classical disturbance term.

The specification also includes a number of time-invariant variables that control for different factors that may affect the magnitude of the flows across provinces. Such variables are summarized in X_i; X_j:

$Coastal_i$; $Coastal_j$: a dummy indicating if the exporting or importing province are coastal or land-locked. Finally, these dummies were considered for *ship,* while for the other modes became non-significant.

$Island_i$; $Island_j$:: a dummy variable identifying the three island provinces of Spain (Islas Baleares, Las Palmas and Santa Cruz de Tenerife) as exporting regions.

External Border France/Andorra$_i$; *External Border France/Andorra*$_j$: a dummy variable identifying Spanish provinces that border on France and Andorra. This variable—taking the value 1 for border provinces and 0 otherwise—is meant to control for expected higher flows into and out of these "gateway" provinces to the EU core. A positive and significant coefficient for the variable should be interpreted as a *symptom* that these border provinces are behaving as "hubs" for international flows; in other words, their exports exceed expected inter-provincial flows (relative to their size, remoteness, etc.) because they are receiving from the EU core international imports of product k, which will be subsequently re-exported domestically (generating an *apparent inter-provincial flow*). Note that by including an equivalent dummy for importing provinces j, we also control for the potential of border provinces to behave as "hubs" and receive domestic imports for subsequent re-exportation to the EU core.

External Border Portugal/Morocco$_i$; *External Border Portugal/Morocco*$_j$: a dummy variable meant to control for the same effect as the previous variable but for Spanish provinces that border on countries to the southeast: that is, Portugal and countries in Africa. The importance of the EU core and these other markets, along with the size of Spain's border provinces, make it worthwhile to consider the effects separately.

---

[6] Note that in all cases, this will correspond to a zero flow in the regression. However, our SAR specification disallows the removal of observations from the sample (a square DO matrix is needed). We also considered (and rejected) the alternative of using zero (or infinity) for the distance variable for the island-inner region pairs.

Finally, three additional dummy variables have been added for the *road* mode, with the aim of controlling for the special case of trade between the Canary Islands and the Balearic Islands with the provinces in the Iberia peninsula, something related with the *'Ro-and-Ro'* logistic strategy. Not doing so ended in really huge predictions about the flows in the forecasting period.

The estimation of the equation adopts a pooled regression format with several fixed effects, following the standard approach in the literature as an alternative to pure panel data specifications, which will absorb the time-invariant dyadic variables such as the distance. The terms μ_{imk} and μ_{jmk} correspond to multilateral-resistance fixed effects for the origin-mode-product and the destination-mode-product, respectively. Their inclusion follows Anderson and van Wincoop (2003) and Feenstra (2002) and is meant to control for competitive effects exerted by the non-observable price index of partner provinces and by other competitors. They are also meant to capture other particular characteristics of the provinces in question. It is worth mentioning that, because of their cross-section dataset, the origin and destination fixed effects in Anderson and van Wincoop (2003) and Feenstra (2002) did not consider their interaction with time. We also cluster the residuals by α_{ijmk}. Following the most recent literature on the estimation of gravity models in presence of a large number of zero flows, we use the Poisson pseudo-maximum likelihood technique (PPML)[7]. Note that with PPML estimation, it is recommended that the endogenous variable will be included in levels rather than in logs (F_{ijt}^{mk}). Time fixed effects are not considered here due to the problems found for the forecasting exercise.

The results obtained in the estimation of the gravity model for each mode are reported in **Table A.1** in the Annex. Regressions are based just on the period 2013-2015, as an attempt to avoid the recent economic crisis. Therefore, the elasticities obtained are based on the most recent relationship between the internal trade, the provincial GDPs, the distance, and the rest of the time-invariant controls. Alternative samples and specifications has also been tested, while the one reported here offers the best results in the forecasting exercise. Having said that, it is important to stress the great sensitivity of the results in terms of levels, something that will affect the final GHG emission estimates. Note that even limiting the sample to this short window of time, and once that the zero flows have been removed in order to increase forecasting accuracy, our regressions consider between 5,103 (railway) and 64,191 (road) observations. Despite of these long panels, the R^2 obtained are reasonable high in all sectors but ship, ranging from 0.6 in railway to 0.89 in aircraft. In general, the coefficients are significant and the signs match with the expected ones. However, interesting variability is found, in line with some previous analysis (Gallego et al., 2015), for each transport mode.

Starting with *road*, whose results are the most standard with the literature, both *GDPs* for the exporting and importing province are significant and positive with values close to the unity. The coefficient for the *log* of distance is negative and close to -1, something that is in line with the standard values for international and interregional deliveries (Feenstra, 2002; Anderson and van Wincoop, 2003; Garmendia et al, 2012). The coefficients for contiguity and *OwnProv* are also positive and significant. Then, the dummies related to the *Islands* are always negative and significant.

The results for the other modes are more surprising but are easy to support: non-significant coefficients for the *GDP* in *ship* and *railway* indicates that some of the provinces more specialized in these two modes are associated with heavy industries and bulk freight movements, which -with some exceptions (País Vasco)- do not correspond to the richest regions in the country. The opposite happens with the positive and high coefficient of GDP_i of the exporting province, and the negative and significant coefficient for the GDP_j of importing province, found in *aircraft*. Such result indicates that the main exporting provinces using this mode correspond to Madrid and

---

[7] It was Silva and Tenreyro (2006) who proposed using the PPML approach, which also sorts out Jensen's inequality (note that the endogenous variable is in levels) and produces unbiased estimates of the coefficients by solving the heteroskedasticity problem.

Barcelona, while the main importers are the Canary and the Balearic Islands. This is also reflected in the *Island* dummies, as well as in the positive and significant coefficient found for the log of *distance*. This result, singular for a gravity model, match perfectly with the intuition that aircraft is more efficient for the furthest destination's.

Forecasting GHG emission factors by mode for each period 2016-2030.

Finally, it is now time to predict the evolution of GHG emission factors e_t^m for each mode *m* in the forecasting window 2016-2030. There is a complex and interesting literature on the prognosis of the efficiency gains affecting the emissions of each transportation mode (Liimatainen et al, 2013; Demir et al., 2014; Transport and Environment, 2015). The analysis of such technical literature is out of the scope of this article. Instead, we opt for a more automatic approach, consisting on the projection of the observed trends in the last 20 years (1995-2015). In order to select the best time-trend option, four different alternatives have been tested for each mode, with following specifications:

$$e_t^m = \alpha^m + \beta^m * t \qquad [8]$$

$$e_t^m = \alpha^m + \beta^m * t \ + \gamma^m * t^2 \qquad [9]$$

$$e_t^m = a^m * (b^m)^t = \alpha^m + \beta^m * ln(t) \qquad [10]$$

$$e_t^m = a^m * t^{b^m} \leftrightarrow ln(e_t^m) = \alpha^m + \beta^m * ln(t) \qquad [11]$$

Where *t* is the time trend variable, and $\alpha^m, \beta^m, \gamma^m$, are the coefficients to be estimated. For each trend specification and transport mode *m*, the statistical significance of each trend was tested by means of the *t-statistics* associated with trend coefficients (β^m, γ^m). Finally, for each mode the best time trend option was selected using the *sum of squared errors*.

Once that the best trend has been selected, and once that the baseline trend (Baseline scenario) has been forecasted, a sensitivity analysis has been performed using the confidence statistical intervals estimated for the trend coefficients β^m. Thus, for each mode we have computed an upper and lower bound by moving the trend coefficient between the 95% confidence interval estimated through the standard error Sd_{β^m} of the trend coefficients.

$$Max. \rightarrow \beta^m + 2 * Sd_{\beta^m} \qquad [12]$$

$$Min. \rightarrow \beta^m - 2 * Sd_{\beta^m} \qquad [13]$$

As we will explain in the next section, these terms will serve to define alternative scenarios. The main econometric results of this section are shown in **Table A.2** in the Annex.

<< Figure 2 about here>>

In order to illustrate the variability of the emission factors obtained, **Figure 2** plots the evolution of the *Observed*, the *Baseline*, the *Max* (upper bound) and *Min*. (lower bound) factors for each mode. Note that in all cases the evolution points out to clear gains in terms of efficiency, which can be explained by the development of greener technology, and the progressive adoption of them within each mode. None exogenous shocks regarding policy actions are considered here.

3.3. Scenarios for reducing GHG emissions by 2030

Once that the entire dataset is obtained, it is now time to define the two main scenarios regarding the modal choice for the flows. We then consider alternative sub-scenarios considering alternative measures for the GHG emission factors defined by **Eq.** from **[8]** to **[11]**. In summary, each scenario is described as follows:

Scenario 1: Baseline.

For the **Baseline scenario**, the GHG emissions are obtained combining the actual flow dataset (observed + predicted) plus the emissions factors described as benchmarks in section 3.2., that is, the ones taken from the SMoPW, combined with Monzón et al, 2009. Two alternative sub-scenarios are contemplated:

a) **Baseline-Max.:** using the 2016-2030 GHG emission factors considering the upper bound (Max.) for each year and mode, as defined by **Eq. [12]**.
b) **Baseline-Min.:** using the 2016-2030 GHG emission factors considering the lower bound (Min.) for each year and mode, as defined by **Eq. [13]**.

Scenario 2: Modal shift from road to railway.

In the second scenario the objective is to analyse additional emissions decreases due to hypothetical shifts from road to railway in certain flows. Based on findings from previous analysis (Llano et al., 2017; Ministerio de Fomento, 2015; 2011), and the descriptive analysis reported in **Figure 5** of this article, this scenario is built upon the following criteria:

i) First, for each *i-j-k-t* in the entire historical sample (1995-2015), we compute the share in tons of railway against the total tons moved for this *i-j-k-t*. Flows loaded/unloaded in the Islands and Ceuta y Melilla are excluded.
ii) Then, for each *i-j-k-t* we identify the maximum share of railway, just considering trips with distances above 600 km in the entire historical sample (1995-2015). If this share for flows by railway for *i-j-k-t* were above 40%, it will be truncated, so we make that the maximum share for each is assume to be 40%. Again, flows from/to the Islands and Ceuta y Melilla are excluded.
iii) Next, for every *i-j-k* triad with distance over 600 km, we compute load transfers from road to railway until the maximum share identified in ii) is fulfilled for this specific *i-j-k* flow. By means of this step, we impose modal shift so that the maximum shares observed in the period for a given *i-j-k* will be applied to every year in the forecasting period, with the limit of 40%.
iv) Once that the three previous steps have been applied to the whole dataset, the GHG emissions are re-calculated, considering the baseline emission factors for each mode. Then, we also consider the two alternative sub-scenarios considered before, using the upper and lower bound from the emission factors predicted for each mode. These sub-scenarios will be label as **Scenario 2-Max**. and **Scenario 2-Min**.

