GREENHOUSE GAS EMISSIONS AND ENERGY INTENSITY OF THE TRANSPORT SECTOR

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DEPARTMENT OF APPLIED ECONOMICS

PhD Programme in Applied Economics

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PhD Dissertation

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"Para alertar a la población acerca de los daños que ocasiona la contaminación del aire, integrantes de estas organizaciones civiles lanzaron un fuerte mensaje visual mediante un graffiti artístico instalado en las ciudades de México, Monterrey, Guadalajara y Toluca, recordando que las ciudades mexicanas se encuentran entre las más contaminadas de América Latina."

Pueblo Bicicletero

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A mis padres

Infinite air was the principle,
from which the things that are becoming,
and that are, and that shall be,
and gods and things divine, all come into being,
and the rest from its products.

Anaximenes

Table of contents

Chapter 1

Introduction

1.1. Background and motivation

At present, there is wide consensus about the threat of climate change at a global level. The Paris Agreement,[1] whose central goal is to keep the rise of Earth's temperature below two degrees Celsius this century, reflects the concern about global warming. Despite the ineffectiveness of an agreement based merely on voluntary contributions to achieve the stated objective (Clémençon, 2016), the European Union has assumed a leading role in the contribution to accomplish this target, and proof of this are the different climate strategies recommended for reducing its own greenhouse gas emissions gradually up to 2050 (European Commission, 2011a, 2011b). Among these strategies there is one related to transport, given the importance of the activity in environmental terms, as it accounts for almost 26% of total European Union-28 greenhouse gas emissions in 2015 (European Environmental Agency, 2017). The 2011 Transport White Paper reports the long-term strategies of the European Union in relation to transport and, specifically, some fundamental challenges related to climate change that are settled. In particular, transport has to diminish energy consumption and to use cleaner energy sources in order to reduce its negative impact on the environment and on natural resources, but without compromising mobility, given that economic growth depends on it (European Commission, 2011c).

This dissertation focuses on the topic of transport and environmental pressure. In particular, three closely related issues are analyzed. These are transport greenhouse gas emissions, transport activity, and transport energy intensity. Moreover, three different approaches are used to address them. Thus, Chapter 2 investigates the driving factors of greenhouse gas emissions in the European Union transport activity during the period 1990–2014. Chapter 3 studies the direct and total greenhouse gas emissions of the transportation and storage sector in Spain in 2014, analyzing its relationship with the rest of economic sectors. Chapter 4 examines the energy intensity trend of road freight transport of heavy goods vehicles and its explanatory factors in Spain during the period 1996–2012.

In Chapter 2 and Chapter 3, greenhouse gas emissions from transport activity are addressed from a macroeconomic perspective, while, in Chapter 4, the analysis is

[1] It was agreed upon on 12 December 2015; it came into force on 4 November 2016, and will be fully operational in 2020.

conducted from a microeconomic perspective. Particularly, in Chapter 2, on the basis of an extension of the STIRPAT model (Dietz and Rosa, 1994, 1997), driving factors of greenhouse gas emissions in transport activity are identified, and panel data econometric analysis is used in order to quantify them. Hence, in Chapter 2, the causes of greenhouse gas emissions due to transport activity are explored. In Chapter 3, however, the impact of the transportation and storage activity on greenhouse gas emissions of the whole economy is investigated through input–output subsystems analysis (Sraffa, 1960; Alcántara, 1995) based on the Ghosh model (Ghosh, 1958). That is, in Chapter 3 the effects of transportation and storage activities on greenhouse gas emissions are examined. In Chapter 4, energy intensity, a driving factor of greenhouse gas emissions, is analyzed in depth by adapting the ASIF methodology (International Energy Agency, 2014) to the study of freight road transport of heavy goods vehicles. The methodologies used in the empirical analysis of Chapter 4 are LMDI-II decomposition analysis (Ang, 2004) and the attribution of changes in Divisia indices (Choi and Ang, 2012). It should be noted that Chapter 2 and Chapter 4 have in common that both the STIRPAT model and the ASIF method used in each one of the chapters respectively are based on the IPAT identity (Ehlrich and Holdren, 1971, 1972). Additionally, Chapter 3 and Chapter 4 stress productive specialization as a key element to be taken into account in the analysis of greenhouse gas of transport activity. Finally, it is important to add that in Chapter 2, the analysis is performed at a multi-country level, whereas in Chapter 3 and Chapter 4 it is carried out at country level; and, in relation to time, Chapter 2 and Chapter 4 perform the analysis over time, while Chapter 3 does it for a single year.

1.2. Three empirical studies on transport activity and greenhouse gas emissions

This section introduces a summary, highlighting the main contributions of the three fundamental chapters of this dissertation.

Chapter 2 analyses the importance of population, economic activity, transport volume, and structural characteristics of transport activity —in terms of transport energy intensity, of transport modes' share, and of energy sources’ mix— as driving factors of greenhouse gas emissions in transport activity in the European Union-28 over the period 1990–2014. The analysis is based on the STIRPAT model, which is broadened to investigate in depth the impact on transport emissions of changes in the transport activity and in the whole economy. Using panel data econometric techniques, the significance of each factor and the impact of its change on emissions are identified. Additionally, the outcomes allow a preliminary assessment of the potential effectiveness of the 2011 Transport White Paper measures aimed at cutting transport emissions.

The results reveal that population and transport energy intensity are more relevant for explaining European Union transport emissions than economic activity and/or transport volume. In particular, the European Union transport emissions show relative decoupling in relation to transport activity as well as in relation to economic activity. Likewise, the substitution of rail for road transport and the switch from oil products to electricity are the measures that have apparently the most important impact on cutting the European Union transport emissions. In relation to the potential success of the actions oriented toward diminishing transport emissions suggested in the 2011 Transport White Paper, the results indicate that the most effective measures would seemingly be those focused on advances in transport energy efficiency and in changes in modal share. From the latter it follows that rail should be the preferred alternative mode of transport to road transport and, in relation to energy mix, electricity should be the favored alternative source of energy instead of oil products. It should be noted, however, that this analysis only takes into account direct emissions.

This chapter offers various contributions to the research on the analysis of transport emissions based on the STIRPAT model. First, it methodologically develops the STIRPAT model as applied to transport emissions by including: i) the modal share and ii) the energy consumption mix. Particularly, the impact of each mode of transport and of each source of energy on transport emissions is analyzed in detail. Furthermore, the energy intensity of the transport sector is measured in real units, i.e. energy intensity[2] is measured in gross ton-kilometers rather than measured through the gross value added of the activity. Second, an empirical contribution is performed as we analyze the emissions of the transport sector in the European Union in the period 1990–2014 given that, as far as we know, there are no similar studies for the European Union. Third, the results are employed to evaluate the potential effectiveness of the actions promoted in the 2011 Transport White Paper, which are aimed at cutting transport emissions in the European Union. This chapter was recently published in the journal Transport Policy (Andrés and Padilla, 2018).

Chapter 3 studies the impact of the transport and storage subsystem sector on greenhouse gas emissions of the whole economy by using input–output subsystems analysis based on the Ghosh model. This new methodology that is developed in the chapter takes into account the whole activity of the subsystem and not only the activity linked to its final demand.

[2] This is the result of energy consumption of passenger and freight activities divided by gross ton-kilometers.

Additionally, in the aim of learning the interrelations in terms of emissions between the subsectors of the subsystem and between them and the activity of the rest of the sectors of the economy, total emissions of the subsystem are decomposed into four explanatory components. These are scale component, net own internal component, feed-back component, and spillover component. The methodology is applied to the Spanish transportation and storage sector in 2014. The analysis provides relevant information for the correct design of environmental policies aimed at reducing greenhouse gas emissions in the subsystem.

The results show that the Spanish transportation and storage subsystem was responsible for 10.6% of direct greenhouse gas emissions and 9.1% of total emissions generated in the economy. The subsystem subsector "Land transport and transport via pipelines" was the one that most contributed to emitting both direct and total emissions. Moreover, the decomposition outcomes point out to scale component as the most important (63%), followed by spillover component (21%), and by net own internal component (15%). Therefore, the substitution of "Rail transport" and/or "Water transport" for "Road transport" and "Air transport", and therefore higher energy efficiency and the use of less polluting fuels should be fostered as adequate measures aimed at cutting greenhouse gas emissions of transport activity. Likewise, given the significance of the net own internal component, especially because of the "warehousing and support activities for transportation” subsector, appropriate transport logistics should be adopted as a crucial environmental measure in order to achieve the reduction in transportation and storage emissions. Lastly, it is shown that the transportation and storage subsystem pulls the other sectors not belonging to the subsystem to pollute less than these other sectors pull the subsystem to pollute.

This chapter offers two main contributions in relation to previous literature based on input–output subsystems analysis. Firstly, a methodological contribution, as an input–output subsystems model from the supply perspective is developed and expanded in order to study the environmental impact of polluting substances. Secondly, it offers an empirical contribution, as we apply the preceding model with the purpose of studying the effects of the activity of the transportation and storage sector on greenhouse gas emissions of the whole economy in Spain in 2014. We take advantage of the results of the analysis to provide suggestions for suitable environmental measures aimed at mitigating transport emissions.

Chapter 4 examines the factors that have influenced the energy intensity trend of the Spanish road freight transport of heavy goods vehicles over the period 1996–2012. The ASIF methodology is adapted to study it, and the chapter uses both annual single-period and chained multi-period multiplicative LMDI-II decomposition analysis. Additionally, the change in energy intensity is analyzed in more depth by quantifying the role of each commodity transported using the methodology of the attribution of changes in Divisia indices. This chapter aims to contribute to a better understanding of energy intensity of road freight transport, its evolution, and its determinant factors and, additionally, to inform the design of measures to improve energy efficiency in the activity.

The results suggest that the decrease in the energy intensity of Spanish road freight transport in the period analyzed is explained by the change in the real energy intensity index (lower energy consumption per ton-kilometer transported), which is partially offset by the behavior of the structural index (greater share in freight transport of those commodities the transportation of which is more energy intensive). Furthermore, the outcomes show that each commodity is involved to a different degree and with different sign in the reduction of energy intensity.

The central contribution of this chapter is to adapt the ASIF methodology to energy intensity in the road freight transport and enhance it by applying decomposition analysis. This allows the in-depth study of the two determinant factors defined in this chapter through commodity approach. These factors are the real energy intensity index, defined as energy consumption per ton-kilometer transported, and the structural index, defined as the relative change in the composition of road freight transport. The results of the decomposition analysis are broadened through a methodological extension, the attribution of changes in Divisia indices applied to road freight transport. This methodology specifically identifies the degree to which each commodity has contributed to the change in energy intensity through the real energy intensity index and through the structural index. Finally, an empirical contribution is provided through the analysis of Spanish road freight transport of heavy goods vehicles over the period 1996–2012. This chapter was published in the journal Energy Policy (Andrés and Padilla, 2015).

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Chapter 2

Driving factors of GHG emissions in the EU transport activity

2.1. Introduction

Greenhouse gas emissions decreased by 22.4% in the EU-28 between 1990 and 2014. All the source sectors contributed to this reduction with one exception, the transport sector. This sector showed completely different behavior, as its emissions increased by 13.3% during the period, from 784,507.0 to 889,065.5 thousand tonnes of CO_2 equivalent (Eurostat, 2016)[3]. Consequently, the contribution of the transport sector has increased considerably since 1990, amounting to 20.8% of the overall greenhouse gas emissions in 2014. The transport sector is currently the second most important source of emissions in the EU-28 after the energy sector.

Table 1. Energy consumption in the EU-28 transport sector, total activity and classification by energy sources (thousand TOE). 1990–2014

	Energy consumption			Share	
	1990	2014	Total change (%)	1990	2014
Total activity	284,171.2	352,936.4	24.2%	100.0%	100.0%
Sources of energy					
Solid fuels	213.5	8.6	-96.0%	0.1%	0.0%
Petroleum products	278,144.5	330,493.1	18.8%	97.9%	93.6%
Gas	338.7	2,955.7	772.7%	0.1%	0.8%
Renewable energies	18.8	14,141.3	75119.7%	0.0%	4.0%
Electrical energy	5,455.7	5,337.7	-2.2%	1.9%	1.5%

Source*:* Prepared by the authors with data from Eurostat (2016).

The upward trend in emissions in the EU-28 transport sector is related to a 24.2% rise in its energy consumption over the period, reaching a total of 352,936.3 thousand tonnes of oil equivalent in 2014, which amounted to 33.2% of the total final energy consumption. Between 1990 and 2007, in a scenario of high economic growth, the energy consumption in the EU-28 transport sector increased by 34.8% and its emissions by 25.9%, whereas,

[3] The seven greenhouse gases considered by Eurostat data are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). The relevant greenhouse gases in the case of transport are CO_2, CH_4 and HFCs.

between 2007 and 2014, a period of economic downturn and lower economic growth, the energy consumption of the transport sector decreased by 7.9% and its emissions by 10.0%. These figures show the difficulty of mitigating greenhouse gas emissions in the transport sector, as they are the result of the level of energy consumption and the mix of energy sources used in transportation (see Table 1).

An in-depth study of the trend of greenhouse gas emissions in the EU transport activity in the last decades is necessary to assess the mitigation policies. This paper focuses on analyzing the driving factors of greenhouse gas emissions in the EU transport activity over the period 1990–2014 and on quantifying the impact of a change in any of them on such emissions using a new, extended version of the STIRPAT model. Moreover, panel data econometrics is employed to quantify the impact of the different factors. This paper, in a novel way, extends the application of the STIRPAT model to the analysis of greenhouse gas emissions in transport activity by accounting for the structural characteristics of the sector. In particular, our model includes population, economic activity, transport volume and structural characteristics—taking into account the energy intensity of the activity, the share of each mode of transport in the total activity and the share of each source of energy in the total transport energy consumption. The objective is to highlight that the effect of the activity on its emissions relies not only on the volume of transport but also on its characteristics, i.e., energy intensity, modal structure and energy source mix. As pointed out by Grazi and van den Bergh (2008), the results of the environmental policies aimed at reducing emissions in the transport sector depend on their effects on the modal split, energy efficiency, fuel type used and transport volume (passenger-kilometers or ton-kilometers). Therefore, both the volume and the structural characteristics of the transport sector are important in explaining the change in its emissions and in designing more accurate policies. Additionally, it is relevant to consider whether there are any significant differences between regions. A further contribution of this paper is that it performs the analysis for the EU as a whole as well as differentiating by regions (western EU and eastern EU), considering their differentiated economic structures and levels of development. Finally, this paper differs from previous research, as it focuses the analysis on the greenhouse gas emissions of the transport sector instead of only the CO_2 emissions. Although CO_2 is the most important greenhouse gas, other greenhouse gases, CH_4 and N_2O, are also emitted during fuel combustion. [4] In addition, transport activities also emit HFC gases resulting from vehicle air conditioning and refrigerated transport. It is, therefore, necessary to take into account all the greenhouse

[4] According to IPCC (Kahn Ribeiro et al., 2007), CO_2 emissions account for around 96%, CH_4 emissions account for 0.1%–0.3% of total transport emissions, whereas N_20 emissions account for 2.0%–2.8% (based on US, Japan and EU data only).

gases emitted by the activity in order to analyze the overall impact of the activity in global warming. In addition, this would eventually avoid erroneous interpretations in the cases that CO_2 emissions declined at the same time that the emissions of the other three gases increased.

The main purpose of the analysis is to inform the design of environmental policies focused on mitigating environmental impacts, besides promoting efficient energy use and energy savings in the transport sector. Using the results of this analysis, our research will also specifically contribute to assessing the potential effectiveness of the environmental strategies proposed in the 2011 Transport White Paper (European Commission, 2011), the aims of which include a 60% reduction in the transport sector emissions by 2050 in relation to 1990.

The rest of the paper is structured as follows. Section 2.2 provides a review of the literature. Section 2.3 describes the data and the methodologies employed. Section 2.4 presents the results and the discussion. Section 2.5 summarizes and concludes the chapter.

2.2. Literature review on the determinants of transport activity emissions

The role of the transport activity in greenhouse gas emissions has been studied broadly. Part of this literature is based on the IPAT identity (Ehlrich and Holdren, 1971, 1972), which is widely used as a basis for analyzing the impact of economic activity on the environment. Founded on ecological principles (York et al., 2003), it states that the environmental impact (I) is the product of population (P), affluence (A) and technology (T).

In particular, most of the investigations that study the driving factors of transport emissions are based on the IPAT identity or, alternatively, on the Kaya identity (Kaya, 1989) or the ASIF methodology (IEA, 1997), which are expanded versions of the IPAT identity. These studies use index decomposition analysis to obtain detailed information on the importance of the different driving factors explaining changes in environmental pressure over time. In this line of research, there are works focused on studying the driving factors of the transport sector emissions as a whole. For example, the investigations reported by Mazzarino (2000), Timilsina and Shrestha (2009), Guo et al. (2014) and Fan and Lei (2016), based on the IPAT identity, find that population, economic activity and transport energy intensity are the main driving forces of transport emissions. [5] Likewise, there are works addressing the specific driving factors of the emissions of passenger and freight transport activities.

[5] The investigation of Mazzarino (2000) does not identify population as a main driving factor.

Examples of these are the investigations conducted by Scholl et al. (1996), Lakshmanan and Han (1997), Steenhof et al. (2006) and M'raihi et al. (2015). These studies are mostly based on the ASIF equation and find that the transport volume, modal share, transport energy intensity and energy mix[6] are the main driving factors of emissions in these activities. Other studies investigate the driving factors of the emissions of a specific mode of transport, for instance those by Andreoni and Galmarini (2012) and Sobrino and Monzon (2014). There are even very concrete studies, such as the work by Kwon (2005) and Papagiannaki and Diakoulaki (2009), focused on finding the driving factors of the cars' emissions. These last investigations are based on the IPAT or Kaya identities and find that the main driving factors are economic activity and/or transport volume and transport energy intensity. However, all these studies, which, in essence, are based on the IPAT identity, present the same two limitations. First, it is an accounting equation and does not allow hypothesis testing, and, second, it assumes that the functional relationship between factors is proportional (York et al., 2003).

A different line of research, also based on the IPAT identity, is developed by Dietz and Rosa (1994, 1997). They propose an alternative model, the STIRPAT model (the Stochastic Impact by Regression on Population, Affluence and Technology model), which is a reformulation of the IPAT identity into a stochastic model that overcomes its limitations, as it allows estimation and hypothesis testing using econometric techniques. Various recent investigations employ the STIRPAT model to analyze the environmental impact of transport activity: Zhang and Nian (2013) and Xu and Lin (2015, 2016) are examples (Table 2).

Another different line of research is the literature focused on analyzing the proper design of environmental policies aimed at reducing transport emissions. The recent investigations of Tight et al. (2005), Hickman and Banister (2007), Hull (2008), Hickman et al. (2010), Banister and Hickman (2013) and Eliasson and Proost (2015) are some examples. Other studies focused on traffic flow models and simulation models and made significant contributions to understand the impacts of different variables on emissions; some examples are the works of Yu (1998), Zhu (2013) and Tang et al. (2015, 2017).