In a nutshell, this **Scenario 2** adopts maximum shares by railway for a given product *k*, as a benchmark for every flow of the same product *k* between any other *i-j* dyad, whose bilateral distance is above 600 km. This filter is applied along the forecasting period. The scenario is *k* specific, in order to consider the singular nature of each product (perishability, transportability, value/volume ratios, required special infrastructures for special *k* products such as dangerous substances or refrigerated loads, etc.), which may limit the likelihood of extrapolating a given share to any other product. In addition, the limit of 600 km is supported by previous analysis conducted in Spain (Llano et al., 2017; Ministerio de Fomento, 2015; 2011), which suggest that railway is competitive with road after this threshold. Although according to **Figure 5**, railway flows in *tons* agglomerates in short distances (< 200 km), a detailed view of the distribution by products suggests that such agglomeration is driven by some specific heavy products, whose performance is not applicable to the ones that are usually delivered by road. Moreover, taking into account the results revised in **Figures 3** and **4**, it sounds reasonable to try to promote modal shifts in the longest-heaviest inter-provincial flows traveling by road between the furthest-most-populated provinces [Sevilla-Madrid-Valencia-Zaragoza-Barcelona], rather than to consider alternative transfers of short-distance deliveries by road. The later are less likely to match with current railway network and absorption capacity, without additional infrastructures. Moreover, the 40% maximum share imposed in point ii), although *ad hoc*, is routed in the following facts: i) currently, as reported in **Figure 5**, the product with the largest share in Spain has 22%; ii) according to the 'White Paper in Transport' published by the EC in 2011, it is expected that between 40% and 60% of traffic in the EU will correspond to railway by 2050. Thus, assuming just 40% for the largest distance by 2030 will be a very optimistic objective in a country with a tiny share for this mode (1,9% according to official estimates).

4. Results

Our analysis starts with the main results reported in **Table 2,** which summarize the main GHG emissions due to freight flows within Spain in the period 1995-2015, and its allocation between regions (Nuts 2). Equivalent results are reported for provinces (Nuts 3) in **Table A.3.** in the Annex. According to our estimates the GHG emissions in 2015 reach a level of 10,105 kt CO_2 equivalent. In order to interpret this figure, it is convenient to consider that, according to the official Spanish inventory SEI (MAPAMA, 2017), the total GHG emission in Spain in 2015 was 335,662 ktCO_2, where 83,316 ktCO2 is attributed to the whole *'Transport'* sector, mixing both passengers and freight intra-national flows. Although there is no official allocation of this figure just for freight deliveries by each mode, the SMoPW has reported that the GHG emission attributed to freight flows in Spain (ship excluded) in 2014 reached the value of 16,661 ktCO_2. Regarding the contribution of each mode to such emissions, our estimate, as well as the official one, point out to a huge share of the road mode (95% for the official estimates; 94% for ours). Then, our estimate obtains a 3% share to ship, while the official one registers a 2%. In our case, both railway and aircraft accounts for a 1% in 2015, while in the official estimates, a*ircraft* reach a 3% while *railway* just contributes to the 0.3% of total transport emissions due to intra-national freight flows.

Difference in the levels between these estimates can be explained by a number of factors. First, it is obliged to remark that the official estimates use top-down approaches. Second, differences can be also related to the statistics used for each mode, both regarding emission factors and traffic in *tons*km*. For example, our estimates considered an emission factor of 17.4 for railway in 2015, which includes direct and indirect emissions due to the use of electric power. Official estimates by SMoPW, although do not publish the exact emission factor and the *tons*km* traveled through railways for every year, it publishes a reference factor of 6.94, which does not include indirect emissions due to electric generation. Another source of difference is the fact that our estimates about *tons*km* by each transport mode are different to the ones used by SMoPW. In our case, the data borrowed from C-intereg in tons is different than the official figures. The reason is that in C-intereg, freight flows are used as proxies to obtain monetary flows between regions. Thus, freight flows by road that do not correspond to economic transactions, such as empty trips, movements of military materials, fairs, removals, etc., are eliminated. In the case of road, the largest mode by far in terms of *tons*km* and GHG emissions, C-intereg data is based on the Spanish EPTMC survey on heavy truck road transportation. Instead, SMoPW estimates are based on a combination of this survey plus the register of movements of heavy trucks trough the Spanish networks (Aforos). As McKinnon and Piecyk, 2009, illustrated for the UK, the use of alternative sources like these ones will lead to differences in the levels of *tons*km* and emissions.

It is also worth mentioning the information reported in the rest of columns in **Table 2**. The main polluting regions (column 4) are the ones with the largest capacity of production and delivery of products within Spain, that is, Cataluña, with almost 17% of the GHG emissions, followed by Andalucía (13,6%), Castilla-León (10,5%) and Comunidad Valenciana (10,5%). Madrid region, surprisingly, just accounts for 6.5% of emissions, a lower level than expected due to its high GDP and centrality, both from the economic and geographical view point. A reason for that could be a tendency towards trading in shorter distances than other more extensive multi-provincial regions, or delivering products with higher value/volume ratios.

Indeed, in terms of *GDP* (column 5), the geographical structure of polluters changes vividly: for example, Cataluña, the largest industrialized region, just accounts for 8.27% of emissions relative to its *GDP*, while Andalucía registers the 9,5% and Madrid the 3.22%. In order to interpret this result, it is important both to consider that these calculations just include interregional exports of goods (no interregional imports), not considering the service and construction sector, which are more relevant in the richest regions.

It is also remarkable, how 63,4% of all emissions are generated by inter-regional flows, while 36,6% by intra-provincial ones. The high value of the former, where short distance trips are prevalent, are explained by the most intensive use of *road* in the shortest distance. This is associated with products with low *value-to-volume ratio*, as the ones included in categories such as stones, minerals and construction materials.

For each region, the shares of inter-regional/intra-regional flows are different. For example, La Rioja and Madrid are the regions with the largest shares of emissions due to inter-regional deliveries (89% and 81%), while Baleares (29.9%) and Andalucía (47.7%) are the ones with the lowest contribution of inter-regional flows, and the largest of the intra-regional deliveries. Note that behind this heterogeneity, the *product-mode-mix* and the *geographical extension* of each region are playing a role. For example, Andalucía has an extension of 87.599 Km^2 and includes 9 provinces, while Madrid is a single-province-region of 8.028 Km^2.

Regarding the growth rates, our results suggest that the GHG emissions due to intra-national freight flows between 2015 and 1995 has decreased by 10%, being more intense the reduction observed after the economic downturn in 2008 (-27,4%). Note that during the period 2009-2015, the Spanish economy has suffered the worst crisis in recent History, with an intense decline of internal consumption and investment, and a clear re-orientation towards international trade. All these factors have impacted to a large extent in the contraction of freight deliveries within the country, which has also converged with additional political and individual measures towards sustainability. Finally, column (8) shows the difference between GHG emissions obtained in 2030 (baseline scenario) and the ones in 2015… By now, it is enough to remark that, according to the last figure, GHG emissions due to internal freight flows in Spain are expected to rise in 51.1% in the forecasting windows. This results will be analyzed in more detail soon.

<< Table 3 about here>>

Focusing now into the bilateral relationships *vis-a-vis* between provinces (Nuts 3), **Table 3** shows the ranking of the 20 highest flows in 1995 and 2015, reporting de point of origin and destination of the trip, as well as the product and mode used in the delivery. Focusing on the left hand side panel, it is remarkable to see that, in 1995, just two out of 20 flows were inter-provincial, that is, flows with an origin different than the destination: the flow 12th corresponds to the one from Valencia to the neighboring Castellón, while the 19th to the one from Tarragona to Barcelona. Moreover, all the main flows but four (15th; 16th; 17th; 20th) corresponds to just one sector, *'Rocks, sand and salt'*, with a very low transportability (low *value/volume* ratio), highly linked to the building sector. The other three are also similar in nature, corresponding to *'Cement and* *limestone'* (15th), '*Coal'* (16th), '*Chemical products'* (17th) and '*Construction materials'* (20th). In all cases, the mode used is road. The other main flows correspond to intra-provincial flows: 1st. Barcelona-Barcelona; 2nd Valencia-Valencia; 3th Navarra-Navarra; 4th Madrid-Madrid. Note that in this analysis we are using a fine spatial scale (provinces Nuts 3). So if the region-scale (Nuts 2) had been used, all flows would have appeared to be intra-regional. The conclusions derived from the other panel (flows in 2015) is very similar: the largest flows correspond to intra-provincial flows, with just three inter-provincial ones, which indeed has scale in the ranking up to the 8th and11th position. The type of products and modes used are very similar, concentrating in the road sector, short distance and very heavy products. All these results suggest a great accumulation of deliveries in the short distance, and how the road, one of the most polluting modes, seems to be un-beatable when accessibility is crucial.

<< Figure 3 about here>>

Digging deeper in the results reported before, **Figure 3**, using a multidimensional *Sankey diagram*, plots the main GHG emissions due to inter-provincial freight flows in 2015, once the dense intra-provincial deliveries are removed. The diagram should be read from the left to the right. The first subdivision (links between columns 1-2) suggests how the overall 10,105 kt GHG emitted by internal freight flows within Spain in 2015 (Baseline scenario), 94% were produced by road, 4% by ship, and 1% for aircraft and railway. Then, focusing on road (links between columns 2-3), the main inter-provincial flows have their origin in Barcelona, Valencia, Madrid, Sevilla, Zaragoza, Navarra, Tarragona, A Coruña, Lleida, Asturias, etc. The first 7 provinces (from Zaragoza to Burgos) are important provinces as exporters by road (origin provinces), but none of them are associated with the most polluting bilateral flows in the country, which are reported by the links between columns 3 and 4. Instead, the other provinces in column (3) corresponds to the origins of the most polluting flows shown in column (4), where the province of destination and type of sector is shown. To this regard, focusing on column (4), after the general label 'Rest of Spain-Other sectors', we can identify the most polluting inter-provincial flows in the country in 2015 as follows:

1) Exports of "Stones, ground and salt" (30,600 kt CO2) by road from Valencia to Castellón.
2) Exports of "Construction materials" (29,500 kt CO2) by road from Castellón to Valencia.
3) Exports of "Woods" (21,500 kt CO2) by road from Asturias to Girona.
4) Exports of "Stones, ground and salt" (18,800 kt CO2) by road from Murcia to Alicante…

The rest of the list should be interpreted equivalently. Similar analysis could be done for the other modes, products and years.

<< Figure 4 about here>>

Next, in order to shed new light to these results and the ones to be analyzed thereafter, **Figure 4** plots two maps: in **panel A)** the main transport infrastructures are reported; **in panel B)** we have computed the kernel distribution of the intensity of traffic of Heavy Duty Vehicles (HDV) in the actual road network (highways and main roads only). The color variability corresponds to the daily intensity of HDV registered in thousands of stations located in each road, as reported by the SMoPW on yearly basis. As expected, the reddest part of the map corresponds to the metropolitan areas of Barcelona, Valencia and Madrid, followed by Zaragoza, Sevilla, Castellón, Navarra, Alicante and Murcia. Note that the intensity of traffic does not reflect the type/weight of the products being moved, or the length of the delivery, two variables with a direct impact on our GHG emissions estimates. However, it serves to illustrate the most likely routes used by the HDV when delivering products both for intra-provincial and inter-provincial flows within Spain. Moreover, it is also worth mentioning the *yellow shadows*. The ones connecting the main cities will correspond to the *corridors* used for the largest inter-provincial deliveries, which seems to be squeezed towards the Mediterranean and the Ebro axis, connecting Sevilla-Madrid-Valencia-Zaragoza-Barcelona, and less clearly, Valladolid-Burgos-Navarra and the Basque Country. Then, it is also remarkable the presence of several isolated *yellow spots*, around some other capital provinces. This can be interpreted in terms of provinces with high intra-provincial deliveries by road (some of which can be linked to inter-modal connections with railway and ship), and lower intensities of inter-provincial deliveries by road. Note that this pattern is prevalent in the southern-western part of the country, as well as in the Cantabric coast, in the north. As commented in Llano et al, 2017, the former can be also explained by a higher use of railway and ship in the northern part of the country, where the difficult orography and the heavier industrial specialization (mining and metallurgy), have promoted the use of these alternative and greener transport modes to road.

4.1. Scenarios for curving freight emissions through modal shift and efficiency gains

As suggested in section 3.1., the aim of this final section is to discuss alternative scenarios for the evolution of GHG emissions in the forecasting period 2016-2030. Before doing that, **Figure 5** offers relevant information in support of our **Scenario 2** defined in section 3.1., regarding the potential promotion of mode sifts from road to railway within Spain.

<< Figure 5 about here>>

Figure 5 is complex but very informative. On the one hand, the scatter plots correspond to the share that railway has over the total flows register for every *i-j-k* triad (*origin-destination-product*), versus the distance traveled in each delivery for these givens *origin-destination* dyad. We use different colors for each *i-j* flows by product *k*, using hollow circles for most of cases, and just colored markers for three sectors of interest. The specific share of railway is reported in the left hand side axis. Thus, for example, if railway is the only mode used for delivering product *k* from *i* to *j* (from i=‘Asturias’ to j=‘Cantabria’ of k=‘Chemical Products’) the share will reach a 100%; inversely, if zero flows are reported by railway for this *i-j-k* combination, a zero share will appear. Note that the number of 100% and 0% shares for *i-j-k* in the graphs are remarkable, since a large number of hollow circles of different colors appears in the 0% and 100% level almost for every distance and product.

In addition, **Figure 5** includes three line-graphs, measured in the right hand side axis. The one in black corresponds to the *kernel distribution* of the *tons* delivered by railway against the *distance,* considering the whole historical sample. As it can be seen easily, the shape of the distribution is clearly concentrated in the shortest distance (below 200km). Note that this reflect the actual distribution of such flows, which in theory, corresponds to a mode which is supposed to compete with road [in standard products] when trips are larger than 600 km. In order to illustrate the heterogeneity hidden within this aggregate distribution, we have also added the kernel regression of the tons of *‘Paper’* (dark orange) and *‘Transport material’* (pale blue), where the intensity of flows in larger distance is much clear.

Moreover, **Figure 5** includes three horizontal thin lines in color. They correspond to the total share registered by railway in the aggregate flows of the three sectors with the largest shares:

i) The thin red line shows the share of railway in *‘Minerals (not ECSC)’* in Spain as a whole, which accounts for the 22% along the historic period. Note that although this 22% is the largest share that any of the 29 products has for railway in the entire country, for some specific *i-j* flows of this product (with distances lower than 400 km), railway registers shares above 80% (red triangles ▲). With that, it should be emphasized that for most of the *i-j* pairs, the read triangles appear in the 0% share, and very few in the 100%. Probably, this short distance trips by railway are mainly explained by the existing interconnecting-railway-networks within industrial clusters of heavy industry, so the bulk of these products are moved very efficiently from maritime ports to factories, and from there to warehouses, storage infrastructures alike and other transformation plants, usually agglomerated in relatively short distances.

ii) The second largest average share is indicated with a green horizontal line, which corresponds to *'Coals'* (12%). The conclusions are similar to the ones commented before: we also see green diamonds (◊) with shares above 12% for specific *i-j* (mainly located between 200 km. and 400 km.).

iii) Finally, orange horizontal line indicates the total railway share for *'Paper'*, the third largest one for railway in Spain as a whole. In this case, it is interesting to see a large number of specific shares for specific *i-j*, marked with (■), in a wider range of distances. This can be interpreted as a sign that for this product, railway is a more credible alternative to road in longer distance than for the other two products, where probably the higher general share is driven by very few *i-j* specific pairs, which enjoy railway infrastructures of specific nature. More interestingly, for the *'Paper'* sector, railway will be a potential substitute for longer distance trips by road. This fact can be clearly seen in the kernel distribution for this product, plot by a dark orange thick line, which has two humps for flows of 700 km and 800 km.

Given the previous analysis, it is worth remembering that railway just accounts for a very small share of the intra-national freight flows in Spain (just 1,97% in terms of *tons*, and 3% in *tons*km,* according to official figures). Note that this small share is compatible with 100% for specific *i-j-k* triads, and total shares of 22%, 12% or 11% for the three peculiar products commented before. However, it seems really difficult to promote the mode shift from road to railway with the intention to reach a total share of 40-60% for the entire country, as the *'White Paper for Transport'* approved by the EC in 2011 has stablished.

Changing individual decisions about preferred mode uses is not easy at all. Railway can appear as the preferred option for some heavy products and certain *i-j* pairs. However, as suggested before, its total share is still below the one for other countries, and the desirable one in order to reduce emission in line with EC and Spanish strategies. A complete exploration of **Figure 5** could help to build alternative scenarios with the aim of promoting modal shift from road to alternative modes, such as railway, with reasonable low emission factors.

As explained before, this is what we have implemented in **Scenario 2**, where the maximum shares by railway observed for a given product *k* for any possible *i-j* dyad, is adopted as a benchmark for every flow of the same product *k* between any other *i-j* dyad, separated by a distance above 600 km, with a limit of 40% for the sake of greater realism. The total amount of *tons transferred* from road to railway for these long-distance deliveries are illustrated in **Figure 6**, where we have computed the *kernel regression* between the tons moved by road in the Scenario 1 (no modal shift) and Scenario 2 (with modal shift). As we can see, the total amount of tons transferred is moderate, which indicates that, due to the particular geographical features of Spain, the 600 km threshold may be too stringent. Alternative distance segments and thresholds will be analyzed in future research.

<< Figure 6 about here>>

We now focus on the evolution of the main aggregate variables combined in our empirical exercise, which are plot in **Figure 7**. The time series included (measured in growth rates) correspond to our GHG estimates (Scenario 1), the intra and inter-provincial trade flows in volume (*Freight_Ton*) and Euros (*Trade_Euros*), as well as their forecasts obtained by means of the gravity model. We also add the evolution of the Spanish GDP, mixing the official trends for the historical period and our forecast (aggregated) for 2016-2030. Moreover, *pro memoria*, we added the evolution of the GHG emissions predicted by the MAPAMA for the entire 'Transport sector' within the last Spanish Emission Inventory (MAPAMA, 2017).

First of all, it is interesting to compare the dynamics of each series before and after the crisis, in order to interpret what is obtained for the forecasting period. Before the crisis (1995-2007), the evolution of the *freight flows in tons* was more dynamic than the *GDP*, the official GHG emission estimates, and our own GHG estimates. During the crisis and the take-off that followed (2008-2015), the GDP is the series with the lowest decline, followed by the official GHG estimates and our GHG estimates. The evolution of the intra-national flows in tons and euros were more volatile than the GDP in this period. Focusing on the forecasting period, the models suggest a continuous positive trend for the GDP in Spain, followed, very closely, by the intra-national trade in Euros. However, the *freight flows in tons* appear to be more dynamic, following similar patterns to the ones observed during the pre-crisis period.

When all these trends are combined with the downward-trend GHG emission factors plot in **Figure 2**, we obtain a **Baseline-Scenario 1** which register permanent positive rates year by year, indicating higher levels of emission than in 2015. These results suggest low levels of decoupling between freight traffic and the GDP (Alises and Vassallo, 2015, so that the efficiency gains predicted in **Figure 2** will be defeated be the expected positive evolution of the economy. Having the blue line as a reference, which corresponds to the MAPAMA official predictions for this period, it is interesting to highlight that also their figures point out to an increase in GHG emissions due to the whole *'Transport sector'* in Spain.

<< Figure 7 about here>>

<< Table 4 about here>>

Zooming into these aggregate results, and considering the alternative scenarios described before, **Table 4** summarize the main results obtained at the national and regional level (Nuts 2). Columns 1 and 2 report the levels for **Scenario 1-Baseline** for 2015 and 2030. Column (3) computes the difference in terms of $ktCO_2$ along the forecasting period, just as a consequence of the inertia projected for the emission factors, which, as reflected in **Figure 2**, point out to greater efficiency in all modes. As commented before, the expected increase in freight traffic will more than compensate the emission efficiency gains, ending in an increase of 5,167 $ktCO_2$, which corresponds to the 51.1% reported in the last column of **Table 2**. Going back to **Table 4**, columns (4) and (5) report the differences for the **Scenario 1** using the **Max.** and **Min.** bounds. In both cases, our results suggest that in both sub-scenarios the larger freight traffic still drown the efficiency gains, causing larger GHG emissions than in 2015. In the case of the **Min,** the additional emissions load reaches the level of 2,760 $ktCO_2$, while in the Max. scale up to 8,018 $ktCO_2$.

Next, we move to the results obtained for **Scenario 2**, shown in columns from (6) to (8). In the case of (6), which implies the same emission factors than in Scenario 1-Baseline (column 1), but considers the modal shift from road to railway, the results obtained for 2030 suggest a total difference of emissions of 4,322 $ktCO_2$ more than Scenario 1, which is slightly lower than the one in column (3). The equivalent increase in emissions for **Scenario 2-Max**, in column (7), is

7,063ktCO$_2$, while for **Scenario 2-Min**, in column (8), is 1,989 ktCO$_2$, the lowest obtained here. Note that the results analyzed here are just the aggregation of the detailed figures obtained for each region, province, product and mode, whose analysis devotes additional space.

5. Conclusion

According to the (EU, 2017), the EU and its 28 Member States have committed to reduce their domestic emissions by at least 40 % between 1990 and 2030. In 2016, the EU GHG were already 23 % below the 1990 level. According to most recent Member States' projections based on existing measures, the 20 % target for 2020 will be met. In 2030, emissions are expected to be 30 % lower than in 1990 if no additional policies are implemented. Emissions not covered by the EU Emission Trade System (ETS) were 11 % lower in 2016 than in 2005, exceeding the 2020 target of a 10 % reduction. In addition, under the Effort Sharing Decision (ESD), EU member states must meet binding annual greenhouse gas emission targets for 2013-2020 in sectors not covered by the ETS, including transportation.