[6] The study by Lakshmanan and Han (1997) does not include the energy mix in the analysis. As regards M'raihi et al. (2015), they point out to economic growth as the main driving factor of transport emissions.

Table 2. Literature on the driving factors of transport emissions based on the IPAT identity

AUTHOR AND YEAR	REGION	PERIOD	AREA	DRIVING FACTORS
INDEX DECOMPOSITION ANALYSIS OF THE IPAT IDENTITITY OR OF ITS EXPANDED VERSIONS, THE KAYA IDENTITY AND THE ASIF EQUATION				
Scholl et al. (1996)	9 OECD countries	1973–1992	Passenger	Passenger activity, modal structure, transport energy intensity and fuel mix
Lakshmanan and Han (1997)	USA	1970–1991	Passenger	Population, people's propensity to travel, modal share, mode energy intensity and interaction term
			Freight	GDP, transport intensity, modal share, mode energy intensity and interaction term
Mazzarino (2000)	Italy	1980-1995	Transport	Population, economic activity, freight transport intensity, mode mix of freight transport, gross energy intensity of freight transport and energy structure
Kwon (2005)	Great Britain	1970–2000	Car travel	Population, car trip distance per person and CO_2 emissions per car trip distance
Steenhof et al. (2006)	Canada	1990–2012	Freight	Transport volume, mode mix, fuel mix and fuel efficiency
Papagiannaki and Diakoulaki (2009)	Greece and Denmark	1990-2005	Passenger cars	Population, vehicles per capita, average distance traveled by car and the shares of cars by engine size, engine technology and fuel type
Timilsina and Shrestha (2009)	Asian countries	1980–2005	Transport	Population, per capita GDP, transport energy intensity, modal shift, fuel mix and fuel emission coefficient
Andreoni and Galmarini (2012)	Europe	2001–2008	Water and aviation	CO_2 intensity, transport energy intensity, structural effect and economic activity
Guo et al. (2014)	China	2005–2012	Transport	Population, economic activity, transport energy intensity and energy structure
Sobrino and Monzon (2014)	Spain	1990–2010	Road	GDP, workers' income intensity, job intensity, motorization rate, use intensity, transport energy intensity and carbon intensity
M'raihi et al. (2015)	Tunisia	1990-2006	Freight	Economic growth, road freight intensity, petroleum intensity of road freight, petroleum share of road freight and average emissions of petroleum
Fan and Lei (2016)	Beijing	1995–2012	Transport	Population, economic activity, transport intensity, output value of per unit traffic turnover, transport energy intensity and energy structure
ECONOMETRIC ANALYSIS OF THE STIRPAT MODEL				
Zhang and Nian (2013)	China	2000–2012	Transport	Population, per capita GDP, transport energy intensity, passenger and freight turnover, and electricity and oil consumption shares
Xu and Lin (2015)	China	1980–2012	Transport	Urbanization level, per capita GDP, transport energy intensity, freight turnover and private vehicle population
Xu and Lin (2016)	China	2000–2012	Transport	Urbanization level, per capita GDP, transport energy intensity, freight turnover and private vehicle population

Source: Prepared by the authors.

This research provides various contributions to the previous literature on the analysis of transport emissions. First, it makes a methodological contribution, as it extends the

STIRPAT model by incorporating the structural composition of transportation where, besides transport, energy intensity, modal share and energy mix are taken into account. Specifically, the impact on transport emissions of a change in the modal share and in the energy mix is analyzed in detail. In particular, it is quantified the impact on emissions of the substitution of rail or waterborne or aviation for road transport, and of the substitution of electricity or renewable energies or gas for oil products. Moreover, the energy intensity of the transport sector is measured in real units, in which the energy consumption of transport activity is related to passenger and freight activity —measured in gross ton-kilometers— instead of the gross value added of the activity. Our definition of energy intensity avoids the identification of increases (reductions) in the value added of the activity as improvements (worsening) in transport energy intensity. Moreover, if transport energy intensity is defined as transport energy consumption with respect to gross ton-moved (both passenger and freight), then transport energy intensity ameliorations would involve less energy use per unit of activity. Second, we make an empirical contribution, as the analysis is applied to the emissions of the transport sector in the EU in the period 1990–2014 and there are no similar studies for the European context. The only exceptions are the work by Andreoni and Galmarini (2012), which, however, only analyzes two specific modes of transport (water and aviation) using decomposition analysis, and the report by the European Commission[7] (2013), which is not based on the IPAT identity but on the Kuznets curve hypothesis and focuses only on road transport. Third, the outcomes are used to assess the potential effectiveness of the actions adopted in the 2011 Transport White Paper oriented towards reducing transport emissions in the EU.

2.3. Data and methodology

2.3.1. Data

To perform the analysis, annual data of the EU countries are collected from different sources for the period 1990–2014. Data on greenhouse gas emissions of the transport sector (in million tonnes of CO_2 equivalent), population (individuals) and, in total and disaggregated by sources, energy consumption in the transport sector (in thousand tonnes of oil equivalent) are obtained from Eurostat (2016), data on real per capita GDP (in constant 2010 US$) are taken from the World Development Indicators (World Bank, 2016) and data

[7] This report analyzes the trends and drivers of the European greenhouse gas emissions, including transport sector emissions, through cause and effect analysis.

on transport volume —both passenger and freight (in gross ton-kilometers)— are from the Odyssee-Mure database (Enerdata, 2016).

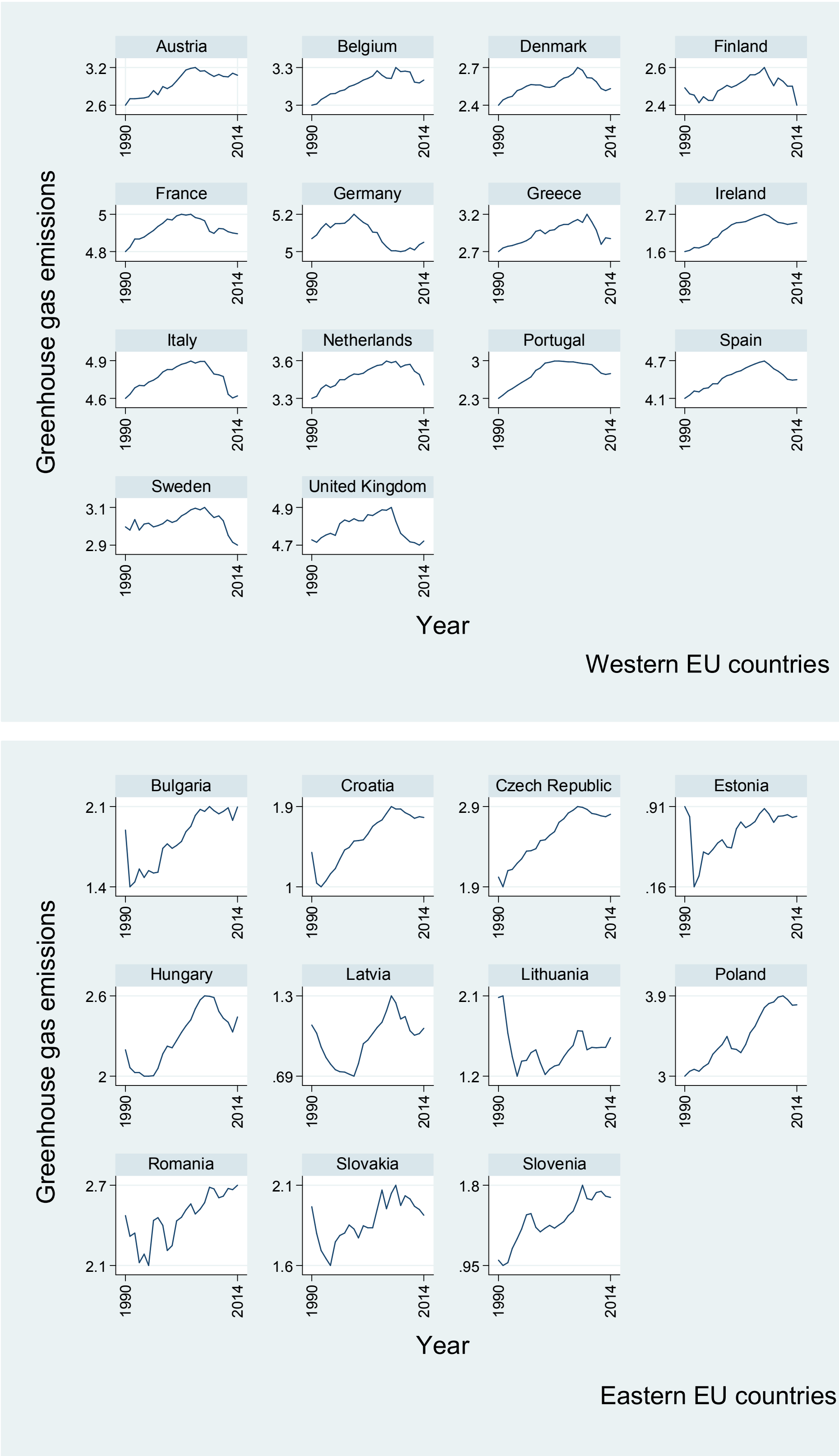
This research takes into account the emissions of the whole transport activity but excludes international bunker emissions (international maritime transport and international aviation emissions). Although international maritime transport emissions and international aviation emissions accounted for 23.4% of total transport emissions in 2014, 11.7% each, (EEA, 2017), they are excluded because the data on the transport volume for international maritime transport are not available and the data for international aviation are provided in different units (in passengers but not in gross ton-kilometers). In addition, coal is not taken into account in the analysis among the sources of energy of the transport activity. Though coal is the most polluting source of energy, during the last decades, its contribution as a source of energy to the transport sector has been reduced dramatically, so its current share in the activity is negligible (Table 1).

Taking into account the above, the analysis is performed for the EU as a whole (with the exception of Cyprus, Luxembourg and Malta) as well as by regions (western EU and eastern EU[8]).

Figure 1 shows the trajectories of the greenhouse gas emissions of the transport activity in the EU countries during the period 1990–2014. Likewise, Figure 2 reports the per capita transport emissions in the EU in 1990 and in 2014 and Figure 3 presents its growth rate during that period. The descriptive statistics of the variables used in the analysis are shown in Table 3.

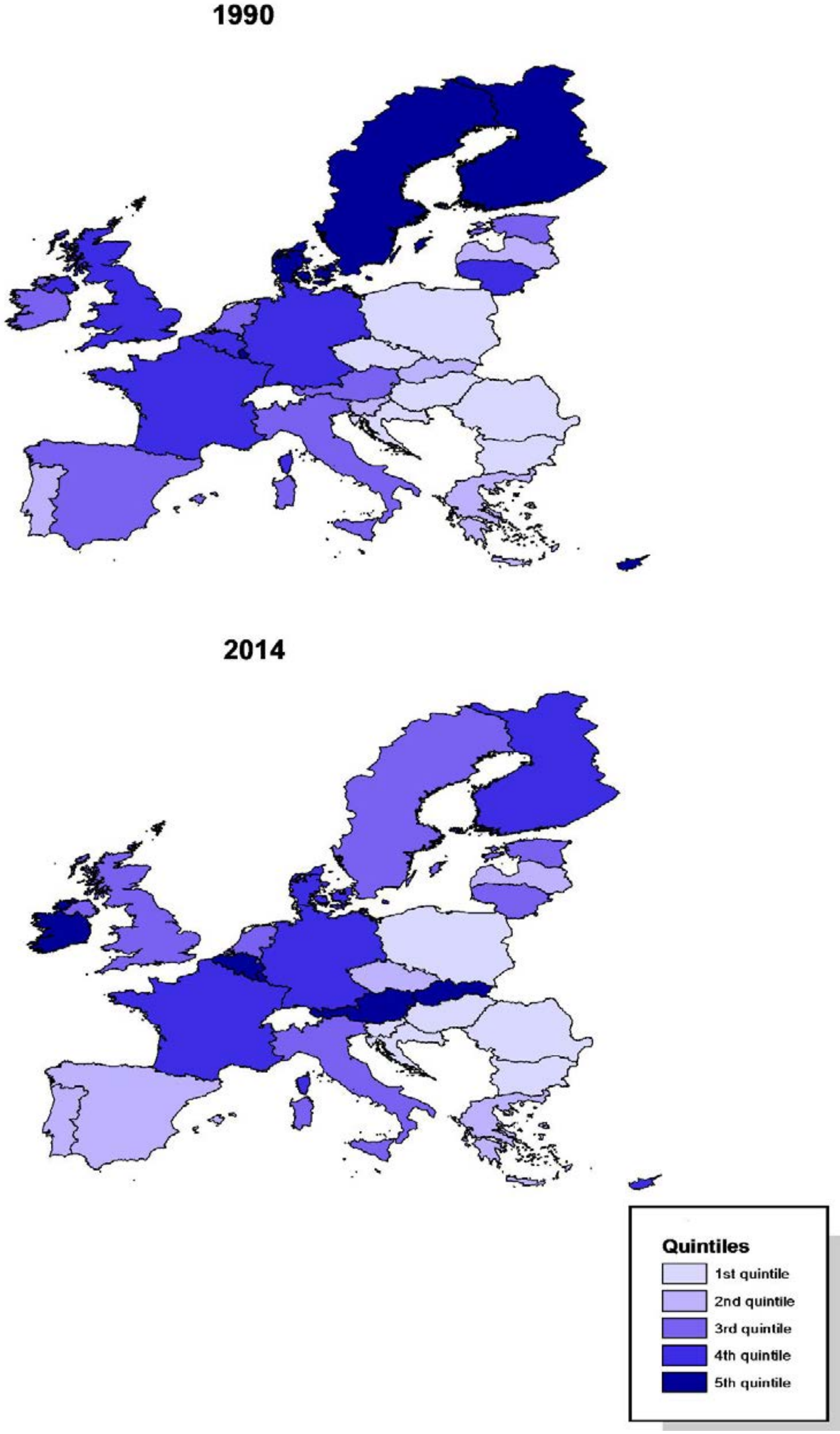
[8] The western EU includes Austria, Belgium, Denmark, Germany, Greece, Finland, France, Ireland, Italy, the Netherlands, Portugal, Spain, Sweden and the United Kingdom. The eastern EU includes Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovenia and Slovakia.

Figure 1. Greenhouse gas emissions of transport activity in western EU region and in eastern EU region, by country. 1990–2014



Source: Prepared by the authors with data from Eurostat (2016).

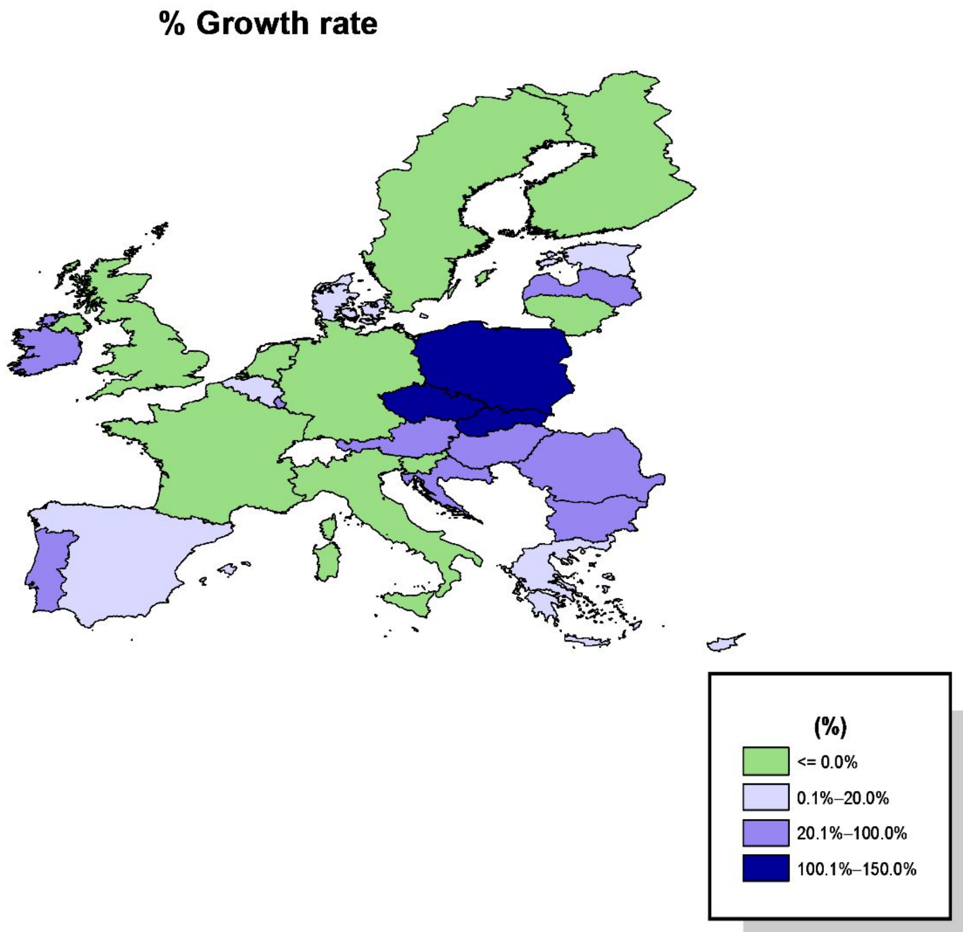
Figure 2. Per capita greenhouse gas emissions of the EU transport activity. 1990–2014



Note: The data for France are from 1991.

Source: Prepared by the authors with data from Eurostat (2016).

Figure 3. Per capita greenhouse gas emissions' growth rate of the EU transport activity. 1990–2014



Note: The data for France are from 1991.

Source: Prepared by the authors with data from Eurostat (2016).

Table 3. Descriptive statistics of the variables

Variable	EU countries				Western EU countries				Eastern EU countries			
	Mean	Std Dev.	Min.	Max.	Mean	Std Dev.	Min.	Max.	Mean	Std Dev.	Min.	Max.
Greenhouse gas emissions	35.747	47.337	1.168	186.778	56.674	54.259	5.135	186.778	9.112	9.053	1.168	48.613
Population	19500000	22500000	1320000	82500000	27200000	26200000	3510000	82500000	9760000	10600000	1320000	38700000
Real per capita GDP	26740.220	15375.053	3535.364	61149.530	37599.188	10025.372	16688.259	61149.530	11353.019	4963.380	3535.364	25448.964
Passenger activity	230.288	304.315	7.706	1118.186	340.686	346.655	33.630	1118.186	61.115	56.720	7.706	254.412
Freight activity	95.606	123.146	3.790	640.622	131.988	142.924	5.919	640.622	42.728	53.207	3.790	313.043
% Road activity	0.831	0.099	0.462	0.975	0.871	0.063	0.728	0.975	0.770	0.113	0.462	0.924
% Rail activity	0.143	0.098	0.021	0.527	0.094	0.047	0.021	0.212	0.219	0.108	0.063	0.527
% Aviation activity	0.007	0.011	0.000	0.081	0.009	0.007	0.000	0.029	0.005	0.014	0.000	0.081
% Waterborne activity	0.018	0.035	0.000	0.177	0.026	0.043	0.000	0.177	0.006	0.010	0.000	0.051
Energy consumption	13496.439	17926.222	408.800	67819.300	21588.275	20413.364	2022.200	67819.300	3197.738	3312.903	408.800	17906.600
% Oil products	0.959	0.042	0.674	0.999	0.968	0.030	0.853	0.999	0.947	0.052	0.674	0.995
% Electricity	0.020	0.017	0.001	0.106	0.016	0.011	0.001	0.054	0.026	0.020	0.003	0.106
% Renewable energies	0.011	0.019	0.000	0.120	0.013	0.021	0.000	0.120	0.009	0.015	0.000	0.062
% Gas	0.010	0.031	0.000	0.278	0.004	0.007	0.000	0.034	0.018	0.045	0.000	0.278

Source: Prepared by the authors with data from Enerdata (2016), Eurostat (2016) and the World Bank (2016).

Note: Greenhouse gas emission units are in million tonnes of CO_2 equivalent; population is measured as the number of people; real per capita GDP is stated in constant 2010 US$; passenger and freight activities are measured in gross ton-kilometers; and energy consumption is given in thousand TOE.

2.3.2. An extended STIRPAT model for the analysis of transport activity emissions

The STIRPAT model formula is as follows:

(1) $$I = a + \beta_1 P + \beta_2 A + \beta_3 T + \varepsilon$$

where *I* is the environmental impact, a is a constant, *P* is the population, *A* is affluence, usually proxied by per capita activity, *T* is technology, typically measured as the impact per unit of activity, ε is the error term and β_i are the estimated parameters. All the variables are taken in log form, so β_i can be interpreted as "ecological elasticities" (York et al., 2003), which indicate the sensitivity of environmental impacts to a change in any driving factor.

This paper employs a new extended STIRPAT model to identify the driving factors of the emissions in transport activity, in which, besides including population and affluence, the technology factor is decomposed in a novel way to obtain more detailed results focused on the activity. In particular, technology is decomposed to take into account not only the transport energy intensity but also the activity volume of the transport sector and its structural composition in terms of modes of transport and sources of energy. The novelty of this methodology relies on, first, introducing into the model the share of all modes of transport in the total activity and the share of all sources of energy in the total transport energy consumption —so that it is stressed that the effect on emissions in the transport sector depends on both the transport volume and its composition (in terms of both activity and energy consumption)— and, second, considering an alternative unit of measurement of transport energy intensity. In the previous literature, the energy intensity of transport activity is measured as the total transport energy consumption with respect to the gross value added of the activity.[9] This definition could lead to misleading results, since increases in the value added of the activity would indicate false improvements in transport energy intensity,[10] whereas if it is defined with respect to gross ton-moved (both passenger and freight), then, transport energy intensity enhancements would involve less energy use per unit of transport activity. Therefore, transport energy intensity is

[9] With the exception of the studies focused on analyzing passenger or freight transport emissions, that is, the works of Scholl et al. (1996), Lakshmanan and Han (1997), Steenhof et al. (2006) and M'raihi (2015) who define energy intensity as energy use per passenger-kilometer (or passenger-mile) or as energy use per ton-kilometer (or ton-mile) depending on whether the study analyzes passenger or freight transport emissions. Another exception is the work of Sobrino and Monzon (2014), who define the energy intensity of road transport as the total energy use per total kilometers driven on the road.

[10] For instance, higher value added of a commodity does not imply that fewer ton-kilometers of it are transported.

defined as transport energy consumption divided by the sum of passenger and freight activities, both measured in gross ton-kilometers.

After performing an analysis of the correlation[11] between the variables and a study of multicollinearity[12] (see Tables A3 and A4 in the Appendix), the econometric model selected takes the following form:

(2) $GHG_{it} = \alpha_i + \gamma_t + \beta_1 P_{it} + \beta_2 GDP_{it} + \beta_3 EI_{it} + \beta_4 TA_{it} + \sum_{j=1}^{J-1} \mu_j M_{jit} + \sum_{k=1}^{K-1} \Omega_k S_{kit} + \varepsilon_{it}$

$i = 1, \ldots, 25$; $t = 1990, \ldots, 2014$

where *i* denotes the country; *t* refers to the year; *j* indicates the different modes of transport, road, rail, aviation and waterborne; and *k* are the sources of energy of the activity, oil, electricity, renewable energies and gas.[13] Likewise, $GHG_{i,t}$ are the total greenhouse gas emissions in the transport sector for country *i* and year *t*; $P_{i,t}$ is the total population; $GDP_{i,t}$ is the real per capita GDP; $EI_{i,t}$ is the transport energy intensity, which is defined as the total transport energy consumption divided by the total transport volume (passenger and freight activities); and TA_{it} is the per capita freight activity and measures the activity volume. All the variables are taken in log form, which implies that the estimated coefficients β_i denote the elasticity of greenhouse gas emissions of the transport activity with respect to each driving factor. The unobserved country-specific variables α_i collect all the fixed factors that characterize each country and are time invariant. The terms γ_t refer to a time-specific constant that brings together all time-related shocks that are common to all countries. M_j is the share of modal transport *j* in the total transport volume, where $J = 4$, given that we consider four modes of transport, with $\sum_{j=1}^{J} M_{jit} = 1, \forall i, t$. Similarly, S_k is the share of energy source *k* in the total energy consumption of the transport activity, where $K = 4$, with $\sum_{k=1}^{K} S_{kit} = 1, \forall i, t$. One mode of transport (M_j) and one source of energy (S_k) are omitted to estimate the above equation to avoid multicollinearity problems. Road transport is the omitted modal transport; thus, the parameter estimates μ_j are semi-elasticities and they must be interpreted as the impact on transport emissions of an increase of 1% in the share on transport activity of an alternative mode of transport —rail, aviation or waterborne— at the expense of a

[11] The pairwise correlation coefficients seem to show some problems of collinearity between transport energy intensity and rail share when considering the EU as a whole and between rail share and electricity share when considering the western EU. However, as we will see later, the results with respect to the three variables involved are robust.

[12] Transport volume was first defined as the sum of passenger and freight activities; however, an analysis of multicollinearity showed problems between transport volume and population. To solve this, transport volume was then defined as only freight activity, and the multicollinearity problems disappeared.

[13] As noted above, coal is not taken into account in the analysis given its negligible value. During the last decade, it has been used only in a few steam locomotives in the UK (Eurostat, 2016).

reduction of 1% in the share of road transport, other things being equal. In the same way, the source of energy omitted is oil products, which means that parameter estimates Ω_k are semi-elasticities and they must be interpreted as the impact on transport emissions originated by a 1% rise in the share of an alternative source of energy —electricity, renewable energies or gas— at the expense of a decrease of 1% in the share of oil products, all other things being equal. Finally, ε_{it} are the error terms.

Table 4. Units and definitions of the data used in the model

Variable	Units of measurement	Definition
GHG	Million tonnes of CO_2 equivalent	Total greenhouse gas emissions of the transport sector
P	Number of people	Population
GDP	Constant 2010 US$	Real per capita gross domestic product
EI	Thousand TOE per gross ton-kilometer	Transport energy intensity defined as the total energy consumption of transport activity divided by the total transport volume (passenger and freight)
TA	Gross ton-kilometers	Transport volume measured as the per capita freight activity
M_j	Percentage	Ratio of mode of transport j in the total transport volume
S_k	Percentage	Ratio of source of energy k in the total energy consumption of transport activity

Source: Prepared by the authors

2.3.3. Estimation methods

There are two basic econometric models that can be used in panel data analysis: the fixed-effects model (FE) and the random-effects model (RE). Given the unobserved country-specific heterogeneity of the panel data, it is appropriate to control all the time-invariant characteristics of each country not considered in the model. By definition, these time-invariant characteristics do not have any influence on the evolution of the dependent variable, as they are constant for each country. In econometric terms the α_i terms are treated as regression parameters. The FE model, unlike the RE model, provides results that are conditional on the country effects of the sample data used, so they cannot be extrapolated to other samples of data (Hsiao, 1986; Stern, 2004). That is, the FE model is suitable if the analysis is restricted to a particular group of countries, while the RE model is appropriate when applied to a random set of countries. After carrying out the test of fixed vs. random effects of overidentifying restrictions implemented by Schaffer and Stillman (2010), which unlike Hausman test allows for heteroskedasticity and within-group correlation, the FE model is chosen to estimate Equation 2 both for the EU as a whole and for the western EU region. In relation to the eastern region, although the previous test pointed out that the pooled OLS model was better than the RE model, [14] the F test rejected equal fixed effects across countries, which indicated that the best

[14] The estimate of sigma_u was equal to zero, therefore, all the country-specific intercepts were the same.

model is the FE model (Table 5). Therefore, the FE model is also chosen to estimate Equation 2 in the eastern EU region.

Table 5. Fixed versus Random Effects

	EU		Western EU		Eastern EU	
	Test stat.	p-value	Test stat.	p-value	Test stat.	p-value
Wald stat.	21.191	0.0198	213.535	0.0000	---	---
F stat.	---	---	---	---	17.20	0.0000

Source: Prepared by the authors with data from Enerdata (2016), Eurostat (2016) and the World Bank (2016).

After estimating our FE model, other tests are carried out to determine whether any of the classic econometric assumptions are violated, that is, if there are problems of autocorrelation, heteroskedasticity or cross-sectional dependence, in which case the estimated parameters of FE would be biased and, instead, the suitable econometric model would be the panel corrected standard error model (PCSE) or the feasible generalized least squares model (FGLS). Both the PCSE and the FGLS analyze panel data with problems of heteroskedasticity and/or contemporaneous correlation, with or without autocorrelation, although the first model is more appropriate when $N > T$ and the second otherwise (Hoechle, 2007).

The tests used to identify the problems mentioned above are: i) the Wooldridge test for serial correlation, which is used to test for autocorrelation, that is, whether or not the errors of each country are temporally correlated (first-order autocorrelation), and the null hypothesis of this test is no first-order autocorrelation; ii) the modified Wald test for heteroskedasticity, which is used to test for heteroskedasticity, that is, whether or not the variances of the errors of each country are constant, the null hypothesis of this test being no heteroskedasticity; iii) the Pesaran CD test, which is used to test for contemporaneous correlation, that is, whether or not the residuals are correlated across countries, the null hypothesis of this test being sectional independence.

All the variables of our model are detrended, taking them as deviations from period means, which is a standard procedure in the literature (Marrero, 2010). Consequently, the time-specific term γ_t is omitted from the model.

Likewise, as taking into account the behavior of the series shown in Figure 1, two facts were taken into account in the estimation of Equation 2. First, the greenhouse gas emissions of the transport activity in the western EU region began to decrease in 2008 as a result of the financial and economic crisis. Second, the greenhouse gas emissions of the transport activity in the eastern EU region showed a sharp plunge in the early nineties as a consequence of the economic crisis endured by the region during those years. As transport emissions seemed to show different patterns during the period analyzed, we tested the significance of these patterns using two different strategies in the estimation of Equation 2: first, we included time dummies for each year of the period analyzed; second, we included time trends for the different years of the period analyzed. However, as the results were robust and not affected by the introduction of the time dummies or the time trends, we did not include them in the final model.

2.4. Results and discussion

The Wooldridge test, the modified Wald test and the Pesaran CD test, when respectively applied to the FE model, point to the existence of heteroskedasticity and serial correlation but not contemporaneous correlation. These results hold when analyzing the EU both as a whole and by regions (Table 6).

Table 6. Group-wise heteroskedasticity, serial correlation and cross-sectional dependence tests

	EU		Western EU		Eastern EU	
	Test stat.	**p-value**	**Test stat.**	**p-value**	**Test stat.**	**p-value**
F stat.	144.287	0.000	32.780	0.000	71.550	0.000
Wald stat.	3883.930	0.000	155.700	0.000	189.780	0.000
CD stat.	0.330	0.741	-1.064	1.713	-0.462	1.356

Source: Prepared by the authors with data from Enerdata (2016), Eurostat (2016) and the World Bank (2016).

To solve these two problems, we estimate a PCSE and an FGLS with country fixed effects when considering the EU as a whole, given that the database is $N = T$. The FE, the PCSE and the FGLS estimates of Equation 2 for the EU are reported in Table 7. When analyzing the EU regions, we also estimate a PCSE and an FGLS with country fixed effects, but, because the database is now $N < T$, the FGLS results are the most appropriate. The FE, the PCSE and the FGLS estimates of Equation 2 for the western EU and the eastern EU are reported in Tables 8 and 9, respectively.

2.4.1. Driving factors of transport emissions in the EU

Table 7 shows the results for the EU as a whole. All the signs of the estimated parameters are as expected. The elasticities of emissions with respect to population, real per capita GDP, transport volume and transport energy intensity are positive and statistically significant. All these elasticities are higher than zero but below the unit, indicating that a change in any of these driving factors, all other things being equal, would mean less than a proportional change in the same sign for transport emissions.

Table 7. Estimates of driving factors of greenhouse gas emissions in the transport activity of the EU

Dependent variable: *Transport emissions*						
	FE		PCSE		FGLS	
Population	1.009***	(0.190)	0.987***	(0.111)	0.881***	(0.084)
Real per capita GDP	0.345***	(0.103)	0.344***	(0.034)	0.304***	(0.025)
Transport energy intensity	0.616***	(0.135)	0.642***	(0.029)	0.704***	(0.025)
Transport volume	0.345***	(0.072)	0.315***	(0.021)	0.317***	(0.017)
Rail share	-0.784***	(0.248)	-0.563***	(0.105)	-0.528***	(0.085)
Aviation share	0.521	(0.994)	0.608	(0.525)	1.298**	(0.540)
Waterborne share	-1.450	(0.918)	-0.770*	(0.413)	-0.959***	(0.247)
Electricity share	1.146	(1.858)	-0.329	(0.548)	-1.149**	(0.533)
Renewable energies' share	-1.328***	(0.422)	-1.191***	(0.213)	-1.023***	(0.136)
Gas share	-0.711**	(0.315)	-0.409*	(0.111)	-0.567***	(0.198)
Constant	2.577***	(0.075)	2.541***	(0.034)	2.583***	(0.025)
Country	Yes		Yes		Yes	
Year	Yes		Yes		Yes	
R^2	0.873		0.994			
F	58.4					
N	538		538		538	

Clustered standard errors by country in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Note: *Transport emissions, population, real per capita GDP, transport energy intensity and transport volume* are taken in natural logarithms.

In particular, the elasticity of transport energy intensity indicates that a 1% decrease in energy intensity contributes to reducing transport emissions in about 0.704%. However, given the parameters estimated for population, real per capita GDP and transport volume, 0.881, 0.304 and 0.317, respectively, its positive effect is limited. The growth of population, economic activity and transport volume counteracts the positive impact of energy efficiency enhancements. In addition, it must be noticed that, when the whole impact of efficiency improvements is evaluated, it has to be taken into account that it may exert an impact on other variables, such as the transport volume, through the rebound effect (see Greening et al., 2000, for a survey of the rebound effect due to energy efficiency improvements). However, we focus here on the direct drivers of transport emissions and, though possible rebound effects have to be considered when analyzing the results, their computation is beyond the scope of this paper.

In relation to the parameter estimates of the modal transport share, rail and waterborne transport are the ones for which the coefficients are statistically significant, being -0.528 and -0.959, respectively. Their negative signs indicate that a reduction in the road transport share in favor of rail or waterborne transport would lead to a decrease in activity emissions. In fact, our results point out that the substitution of rail for road is apparently more effective in reducing transport emissions than the substitution of waterborne transport for road. As regards the estimated coefficient for the aviation transport share, although positive, it is not statistically significant, at least not in all the specifications. It should be recalled that international aviation is not taken into account in this study because of a lack of equivalent data. Had we been able to add international aviation, the expected estimated parameter is very likely to have been statistically significant and would probably have indicated that an increase in the aviation transport share at the expense of road transport increases the greenhouse gas emissions of the EU transport activity.

As for the energy sources, the parameter estimates for renewable energies and gas, with coefficients of -1.023 and -0.567, respectively, are statistically significant in all the specifications, while electricity is statistically significant in the FGLS. The negative sign of their estimated coefficients indicates that the substitution of electricity, renewable energies or gas for oil products would result in a reduction of greenhouse gas emissions in transport activity. Taking into account the fact that our analysis is not conclusive regarding electricity, the results show that the greatest effect corresponds to renewable energies, as evidenced by their higher estimated parameter. Although this outcome related to electricity is surprising, the analysis by regions could shed some light on it.

2.4.2. Driving factors of transport emissions in the EU regions

The FGLS outcomes shown in Tables 8 and 9 reveal that there are no great differences between the results of the western and eastern regions as regards the signs and significance of the estimated parameters. The outcomes of the estimations for these groups confirm those obtained for the EU as a whole, which is proof of the robustness of our results.

In particular, the elasticities of greenhouse gas emissions with respect to population, real per capita GDP, transport volume and transport energy intensity are positive but below the unity and statistically significant in both regions. Regardless of the region, the effect on emissions of a change in the population or transport energy intensity is greater than that of real per capita GDP or transport volume. However, it is worth noting that, in the western region, the larger relative impact on transport emissions corresponds to a change in the population with an elasticity of 0.819%, while the transport energy intensity with an elasticity of 0.814% is the driving factor with the greater relative impact on emissions in the eastern region. While energy efficiency would contribute to mitigating the emissions of the transport sector in both regions, its impact would be larger in the eastern EU region. We explain in the discussion and policy implications' section the reason for the larger significance of transport energy intensity for the eastern EU region.

Table 8. Estimates of driving factors of greenhouse gas emissions in the transport activity of the western EU

Dependent variable: *Transport emissions*						
	FE		PCSE		FGLS	
Population	0.482*	(0.255)	0.640***	(0.133)	0.819***	(0.114)
Real per capita GDP	0.565***	(0.133)	0.561***	(0.044)	0.399***	(0.039)
Transport energy intensity	0.483***	(0.115)	0.598***	(0.036)	0.634***	(0.033)
Transport volume	0.141**	(0.064)	0.168***	(0.020)	0.216***	(0.020)
Rail share	-5.829***	(1.051)	-3.484***	(0.285)	-2.851***	(0.254)
Aviation share	-0.405	(5.143)	-0.903	(1.285)	1.257	(1.215)
Waterborne share	-0.564	(0.681)	-0.707**	(0.357)	-0.761***	(0.295)
Electricity share	-6.861***	(1.696)	-4.496***	(0.967)	-2.646***	(0.840)
Renewable energies' share	-0.835	(0.486)	-1.168***	(0.197)	-1.067***	(0.163)
Gas share	-1.303	(1.798)	-0.574	(0.695)	-1.278**	(0.614)
Constant	2.614***	(0.140)	2.762***	(0.040)	2.764***	(0.039)
Country	Yes		Yes		Yes	
Year	Yes		Yes		Yes	
R^2	0.928		0.997			
F	453.5					
N	330		330		330	

Clustered standard errors by country in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Note: *Transport emissions, population, real per capita GDP, transport energy intensity and transport volume* are taken in natural logarithms.