In this context, we have estimated a rich database of GHG emissions for the intra and inter-provincial flows taking place within Spain for the period 1995-2015, which considers 29 products and 4 transport modes (*road*, *train*, *ship* and *aircraft*). We have also obtained origin-destination-product-mode specific estimates for the flows and the corresponding emissions for the period 2016-2030.

Once that the new dataset is built, we generate and analyze the temporal, sectoral and spatial pattern of the Spanish inter-regional GHG flows. We then address the possibility of promoting transport mode shifts in search for a more sustainable freight system within the country, substituting specific origin-destination-product flows by road to railway. This scenario implies searching for better mode-mix attainable for the Spanish case, considering the actual flows, the transportability of the products and the sustainability of modes for each distance. In addition, three alternative trends are considered for the evolution of the GHG emission factors for each mode for the forecasting period.

The results suggest that Spain has reduced GHG emissions in -10% between 1995-2015, with larger reductions in the most polluting regions, the ones with denser industrial activity and higher trading volumes within the country. In addition, our baseline scenario suggests that this reduction might be a *mirage*, caused by the profound economic downturn suffered between 2008-2012, which induced great reductions in GDP and freight deliveries. In our baseline scenario, even considering strong efficiency gains in the GHG emission factor for each mode, the assumption of positive GDP growth rates in the next 15 years will induce similar patterns of traffic within the country than the ones observed before the crisis. Even in our alternative scenario, which assumes an important modal shift in long-distance trips from road to railway, no net gains in GHG emissions are obtained for the forecasting period.

According to these results, if our predictions for the GDP holds, and nothing else happens, even our best scenario still predicts that GHG emissions in 2030 will be higher than in 2015. Note that this is in contrast to the national and international commitments towards decarbonization of the transport sector, but maybe not so different to recent official predictions published by the Spanish government for the whole transport sector.

6. References:

Abrell, J. (2010), 'Regulating CO Emissions of Transportation in Europe: A CGE-Analysis Using Market Based Instruments', Transportation Research Part D, 15, 4, 235–39

Ahmad, N., Wyckoff, A., (2003). Carbon dioxide emissions embodied in international trade of goods. OECD Science, Technology and Industry Working Paper. 15.

Alises and Vassallo, (2015): Comparison of road freight transport trends in Europe. Coupling and decoupling factors from an Input–Output structural decomposition analysis. Transportation Research Part A 82 (2015) 141–157.

Alvaro-Fuentes, J., del Prado, A., Yañez-Ruiz, D.R., (2014): Greenhouse gas mitigation in the agricultural sector in Spain. Mitig. Adapt. Strateg. Glob. Change. http:// dx.doi.org/10.1007/s11027-014-9596-x (in press).

Anderson, J. E. & van Wincoop, E. (2003) Gravity with gravitas: a solution to the border puzzle, American Economic Review, 93, 170–192.

Cadarso María-Ángeles, Luis-Antonio López, Nuria Gómez, María-Ángeles Tobarra (2015): CO2 emissions of international freight transport and offshoring: Measurement and allocation. Journal of Cleaner Production 103 (2015) 423e436

Cadarso, M.A., Gómez, N., López, L.A., Tobarra, M.A., (2010): CO2 emissions of international freight transport and offshoring: measurement and allocation. Ecol. Econ. 69, 1682e1694. doi:10.1016/j.ecolecon.2010.03.019

Cadarso, M.A., López, L.A., Gomez, N., Tobarra, M.A., (2012): International trade and shared environmental responsibility by sector. An application to the Spanish economy. Ecol. Econ. 83, 221e235.

Cansino, J.M., Cardenete, M.A., Ordóñez, M., Roman, R., (2012): Economic analysis of greenhouse gas emissions in the Spanish economy. Renew. Sustain. Energy Rev. 16 (8), 6032e6039.

Cristea A., David Hummels, Laura Puzzello, Misak Avetisya (2013): Trade and the greenhouse gas emissions from international freight transport. Journal of Environmental Economics and Management 65, 153–173.

Demir E., Bektas T., Laporte G. (2014): A review of recent research on green road freight transportation. European Journal of Operational Research 237, 775–793.

Diaz-Lanchas, J., Llano-Verduras C., Zofío J. (2013): ‘Trade Margins, Transport Cost Thresholds, and Market Areas: Municipal Freight Flows and Urban Hierarchy’, no. 2013/10, Working Papers in Economic Theory from Universidad Autónoma de Madrid (Spain), Department of Economic Analysis (Economic Theory and Economic History).

ECMT (2007): “Cutting transport CO2 emissions: what progress?”, European Conference of Ministers of Transport, OECD publications, Paris, pp. 264.

Endresen, O., Sorgard, E., Sundet, J.K., Dalsoren, S.B., Isaksen, I.S.A., Berglen, T.F., Gravir, G., (2003). Emission from international sea transportation and environmental impact. Journal of Geophysical Research 108 (D17), 4560. doi:10.1029/2002JD002898.

EU: Two years after Paris Progress towards meeting the EU's climate commitments. https://ec.europa.eu/clima/sites/clima/files/strategies/progress/docs/swd_2017_xxx_en.pdf

European Commission, (2006). Keep Europe Moving: Sustainable Mobility for Our Continent, Luxembourg.

European Commission, (2009). EU Energy and transport in figures 2009. Directorate – General for energy and Transport. EC, Brussels.

Feenstra R (2002). Border effect and the gravity equation: consistent methods for estimation, Scottish Journal of Political Economy, 49(5), 1021–1035.

Feo, M.; Espino, R.; García, L. (2011) An stated preference analysis of Spain freight forwarders modal choice on the south-west Europe motorway of the sea. Transp. Policy 2011, 18, 60–67.

Ferng, J.J., (2003). Allocating the responsibility of CO2 over-emissions from the perspectives of benefit principle and ecological deficit. Ecological Economics 46, 121–141.

Gallego N., Llano C., De la Mata T., Díaz-Lanchas J. (2015): ‘Intranational Home Bias in the Presence of Wholesalers, Hub-Spoke Structures and Multimodal Transport Deliveries’, *Spatial Economic Analysis.* **10** (3), 369-399.

Garcia, L.; Feo, M. (2009) European common transport policy and short-sea shipping: Empirical evidence based on modal choice models. Transp. Rev., 29, 239–259.

Garmendia A., Llano-Verduras C., Minondo A., Requena-Silventre F. (2012): ‘Networks and the Disappearance of the Intranational Home Bias’, *Economic Letters* **116**, 178–182.

Head, K. and Mayer, T., (2014). Gravity Equations: Workhorse, Toolkit, and Cookbook. Chapter 3 in Gopinath, G, E. Helpman and K. Rogoff (eds), vol. 4 of the Handbook of International Economics, Elsevier: 131–-195.

Kamakaté, F. Y L. Schipper (2008): Trends in truck freight energy use and carbon emissions in selected OECD countries from 1973 to 2003, Transportation Research Board, TRB, National Research Council, Washington.

LeSage, James P., Carlos Llano-Verduras (2014). “Forecasting spatially dependent origin and destination commodity flows”. Empirical Economics, January 2014, 1-20. DOI: 10.1007/s00181-013-0786-2

Lenzen, M. (1999): Total requirements of energy and greenhouse gases for Australian transport, Transportation Research Part D: Transport and Environment 4, Elsevier, Amsterdam, 265-290 pp.

Lenzen, M., Pade, L.L., Munksgaard, J., 2004. CO2 multipliers in multi-region input– output models. Economic System Research 16 (4), 391–412.

Liimatainen H., Inger Beate Hovi, Niklas Arvidsson, Lasse Nykänen, (2015) "Driving forces of road freight CO2 in 2030", International Journal of Physical Distribution & Logistics Management, 45, 3, 260-285, https://doi.org/10.1108/IJPDLM-10-2013-0255

Llano C., De la Mata T., Díaz-Lanchas J., Gallego N. (2017) Transport-mode competition in intra-national trade: An empirical investigation for the Spanish case. Transportation Research Part A 95, 334–355.

Llano C., Esteban A., Pulido A., Pérez J. (2010): 'Opening the Interregional Trade Black Box: The C-intereg Database for the Spanish Economy (1995–2005)', *International Regional Science Review*, **33**, 302-337.

López L.A., María-Angeles Cadarso, Nuria Gómez, María-Angeles Tobarra (2015) Food miles, carbon footprint and global value chains for Spanish agriculture: assessing the impact of a carbon border tax. Journal of Cleaner Production 103, 423-436.

López-Navarro Miguel Ángel (2014): Environmental Factors and Intermodal Freight Transportation: Analysis of the Decision Bases in the Case of Spanish Motorways of the Sea

MAPAMA (2017): Sistema Español de Inventario de Emisiones: http://www.mapama.gob.es/es/calidad-y-evaluacion-ambiental/temas/sistema-espanol-de-inventario-sei-/volumen2.aspx

Machado, G., Schaeffer, R., Worrell, E., (2001). Energy and carbon embodied in the international trade of Brazil: an input–output approach. Ecological Economics 39, 409–424.

McKinnon (2015): European Freight Transport Statistics: Limitations, Misinterpretations and Aspirations. Report prepared for the 15th ACEA Scientific Advisory Group Meeting http://www.acea.be/uploads/publications/SAG_15_European_Freight_Transport_Statistics.pdf

McKinnon, A.C.; Piecyk M.I. (2009) Measurement of CO2 emissions from road freight transport: A review of UK experience. Energy Policy 37 (2009) 3733–3742

Miller (2016): Reducing CO2 emissions from road transport in the European Union: An evaluation of policy options: https://www.theicct.org/sites/default/files/publications/ICCT_EU-CO2-policies_201606.pdf

Ministerio de Fomento (2011): OBSERVATORIO DEL TRANSPORTE INTERMODAL TERRESTRE Y MARÍTIMO. Documento Final. https://www.fomento.gob.es/NR/rdonlyres/DF10A112-74FF-482F-8953-67DE0DDF3D24/103643/OBSERVATORIO_Documento_Final.pdf

Ministerio de Fomento (2015): ESTUDIO PARA EL DESARROLLO DE AUTOPISTAS FERROVIARIAS EN LA PENÍNSULA IBÉRICA, https://www.fomento.gob.es/NR/rdonlyres/58D8E964-F722-4539-A3D7-DA52FFDC9602/134015/EstudioAutopistasFerroviarias2015.pdf

Mongelli, I., Tassielli, G., Notarnicola, B., (2006). Global warming agreements, international trade and energy/carbon embodiments: an input–output approach to the Italian case. Energy Policy 34 (1), 88–100.

Monzón. A., Pérez P., Di Ciommo, F. (2009). La Eficiencia energética y ambiental de los modos de transporte en España. Consejo Superior de Cámaras. https://www.researchgate.net/publication/265927638_LA_EFICIENCIA_ENERGETICA_Y_AMBIENTAL_DE_LOS_MODOS_DE_TRANSPORTE_EN_ESPANA

Moral Cancedo, J y J. Pérez García (2015): «Feeding Large Econometric Models by a Mixed Approach of Classical Decomposition of Series and Dynamic Factor Analysis: Application to Wharton-UAM Mode», Estudios de Econonía Aplicada., Vol. 3, 2015, pp. 487-512.