For the transport mode share, the shift from road to rail is the only one that would cut transport emissions in both regions, as the estimated parameters, with a coefficient of -2.851 for the western EU region and -0.444 for the eastern EU region, have the expected negative sign and are statistically significant. Likewise, the reduction in emissions would be greater in the western countries as a consequence of this switch. With regard to waterborne transport, the reduction in transport emissions by shifting from road to waterborne transport would only be effective in the western region, where the negative estimated coefficient, -0.761, is statistically significant at a significance level of 1%. According to this regional analysis, the replacement of road with rail or waterborne transport would have a greater impact on emission reduction in the western region. Finally, concerning aviation, the positive coefficient estimated is statistically significant in the eastern region; thus, a larger share of aviation at the expense of road transport would mean higher transport emissions in this region. As mentioned in the previous section, aviation only covers domestic aviation activity. If aviation included international activity, the result is very likely to be statistically significant in the western region too.

Regarding the mix of energy sources, shifting from oil products towards renewable energies or gas would improve the transport emissions in both regions, as their estimated coefficients are negative and statistically significant. However, the effect of switching from oil products to renewable energies on reducing transport emissions is apparently greater in the eastern region, with a coefficient of -1.500, while the effect of a shift towards gas is greater in the western region, with a coefficient of -1.278. In relation to electricity, the analysis of the EU transport activity as a whole did not provide a conclusive result. However, we are now in a position to give a response. The replacement of oil products with electricity would decrease the emissions in the western region, given that its estimated parameter, -2.646, is negative and statistically significant, while it seems that it would not have any impact in the eastern region, given that its coefficient is not statistically significant at any significance level. The result for the western region is as expected, as the use of electricity as a source of energy is less polluting than the use of oil products. In the next section, we provide an explanation for this result for the eastern region in relation to electricity.

Table 9. Estimates of driving factors of greenhouse gas emissions in the transport activity of the eastern EU

Dependent variable: *Transport emissions*						
	FE		PCSE		FGLS	
Population	0.498	(0.302)	0.603**	(0.240)	0.691***	(0.204)
Real per capita GDP	0.129	(0.115)	0.115**	(0.057)	0.221***	(0.048)
Transport energy intensity	0.889***	(0.072)	0.742***	(0.043)	0.814***	(0.040)
Transport volume	0.544***	(0.062)	0.498***	(0.037)	0.469***	(0.034)
Rail share	-0.685***	(0.174)	-0.622***	(0.126)	-0.444***	(0.101)
Aviation share	1.172*	(0.595)	1.063*	(0.590)	1.324***	(0.477)
Waterborne share	-1.501	(1.224)	0.181	(0.979)	-0.874	(1.111)
Electricity share	1.945**	(0.821)	0.394	(0.745)	0.377	(0.750)
Renewable energies' share	-2.358***	(0.732)	-1.817***	(0.434)	-1.500***	(0.375)
Gas share	-0.789***	(0.213)	-0.434***	(0.136)	-0.562***	(0.201)
Constant	2.409***	(0.140)	2.558***	(0.070)	2.715***	(0.060)
Country	Yes		Yes		Yes	
Year	Yes		Yes		Yes	
R^2	0.930		0.989			
F	10955.7					
N	208		208		208	

Clustered standard errors by country in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Note: *Transport emissions*, *population*, *real per capita GDP*, *transport energy intensity* and *transport volume* are taken in natural logarithms.

2.4.3. Discussion and policy implications

The above results indicate that population, economic activity, transport volume, transport energy intensity, modal share and energy mix are driving factors of transport emissions in the EU in the period 1990–2014. In particular, population followed by transport energy intensity are more meaningful in explaining transport emissions than economic activity and/or transport volume. This outcome somewhat differs from the previous empirical evidence for other regions and periods, given that in most investigations economic activity is the main driving factor of transport emissions followed by population or, alternatively, by transport energy intensity (Lakshmanan and Han, 1997; Mazzarino, 2000; Timilsina and Shrestha, 2009; Guo et al., 2014; M'raihi et al., 2015; Fan and Lei, 2016; Xu and Lin,[15] 2015, 2016). In some other cases, transport volume turns to be the main driving factor (Scholl et al., 1996; Kwon, 2005; Steenhof et al., 2006). The result of the great importance of transport energy intensity as a driving factor of the EU transport emissions, especially in the eastern region, is very relevant. It shows that improvements in energy intensity can contribute to alleviating the transport emissions' growth considerably. In other words, environmental policies focused on driving energy efficiency in transport activity, for instance replacing old vehicles with other technologically more energy-efficient ones, the use of higher-quality fuels and infrastructure improvements, would have a greater impact on reducing the transport emissions in the EU, with a higher transport energy intensity elasticity, than in other world regions, for example China (Zhang and Nian, 2013; Xu and Lin, 2015, 2016). Moreover, it is worth mentioning that the positive effect on the EU transport emissions derived from improvements in energy efficiency would be limited or even insufficient if they were accompanied by significant increases in population, economic activity and/or transport volume.

Another finding of our work is that the EU transport emissions show relative decoupling in relation to transport activity in particular and economic activity in general. Relative decoupling means that the growth rate of transport emissions is lower than the growth rate of transport (or economic) activity; then, the environmental impact per unit of transport activity (or economic output) drops (UNEP, 2011) —though the transport emissions could be rising in absolute terms. Likewise, the phenomenon of relative decoupling occurs in both regions. However, when it is related to economic activity, the decoupling is greater in the eastern region, while, when related to transport activity, it is greater in the western region. Various previous works also find relative decoupling among transport emissions, economic activity and transport volume, such as those on China by Zhang and Nian (2013) and Xu and Lin (2016). In these relative decoupling is much less important regarding the Chinese economic activity, but, in relation to transport volume, our work is in the same vein as the results for China of Xu and Lin (2016), while the work for China of Zang and Nian (2013) shows a higher relative level of decoupling.

Another outstanding result of the analysis is related to the modal share and energy source mix. Previous literature, for instance the works of Scholl et al. (1996) on nine OCDE countries, Lakshmanan and Han (1997) on the USA and Steenhof et al. (2006) on Canada, find that the modal share is a significant driving factor of transport emissions, but, on the contrary, the investigation of Timilsina and Shrestha (2009) into selected

[15] In the study by Xu and Lin (2015, 2016), urbanization level and private car ownership are substituted for population.

Asian countries points out that the modal share is a minor driving factor. As regards the energy mix, the previously mentioned works of Steenhof et al. (2006) and Timilsina and Shrestha (2009), and the studies on China by Guo et al. (2014) and on Beijing by Fan and Lei (2016), determine that the energy mix is a minor driving factor of transport emissions. Nevertheless, the aforementioned literature analyzes the importance of the modal share and/or of the energy mix as a whole. By contrast, our investigation takes a step further by studying the modal share in detail through quantifying the impact on transport emissions resulting from the substitution of rail or waterborne or aviation for road transport and by analyzing the energy source mix in detail through quantifying the impact on transport emissions resulting from the substitution of electricity or renewable energies or gas for oil products. That is, our analysis allows us to determine the contribution to transport emissions of a change in modal share and of a change in energy mix. We conclude that both the modal share and the energy mix are driving factors of the EU transport emissions during the period analyzed.

In particular, in relation to the modal share, we find that the preferred alternative mode of transport to road is rail, given that, when substituting road with the other alternative modes of transport —rail, waterborne or aviation— rail would lead to a larger decline in transport emissions. However, the intensity of diminishing transport emissions due to this substitution would depend on the energy source mix used in the modes of transport involved. For instance, the analysis by regions shows that the impact on diminishing transport emissions as a result of shifting from road to rail is greater in the western EU region. This is because electricity accounts for 69.3% of the total rail energy consumption in the western region in 2014, while in the eastern region electricity only achieves 54.1%; that is, the use of oil products as a source of energy in rail is lower in the western region (30.0%) than in the eastern region (45.4%) (see Tables A1 and A2 in the Appendix); hence, the impact on transport emissions from substituting rail for road would be larger in the EU western region.

Regarding the energy source mix, we find that, among the alternative sources of energy —electricity, renewable energies or gas— from an environmental point of view, the preferred sources of energy to substitute oil products are electricity and renewable energies, due to their greater contribution to diminishing the EU transport emissions. However, despite the positive impact on transport emissions derived from substituting electricity for oil products, the analysis by regions detects a significant reduction in electricity consumption in the eastern region in a period of increasing use of energy on transport activity, which, in turn, produces an unexpected outcome; that is, electricity appears not to be a major driving factor of transport emissions in the eastern region. Nevertheless, there is an explanation for the outcome of non-significance for electricity in that region. During the period 1990–2014, energy use on transport activity increased in the eastern region by 67.3%. Moreover, this growth was accompanied by a change in the energy source mix, increasing the consumption of all sources of energy with the exception of electricity, which decreased. As a result of these changes, the share in the total energy consumption of oil products and electricity decreased, while it increased for renewable energies and gas. That is, renewable energies and gas "substituted" for electricity consumption and, as a consequence, the impact of electricity on transport emissions was "negligible" in the eastern region during the period analyzed (see Table A2 in the Appendix).

The reason for the decrease in electricity consumption in the eastern region is related to the use of rail as a mode of transport. Rail is the main mode of transport that uses electricity as a source of energy. Thus, in 2014 rail's electricity consumption amounted to 88.8% of the total electricity consumption in transport activity in the eastern region. During 1990–2014 rail's energy consumption in this region decreased by 44.9%, which resulted in a reduction of electricity consumption by 25.8%. This decline in rail's energy consumption, and hence the reduction of electricity use, was a consequence of rail's activity contraction during the period analyzed. The study by Pucher and Buehler (2005) makes reference to a transport revolution since the extinction of Communism in the late 1980s in these countries. It points out the extraordinary growth of private car ownership and use and the associated downturn in public transport use; in addition, this pattern in passenger transport is accompanied by a shift in freight transport from rail to truck. Thus, rail activity loses significance in favor of road transport, cutting the consumption of electricity in transport activity in the eastern region. At the same time, this substitution of road for rail means, in fact, a shift from electricity to oil products, which explains the higher transport energy intensity level and its significance as a driving factor in the eastern region; indeed, the energy intensity of transport activity in the eastern region increased during the period analyzed, whereas it experienced a reduction in the western region. In short, data showed that between 1995 and 2013, transport energy intensity decreased by 7.4% in western EU, whereas it increased 21.4% in eastern EU. Therefore, given these results, policies promoting the use of rail, such as investments in rail infrastructures that facilitate multimodality,[16] or measures fostering the use of

[16] Multimodality refers to the integration of all modes of transport by guaranteeing the interoperability of the transport system at all levels.

electricity, for instance investments in electrifying the rail network or encouraging the use of electric vehicles, will help substantially in curbing EU transport emissions.

Finally, in the 2011 Transport White Paper, some guidance it is provided to achieve the goal of reducing the transport activity emissions by 60% by 2050 in relation to 1990. Specifically, the proposals are: i) to eliminate gradually conventionally fueled cars in cities, ii) to substitute rail and waterborne transport for 50% of road transport, iii) to use 40% of low-carbon fuels in aviation and, finally, iv) to reduce shipping emissions by at least 40% (European Commission, 2011). Given the results obtained in this research, it can be said in relation to these proposals that, first, regarding the gradual elimination of conventionally fueled cars in cities, it will effectively decrease EU transport emissions, given that switching from oil products to alternative sources of energy, such as electricity, renewable energies or even gas, leads to a reduction in transport emissions, although electricity should be the preferred source due to its larger impact on the reduction of EU transport emissions. With regard to substituting rail or waterborne transport for 50% of road transport, it will in effect lessen the EU transport emissions, as the shift from road to rail or waterborne transport cuts transport emissions, but rail should be the favored alternative mode of transport given that its impact on cutting emissions is greater than that of waterborne transport. As regards the promotion of low-carbon fuels in aviation, our empirical analysis shows that an increase in aviation activity at the expense of roads will lead to an increase in the EU transport emissions.[17] Therefore, the only effective measure to reduce aviation emissions will be precisely to draw on low-carbon fuels and, when possible, switch to other transport modes, at least until the development of new technologies in the future that allow the use of alternative sources of energy in aviation —new technologies, such as solar energy, have been developed recently, but they still cannot be used commercially. To conclude, in relation to the target of reducing shipping emissions by at least 40%, to achieve this goal, besides a reduction in shipping needs by improving logistics, three other measures could be adopted: i) shifting from oil products to other sources of energy, such as renewable energies, gas or electricity; ii) encouraging the use of sustainable low-carbon fuels; and, finally, iii) improving energy efficiency. We have just seen empirically that these three measures could work.

Nevertheless, some limitations of the previous analysis must be considered. First, this research excludes international bunker emissions (international maritime transport and international aviation emissions) from the analysis due to a lack of data or equivalent

[17] The corresponding estimated coefficients are positive for the EU as a whole, the western EU and the eastern EU, although they are only statistically significant in the FGLS estimates for the EU as a whole and in the PCSE and FGLS estimates for the eastern EU.

data. Taking into account that maritime bunker fuels accounted for 11.5% of the total EU transport energy consumption in 2012 and that aviation[18] accounted for 12.4% (DG MOVE, 2015), and that in 2014 in terms of emissions each one accounted for 11.7% of transport emissions (EEA, 2017), our results could be misleading. In fact, in the various econometric models estimated, the results for the parameters of aviation and waterborne transport are slightly or not significant. It is likely that the inclusion of these data led to more significant outcomes for aviation and waterborne transport parameters independently of the EU region analyzed and the econometric model used. In this sense the availability of data on the activities of passengers and freight in international aviation and waterborne transport, in equivalent units to those used in other modes of transport, would be particularly relevant to improving the estimation of the impact of these two modes of transport. Second, it is noticeable that the impact of the different renewable energies on transport emissions differs substantially. Let us take biofuels, the most important alternative fuel among renewable energies, as an example. There are three types of biofuels, referred to as first-, second- and third-generation biofuels. The second- and third-generation biofuels are more sustainable than the first-generation biofuels, as they can achieve greater transport emission savings (DG MOVE, 2015). Thus, the renewable energies mix is important in studying their impact on transport emissions. Due to a lack of data, this is a limitation of our work that must be considered. Third, to conclude, it would also be important to include in the previous analysis the interdependencies among countries, especially those cases in which the transport emissions in some countries could be explained, at least partially, by the transport activity in other countries.

2.5. Conclusions

The greenhouse gas emissions of the EU transport activity increased by 13.3% in the period 1990–2014 and are currently the second-largest source of emissions after the energy sector. This trend in transport emissions needs to be reversed to satisfy the 2011 Transport White Paper objective, which consists of reducing the activity's emissions by 60% by 2050 in relation to 1990 (European Commission, 2011).

The objective of this paper is to identify the driving factors of the transport emissions in the EU during the period 1990–2014. With this purpose, we employ an extended STIRPAT model, which allows us to include several driving factors: population, economic activity, transport volume, transport energy intensity and transport activity composition in

[18] Domestic aviation accounts for about 11.0% of the energy consumption of EU aviation (Eurostat, 2016).

terms of modal share and of energy source mix. Unlike the previous literature, the introduction into the STIRPAT model of the shares of each mode of transport and of each source of energy allows us to identify the modes of transport and the sources of energy that would contribute more to cutting transport emissions. The use of panel data econometric techniques enables to quantify the impact of each driving factor on transport emissions. Moreover, the analysis is performed considering the EU as a whole as well as by regions, the western EU and the eastern EU, which differ in their geographical position, economic structure and level of development.

We conclude that the population, real per capita GDP, transport volume, transport energy intensity, and changes in modal share and in energy source mix are driving factors of greenhouse gas emissions in the EU transport sector in the period 1990–2014. The outcomes of the analysis by region are similar to the results obtained for the whole EU. Regardless of the region analyzed, the impact on transport emissions of the different drivers are the same qualitatively but not quantitatively. This regional analysis could thus also be interpreted as a robustness test of the findings achieved for the EU as a whole.

In particular, the outcomes show that population and transport energy intensity are more meaningful in explaining EU transport emissions than economic activity and/or transport volume. Specifically, the EU transport emissions show relative decoupling in relation to transport activity in particular and economic activity in general. In the same way, the preferred alternative mode of transport to road is rail, and electricity is the favored alternative source of energy to oil products, since both, changing to rail and changing to electricity, have the most significant impact on reducing the EU transport emissions.

These results are crucial for designing environmental policies focused on successfully reducing emissions in the EU transport activity. They should be aimed especially at promoting energy saving and efficient energy use but also encouraging the shift from road to other modes of transport that are more environmentally friendly, such as rail, or substituting the use of oil products as a source of energy with other less polluting sources of energy, such as electricity.

In terms of the environmental actions promoted by the 2011 Transport White Paper to achieve the objective of cutting transport emissions, the above results point out that, among all the targets proposed, the most effective in reducing transport emissions would apparently be improvements in transport energy intensity, the substitution of rail for road transport and, finally, the switch from oil products to electricity. It should be noted that the results obtained here only take into account direct transport emissions; therefore, the effectiveness in diminishing the total —direct and indirect— transport emissions from the substitution of electricity for oil products depends on the source used to obtain this electricity. However, it is worth mentioning that all of the measures proposed in the Transport White Paper would contribute to cutting transport emissions.

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Appendix

Table A1. Energy consumption by mode of transport and source of energy: western EU region. 1990–2014

Western EU		Oil products	Electricity	Renewable	Gas	Solid fuel	Total
	1990	214531.6	1.5	5.7	208.6	0	214747.4
Road	2014	232564.9	32	12225.5	1311.7	0	246134.1
	Variation						14.6%
	1990	2904.8	3230	0	0	19.8	6154.6
Rail	2014	1513.9	3492.1	26.1	0	7.7	5039.8
	Variation						-18.1%
	1990	22197.3	0	0	0	0	22197.3
Aviation international	2014	41665.5	0	0	0	0	41665.5
	Variation						87.7%
	1990	5402.1	0	0	0	0	5402.1
Aviation domestic	2014	5214.7	0	0	0	0	5214.7
	Variation						-3.5%
	1990	5801.5	0	0	0	0	5801.5
Waterborne transport	2014	4173	0	4.7	0	0	4177.7
	Variation						-28.0%
	1990	0	52.1	0	96.7	0	148.8
Pipelines	2014	0	54	0	750.2	0	804.2
	Variation						440.5%
	1990	306.9 [a]	763.8	0	0	0	1070.7
Others	2014	369.2	1037.5	7.3	33.4	0	1447.4
	Variation						35.2%
	1990	251144.2	4047.4	5.7	305.3	19.8	255522.4
Total	2014	285501.2	4615.6	12263.6	2095.3	7.7	304483.4
	Variation	13.7%	14.0%	215050.9%	586.3%	-61.1%	19.2%

Source: Prepared by the authors with data from Eurostat (2016).
Note: [a] Data for Germany are not available for this year.

Table A2. Energy consumption by mode of transport and source of energy: eastern EU region. 1990–2014

Eastern EU		Oil products	Electricity	Renewable	Gas	Solid fuel	Total
	1990	21836.9	20.3	0	7.4	0	21864.6
Road	2014	38853.4	31.9	1785.1	136.2	0	40806.6
	Variation						86.6%
	1990	1081[a]	850.5	0	0	188.2	2119.7
Rail	2014	530.3	631.2	4.8	0	0.9	1167.2
	Variation						-44.9%
	1990	1514.6	0	0	0	0	1514.6
Aviation international	2014	1833.7	0	0	0	0	1833.7
	Variation						21.1%
	1990	58	0	0	0	0	58
Aviation domestic	2014	91.6	0	0	0	0	91.6
	Variation						57.9%
	1990	580.5	0	0	0	5.5	586
Waterborne transport	2014	111.9	0	0	0	0	111.9
	Variation						-80.9%
	1990	0	20.8	0	25.9	0	46.7
Pipelines	2014	1	39.6	0	715.9	0	756.5
	Variation						1519.9%
	1990	72.6	512.1	13.1	0	0	597.8
Others	2014	39.2	8.4	1.8	8.5	0	57.9
	Variation						-90.3%
	1990	25143.6	1403.7	13.1	33.3	193.7	26787.4
Total	2014	41461.1	711.1	1791.7	860.6	0.9	44825.4
	Variation	64.9%	-49.3%	13577.1%	2484.4%	-99.5%	67.3%

Source: Prepared by the authors with data from Eurostat (2016).
Note: [a] Data for Romania are not available for this year.

Table A3. Correlation coefficients between the variables

EU	P	GDP	EI	TA	RAIL	AVIA	NAV	ELE	REN	GAS
P	1.0000									
GDP	0.2322*	1.0000								
EI	0.2123*	0.6230*	1.0000							
TA	-0.1975*	0.2521*	-0.3397*	1.0000						
RAIL	-0.3244*	-0.5850*	-0.7260*	0.2946*	1.0000					
AVIA	0.0822	0.0935	-0.0980	0.2662*	0.0518	1.0000				
NAV	0.2289*	0.2686*	0.1055	0.1983*	-0.1626*	-0.0637	1.0000			
ELE	0.1459*	-0.3426*	-0.3906*	0.0561	0.5020*	-0.1309*	0.0313	1.0000		
REN	0.1628*	0.2327*	-0.0639	0.2422*	-0.0624	0.0924	0.0454	-0.0521	1.0000	
GAS	-0.0702	-0.1884*	-0.1391*	0.0413	0.0562	0.1628*	-0.0470	0.0571	0.1148*	1.0000

Western EU region

	P	GDP	EI	TA	RAIL	AVIA	NAV	ELE	REN	GAS
P	1.0000									
GDP	-0.1570*	1.0000								
EI	-0.4047*	-0.2180*	1.0000							
TA	-0.0257	0.4736*	-0.4835*	1.0000						
RAIL	-0.0586	0.4318*	-0.4200*	0.5871*	1.0000					
AVIA	0.2912*	-0.4587*	-0.1976*	0.0897	-0.0675	1.0000				
NAV	0.0986	0.2114*	-0.2037*	0.4008*	0.0316	-0.2062*	1.0000			
ELE	0.2047*	0.2832*	-0.3988*	0.4769*	0.8488*	0.0052	0.0815	1.0000		
REN	0.1007	0.2808*	-0.3171*	0.1949*	0.2796*	0.0490	0.0313	0.1891*	1.0000	
GAS	0.0405	0.1614*	-0.1902*	0.2261*	0.5314*	-0.1416*	-0.1261	0.6326*	0.3203*	1.0000

Eastern EU region

	P	GDP	EI	TA	RAIL	AVIA	NAV	ELE	REN	GAS
P	1.0000									
GDP	-0.3735*	1.0000								
EI	0.0747	0.2295*	1.0000							
TA	-0.4331*	0.5823*	-0.4554*	1.0000						
RAIL	-0.0692	-0.3718*	-0.5761*	0.2834*	1.0000					
AVIA	-0.2193*	0.0992	-0.3585*	0.3725*	0.2913*	1.0000				
NAV	0.3837*	-0.3918*	-0.0084	-0.3322*	-0.0160	-0.0539	1.0000			
ELE	0.4669*	-0.3482*	-0.2480*	-0.2120*	0.2931*	-0.1438	0.4032*	1.0000		
REN	0.1762*	0.4031*	-0.0194	0.3446*	-0.2647*	0.1284	-0.0469	-0.2261*	1.0000	
GAS	0.0449	0.0241	0.0967	0.0239	-0.2022*	0.2713*	0.2443*	-0.0830	0.1909*	1.0000

* Significance at the 0.01% level

Table A4. Collinearity diagnostics

EU

Variable	VIF	SQRT VIF	Tolerance	R-Squared
P	1.70	1.30	0.5878	0.4122
GDP	4.06	2.02	0.2463	0.7537
EI	3.62	1.90	0.2762	0.7238
TA	2.74	1.65	0.3652	0.6348
RAIL	3.55	1.88	0.2819	0.7181
AVIA	1.27	1.13	0.7894	0.2106
NAV	1.22	1.10	0.8192	0.1808
ELE	1.89	1.37	0.5296	0.4704
REN	1.24	1.12	0.8035	0.1965
GAS	1.21	1.10	0.8247	0.1753
Mean VIF	2.25			

Western EU region

Variable	VIF	SQRT VIF	Tolerance	R-Squared
P	1.89	1.37	0.5297	0.4703
GDP	2.28	1.51	0.4395	0.5605
EI	1.91	1.38	0.5239	0.4761
TA	2.89	1.70	0.3462	0.6538
RAIL	6.76	2.60	0.1480	0.8520
AVIA	2.16	1.47	0.4622	0.5378
NAV	1.74	1.32	0.5750	0.4250
ELE	6.77	2.60	0.1478	0.8522
REN	1.48	1.22	0.6736	0.3264
GAS	2.33	1.53	0.4298	0.5702
Mean VIF	3.02			

Eastern EU region

Variable	VIF	SQRT VIF	Tolerance	R-Squared
P	2.41	1.55	0.4148	0.5852
GDP	5.67	2.38	0.1764	0.8236
EI	3.39	1.84	0.2949	0.7051
TA	7.15	2.67	0.1398	0.8602
RAIL	3.42	1.85	0.2925	0.7075
AVIA	1.63	1.28	0.6119	0.3881
NAV	1.54	1.24	0.6483	0.3517
ELE	2.76	1.66	0.3627	0.6373
REN	1.91	1.38	0.5231	0.4769
GAS	1.47	1.21	0.6811	0.3189
Mean VIF	3.14			

Chapter 3

Transportation and storage sector and greenhouse gas emissions: an input–output subsystem analysis from a supply-side perspective

3.1. Introduction

There is growing concern about the consequences of climate change at an international level. A proof of this concern is the Paris Agreement, which came into force in 2016 and which will be operational in 2020 and which aims to reduce GHG emissions globally in order to limit Earth's warming to below 2°C.

Transport is one of the economic activities that contributes most to global GHG emissions, since it is responsible for 20% of the emissions from fuel combustion (World Bank, 2017). In the case of the European Union-28, transport emissions account for 21% of total GHG emissions and their contribution have increased since the 1990s (Eurostat, 2016). In particular, in Spain transport activity is responsible for 25% of total GHG emissions, moreover, these have increased by 50% since 1990 (MAPAMA, 2017). In this scenario, the European Union has implemented different environmental strategies related to transport activity in order to reduce its emissions. The main goal of these measures, as revealed in the Transport White Paper 2011, is to contribute to the target of reducing total greenhouse gases. In particular, the European Union have committed to reducing its GHG transport emissions in 2050 by 60% compared to 1990 (European Commission, 2011).

The input–output Leontief model (1951) has been widely used in the literature as a method to study emissions of an economy given the productive structure of the economy and the relationships between the different economic sectors. In particular, a methodological extension of the model, the analysis of subsystems proposed by Sraffa (1960) and developed by Alcántara (1995) for the case of air pollution, has allowed us to analyze how a sector or a group of sectors —a subsystem— induces itself and the rest of the sectors of the economy to pollute to satisfy its own final demand. Therefore, the analysis of subsystems from the demand-side perspective has been a useful instrument for analyzing direct and indirect emissions related to the activity of a productive sector or group of sectors based on its own final demand and the productive structure of the economy. Some references in this line are, for example, the works whose objective is to study the emissions of all sectors of an economy. This is the case of the investigations carried out by Llop and Tol (2013), which examine the case of the Irish economy in 2005 and conclude that there are strong asymmetries both in the contribution of the different economic sectors to total emissions, as well as in the different decomposed components of this contribution; by Ge et al. (2016), who identify the role of each sector in the total emissions of Beijing in China in 2010 and determine that the main sector responsible is the service sector; or Yuan et al. (2018), who investigate the case of China for the period 1997–2012 and determine that the main sectors responsible for environmental contamination are equipment manufacturing, construction, and service sectors. In addition, it is worth mentioning those works whose purpose is to study the emissions of a particular economic sector, thus, Alcántara and Padilla (2009) analyze CO_2 emissions of the service sector in Spain in 2000, studying the behavior shown by their different productive subsectors, and highlight the weight of transport in direct emissions and of the other services in indirect emissions, and note the scant attention that environmental policies have paid to these other services, despite their importance as being heavily responsible for emissions; Ge and Lei (2014) study the service sector in Beijing and determine that the transportation, storage, mail, and telecommunications subsectors are the main subsectors responsible for the direct emissions of the service sector, while the scientific studies and technical services, hotels and restaurants, and health care, social security and social welfare subsectors contribute significantly to the indirect emissions of this sector; and Piaggio et al. (2015) inquire about the role of CO_2 emissions of the service sector in Uruguay in 2004, and point out that the direct emissions of this sector are mainly due to the transport subsector, although the emissions that the service sector induces in the rest of the sectors of the economy is considerable and are due to those service subsectors not related to transport activities. Finally, the works focused on the study of the emissions of a specific greenhouse gas are equally relevant, such as the investigations by Navarro and Alcántara (2010), which present an analysis of the methane emissions of the processed food sector in Catalonia in 2001 and emphasize that the implemented policies in this sector should take into account the importance of intrasectoral relations between the different subsectors of the processed food sector; and Alcántara et al. (2017), who investigate the nitrogen oxide emissions of the different productive sectors in Spain in 2007, studying all sectors as subsystems of the economy, and offering guidance on the policies to be applied in the different sectors to mitigate these emissions.

To sum up, all these previous studies used the analysis of input–output subsystems under a demand-side approach. Nevertheless, in the particular case of the transport sector, its intermediate demand is crucial, since its activity and emissions are mainly explained by the inputs it produces for the other sectors of the economy. Therefore, both the intermediate demand and the final demand are significant for explaining the activity and emissions of transportation. Then, it is appropriate to adopt a perspective for the analysis of this sector that, regardless of the end use of its production, analyzes the interrelations in terms of emissions that its activity establishes when it uses its primary inputs with the rest of the sectors of the economy. The knowledge of these relations can help determine the correct design of environmental policies whose aim is the abatement of GHG emissions of the transport sector. Taking into account the above, we base our methodology on the Ghosh model (1958), as it allows us to address the problem of transport emissions from a production perspective or *output approach.* Unlike the Leontief model —or *input approach*—, which is based on a theoretical model[19] widely accepted in the economic literature in which the technology used in the production of a good is fixed, that is, the proportion of inputs required in the production of a good is constant, the Ghosh model is a controversial one that is the object of debate.[20] The Ghosh model is based on the assumption of fixed distribution of output, an assumption that is not based on any economic theory (Cronin, 1984), and which implies that the proportion of output allocated to different consumers is constant (for a more detailed analysis see, for example, Oosterhaven, 1988, 1996, 2012; Gruver, 1989; Dietzenbacher, 1989, 1997; Lenzen, 2003; De Mesnard, 2009; Guerra and Sancho, 2011). However, despite the criticisms it has received, there is consensus when it comes to justifying its use as an instrument to carry out comparative studies at the international level and for the identification of key sectors and intersectoral relations (Oosterhaven, 1998; Lenzen, 2003).

The Ghosh model is suitable for studying the total emissions generated by the transport sector activity, basically, for two reasons. First, the analysis of the transport sector from the perspective of demand does not take into account the sector activity as an input supplier of other sectors of the economy, as it only analyzes the emissions associated to the satisfaction of its final demand. Nevertheless, transport sector activity is not only meaningful as a service supplier of the final demand but also as an input supplier of other sectors of the economy, so the subsystem analysis from a demand-side perspective

[19] However, it is not free of criticism. For a brief summary of such criticisms, see Lenzen (2003).

[20] The main criticisms related to the Ghosh model lie in the discussion of what is its correct economic interpretation and, consequently, the misuse of it that some authors have made in practice. For example, Oostherhaven (1988) emphasizes the fact that it is not credible that the increase in the value added of one sector has no effect on the value added of the other sectors. In a similar way, Gruver (1989) focuses his criticism on the perfect substitutability between the inputs of the production function of each sector, according to which no input is essential in the production process given that any input can be substituted by the rest of inputs. Finally, De Mesnard (2009) focuses on criticizing the fact that the demand is infinitely elastic, that is, that demand absorbs any increase in the supply of a good, i.e., buyers buy as much output as is produced.

would not adequately capture the emissions related to a significant part of its activity. This would be, for example, the case of freight transport (by road or by rail) in land transport activity. Whereas, the supply-side analysis overcomes this problem by considering the whole activity of the sector via the use of its primary inputs, whatever the final use of its output is (final demand or intermediate demand). Second, the objective of this work is to study *a posteriori* the impact of transport activity on the emissions of the whole economy by taking into account its productive structure; that is, it investigates *ex post* the structural relationship in terms of emissions between the activity of the transport sector and the rest of the sectors of the economy.

This work presents two novelties regarding previous research in the literature that analyzes the environmental impact of the activity of a sector or group of sectors in the economy, given its productive structure and its sectoral interrelations. Firstly, we develop the method of subsystem analysis from the supply-side perspective, which, in turn, we extend in order to study the environmental impact of pollutant substances. Secondly, we carry out an empirical analysis of the impact of transportation and storage subsystem on GHG emissions of the whole economy by applying the model to the Spanish economy in 2014. The approach proposed here allows us to examine in detail the relationships established in terms of emissions between the different productive subsectors of the subsystem, and between them and the rest of the productive sectors of the economy, with independence of the end use of the production —intermediate demand or final demand. The knowledge of these relationships will help the adequate design of environmental policies aimed at reducing emissions in the transportation and storage subsystem. It is important to emphasize that the Ghosh model is a descriptive analysis tool that informs on the interrelations between transport activity and other productive sectors, and that we cannot extrapolate the results here obtained to other economies or other periods, which would be possible in the case of Leontief's demand-side perspective (*backward linkages* perspective). In spite of these limitations, the analysis of emissions from a supply-side perspective can help to implement environmental policies aimed at reducing the emissions of a sector or group of sectors as long as its demand structure remains stable in the short term. It is also worth noting that we perform the study of total emissions of transportation and storage activities of productive sectors (intermediate and final demands) and, therefore, we leave out of the analysis private transportation and storage activities.

We organize the rest of this chapter as follows. In Section 2 we describe the methodology. In Section 3 we present the data, along with the results and discussion. In Section 4 we summarize and conclude the investigation.

3.2. Methodology

3.2.1. The Ghosh model

Let us assume that the economy can be classified into *n* productive sectors. From the information contained in an input–output table we may write:

(1) $\mathbf{x}' = \mathbf{u}'\mathbf{Z} + \mathbf{v}'$

where $\mathbf{x}$ is a (*n* x 1) vector that denotes total output and its characteristic element x_i depicts the gross output of sector *i*; $\mathbf{Z}$ is a (*n* x *n*) matrix that represents the intermediate inputs and its characteristic element Z_{ij} represents the sector's *j* use of sector *i* production; and $\mathbf{v}$ is a (*n* x 1) vector that designates primary inputs used by the different productive sectors and its characteristic element v_i is the value of primary inputs available for sector *i*. All three variables are expressed in monetary terms. Moreover, $\mathbf{u}$ is a summation vector of appropriate dimension; (′) denotes the transposition of a vector or a matrix; vectors and matrices are written in bold, vectors with a lowercase letter and matrices with capital letters, and scalars in italics.

If the allocation coefficients are defined as:

(2) $b_{ij} = \frac{z_{ij}}{x_i}$

b_{ij} denotes the share of sector's *i* output used by sector *j*.

Then, for the whole economy and in compact form, we can write:

(3) $\mathbf{B} = \hat{\mathbf{x}}^{-1}\mathbf{Z}$

where (^) denotes the diagonalization of a vector.

Given the allocation coefficients, we can rewrite equation (1) as follows:

(4) $\mathbf{x}' = \mathbf{x}'\mathbf{B} + \mathbf{v}'$

and operating:

(5) $\mathbf{x}' = \mathbf{v}'(\mathbf{I} - \mathbf{B})^{-1} = \mathbf{v}'\mathbf{G}$

where $\mathbf{G}$ is the Ghosh inverse matrix, and its characteristic elements G_{ij} denotes the total, direct and indirect, value of sector's *j* output per unit of primary input of sector *i*.

3.2.2. Input–output subsystem analysis from a supply-driven perspective

It is possible to construct subsystems, in the vein of Sraffa (1960), from a supply-side perspective in an analogous way to the subsystems built from the demand-side perspective.

We split matrix B into two groups, s and r, so that s depicts the productive sectors from 1 to *k* that belong to the subsystem, and r depicts the rest of productive sectors from *k*+1 to *n* of the economy, such as:

$$\mathbf{B} = \begin{pmatrix} \mathbf{B}_{\mathrm{ss}} & \mathbf{B}_{\mathrm{sr}} \\ \mathbf{B}_{\mathrm{rs}} & \mathbf{B}_{\mathrm{rr}} \end{pmatrix}$$

Then, we can rewrite equation (1) as:

$$(6) \qquad (\mathbf{x}'_{\mathrm{s}} \quad \mathbf{x}'_{\mathrm{r}}) = (\mathbf{x}'_{\mathrm{s}} \quad \mathbf{x}'_{\mathrm{r}}) \begin{pmatrix} \mathbf{B}_{\mathrm{ss}} & \mathbf{B}_{\mathrm{sr}} \\ \mathbf{B}_{\mathrm{rs}} & \mathbf{B}_{\mathrm{rr}} \end{pmatrix} + (\mathbf{v}'_{\mathrm{s}} \quad \mathbf{v}'_{\mathrm{r}})$$

Then:

$$\mathbf{G} = (\mathbf{I} - \mathbf{B})^{-1} = \left[\begin{pmatrix} \mathbf{I}_{\mathrm{ss}} & \mathbf{0} \\ \mathbf{0} & \mathbf{I}_{\mathrm{rr}} \end{pmatrix} - \begin{pmatrix} \mathbf{B}_{\mathrm{ss}} & \mathbf{B}_{\mathrm{sr}} \\ \mathbf{B}_{\mathrm{rs}} & \mathbf{B}_{\mathrm{rr}} \end{pmatrix} \right]^{-1} = \begin{pmatrix} \mathbf{G}_{\mathrm{ss}} & \mathbf{G}_{\mathrm{sr}} \\ \mathbf{G}_{\mathrm{rs}} & \mathbf{G}_{\mathrm{rr}} \end{pmatrix}$$

where $\mathbf{I}_{\mathrm{ss}}$ and $\mathbf{I}_{\mathrm{rr}}$ are identity matrices.