Pérez-Martínez, P.J (2009): The vehicle approach for freight road transport energy and environmental analysis in Spain», Eur. Transp. Res. Rev., Vol. 1(2), 2009, pp. 75-85.

Pérez-Mesa, J.C.; Céspedes, J.J.; Salinas, J.A (2010). Feasibility study for a Motorway of the Sea (MoS) between Spain and France: Application to the transportation of perishable cargo. Transp. Rev., 30, 451–471.

Piecyk Maja I.; Alan C. McKinnon (2010): Forecasting the carbon footprint of road freight transport in 2020. Int. J. Production Economics 128 (2010) 31–42

Pulido San Román, A. y J. Pérez García, J. (2001). Modelos Econométricos. Ed. PIRAMIDE Madrid.

Sánchez-Chóliz, J., Duarte, R., (2004). CO2 emissions embodied in international trade: evidence for Spain. Energy Policy 32, 1999–2005.

Silva, J. and Tenreyro, S. (2006). "The log of gravity", *Review of Economics and Statistics*, **88**, 4, 641-658.

Steenhof Paul, Clarence Woudsma, Erik Sparling (2006): Greenhouse gas emissions and the surface transport of freight in Canada. Transportation Research Part D 11 (2006) 369–376

Steenhof, P., C. Woudsma Y E. Sparling (2006): «Greenhouse gas emissions and the surface transport of freight in Canada», en: Transportation Research Part D: Transport and Environment 11, Elsevier, Amsterdam, 369-376 pp.

Tarancón, M.A., del Río, P., (2007). Structural factors affecting land-transport CO2 emissions: a European comparison. Transportation Research Part D: Transport and Environment 12 (4), 239–253.

Transport and Environment (2015) "Too big to ignore: truck CO 2 emissions in 2030". https://www.transportenvironment.org/publications/too-big-ignore-%E2%80%93-truck-co2-emissions-2030

TRENDS (2003): «Calculation of indicators of environmental pressure caused by transport, Main report», European Commission, Office for Official Publications of the European Communities, Luxembourg.

Van Veen-Groot, D., Nijkamp, P., (1999). Globalisation, transport and the environment: new perspectives for ecological economics. Ecological Economics 31, 331–346.

Van Veen-Groot, D.B., Njkamp, P., van den Bergh, C.J.M., (2001). A scenario study of globalization impacts on international transport and the environment: an application to the Dutch paper industry. Journal of Environmental Planning and Management 44 (1), 21–40.

Van Wee, B., P. Janse Y R. Van Den Brink (2005): "Comparing energy use and environmental performance of land transport modes", Transport Reviews 25, 3-2.

Vohringer Frank, Jean-Marie Grether and Nicole A. Mathys. Trade and Climate Policies: Do Emissions from International Transport Matter? The World Economy (2013), 280-302 doi: 10.1111/twec.12052

Wiedman, T., Lenzen, M., Turner, K., Barret, J., 2007. Examining the global environmental impact of regional consumption activities —Part 2: Review of input–output models for the assessment of environmental impacts embodied in trade. Ecological Economics 61, 15–26.

Zanni Alberto M., Abigail L. Bristow (2010): Emissions of CO2 from road freight transport in London: Trends and policies for long run reductions. / Energy Policy 38 (2010) 1774–1786.

Zofío, José & Condeço-Melhorado, Ana & Maroto Sanchez, Andres & Gutiérrez, Javier. (2014). Generalized transport costs and index numbers: A geographical analysis of economic and infrastructure fundamentals. Transportation Research Part A Policy and Practice. 67. 10.1016/j.tra.2014.06.009.

Tables

Table 1. Review of alternative values for GHG emission factors by mode.

	CO$_2$ emission intensity (gCO$_2$/T*Km)	Type of Energy	Scope	Source
Ship	**10.1**	**Total**	**World**	**Cristea et al., 2013**
	21.37*	**Total**	**Spain**	**Spanish Ministry of Public Works (Fomento), 2016**
	30.9	**Total**	**Spain**	**ECMT (2007), TRENDS (2003)** cited in Monzón et al. (2009).
	15.5	Fueloil	España	Góngora (2008) cited in Monzón et al. (2009).
	18.9	Fueloil	Global	Kristensen (2002) cited in Monzón et al. (2009).
	20	Fueloil	Australia	Lenzen (1999) cited in Monzón et al. (2009).
	23.4	Fueloil	EEUU	Kamakaté y Schipper (2007) cited in Monzón et al. (2009).
	32.8	Fueloil	Canada	Steenhof (2006) cited in Monzón et al. (2009).
	44	Fueloil	Holanda	Van Bee (2005) cited in Monzón et al. (2009).
Railway	**22.7**	**Total**	**World**	**Cristea et al., 2013**
	6.94 (for 2015)	**Total**	**Spain**	**Spanish Ministry of Public Works (Fomento), 2016**
	22.8*	**Mix**	**UE 15**	**ECMT (2007), TRENDS (2003)** cited in Monzón et al. (2009).
	17.7	Mix	Canada	Steenhof (2006) cited in Monzón et al. (2009).
	19.4	Mix	EEUU	Kamakaté y Schipper (2007) cited in Monzón et al. (2009).
	40	Mix	Australia	Lenzen (1999) cited in Monzón et al. (2009).
	44	Mix	Holanda	Van Bee (2005) cited in Monzón et al. (2009).
	45	Gasóleo y Mix	Holanda	Van Bee (2005) cited in Monzón et al. (2009).
Road	**119.7**	**Total**	**World**	**Cristea et al., 2013**
	83.93*	**Total**	**Spain**	**Spanish Ministry of Public Works (Fomento), 2016**
	123.1	**Mix**	**UE 15**	**ECMT (2007), TRENDS (2003)**
	110	Diesel. Art. Trucks.	Australia	Lenzen (1999) cited in Monzón et al. (2009).
	160.7	Diesel. Art. Trucks.	Canada	Steenhof (2006) cited in Monzón et al. (2009).
	226.5	Diesel. Road total	France	Kamakaté y Schipper (2007) cited in Monzón et al. (2009).
	260	Diesel. Rigid. Trucks.	Australia	Lenzen (1999) cited in Monzón et al. (2009).
	490.2	Diesel. Rigid. Trucks.	Canada	Steenhof (2006) cited in Monzón et al. (2009).
Air	**809.2**	**Total**	**World**	**Cristea et al., 2013**
	139.72*	**Total**	**Spain**	**Spanish Ministry of Public Works (Fomento), 2016**
	358.6	**Kerosene**	**UE 15**	Steenhof (2006)

Note: figures market with an * are the ones used as benchmark for each mode in the reference year.

Source: Own elaboration departing from the information published by several sources: Cristea et al., 2013; Ministerio de Fomento (www.fomento.es); See Monzón et al. (2009) for a larger list of references.

Table 2. GHG emissions by regions (Nuts 2). Structure and evolution. ktCO$_2$ eq.

	2015					Growth rates (%)		
	Total	**Intra-regional**	**Inter-regional**	**%**	**Total/GDP**	**2015-1995**	**2015-2009**	**2030-2015**
	(1)	(2) in % of (1)	(3) in % of (1)	(4)=(1)/Spain	(5)	(6)	(7)	(8)
Andalucía	1,378.78	52.3%	47.7%	13.6%	0.951	-11.6%	-30.4%	59.1%
Aragón	603.35	29.5%	70.5%	6.0%	1.804	4.4%	-19.3%	50.2%
Asturias	304.01	23.2%	76.8%	3.0%	1.433	-28.1%	-33.4%	43.3%
Baleares	30.73	70.1%	29.9%	0.3%	0.112	26.9%	-20.1%	76.8%
Canarias	105.93	46.1%	53.9%	1.0%	0.259	50.9%	-12.5%	49.2%
Cantabria	189.80	22.6%	77.4%	1.9%	1.556	-21.3%	-15.7%	51.3%
Castilla y León	1,061.88	39.1%	60.9%	10.5%	1.979	4.2%	-27.4%	46.1%
C. - La Mancha	807.23	28.4%	71.6%	8.0%	2.156	2.5%	-33.2%	58.6%
Cataluña	1,699.45	46.1%	53.9%	16.8%	0.827	-24.4%	-29.2%	52.5%
C. Valenciana	1,063.11	41.1%	58.9%	10.5%	1.055	-11.8%	-26.4%	55.4%
Extremadura	225.97	42.5%	57.5%	2.2%	1.294	7.4%	-32.6%	81.0%
Galicia	700.12	42.5%	57.5%	6.9%	1.243	-5.5%	-24.7%	53.9%
Madrid	656.57	15.3%	84.7%	6.5%	0.322	0.9%	-29.7%	17.5%
Murcia	342.43	22.3%	77.7%	3.4%	1.214	1.0%	-13.6%	63.3%
Navarra	323.64	24.3%	75.7%	3.2%	1.743	-4.6%	-18.8%	59.6%
País Vasco	503.82	18.5%	81.5%	5.0%	0.758	-26.2%	-29.1%	36.2%
Rioja, La	107.75	10.9%	89.1%	1.1%	1.372	-3.2%	-18.7%	32.2%
Ceuta	0.39	0.0%	100.0%	0.0%	0.025	1045.1%	3950.7%	-36.0%
Melilla	0.24	0.0%	100.0%	0.0%	0.016	1931.9%	570.2%	76.0%
Total-Spain	**10,1052.1**	**36.6%**	**63.4%**	**100.0%**	**0.936**	**-10.0%**	**-27.4%**	**51.1%**

Pro memoria: Total official GHG emission in Spain in 2015= 335,662 ktCO$_2$; Total official GHG emission of the Transport sector (passengers + freight flows) in Spain in 2015= 83,316 ktCO$_2$; GHG emission attributed to Freight flows in Spain (ship excluded) by SMoPW (year 2014) = 16,661 ktCO2.

Source: Own elaboration.

Table 3. Ranking of the 20 largest flows in terms of GHG emissions within Spain by Origin-destination-product-mode. 1995 vs 2015.