Likewise, we can rewrite equation (2) as follows:

$$(7) \qquad (\mathbf{x}'_{\mathrm{s}} \quad \mathbf{x}'_{\mathrm{r}}) = (\mathbf{v}'_{\mathrm{s}} \quad \mathbf{v}'_{\mathrm{r}}) \begin{pmatrix} \mathbf{G}_{\mathrm{ss}} & \mathbf{G}_{\mathrm{sr}} \\ \mathbf{G}_{\mathrm{rs}} & \mathbf{G}_{\mathrm{rr}} \end{pmatrix}$$

In our subsystem analysis from a supply-driven perspective, the relevant issue is the relationships between the different economic sectors when the subsystem uses its primary inputs, that is, $\mathbf{v}_{\mathrm{s}}$. In order to isolate the interrelations of the subsystem, i.e., the relations between the sectors of the subsystem and between the subsystem and the rest of sectors of the economy, we establish $\mathbf{v}_{\mathrm{r}} = 0$ in equation (7), so that:

$$(8) \qquad (\mathbf{x}^{\mathbf{s}\prime}_{\mathrm{s}} \quad \mathbf{x}^{\mathbf{s}\prime}_{\mathrm{r}}) = (\mathbf{v}'_{\mathrm{s}} \quad \mathbf{0}') \begin{pmatrix} \mathbf{G}_{\mathrm{ss}} & \mathbf{G}_{\mathrm{sr}} \\ \mathbf{G}_{\mathrm{rs}} & \mathbf{G}_{\mathrm{rr}} \end{pmatrix} = (\mathbf{v}'_{\mathrm{s}}\mathbf{G}_{\mathrm{ss}} \quad \mathbf{v}'_{\mathrm{s}}\mathbf{G}_{\mathrm{sr}})$$

where the superscript s in the left part of the equation indicates that the subsystem is the only recipient of the output vectors obtained.

This expression can help to understand the nature of the subsystems analysis from a supply-side perspective. Thus, $\mathbf{v}'_{\mathrm{s}}\mathbf{G}_{\mathrm{ss}}$ is a row vector that shows the output that each one of the sectors of the subsystem had to produce induced by the sectors of the subsystem when they used their primary inputs. We can also interpret the result in another way if we transform the previous expression in $\hat{\mathbf{v}}\,\mathbf{G}_{\mathrm{ss}}\mathbf{u}$, a column vector that shows the total, direct and indirect, output that the subsystem sectors had to produce in relation to the primary inputs used by each one of them. Regardless of whether we analyze it by rows or columns, from now on, this component collects what we define as the internal component. The matrix $\hat{\mathbf{v}}\,\mathbf{G}_{\mathrm{ss}}$ refers to the output of the subsystem according to its primary inputs.

In the same way, we proceed with respect to the other component of equation (8). $\mathbf{v}'_{\mathrm{s}}\mathbf{G}_{\mathrm{sr}}$ is a row vector that collects the output that each sector that do not belong to the subsystem had to produce based on the primary inputs used by the subsystem sectors. $\hat{\mathbf{v}}\,\mathbf{G}_{\mathrm{sr}}\mathbf{u}$ is a column vector that depicts the output that the sectors that do not belong to the subsystem had to produce given the level of primary inputs used by each sector of the subsystem. The matrix $\hat{\mathbf{v}}\,\mathbf{G}_{\mathrm{sr}}$ denotes the output of the rest of the sectors of the economy as a consequence of the activity of the subsystem. It is worth pointing out that this is a spillover component, but from a forward linkages perspective.

3.2.3. Supply-driven input–output subsystems analysis and environmental pressures

We can generalize the previous method in order to analyze the environmental behavior regarding some pollutants, energy consumption, or the use of natural sources, etc., analogously to the development of the subsystem analysis from a demand-side perspective[21] (or input approach) based on the Leontief model.

Let $\mathbf{e}$ be a (n x 1) vector of sectoral emissions, then $\hat{\mathbf{x}}^{-1}\mathbf{e} = \mathbf{c}$, where $\mathbf{c}$ is a (n x 1) vector that depicts the emission per unit of sectoral output, which we can divide into two subsets, the subsystem and the rest of sectors of the economy, such as: $\mathbf{c} = \begin{pmatrix} \mathbf{c}^{\mathrm{s}} \\ \mathbf{c}^{\mathrm{r}} \end{pmatrix}$.

If we diagonalize the value added of the subsystem in equation (8) and post-multiply it by $\mathbf{c}$, we have:

(9) $\mathbf{f}^{\mathrm{s}} = \hat{\mathbf{v}}_{\mathrm{s}}\,\mathbf{G}_{\mathrm{ss}}\mathbf{c}^{\mathrm{s}} + \hat{\mathbf{v}}_{\mathrm{s}}\,\mathbf{G}_{\mathrm{sr}}\mathbf{c}^{\mathrm{r}}$

[21] For the construction of subsystems from a demand-side perspective, see Alcántara (1995), Alcántara and Padilla (2009), Navarro and Alcántara (2010) and Navarro (2012).

where $\mathbf{f}^{\mathrm{s}}$ are the total, direct and indirect, emissions of the subsystem from a forward linkages perspective. From this perspective, total emissions are easily differentiable into two components. First, the component corresponding to the first summand on the right-hand-side of equation (9):

$$(10) \quad \mathbf{f}_{\mathrm{s}}^{s} = \hat{\mathbf{v}}_{\mathrm{s}}\, \mathbf{G}_{\mathrm{ss}}\mathbf{c}^{\mathrm{s}}$$

$\mathbf{f}_{\mathrm{s}}^{s}$ corresponds to the internal component, as mentioned above, but now extended to the study of environmental pressures. Second, the component corresponding to the second summand on the right-hand-side of equation (9):

$$(11) \quad \mathbf{f}_{\mathrm{r}}^{s} = \hat{\mathbf{v}}_{\mathrm{s}}\, \mathbf{G}_{\mathrm{sr}}\mathbf{c}^{\mathrm{r}}$$

$\mathbf{f}_{\mathrm{r}}^{s}$ corresponds to the spillover component extended to analyze environmental pressures but from a forward linkages perspective.

Equations (10) and (11) reveal two meaningful components of the analytical approach proposed here. Nevertheless, in order to obtain further relevant information related to the nature of the emissions of a given subsystem, we disaggregate equation (10) even more. Then, considering the inverse of a partitioned matrix, we can write:

$$(12) \quad \mathbf{G}_{\mathrm{ss}}\mathbf{c}^{\mathrm{s}} = (\mathbf{I}_{\mathrm{ss}} - \mathbf{B}_{\mathrm{ss}})^{-1}\mathbf{c}^{\mathrm{s}} + (\mathbf{I}_{\mathrm{ss}} - \mathbf{B}_{\mathrm{ss}})^{-1}\mathbf{B}_{\mathrm{sr}}\mathbf{G}_{\mathrm{rs}}\mathbf{c}^{\mathrm{s}}$$

which decomposes the internal component into two new components: the first summand on the right-hand-side of equation (12) shows the own internal component of the subsystem, and the second summand on the right-hand-side of the equation depicts the feedback component that corresponds to the relations between the subsystem and the rest of sectors of the economy. The interpretation of these two components is relatively simple, but not as straight as it would be in the case of a model generated from a demand-side perspective. Given the expression of the own internal component, after the diagonalization of the vector $\mathbf{c}^{\mathrm{s}}$, we obtain a matrix whose characteristic element $[(\mathbf{I}_{\mathrm{ss}} - \mathbf{B}_{\mathrm{ss}})^{-1}\hat{\mathbf{c}}^{\mathrm{s}}]_{\mathrm{s_i s_j}}$ shows the pollution generated by the s_j sector due to the output it had to produce per unit of value added of s_i. As regards the feedback component, we use a similar transformation to the previous one in order to obtain a matrix whose characteristic element $[(\mathbf{I}_{\mathrm{ss}} - \mathbf{B}_{\mathrm{ss}})^{-1}\mathbf{B}_{\mathrm{sr}}\mathbf{G}_{\mathrm{rs}}\hat{\mathbf{c}}^{\mathrm{s}}]_{\mathrm{s_i s_j}}$ shows the pollution generated by the s_j sector due to the increase of its output as a consequence of the increase in the output of the sectors that do not belong to the subsystem per unit of value added of the sector s_i.

Substituting in equation (9) the values found in equation (12), we have:

(13) $$\mathbf{f}^{\mathrm{s}} = \hat{\mathbf{v}}_{\mathrm{s}}(\mathbf{I}_{\mathrm{ss}} - \mathbf{B}_{\mathrm{ss}})^{-1}\mathbf{c}^{\mathrm{s}} + \hat{\mathbf{v}}_{\mathrm{s}}(\mathbf{I}_{\mathrm{ss}} - \mathbf{B}_{\mathrm{ss}})^{-1}\mathbf{B}_{\mathrm{sr}}\mathbf{G}_{\mathrm{rs}}\mathbf{c}^{\mathrm{s}} + \hat{\mathbf{v}}_{\mathrm{s}}\mathbf{G}_{\mathrm{sr}}\mathbf{c}^{\mathrm{r}}$$

Given that the most relevant, from the perspective of our research, is to quantify intersectoral relations, we can rewrite equation (13) as follows:

(14) $$\mathbf{f}^{\mathrm{s}} = \hat{\mathbf{v}}_{\mathrm{s}}[(\mathbf{I}_{\mathrm{ss}} - \mathbf{B}_{\mathrm{ss}})^{-1} - \mathbf{I}_{\mathrm{ss}}]\mathbf{c}^{\mathrm{s}} + \hat{\mathbf{v}}_{\mathrm{s}}(\mathbf{I}_{\mathrm{ss}} - \mathbf{B}_{\mathrm{ss}})^{-1}\mathbf{B}_{\mathrm{sr}}\mathbf{G}_{\mathrm{rs}}\mathbf{c}^{\mathrm{s}} + \hat{\mathbf{v}}_{\mathrm{s}}\mathbf{G}_{\mathrm{sr}}\mathbf{c}^{\mathrm{r}} + \hat{\mathbf{v}}_{\mathrm{s}}\mathbf{c}^{\mathrm{s}}$$

In equation (14), the direct emissions of the different sectors of the subsystem corresponding to its value added are isolated. Consequently, we divide the total impact of the subsystem in terms of emissions into four explanatory components.

Net own internal component:

(15) $$\mathrm{NOIC} = \hat{\mathbf{v}}_{\mathrm{s}}[(\mathbf{I}_{\mathrm{ss}} - \mathbf{B}_{\mathrm{ss}})^{-1} - \mathbf{I}_{\mathrm{ss}}]\mathbf{c}^{\mathrm{s}}$$

This depicts the direct and indirect emissions in net terms generated by each one of the subsystem sectors due to the productive activity of the other sectors of the subsystem.

Feedback component:

(16) $$\mathrm{FBC} = \hat{\mathbf{v}}_{\mathrm{s}}(\mathbf{I}_{\mathrm{ss}} - \mathbf{B}_{\mathrm{ss}})^{-1}\mathbf{B}_{\mathrm{sr}}\mathbf{G}_{\mathrm{rs}}\mathbf{c}^{\mathrm{s}}$$

This accounts for the direct and indirect emissions generated by the subsystem sectors due to the increase of the output of the sectors that do not belong to the subsystem that, in turn, had been induced by the productive activity of the subsystem.

Scale component:

(17) $$\mathrm{SC} = \hat{\mathbf{v}}_{\mathrm{s}}\mathbf{c}^{\mathrm{s}}$$

It measures the direct emissions of a subsystem sector generated when it used its primary inputs.

Spillover component:

(18) $$\mathrm{SOC} = \hat{\mathbf{v}}_{\mathrm{s}}\mathbf{G}_{\mathrm{sr}}\mathbf{c}^{\mathrm{r}}$$

It shows the emissions corresponding to the output that the sectors that do not belong to the subsystem had to produce once the subsystem initiated its productive activity.

It is not difficult to consider the impact that the activity of the sectors that do not belong to the subsystem had on the subsystem. If in equation (7) we establish $\mathbf{v}'_{\mathrm{s}} = 0$, then, we obtain:

$$(19) \quad (\mathbf{x}^{r\prime}{}_{\mathrm{s}} \quad \mathbf{x}^{r\prime}{}_{\mathrm{r}}) = (\mathbf{0}' \quad \mathbf{v}'_{\mathrm{r}}) \begin{pmatrix} \mathbf{G}_{\mathrm{ss}} & \mathbf{G}_{\mathrm{sr}} \\ \mathbf{G}_{\mathrm{rs}} & \mathbf{G}_{\mathrm{rr}} \end{pmatrix} = (\mathbf{v}'_{r}\mathbf{G}_{\mathrm{rs}} \quad \mathbf{v}'_{\mathrm{r}}\mathbf{G}_{\mathrm{rr}})$$

It is worth noting that now the vector $\mathbf{v}'_{\mathrm{r}}\mathbf{G}_{\mathrm{rs}}\hat{\mathbf{c}}^{\mathrm{s}}$ denotes the emissions of each one of the sectors of the subsystem as a function of the production of the rest of the sectors of the economy, i.e., the sectors that do not belong to the subsystem. In the same way, $\hat{\mathbf{v}}_{\mathrm{r}}\mathbf{G}_{\mathrm{rs}}\mathbf{c}^{\mathrm{s}}$ depicts the emissions of the subsystem as a whole related to the primary inputs of the sectors of the rest of the economy.

3.3. Data, results and discussion

3.3.1 Data

We define the transportation and storage subsystem, which is the object of study of this research, as the subsystem composed of the different subsectors of transportation and storage sector according to the NACE classification of 2009 (INE, 2017). In particular, these subsectors are "Land transport and transport via pipelines", "Air transport", "Water transport", "Warehousing and support activities for transportation" and "Postal and courier activities".

This research obtains the input–output table of the Spanish economy for 2014 from the World Input–Output Database (WIOD, 2017). The database provides input–output tables for the 28 countries of the European Union and 15 other major countries worldwide (WIOT) for the period 2000–2014. Likewise, the input–output table of each country is divided into 55 sectors and its units are expressed in millions of dollars at current prices (Timmer et al., 2015).

In addition, we obtain the GHG emissions data by economic sectors for Spain in 2014 from the Air Emissions Accounts published by the National Institute of Statistics (INE, 2017). This database contains information for a total of 66 economic sectors. In order to make the input–output table compatible with the sectoral emissions data, we aggregate the GHG emissions of the Air Emissions Accounts, which present a higher degree of disaggregation, of the following sectors: "Administrative and support service activities"; "Human health and social work activities"; "Arts, entertainment, and recreation”; and “Other service activities".

It is worth mentioning that a more detailed analysis could have been done if the data of the "Land transport and transport via pipelines" subsector had been disaggregated. These would have allowed the taking into account of the activity related to the additional intrarelationships between the different subsectors of the subsystem and between them and the rest of the sectors of the economy. Nevertheless, in the absence of such data, it is not possible to carry out this potential analysis.

Lastly, it is important to point out that the World Input–Output Data Base (WIOD) shows that the Spanish transportation and storage subsystem allocated 64.1% of its production to the other productive sectors of the economy in the form of intermediate goods, while the remaining 35.9% went to satisfy its final demand.

3.3.2. Results and discussion

3.3.2.1. GHG emissions of the transportation and storage subsystem in Spain in 2014

In 2014, direct GHG emissions of the transportation and storage subsystem in Spain were 34,419.7 thousand tons of CO_2 equivalent ($CO_{2\text{-eq}}$). Meanwhile, the input–output analysis indicates that total, direct and indirect, GHG emissions of the transportation and storage subsystem reached 29,628.3 thousand tons of $CO_{2\text{-eq}}$. Thus, the subsystem was responsible for 10.6% of direct and 9.1% of total GHG emissions of the whole economy (Table 1).

The absolute values of direct and total GHG emissions show significant dissimilarities in the different sectors of the transportation and storage subsystem, although in terms of relative values these dissimilarities do not seem especially relevant. The subsector of the subsystem that contributed most to emitting greenhouse gases, either directly or indirectly, was the "Land transport and transport via pipelines" subsector, although its participation in total economy emissions was lower when considering total emissions than when considering only direct emissions. The same result took place in the "Water transport" and "Air transport" subsectors. While the subsystem subsectors with a higher share of total emissions than direct emissions were "Warehousing and support activities for transportation" and "Postal and courier activities". From the above, we can assert that the subsectors of the subsystem, whose direct emissions were higher than total emissions, explained their emissions to a great extent by the output that they had to produce induced by the productive activity of the rest of the sectors of the economy.

Table 1. Direct and total GHG emissions of transportation and storage subsystem. Spain, 2014

	Direct GHG emissions		Total GHG emissions	
	Thousands of tons of $CO_{2\text{-eq}}$	%	Thousands of tons of $CO_{2\text{-eq}}$	%
Land transport and transport via pipelines	29,027.9	9.0%	21,191.3	6.5%
Water transport	1,121.6	0.3%	553.4	0.2%
Air transport	3,306.4	1.0%	1,703.1	0.5%
Warehousing and support activities for transportation	708.7	0.2%	5,811.7	1.8%
Postal and courier activities	255.1	0.1%	368.8	0.1%
Total transportation and storage subsystem	34,419.7	10.6%	29,628.3	9.1%
Total economy *	324,171.4	100.0%	324,171.4	100.0%

** Pro memoria: The direct emissions of households amounted to 70,375.2 thousand tons of $CO_{2\text{-eq}}$ while the total sectors emitted 253,796.2 thousand tons of $CO_{2\text{-eq}}$.*

Source: Prepared by the authors with the data from INE (2017), and WIOD (2017).

This result corroborates that obtained in the investigations of Tarancon and del Río (2007) and Alcántara and Padilla (2009) for Spain, and Piaggo et al. (2015) for Uruguay. However, it differs from the works of Butnar and Llop (2011) for Spain, and Ge et al. (2016) for Beijing. This discrepancy in the results could be explained because in the first three investigations the transportation and storage sector is the object of analysis, either aggregated or disaggregated by subsectors; meanwhile, in the last two investigations, the object of analysis is the aggregated transport, storage, and communications sector.

Table 2. Decomposition of total GHG emissions (thousands of tons of $CO_{2\text{-eq}}$) of the transportation and storage subsystem. Spain, 2014

	Net own internal component	%	Feedback component	%	Scale component	%	Spillover component	%	GHG total emissions	%
Land transport and transport via pipelines	866.3	20.0%	175.5	53.7%	16,421.2	87.4%	3,728.3	60.3%	21,191.3	71.5%
Water transport	15.3	0.4%	6.9	2.1%	468.0	2.5%	63.3	1.0%	553.4	1.9%
Air transport	115.7	2.7%	20.2	6.2%	1,417.8	7.5%	149.4	2.4%	1,703.1	5.7%
Warehousing and support activities for transportation	3,329.8	76.9%	116.4	35.6%	339.5	1.8%	2,026.0	32.8%	5,811.7	19.6%
Postal and courier activities	0.5	0.0%	8.1	2.5%	146.0	0.8%	214.2	3.5%	368.8	1.2%
Total transportation and storage subsystem	4,327.6	100.0%	327.0	100.0%	18,792.4	100.0%	6,181.2	100.0%	29,628.3	100.0%
% total GHG emissions of the transportation and storage subsystem	14.6%		1.1%		63.4%		20.9%		100.0%	

Source: Prepared by the authors with data from INE (2017), and WIOD (2017).