	1995						2015					
Rank	**Origin**	**Destination**	**Product**	**Mode**	**Emis. ktCO$_2$**	**% (overall in the year)**	**Origin**	**Destination**	**Product**	**Mode**	**Emis. ktCO$_2$**	**% (overall in the year)**
1º	Barcelona	Barcelona	Rocks, sand and salt	Road	218.0	1.94%	Barcelona	Barcelona	Rocks, sand and salt	Road	79.8	0.79%
2º	Valencia	Valencia	Rocks, sand and salt	Road	86.8	0.77%	Madrid	Madrid	Rocks, sand and salt	Road	43.2	0.43%
3º	Navarra	Navarra	Rocks, sand and salt	Road	73.8	0.66%	Lleida	Lleida	Rocks, sand and salt	Road	39.0	0.39%
4º	Madrid	Madrid	Rocks, sand and salt	Road	73.4	0.65%	Valencia	Valencia	Rocks, sand and salt	Road	36.4	0.36%
5º	Granada	Granada	Rocks, sand and salt	Road	56.7	0.50%	Castellón	Castellón	Rocks, sand and salt	Road	33.7	0.33%
6º	Murcia	Murcia	Rocks, sand and salt	Road	50.4	0.45%	Barcelona	Barcelona	Processed food products	Road	32.9	0.33%
7º	Girona	Girona	Rocks, sand and salt	Road	48.6	0.43%	Sevilla	Sevilla	Rocks, sand and salt	Road	32.5	0.32%
8º	Sevilla	Sevilla	Rocks, sand and salt	Road	41.4	0.37%	Valencia	Castellón	Rocks, sand and salt	Road	30.6	0.30%
9º	Lugo	Lugo	Rocks, sand and salt	Road	41.1	0.37%	Girona	Girona	Rocks, sand and salt	Road	30.4	0.30%
10º	Castellón	Castellón	Rocks, sand and salt	Road	40.6	0.36%	Almería	Almería	Cement and limestone	Road	29.9	0.30%
11º	Lleida	Lleida	Rocks, sand and salt	Road	40.0	0.36%	Castellón	Valencia	Construction materials	Road	29.5	0.29%
12º	Valencia	Castellón	Rocks, sand and salt	Road	36.9	0.33%	Burgos	Burgos	Rocks, sand and salt	Road	29.0	0.29%
13º	Asturias	Asturias	Rocks, sand and salt	Road	33.6	0.30%	Barcelona	Barcelona	Cement and limestone	Road	28.1	0.28%
14º	Málaga	Málaga	Rocks, sand and salt	Road	33.4	0.30%	Granada	Granada	Rocks, sand and salt	Road	25.1	0.25%
15º	Barcelona	Barcelona	Cement and limestone	Road	31.8	0.28%	Navarra	Navarra	Rocks, sand and salt	Road	24.1	0.24%
16º	León	León	Coal	Road	30.1	0.27%	Cantabria	Cantabria	Rocks, sand and salt	Road	22.7	0.22%
17º	Barcelona	Barcelona	Chemical products	Road	29.8	0.27%	Alicante	Alicante	Rocks, sand and salt	Road	22.3	0.22%
18º	Toledo	Toledo	Rocks, sand and salt	Road	29.8	0.27%	Coruña, A	Coruña, A	Woods	Road	22.1	0.22%
19º	Tarragona	Barcelona	Rocks, sand and salt	Road	29.2	0.26%	Asturias	Girona	Woods	Road	21.5	0.21%
20º	Barcelona	Barcelona	Construction materials	Road	281	0.25%	Barcelona	Barcelona	Chemical products	Road	21.1	0.21%

Source: Own elaboration.

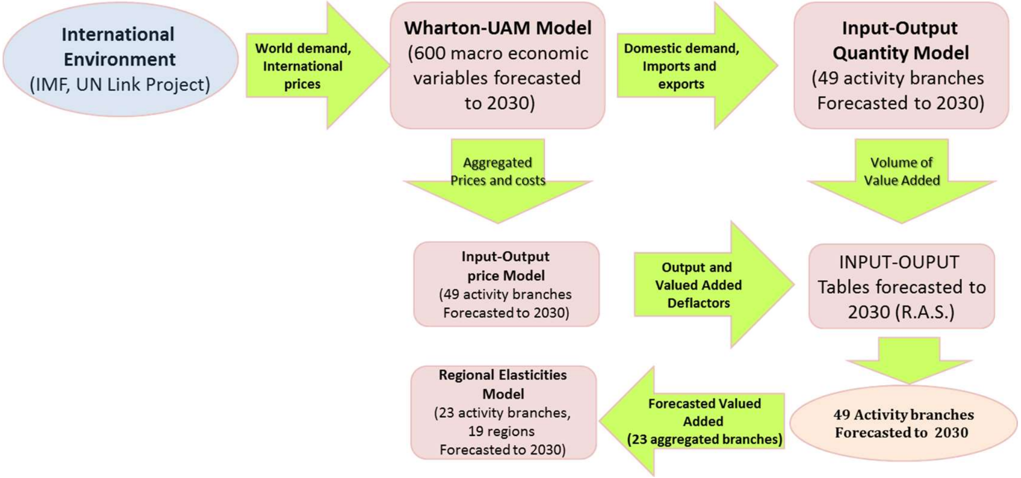
Table 4. GHG emission scenarios for the period 2015-2030 in ktCO_2.

	Scenario 1					Scenario 2		
		Baseline		Max	Min	Baseline	Max	Min
	2015	2030	Difference	2030	2030	Difference	2030	2030
	(1)	(2)	(3) = (2)-(1)	(4) = Max-(1)	(5) = Min-(1)	(6) = Baseline_2 - (1)	(7) = Max_2-(1)	(8) = Min_2-(1)
Andalucía	1,379	2,193	815	1,227	468	675	1,068	343
Aragón	603	906	303	467	164	270	430	134
Asturias	304	436	132	215	61	102	181	34
Baleares	31	54	24	35	14	24	35	14
Canarias	106	158	52	92	20	52	92	20
Cantabria	190	287	97	150	53	77	127	35
Castilla y León	1,062	1,551	489	767	253	418	686	189
C. - La Mancha	807	1,280	473	702	279	441	665	250
Cataluña	1,699	2,591	892	1,370	487	725	1,184	332
C. Valenciana	1,063	1,652	589	895	332	514	809	263
Extremadura	226	409	183	256	121	159	229	100
Galicia	700	1,077	377	576	209	270	454	113
Madrid	657	772	115	282	-26	90	254	-50
Murcia	342	559	217	322	129	177	278	91
Navarra	324	517	193	288	113	163	255	85
País Vasco	504	686	182	315	72	134	260	29
Rioja, La	108	142	35	62	12	30	56	8
Ceuta	0	0	-0	-0	-0	-0	-0	-0
Melilla	0	0	0	0	0	0	0	0
Total-Spain	10,105	15,272	5,167	8,018	2,760	4,322	7,063	1,989

Source: own elaboration

Figures

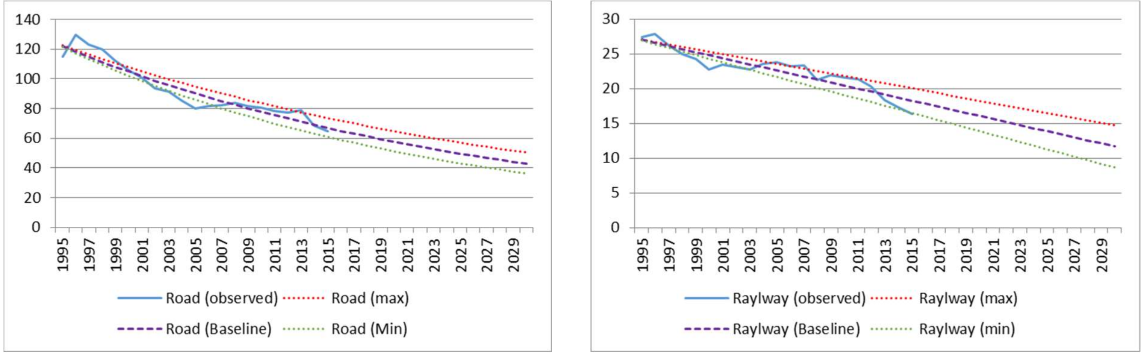
Figure 1. General outline of the long-term forecasting model: regional level (Nuts2)



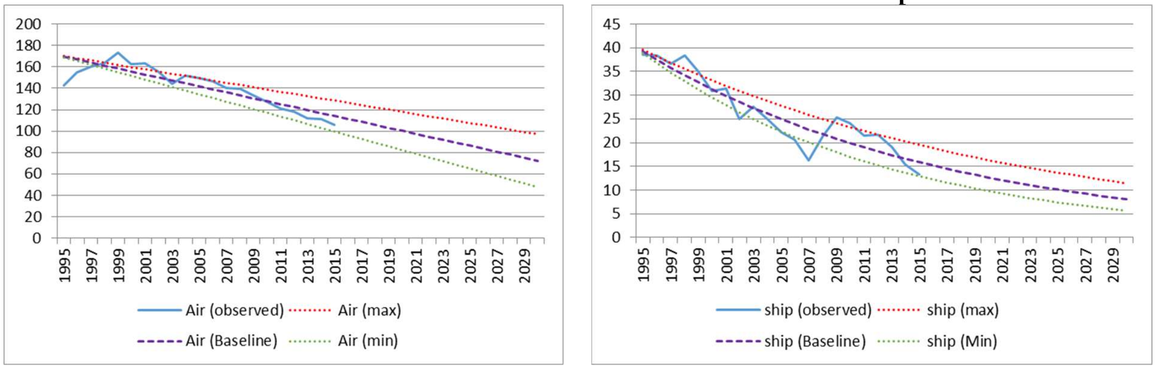
Source: own elaboration

Figure 2. GHG emission factors by mode during the period 1995-2030: gCO2/T*km.