Table 2 presents the outcomes of the decomposition of total GHG emissions related to the activity of the transportation and storage subsystem in Spain in 2014, following our methodology of subsystem analysis from the supply-side perspective. These results show that the internal component was responsible for 79.1% of the total emissions of the subsystem. This component depicts the subsystem emissions due to the productive activity of the subsystem. The decomposition of the internal component, in turn, reveals that the scale component was the most important of its components with 63.4% of the total emissions of the transportation and storage subsystem. In other words, the emissions that each subsector of the subsystem generated once it used its primary inputs explained more than three-fifths of the total GHG emissions of the subsystem. Likewise, the main subsectors responsible for this component corresponded to the most polluting subsystem subsectors in terms of direct emissions; that is, "Land transport and transport via pipelines" and "Air transport" subsectors with 55.4% and 4.8% respectively of total subsystem emissions. This outcome indicates that the productive activity of these two subsectors significantly explained the GHG emissions of the subsystem. Moreover, if we consider that the direct emissions of the "Land transport and transport via pipelines"[22] subsector basically correspond to the activities of "Road transport" and "Transport via pipelines", we can derive some implications in terms of environmental policies. Firstly, the authorities should promote the replacement of "Road transport" and "Air transport" with "Rail transport" and/or "Water transport". Secondly, "Road transport" and "Air transport" activities should be more efficient from the energy point of view; therefore, the authorities should encourage measures such as technological improvements in vehicles, the use of fuels, and infrastructure. Thirdly, the authorities should stimulate the use of less harmful sources of energy in environmental terms. On the other hand, another meaningful internal component was the net own internal component, given that it accounted for 14.6% of the total GHG emissions of the subsystem. The net own internal component denotes the emissions of each subsector of the subsystem as a result of the output it had to produce when the other subsectors of the subsystem carried out their productive activity. The results determine that "Warehousing and support activities for transportation" with 11.2% of the total GHG emissions of the subsystem was the most important productive subsector in explaining this component. In terms of environmental policies, this outcome should lead the authorities to encourage the continuous introduction of new improvements in transport logistics, such as e.g. minimizing empty running or improving transport efficiency (tons carried per vehicle), which could result in significant reductions of GHG transport emissions (Andrés and Padilla, 2015). Regarding

[22] Rail transport does not directly emit greenhouse gases, since its main source of energy is electricity.

the feedback component, the last component of the internal component, this only explained 1.1% of the total GHG emissions of the subsystem. This component shows the emissions of the subsystem subsectors due to the output they had to produce induced by the productive activity of the sectors that do not belong to the subsystem that, in turn, had been induced by the productive activity of the subsystem. Since this the feedback component is not very relevant for explaining the subsystem emissions, any mitigation measure based on it would have a minor impact.

As regards the spillover component, it explained the remaining 20.9% of total GHG emissions of the transportation and storage subsystem. This component computes the emissions of the rest of the sectors of the economy, those sectors that do not belong to the subsystem, because of the output they had to produce induced by the productive activity of the subsystem. Therefore, the activity of the subsystem induced the rest of the sectors of the economy to emit greenhouse gases. The activity of "Land transport and transport via pipelines" and "Warehousing and support activities for transportation" subsectors explained, largely, these indirect emissions with 12.6% and 6.8% of the total emissions of the subsystem respectively.

Table 3 shows the detailed results of the spillover component. We note that the transportation and storage subsystem induced the "Manufacturing” sector to emit more greenhouse gases than any other sector, since it accounted for 56.4% of the emissions due to this component. In addition, it is worth noting that, within “Manufacturing”, the subsectors of "Manufacture of other non-metallic mineral products", "Manufacture of basic metal" —both subsectors closely related to “Construction” sector given that they provide it with raw material—, and "Manufacture of chemicals and chemical products" with 26.9%, 8.0%, and 7.5%, respectively, were the most induced to emit by the subsystem. Also, the subsystem induced other productive sectors to emit significant amounts of greenhouse gases; basically, these were "Electricity, gas, steam and air conditioning supply" with 15.3%; "Agriculture, forestry and fishing" with 11.7%, and "Water supply; sewerage, waste management and remediation activities" with 6.1%. Regarding the impact of the activity of the transportation and storage subsystem on the emissions of the rest of sectors of economy, that is, “Mining and quarrying”, “Construction” and the other service sectors, it was not significant.

Table 3. GHG emissions (thousands of tons of $CO_{2\text{-eq}}$) of the rest of the sectors of the economy induced by the transportation and storage subsystem. Spain, 2014

	Land transport and transport via pipelines	Water transport	Air transport	Warehousing and support activities for transportation	Postal and courier activities	Total subsystem	%
Agriculture, forestry and fishing	307.3	5.8	15.6	302.7	94.8	726.2	11.7%
Mining and quarrying	148.0	1.1	3.6	85.1	1.2	239.0	3.9%
Manufacturing	2,207.1	29.6	62.0	1,096.0	93.9	3,488.5	56.4%
Electricity, gas, steam and air conditioning supply	636.5	11.0	30.7	253.3	12.5	944.0	15.3%
Water supply; sewerage, waste management and remediation activities	226.1	7.3	12.8	126.6	6.0	378.8	6.1%
Construction	12.0	0.3	0.6	6.9	0.4	20.2	0.3%
Wholesale and retail trade; repair of motor vehicles and motorcycles	126.5	3.2	6.5	113.6	2.5	252.3	4.1%
Accommodation and food service activities	10.3	0.2	0.5	5.4	1.0	17.4	0.3%
Information and communication	5.5	0.2	0.4	3.0	0.3	9.3	0.2%
Financial and insurance activities	1.8	0.1	1.6	1.4	0.1	5.0	0.1%
Real estate activities	0.1	0.0	0.0	0.0	0.0	0.1	0.0%
Professional, scientific and technical activities	3.2	0.2	0.4	2.3	0.2	6.3	0.1%
Administrative and support service activities	14.8	3.2	9.8	9.7	0.4	38.0	0.6%
Public administration and defense; compulsory social security	19.0	0.7	2.8	13.7	0.4	36.6	0.6%
Education	1.8	0.1	0.2	1.0	0.1	3.2	0.1%
Human health and social work activities	5.9	0.2	1.2	4.1	0.4	11.8	0.2%
Arts, entertainment and recreation and Other service activities	2.3	0.1	0.6	1.3	0.1	4.4	0.1%
Total of the rest of the productive sectors of the economy	3,728.3	63.3	149.4	2,026.0	214.2	6,181.2	100.0%
%	60.3%	1.0%	2.4%	32.8%	3.5%	100.0%	

Source: Prepared by the authors with data from INE (2017), and WIOD (2017).

It should be noted that our outcomes, using the analysis of subsystems from the supply-side perspective, are analogous in qualitative but not quantitative terms to those obtained by Alcántara and Padilla (2009). Their analysis is focused on the services sector subsystem, where transportation and storage subsector is just one more subsector of the subsystem, and it is performed from the demand-side perspective, so that their results only reflect the impact on emissions related to the final demand of the services sector. Furthermore, it is important to highlight that the environmental policy measures aimed at reducing GHG emissions on the transportation and storage subsystem suggested in this study are aligned with the proposals of previous research that, even with different objectives and using different methodologies, obtained comparable results to ours (see, for example, the works of Timilsina and Shresta, 2009; and Andrés and Padilla, 2018, for the environmental policy measures related to the scale component, such as the use of cleaner fuels, less polluting modes of transport, or more energy efficient vehicles; and McKinnon, 2015, for environmental policy measures related to the net own internal component, where improvements in the logistics of freight transport and its storage is a relevant issue).

3.3.2.2. The transportation and storage subsystem emissions induced by the rest of the sectors of the economy

Table 4 presents the GHG emissions of the transportation and storage subsystem due to the output it had to produce as a consequence of the productive activity of the sectors that do not belong to the subsystem. These emissions reached 13,819.9 thousand tons of $CO_{2\text{-}eq}$. The analysis reveals that the sectors that do not belong to the subsystem that induced the subsystem to emit more were, in order of importance, "Manufacturing" (19.4%); "Construction" (17.8%); "Wholesale and retail trade; repair of motor vehicles and motorcycles" (15.7%); "Public administration and defense; compulsory social security" (7.4%); "Real estate activities" (7.3%); "Administrative and support service activities" (6.9%); "Financial and insurance activities" (6.6%); and "Professional, scientific and technical activities" (5.2%). While the activity of the rest of the sectors of the economy basically did not affect the subsystem, since their activity explained less than 5% of emissions induced by the sectors that do not belong to the subsystem. Moreover, the analysis also shows that the higher impact of the activity of the rest of the sectors of the economy on the subsystem emissions fell mainly on the "Land transport and transport via pipelines" subsector, with 78.5% of these emissions.

The aggregation of the different service sectors, with the exception of the transportation and storage activities, provides information on the impact of the activity of these other service sectors on the subsystem emissions. We can observe that the output that the subsystem had to produce due to the productive activity of the service sectors not related to transport activities explained meaningfully the subsystem emissions, being the main responsible with 57.5% of these emissions. The other two activities that induced the subsystem to emit more were the “Manufacturing” and “Construction” sectors, although their contribution was much more modest. This outcome shows that the output that the subsystem had to produce once the other service sectors initiated their productive activity largely explains the subsystem emissions. This result corroborates the analysis of the previous section, and is in line with the results obtained from a final demand perspective by Alcántara and Padilla (2009) and Piaggio et al. (2015) for the Spanish and the Uruguayan economy, respectively.

Table 4. GHG emissions (thousands of tons of $CO_{2\text{-eq}}$) of the transportation and storage subsystem induced by the rest of the sectors of the economy. Spain, 2014

	Land transport and transport via pipelines	Water transport	Air transport	Warehousing and support activities for transportation	Postal and courier activities	Total subsystem	%
Agriculture, forestry and fishing	140.1	6.9	24.0	3.5	4.9	179.5	1.3%
Mining and quarrying	10.6	0.6	1.6	0.3	0.5	13.6	0.1%
Manufacturing	2,054.5	108.4	429.8	48.7	39.4	2,680.8	19.4%
Electricity, gas, steam and air conditioning supply	350.6	16.1	26.1	8.3	13.9	415.1	3.0%
Water supply; sewerage, waste management and remediation activities	112.8	3.5	7.9	2.4	2.1	128.7	0.9%
Construction	2,380.3	14.8	35.8	12.6	10.1	2,453.7	17.8%
Wholesale and retail trade; repair of motor vehicles and motorcycles	1,313.2	43.7	105.7	33.3	668.4	2,164.2	15.7%
Accommodation and food service activities	136.5	8.0	23.5	3.5	4.5	176.0	1.3%
Information and communication	523.9	13.4	107.6	11.1	14.1	670.2	4.8%
Financial and insurance activities	765.2	30.9	72.2	15.4	28.6	912.4	6.6%
Real estate activities	717.2	88.1	79.3	28.8	101.3	1,014.6	7.3%
Professional, scientific and technical activities	573.0	37.5	63.7	13.6	26.8	714.5	5.2%
Administrative and support service activities	670.6	61.2	180.0	20.8	26.1	958.7	6.9%
Public administration and defense; compulsory social security	854.6	36.0	97.1	27.9	8.0	1,023.7	7.4%
Education	62.3	2.1	16.3	1.1	3.8	85.6	0.6%
Human health and social work activities	46.3	1.4	3.8	0.7	3.8	56.0	0.4%
Arts, entertainment and recreation and Other service activities	141.4	6.7	15.9	3.7	4.7	172.5	1.2%
Total of the rest of the productive sectors of the economy	10,853.2	479.3	1,290.5	235.9	961.0	13,819.9	100.0%
Total of the rest of the productive sectors of the economy (%)	78.5%	3.5%	9.3%	1.7%	7.0%	100.0%	

Source: Prepared by the authors with data from INE (2017), and WIOD (2017).

3.3.2.3. The emissions exchange between the transportation and storage subsystem and the rest of sectors of the economy

We have just seen in previous sections that the transportation and storage subsystem induced the rest of the productive sectors of the economy to emit 6,181.2 thousand tons of $CO_{2\text{-eq}}$. Likewise, the rest of the sectors of the economy induced the subsystem to emit 13,819.9 thousand tons of $CO_{2\text{-eq}}$. Therefore, the rest of the sectors of the economy induced in net terms the transportation and storage subsystem to emit more greenhouse gases than the opposite. This outcome explains the lower relative share of the subsystem in relation to the total emissions of the economy if direct and indirect emissions are taken into account than if only direct emissions are considered.

Table 5 shows the detailed results of this analysis. These indicate that almost all of the productive sectors that do not belong to the transportation and storage subsystem induced the subsystem to emit more than the opposite, with the exception of, in order of importance, "Manufacturing"; "Agriculture, forestry and fishing"; "Electricity, gas, steam and air conditioning supply"; "Water supply; sewerage, waste management and remediation activities"; and "Mining and quarrying". Whereas, among the sectors of the economy that induced the subsystem to emit more greenhouse gases were "Construction"; "Wholesale and retail trade; repair of motor vehicles and motorcycles"; "Real estate activities"; "Public administration and defense; compulsory social security"; and, finally, "Administrative and support service activities". Likewise, all the subsectors of the transportation and storage subsystem induced the rest of the sectors of the economy to emit less than vice versa, with the exception of the "Warehousing and support activities for transportation" subsector.

Table 5 reveals that the subsystem induced “Agriculture, forestry and fishing”, “Mining and quarrying” and “Manufacturing” sectors to emit more than was induced by them. On the other hand, “Construction” and the service sectors not related to transport activities induced the subsystem to emit more than vice versa. This outcome indicates that the different contributions of the transportation and storage subsystem in terms of direct and of total direct and indirect emissions, with respect to the emissions of the whole economy, lies on its indirect emissions generated by the activities of the “Construction” sector and the service sectors not related to transport activities. Particularly, the activities of “Retail trade”, “Real estate activities” —with a direct relationship with the “Construction” sector—, and “Renting and leasing of motor vehicles” were the other service sectors that induced the subsystem to emit more greenhouse gases. From the analysis performed, as each productive sector is involved to a different degree in the subsystem emissions, in terms of environmental policies, we can point out that the identification of the main activities responsible for transportation and storage subsystem emissions should be key in the design of environmental measures aimed at reducing or, at least, mitigating the growth of emissions from the transportation and storage subsystem. In particular, in the case of Spain in 2014, the improvement of transportation and storage related to the activities of “Retail trade” and of “Construction” sectors seem quite relevant in mitigating the emissions of transportation and storage sector.

Table 5. The exchange of GHG emissions (thousands of tons of $CO_{2\text{-eq}}$) between the transportation and storage subsystem and the rest of the sectors of the economy. Spain, 2014

	Land transport and transport via pipelines	Water transport	Air transport	Warehousing and support activities for transportation	Postal and courier activities	Total subsystem
Agriculture, forestry and fishing	167.2	-1.1	-8.4	299.1	89.9	546.7
Mining and quarrying	137.4	0.5	2.0	84.8	0.8	225.5
Manufacturing	152.5	-78.7	-367.8	1,047.2	54.5	807.7
Electricity, gas, steam and air conditioning supply	285.9	-5.1	4.6	244.9	-1.5	528.9
Water supply; sewerage, waste management and remediation activities	113.3	3.9	4.9	124.2	3.9	250.1
Construction	-2,368.3	-14.6	-35.2	-5.7	-9.7	-2,433.5
Wholesale and retail trade; repair of motor vehicles and motorcycles	-1,186.7	-40.5	-99.2	80.3	-665.8	-1,912.0
Accommodation and food service activities	-126.3	-7.7	-23.0	1.9	-3.5	-158.6
Information and communication	-518.4	-13.3	-107.2	-8.1	-13.8	-660.9
Financial and insurance activities	-763.4	-30.8	-70.6	-14.0	-28.6	-907.4
Real estate activities	-717.1	-88.1	-79.3	-28.7	-101.3	-1,014.5
Professional, scientific and technical activities	-569.7	-37.3	-63.3	-11.3	-26.6	-708.1
Administrative and support service activities	-655.8	-58.0	-170.2	-11.1	-25.7	-920.8
Public administration and defense; compulsory social security	-835.6	-35.4	-94.3	-14.2	-7.7	-987.1
Education	-60.4	-2.0	-16.1	-0.1	-3.7	-82.4
Human health and social work activities	-40.3	-1.2	-2.6	3.3	-3.4	-44.2
Arts, entertainment and recreation and Other service activities	-139.1	-6.7	-15.3	-2.4	-4.6	-168.1
Total of the rest of the productive sectors of the economy	-7,124.9	-416.0	-1,141.0	1,790.1	-746.9	-7,638.6

Source: Prepared by the authors with data from INE (2017), and WIOD (2017).

3.4. Conclusions

We have developed an input–output subsystem analysis from a supply-side perspective based on the Ghosh model and have extended it to the analysis of the polluting behavior of the subsystem. The input–output subsystem analysis allows the studying of the interrelations of emissions between the different subsystem subsectors and between the subsystem and the rest of the sectors of the economy. In contrast to previous subsystem analysis that has been done from a demand-side perspective, our supply-side method allows us to consider the emissions of the whole activity of the subsystem and not only those related to its final demand. This is particularly useful for studying the whole impact of the activity of sectors, such as the transportation and storage sector, whose production is mainly used as input for other sectors.

We have applied the method to study the impact on GHG emissions of the whole economy of the activity of the transportation and storage sector for the case of Spain in 2014. We have analyzed the polluting behavior in terms of GHG emissions of the transportation and storage subsystem through an in-depth study of the existing linkages between the activity of its different subsectors and the interrelations that these establish with the rest of the sectors of the economy. The outcomes and their discussion provide relevant information for an accurate design of environmental policies aimed at reducing GHG emissions in this sector.

The activity of the sectors that do not belong to the subsystem was fundamental to explain the productive activity of the subsectors of the subsystem, since the output of the subsystem purchased by these sectors was even more important than the output of the subsystem purchased by the final demand.

The direct GHG emissions of the transportation and storage subsystem were 34,419.7 thousand tons of $CO_{2\text{-eq}}$ in Spain in 2014. Meanwhile, the input–output subsystem analysis from a supply-side perspective indicates that the total, direct and indirect, GHG emissions of the transportation and storage subsystem reached 29,628.3 thousand tons of $CO_{2\text{-eq}}$. That is, the transportation and storage subsystem was responsible for 10.6% of direct GHG emissions and 9.1% of total emissions of the whole economy. Moreover, the "Land transport and transport via pipelines" subsector was the highest polluter of the subsystem.