A: Road **B: Railway**

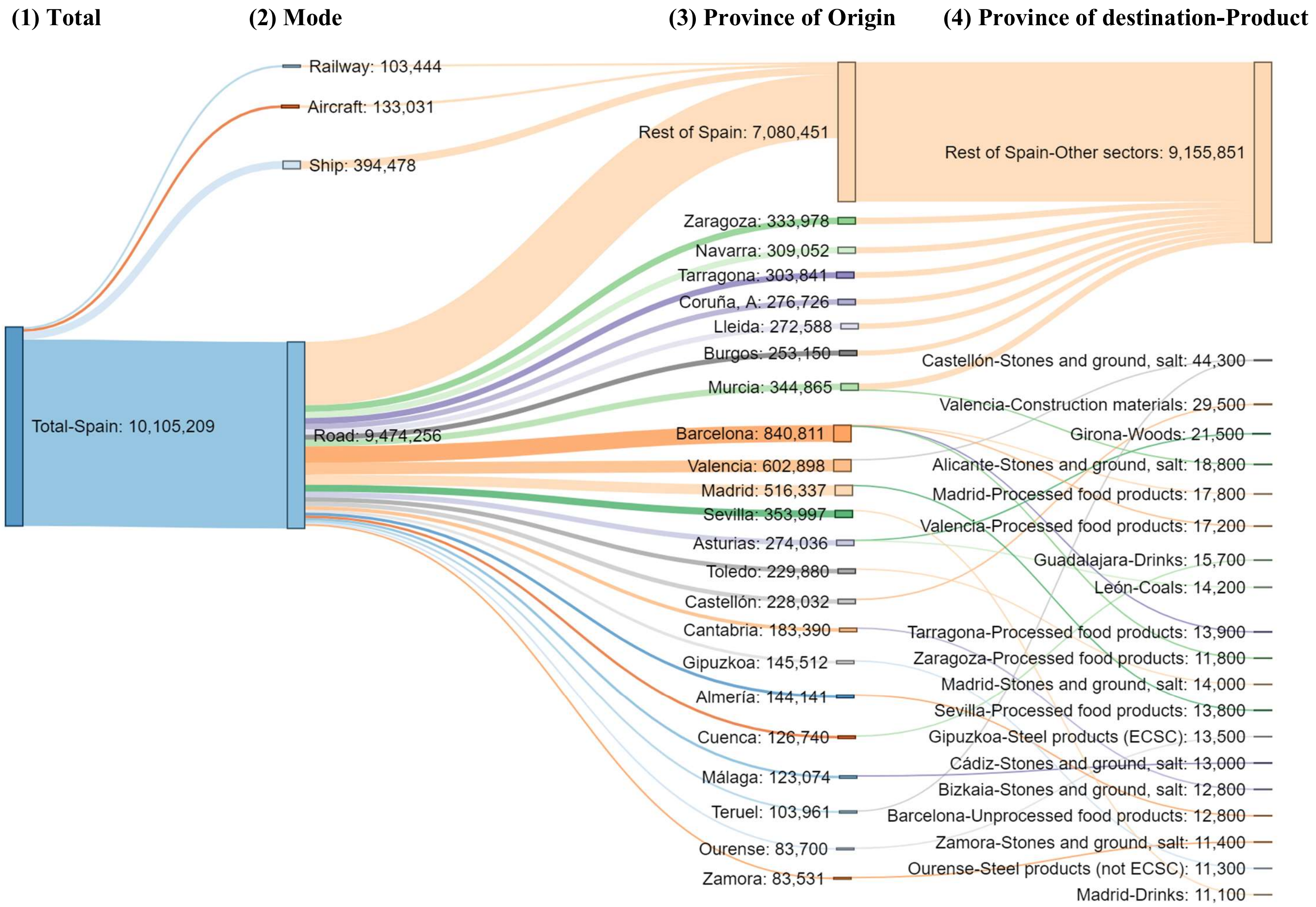


C: Air **D: Ship**



Source: own elaboration base on several sources (Mainly Spanish Ministry of Public Works)

Figure 3. The main inter-provincial flows in terms of GHG emissions. 2015. tCO2

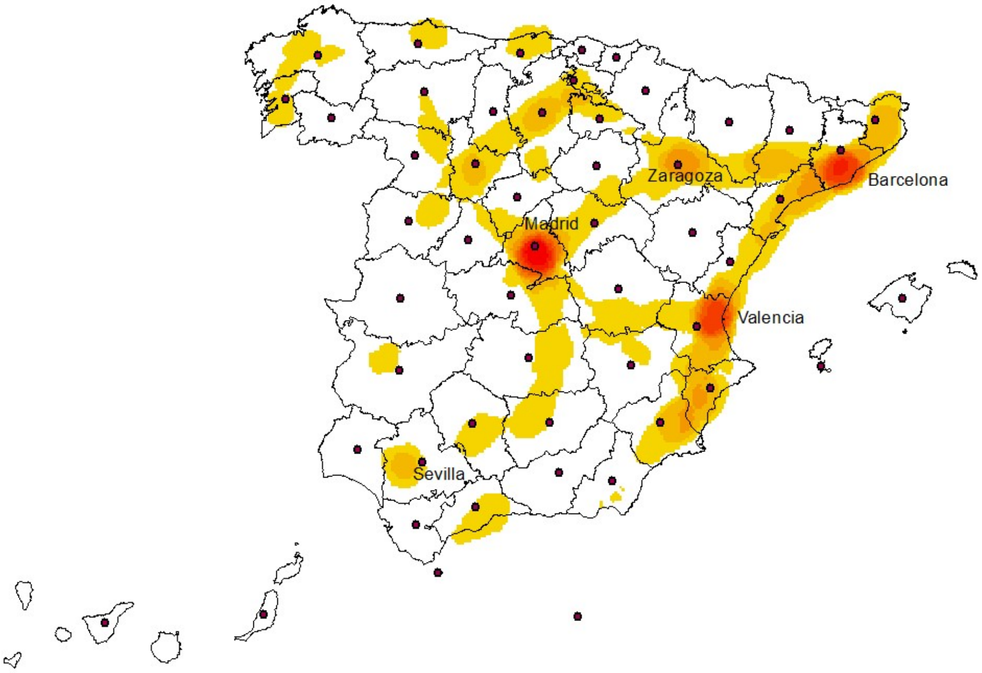


Source: own elaboration base using http://sankeymatic.com/build/

Figure 4. Spanish transport system in a glance

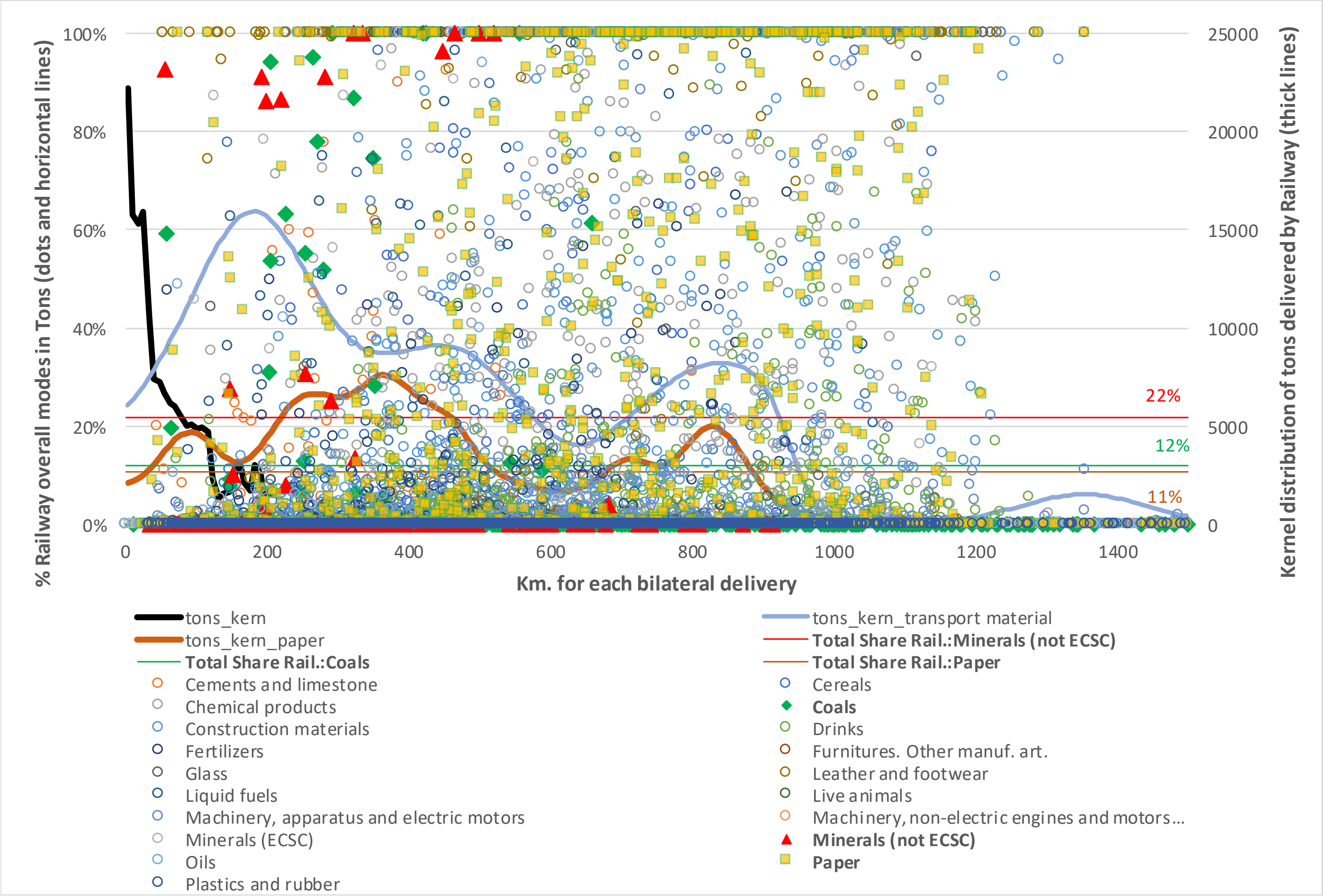
A) Spanish main transport infrastructures

B) Heavy Duty Vehicles traffic intensity by Road (IMD). 2016.



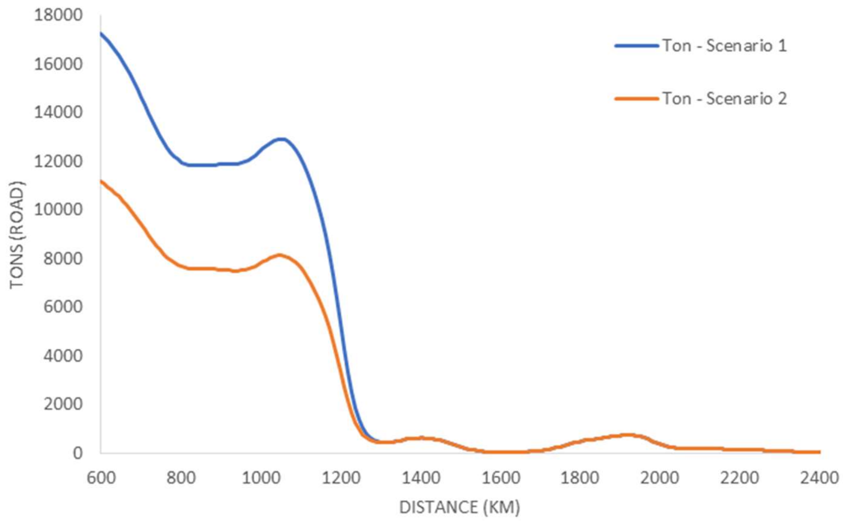
Source: Own elaboration based on information from the National Geographic Institute and the Spanish Ministry of Public Works and Transportation (Ministerio de Fomento)

Figure 5. Share of Railway for each origin-destination-product triad vs selected Kernel distributions. 1995-2015.



Source: own elaboration

Figure 6. Kernel distribution of the volume moved by road before/after the modal shift



Source: Own elaboration

Figure 7. Observed and predicted evolution of the main aggregates. Growth rates in %

Source: Own elaboration

Annex

Table A.1. Econometric results for the gravity equation, used to forecast the inter-provincial flows by mode. Estimation period 2013-15. Forecasting period: 2016-2030.

	M1	M2	M3	M4
Period	2013-2015	2013-2015	2013-2015	2013-2015
Transportation mode	Ship	Railway	Road	Aircraft
VARIABLES	Ton	Ton	Ton	Ton
Log GDP origin	-0.499	1.385	0.931**	5.328***
	(1.833)	(1.294)	(0.437)	(1.984)
Log GDP Destination	2.223	0.231	0.879*	-3.312*
	(2.486)	(1.422)	(0.453)	(1.944)
Log Distance	-0.541***	-0.521***	-1.011***	0.902***
	(0.0874)	(0.129)	(0.0542)	(0.128)
Contiguity	-0.884**	0.220	0.467***	-0.307
	(0.414)	(0.269)	(0.0694)	(0.815)
Own_Prov	-2.174**	-0.924**	1.732***	0.289
	(0.879)	(0.389)	(0.102)	(0.760)
Island origin	2.501	-1.081	-1.562***	-3.038*
	(1.921)	(1.630)	(0.550)	(1.821)
Island destination	2.061	0.0559	0.806	3.734**
	(2.814)	(1.391)	(0.602)	(1.883)
Coast origin	-1.993*			
	(1.022)			
Coast destination	-0.889			
	(1.325)			
Canary islands exports to Peninsula			-4.203***	
			(0.602)	
Canary islands imports from Peninsula			-1.357**	
			(0.588)	
Balearic islands imports from Peninsula			-0.968**	
			(0.492)	
Constant	-8.182***	-8.540***	-5.036***	-41.68***
	(3.176)	(2.147)	(0.809)	(13.31)
Observations	20,928	5,103	64,191	20,745
R-squared	0.262	0.600	0.728	0.895
Time FE	NO	NO	NO	NO
Sector FE	YES	YES	YES	YES
Region Origin FE	YES	YES	YES	YES
Region Destination FE	YES	YES	YES	YES

Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Source: Own elaboration

Table A.2. Econometric results for the forecast of GHG emission factors.

Road

Time-trend	β^m	Sd_{β^m}	Prob.T-Stat.	γ^m	Sd_{γ^m}	Prob.T-Stat.	Error Sum.of squares
Linear	-1,013	0,356	0,022				40,721
Quadratic	8,925	2,780	0,015	-0,321	0,089	0,009	26,780
Exponential	-0,013	0,005	0,023				32,730
Potential	-0,187	0,077	0,040				74,505

The Quadratic trend has been ruled out because of inconsistency in forecast. Exponential trend has been used instead.

Railway

Time-trend	β^m	Sd_{β^m}	Prob.T-Stat.	γ^m	Sd_{γ^m}	Prob.T-Stat.	Error Sum.of squares
Linear	-0,661	0,086	0,000				1,157
Quadratic	1,247	0,876	0,198	-0,062	0,028	0,065	1,088
Exponential	-0,032	0,005	0,000				1,246
Potential	-0,471	0,079	0,000				2,204

The Quadratic trend has been ruled out because of inconsistency in forecast .Linear trend has been used instead.

Air

Time-trend	β^m	Sd_{β^m}	Prob.T-Stat.	γ^m	Sd_{γ^m}	Prob.T-Stat.	Error Sum.of squares
Linear	-4,581	0,191	0,000				81,954
Quadratic	-4,520	2,515	0,115	-0,002	0,081	0,981	32,518
Exponential	-0,035	0,002	0,000				97,076
Potential	-0,532	0,033	0,000				228,323

The Quadratic trend has been ruled out because of non-statistical significativity in trend coefficients. Linear trend has been used instead.

Ship

Time-trend	β^m	Sd_{β^m}	Prob.T-Stat.	γ^m	Sd_{γ^m}	Prob.T-Stat.	Error Sum.of squares
Linear	-1,145	0,129	0,000				9,604
Quadratic	-2,353	0,472	0,000	0,058	0,022	0,017	7,782
Exponential	-0,043	0,005	0,000				8,013
Potencial	-0,300	0,041	-7,242				17,516

The Quadratic trend has been ruled out because of inconsistency in forecast.Linear trend has been used instead.

Source: Own elaboration

Table A.3. GHG emissions by province (Nuts 3). Structure and evolution. ktCO$_2$ eq.

	2015					Growth rates		
	Total (1)	Intra-provincial (2) in % of (1)	Inter-provincial (3) in % of (1)	% (4)=(1)/Spain	Total/GDP (5)	2015-201995 (5)	2015-2009 (6)	2030-2015 (7)
Araba	97.5	5.8%	94.2%	0.1%	8.50	-8.6%	-32.0%	34.2%
Albacete	119.2	17.0%	83.0%	0.1%	16.50	-23.9%	-35.5%	53.6%
Alicante	190.1	25.3%	74.7%	0.2%	5.68	-11.2%	-26.4%	49.2%
Almería	149.8	39.1%	60.9%	0.1%	11.69	-2.0%	-12.4%	89.5%
Ávila	48.7	9.9%	90.1%	0.0%	16.24	40.3%	-31.0%	51.2%
Badajoz	166.1	26.6%	73.4%	0.2%	15.37	21.3%	-31.8%	76.5%
Balears, Illes	30.7	70.1%	29.9%	0.0%	1.12	26.9%	-20.1%	76.8%
Barcelona	923.3	28.9%	71.1%	0.9%	6.11	-23.6%	-30.2%	39.7%
Burgos	258.4	20.3%	79.7%	0.3%	27.67	-0.6%	-19.7%	35.1%
Cáceres	59.9	47.9%	52.1%	0.1%	9.00	-18.5%	-34.9%	93.4%
Cádiz	157.0	24.4%	75.6%	0.2%	7.88	-15.0%	-25.7%	58.0%
Castellón	243.3	26.5%	73.5%	0.2%	18.43	-21.9%	-20.0%	62.4%
Ciudad Real	170.9	11.4%	88.6%	0.2%	17.62	-3.4%	-15.7%	37.5%
Córdoba	129.8	23.8%	76.2%	0.1%	9.76	-14.3%	-24.8%	50.6%
Coruña, A	294.8	33.1%	66.9%	0.3%	12.06	6.1%	-20.3%	74.2%
Cuenca	127.1	17.5%	82.5%	0.1%	31.27	12.0%	-45.4%	49.3%
Girona	174.2	35.9%	64.1%	0.2%	8.74	-29.5%	-38.6%	72.0%
Granada	153.8	31.3%	68.7%	0.2%	9.88	-26.1%	-45.8%	80.8%
Guadalajara	157.1	8.5%	91.5%	0.2%	34.26	93.8%	-12.5%	51.9%
Gipuzkoa	158.9	9.6%	90.4%	0.2%	7.29	-10.5%	-31.8%	16.1%
Huelva	174.7	17.5%	82.5%	0.2%	19.35	-5.4%	-8.7%	41.6%
Huesca	149.3	20.6%	79.4%	0.1%	26.59	-2.8%	-19.4%	62.5%
Jaén	105.9	23.8%	76.2%	0.1%	9.76	-25.4%	-38.8%	56.1%
León	161.6	22.0%	78.0%	0.2%	17.22	-27.3%	-40.0%	74.1%
Lleida	274.5	33.5%	66.5%	0.3%	22.54	-26.4%	-24.3%	67.3%
Rioja, La	107.8	10.9%	89.1%	0.1%	13.72	-3.2%	-18.7%	32.2%
Lugo	173.1	16.5%	83.5%	0.2%	24.49	-13.4%	-13.0%	34.2%
Madrid	656.6	15.3%	84.7%	0.6%	3.22	0.9%	-29.7%	17.5%
Málaga	132.5	24.1%	75.9%	0.1%	4.78	10.4%	-40.7%	77.2%
Murcia	342.4	22.3%	77.7%	0.3%	12.14	1.0%	-13.6%	63.3%
Navarra	323.6	24.3%	75.7%	0.3%	17.44	-4.6%	-18.8%	59.6%
Ourense	85.0	18.6%	81.4%	0.1%	13.77	35.4%	-23.5%	9.8%
Asturias	304.0	23.2%	76.8%	0.3%	14.33	-28.1%	-33.4%	43.3%
Palencia	113.4	16.4%	83.6%	0.1%	28.55	0.5%	-26.8%	52.1%
Palmas, Las	57.3	40.3%	59.7%	0.1%	2.69	21.1%	34.4%	22.6%
Pontevedra	147.1	26.8%	73.2%	0.1%	7.89	-26.4%	-41.2%	61.9%
Salamanca	67.3	24.8%	75.2%	0.1%	10.17	8.0%	-24.9%	40.4%
S.C.d Tenerife	48.7	45.2%	54.8%	0.0%	2.48	112.2%	-38.0%	80.6%
Cantabria	189.8	22.6%	77.4%	0.2%	15.56	-21.3%	-15.7%	51.3%
Segovia	106.6	12.7%	87.3%	0.1%	32.25	39.1%	-25.8%	54.2%
Sevilla	375.2	22.6%	77.4%	0.4%	10.47	-9.8%	-32.2%	44.0%
Soria	55.3	13.3%	86.7%	0.1%	25.20	30.4%	-13.3%	34.5%
Tarragona	327.4	12.5%	87.5%	0.3%	14.70	-21.7%	-23.9%	65.8%
Teruel	104.8	25.9%	74.1%	0.1%	31.52	-2.4%	-20.8%	47.8%
Toledo	232.8	15.4%	84.6%	0.2%	19.64	-10.1%	-43.1%	86.2%
Valencia	629.6	22.4%	77.6%	0.6%	11.64	-7.4%	-28.5%	54.6%
Valladolid	166.6	15.0%	85.0%	0.2%	13.38	13.0%	-25.2%	27.3%
Bizkaia	247.4	14.6%	85.4%	0.2%	7.45	-37.9%	-26.1%	49.8%
Zamora	84.1	26.0%	74.0%	0.1%	24.78	39.8%	-34.0%	53.8%
Zaragoza	349.3	19.9%	80.1%	0.3%	14.26	10.1%	-18.8%	45.7%
Ceuta	0.4	0.0%	100.0%	0.0%	0.25	1045.1%	3950.7%	-36.0%
Melilla	0.2	0.0%	100.0%	0.0%	0.16	1931.9%	570.2%	76.0%
Total-Spain	**10,105.2**	**36.6%**	**63.4%**	**100.0%**	**9.36**	**-10.0%**	**-27.4%**	**51.1%**

Source: Own elaboration.

Table A.4 Products covered by the C –Intereg database.

Code	Product
1	Live animals
2	Cereals
3	Unprocessed food products
4	Woods
5	Processed food products
6	Oils
7	Tobacco
8	Drinks
9	Coals
10	Minerals (not ECSC)
11	Liquid fuels
12	Minerals (ECSC)
13	Steel products (ECSC)
14	Steel products (not ECSC)
15	Stones and ground, salt
16	Cements and limestone
17	Glass
18	Construction materials
19	Fertilizers
20	Chemical products
21	Plastics and rubber
22	Machinery, non-electric engines and motors…
23	Machinery, apparatus and electric motors
24	Transport material
25	Textile and clothing
26	Leather and footwear
27	Paper
28	Wood and cork
29	Furniture and furnishings, new. Other manufactured articles.

Source: Own elaboration based on c-intereg (www.c-intereg.es).