In addition, the outcomes indicate that the internal component —the subsystem emissions due to its productive activity— was responsible for 79.1% of total GHG emissions of the transportation and storage subsystem in Spain in 2014. Similarly, the spillover component

—the emissions of the sectors that do not belong to the subsystem that correspond to the output that they had to produce because of the productive activity of the subsystem—, was responsible for 20.9% of the total subsystem emissions. The decomposition, in turn, of the internal component points to the scale component —the direct emissions of each of the subsectors of the subsystem generated when using its primary inputs— as the principal component with more than three-fifths of the total emissions of the subsystem. Additionally, the subsectors of the subsystem that mainly explained this result were "Land transport and transport via pipelines" and "Air transport", that is, the most polluting subsectors of the subsystem in terms of direct emissions. As regards the net own internal component —the direct and indirect emissions in net terms generated by each one of the subsystem sectors due to the productive activity of the other subsectors of the subsystem—, it determined one-seventh of the total GHG emissions of the subsystem. The main responsible subsector of this component was "Warehousing and support activities for transportation". As regards the feedback component —the subsystem emissions due to the output that it had to produce as a result of the expansion of the activity of the sectors that do not belong to the subsystem once that the subsystem initiated its productive activity—, it is the last component of the internal component, and its importance as responsible in total GHG emissions of the subsystem was negligible.

The comparison of the emissions of the rest of the sectors of the economy that do not belong to the subsystem induced by the subsystem, an amount of 6,181.2 thousand tons of CO_{2-eq}, in relation to the subsystem emissions induced by the rest of the sectors of the economy, an amount of 13,819.9 thousand tons of CO_{2-eq}, shows that the rest of the productive sectors of the economy induced the transportation and storage subsystem to emit more than the opposite.

From this empirical analysis, in terms of the environmental policy, we can derive a series of proposals aimed at cutting GHG emissions of the subsystem subsectors. Firstly, the magnitude of the scale component reveals the importance of, on one hand, introducing environmental measures that lead to the substitution of "Rail transport" and/or "Water transport" for "Road transport" and "Air transport"; and, on the other hand, achieving higher energy efficiency and using less polluting fuels in transport, especially, in "Road transport "and "Air transport" activities. Secondly, the net own internal component identifies "Warehousing and support activities for transportation" subsector as the most important in explaining this component and shows the relevance of an appropriate design in transport logistics. Lastly, the in-depth analysis both of the spillover component and of the emissions of the transportation and storage subsystem induced by the rest of the sectors of the economy shows the relevance of identifying the key activities responsible for transportation and storage subsystem emissions in the design of environmental policies aimed at their abatement. In particular, the activities of the “Construction” sector and of “Retail trade” had great impact on the subsystem emissions for Spain in 2014, therefore, the environmental measures whose objective were a significant reduction of GHG emissions of the subsystem should strongly consider reducing emissions of freight transport corresponding to these two activities.

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Chapter 4

Energy intensity in road freight transport of heavy goods vehicles in Spain

4.1. Introduction

In recent decades there has been growing concern to achieve more efficient energy use (IEA, 2013, 2014). The interest in improving energy efficiency lies in the reduction of energy costs, as well as lower energy consumption and the reduction of greenhouse gas emissions and other air pollutants resulting from fuel consumption. An in-depth analysis of the determinants of change in energy consumption is therefore important to facilitate the implementation of policies that promote savings, more efficient energy use and lower environmental impacts.

Between 1996 and 2012, greenhouse gas emissions showed a different behaviour in Spain in relation to the European Union (EU). Spanish emissions increased by 8.2% over the period compared to a 15.2% reduction in the 28 EU member states (equivalent CO_2 emissions of the six gases covered by the Kyoto Protocol, European Commission, 2014).[23] The transport sector has significantly contributed to this undesirable growth in emissions. The Spanish transport sector's emissions increased by 7.3% over the period compared to the 3.3% increase in the EU 28, contributing to 23.7% of total emissions in 2012, of which 92.1% corresponds to road transport. The upward trend in emissions in the Spanish transport sector is explained by a 18.5% rise in energy consumption over the period, reaching 40.1% of total final energy consumption in 2012 (European Commission, 2014). These results show that between 1996 and 2012, the Spanish transport sector was unable to reverse the upward trend in terms of energy consumption observed since the 1970s (Stead, 2001), which explains the difficulty in reducing the related greenhouse gas emissions.

Numerous investigations have examined the role of the transport sector in final energy consumption and/or related emissions. Part of this literature employs IPAT descriptive models (the IPAT equation states that environmental impact (I) is the product of population (P), affluence (A), and technology (T)) (Ehlrich and Holdren, 1971, 1972). Based on these models, the International Energy Agency has developed the ASIF equation, where

[23] While some increase in emissions was expected, as the target for Spain under the Kyoto Protocol for 2008–2012 with respect to 1990 was an increase of 15%, there was an increase of 20.1% in the whole period 1990–2012.

emissions are expressed as the product of different factors to study the drivers of any pollutant's emissions in the transport sector. These factors are total transport activity (A), structure, measured as the share of transport mode in total activity (S), energy intensity of every transport mode (I), and fuel used by transport mode (F). Following this line, two distinct activities are distinguished: passengers and freight. It should be added that some investigations include parametric decomposition analyses, from traditional methods such as the Laspeyres index (Millard-Ball and Schipper, 2010) to more recent and improved methods, such as the log mean Divisia Index (LMDI) (Sorrell et al., 2009, 2012).

Concerning road freight transport, a number of works should be pointed out. Kamakaté and Schipper (2009) study the energy use of road freight transport in Australia, France, Japan, the United States and the United Kingdom between 1973 and 2005. They conclude that reductions in trucking energy use will be achieved not only through fuel economy of vehicles but also with better logistics and driving. Vanek and Campbell (1999) explore energy consumption and energy intensity trends of road transport for 14 commodity groups between 1985 and 1995 in the United Kingdom. They note the growth in length and complexity of supply chains as the main driver of increasing freight energy consumption and also identify some of the determinants of energy intensity such as the mix of vehicles used and average payload. Vanek and Morlok (2000) investigate the change in energy consumption in freight transport in the United States disaggregated by commodities and transport modes. They suggest that the techniques based on modal transport will not reverse the rapidly growing energy use in the US freight transport, and conclude that a commodity-based approach is needed to make mode-based techniques more effective and to introduce new techniques, such as length of haul of the total demand for tonne-kilometre of freight. Sorrell et al. (2009, 2012) estimate the relative contribution of ten key ratios plus GDP to the change in UK road freight energy use between 1989 and 2004. They discover a relative but not absolute decoupling of road freight energy consumption from GDP, mainly explained by the declining value of manufactured goods relative to GDP, and also by reductions in the average payload weight, the amount of empty running and the fuel use per vehicle-kilometre.

Changes in energy consumption and related emissions in the transport sector in Spain are investigated by Mendiluce and Schipper (2011). They analyse the energy consumption and emissions trends for the Spanish transport sector between 1990 and 2008 differentiating between passenger and freight transport modes. These authors find out that both activities have increased over the period and that the increasing trend in energy consumption and emissions will continue if there are not policies aimed to reduce transport activity. Pérez

Martínez (2009) reviews certain indicators of efficiency and performance in the Spanish road freight transport between 1997 and 2003. He concludes that energy and environment efficiencies have poorly improved during the period. Pérez Martínez (2010) investigates the energy consumption of freight transport and related emissions for the period 1990–2007 and projections for 2025. He determines that the increasing growth in energy use will not stop unless there were significant reductions in the energy intensities of road freight, a change in the modal share, and an improvement in the average performance of road diesel vehicles. Finally, Pérez Martínez and Monzón de Cáceres (2008) compare the change in environmental indicators, such as energy consumption and carbon dioxide emissions, in the Spanish transport sector with EU countries for 1988 and 2006. They show that emissions growth in Spain was twice as that of EU, due to higher weight of more inefficient modal transport and to the fact that the improvements in energy efficiency achieved through more efficient technologies had been offset by increasing activity and more powerful vehicles.

In this chapter, we focus on the study of the energy intensity of road freight transport, its progression and its determinant factors. Moreover, the analysis is disaggregated by commodities. While most studies in the mentioned literature focus on energy consumption, this investigation deepens understanding of one of its main components, energy intensity, a variable that is key in achieving a more efficient use of energy in transport. The main contribution of this chapter is the application of decomposition analysis to energy intensity in the road freight transport and the in-depth study of its two determinant factors defined in this paper through commodity approach. These factors are the real energy intensity index (measured as energy consumption per tonne-kilometre transported) and the structural index (the relative change in the composition of road freight transport). Thereby, this chapter aims to contribute to a better understanding of the changes in the energy intensity of road freight transport. The analysis relates to Spanish road freight transport of heavy goods vehicles over the period 1996–2012. It adapts the ASIF methodology and is further enhanced by applying annual single-period and chained multi-period multiplicative LMDI-II decomposition analysis. To expand the results of the decomposition analysis, an extension is also applied: the attribution of changes in Divisia indices. This novel methodology precisely identifies the degree to which each commodity group has contributed to the change in energy intensity through the real energy intensity index and through the structural index. The results can inform the design of policies the purpose of which is to achieve more efficient energy use in road freight transport.

The rest of the chapter is organised as follows. Section 2 discusses the data and estimation methodology. Section 3 describes the results of energy intensity analysis (aggregated and by commodity). Section 4 presents the results of the decomposition analysis and its extension. Section 5 summarises and concludes the chapter.

4.2. Data and methodology

This section presents the data employed, detailing the data sources and the estimations made for this study (Subsection 4.2.1), and the methodology applied in our research. As regards the methodology, it, first, describes the road freight energy intensity identity employed in our analysis, which disaggregates it as the product of two factors (Subsection 4.2.2). Then, it shows the methodology applied to decompose energy intensity changes into structural and real energy intensity effects (Subsection 4.2.3). Finally, it describes the methodology used to attribute the changes in energy intensity to structural and real energy intensity indices, by commodity groups (Subsection 4.2.4).

4.2.1. Data

The database used is that of the Spanish Continuing Survey of Road Goods Transport (Encuesta Permanente del Transporte de Mercancías por Carretera, EPTMC) for the years 1996–2012, a survey of road freight carried out by the Ministry of Public Works and Transport (Ministerio de Fomento, 2013). The main objective of this survey is to investigate the transport operations of heavy goods vehicles to measure the extent of the sector's activity in Spain. The survey is continuous and registers the movements of Spanish heavy goods vehicles with a gross weight in excess of 3.5 tonnes or maximum permissible laden weight above 6.0 tonnes. All operations performed by these vehicles are investigated both nationally and abroad. The survey collects information on origin, destination, distance of the operation and vehicle characteristics for different commodity groups, which follow the NST/R nomenclature (standard goods classification for transport statistics) disaggregated to two digits.

Table 1 summarises the technical characteristics of heavy goods vehicles which define different types of vehicles.

Table 1. Heavy goods vehicle categories

Vehicle type	Gross vehicle weight
Rigid vehicles	≤ 7.5 tonnes >7.5 tonnes ≤ 18 tonnes >18 tonnes
Articulated vehicles	≤ 26 tonnes >26 tonnes ≤ 40 tonnes >40 tonnes

Source: Prepared by the authors with data from Ministerio de Fomento (2013) and IDAE (2006).

It should be noted that until 2002 the EPTMC did not collect data on operations within the same municipality. For this reason and to obtain a homogeneous set of data, this analysis only includes operations between municipalities, which accounted for at least 97.1% of total road freight activity in the period considered.

To conduct the decomposition analysis of road freight energy intensity, we require annual data on energy consumption and activity disaggregated by commodity groups during the period 1996–2012. The EPTMC directly provides data on freight transport by commodity groups, whereas the data on the energy consumption of freight transport by commodity groups need to be estimated. Then, the energy consumption of freight transport of commodity group c in year t ($E_{c,t}$) is calculated as follows:[24]

(1) $$E_{c,t} = \sum_k E_{c,k,t} = \sum_k VKM_{c,k,t}\ AF_k\ e$$

where $VKM_{c,k,t}$ is the annual distance travelled measured in kilometres by vehicle of type *k* in year *t* when transporting commodity group *c*, AF_k is the average annual fuel consumption per distance of vehicle type *k*, and *e* is the conversion factor —energy/fuel— provided by the Spanish Energy Efficiency Agengy (Instituto para la Diversificación y Ahorro de Energía, IDAE, 2010b).

Although the EPTMC directly provides $VKM_{c,k,t}$, a problem arises when the activity is disaggregated by commodity group: empty running is classified as another commodity group. That is, there is no information concerning the correspondence between the loaded distance travelled for commodity groups and the amount of empty running. However, as loaded and empty running operations are recorded for each vehicle, the amount of empty running travelled by vehicle has been assigned proportionally to the loaded distance travelled by the vehicle in transporting each commodity group.

[24] This analysis only considers the direct consumption of final energy required for freight transport and does not take into account indirect energy consumption (in the manufacture of vehicles, infrastructure and its maintenance, decommissioning and recycling of vehicles, or in the extraction, refining and distribution of fuel).

The allocation of fuel consumption per kilometre AF_k to each type of vehicle is made taking into account: i) the guidelines provided by IDAE (2006), which contain the general reference standards of efficiency in the fuel consumption of the different fleet vehicles; ii) the average fuel consumption per vehicle indicated in Ministerio de Fomento (2010a). Once the assignment was completed following equation (1), from the resulting total annual fuel consumption of heavy goods vehicles, we calculated the average annual fuel consumption for each year of the period 1996–2012 and we checked that it corresponded to that published by IDAE (2010a), (Table 7). It could be noted that the deviation of estimated average fuel consumption with respect to IDAE (2010a) is below 1%, with the exception of years 1996 and 1997 (below 2% and 1.25% respectively).

4.2.2. The road freight energy intensity identity

In this subsection we define the identity that will be employed for our decomposition analysis. The aim of this research is to analyse the energy intensity of road freight. Therefore, in contrast to the ASIF equation described in the introduction, transport mode and fuel are not the variables used to disaggregate the analysis. Instead, the disaggregation is carried out by commodity group I.

The energy consumption of road freight can be disaggregated as follows:

(2) $$E_t = \sum_{c=1}^{n} E_{c,t} = \sum_{c=1}^{n} TKM_t \; S_{c,t} \; I_{c,t}$$

where E_t is the energy consumption of road freight expressed in megajoules in year t, $E_{c,t}$ is the the energy consumption of freight transport of commodity group c estimated following equation (1), TKM_t is the activity of road freight measured in tonne-kilometre, $S_{c,t}$ represents the share of transport of commodity group *c* in road freight activity ($\frac{TKM_{c,t}}{TKM_t}$), and $I_{c,t}$ is the energy intensity of transport of commodity group c expressed in megajoules per tonne-kilometre ($\frac{E_{c,t}}{TKM_{c,t}}$).

Thus, the aggregate energy intensity in year t, I_t, can be expressed as:

(3) $$I_t = \sum_{c=1}^{n} \frac{E_{c,t}}{TKM_t} = \sum_{c=1}^{n} S_{c,t} I_{c,t}$$

4.2.3. The multiplicative Log Mean Divisia Index decomposition

This subsection explains the methodology applied to decompose energy intensity changes into structural and real energy intensity effects, which are the changes associated to the variations in the two factors of the identity of equation (3). The Index Decomposition Analysis (IDA) technique is widely used in energy studies. The object of IDA is to disaggregate the changes in the variable to be analysed into different explanatory effects. In the case of energy consumption, the decomposition usually has three effects: scale, structure and intensity. To study the impact of structural change in the road freight transport sector in Spain, we apply the decomposition method of the logarithmic mean Divisia index in its multiplicative form (M-LMDI-II) in relation to energy intensity rather than to energy consumption. Although the analysis of energy consumption is relevant, we focus the analysis on energy intensity and not on energy consumption to avoid the problem that appears when considering an extended period of analysis in which activity grows at a high rate: the scale effect estimated tends to be very significant and much higher than the other two effects (Ang, 1994). Thus, energy intensity is the most appropriate study variable in this case.

The energy intensity decomposition of this study comprises two indices: i) a structural index (*SE*), which provides a measure of change in energy intensity due to the relative change in the share of the commodity groups ($S_{c,t}$) that are more energy intensive in terms of transport; ii) a real energy intensity index (*EI*), defined as an indicator of energy intensity change due to the variation in the apparent energy efficiency of road freight transport in the transportation of the different commodities ($I_{c,t}$), the variation of which may be due to a change in fuel consumption per tonne-kilometre, traffic, and driving conditions or road conditions, among other factors.

The choice of the M-LMDI-II method is due to its theoretical foundation and its desirable properties (Ang, 2004).[25] The properties of the various decomposition methods are analysed in, for example, Ang and Zhang (2000), Sun and Ang (2000), Lenzen (2006) and Ang and Liu (2007).

[25] First, it is a perfect decomposition method; that is, residual terms do not appear in the results, so it overcomes the test of reversibility. Second, the test shows robustness to the value 0 as it works properly when replaced by a very small value. Third, it passes the test of reversibility in time, that is, the results are identical if the decomposition is carried out forward or backward in time. Fourth, it overcomes the aggregation test, so it is consistent in aggregating the results of the decomposition by subgroup, regardless of how these subgroups are defined. Fifth, it is easily applied and its results are easily interpreted. Sixth, it is adaptable, which means that it can be applied even when data base contains zeros, negative values and a high dispersion. Also, the absence of negative data in the database does not necessitate the use of alternative methods related to the Laspeyres index. Finally, the results obtained in the multiplicative version of this method are related to those obtained in the additive version through a simple formula.

Through the yearly single-period decomposition, the change in energy intensity (3) between two consecutive years can be expressed as $\frac{I_t}{I_{t-1}}$ and can be decomposed into a real energy intensity index and a structural index as follows:

(4) $$\frac{I_t}{I_{t-1}} = \frac{IE_t}{IE_{t-1}} \times \frac{SE_t}{SE_{t-1}}$$

According to the M-LMDI-II, the formulae of the real energy intensity index and the structural index are respectively given by:

(5) $$\frac{IE_t}{IE_{t-1}} \equiv exp\left(\sum_{c=1}^{n} w_c \, ln \frac{I_{c,t}}{I_{c,t-1}} \right)$$

(6) $$\frac{SE_t}{SE_{t-1}} \equiv exp\left(\sum_{c=1}^{n} w_c \, ln \frac{S_{c,t}}{S_{c,t-1}} \right)$$

where $w_c = \frac{L\left(\frac{E_{c,t}}{E_t}, \frac{E_{c,t-1}}{E_{t-1}}\right)}{\sum_{c=1}^{n} L\left(\frac{E_{c,t}}{E_t}, \frac{E_{c,t-1}}{E_{t-1}}\right)}$ and $L(a,b) = \begin{cases} \frac{(a-b)}{(ln\,a - ln\,b)}, & a \neq b \\ a \quad , & a = b \end{cases}$

being *L(a, b)* the logarithmic average of two positive numbers *a* and *b*.

In chained multi-period decomposition, changes in Divisia energy intensity index are described as:

(7) $$\frac{\mathrm{I_T}}{\mathrm{I_0}} = \prod_{\mathrm{t=1}}^{\mathrm{T}} \frac{\mathrm{I_t}}{\mathrm{I_{t\text{-}1}}} = \frac{\mathrm{IE_T}}{\mathrm{IE_0}} \times \frac{\mathrm{SE_T}}{\mathrm{SE_0}}$$

where:

(8) $$\frac{IE_T}{IE_0} = \prod_{t=1}^{T} \frac{IE_t}{IE_{t-1}}$$

(9) $$\frac{SE_T}{SE_0} = \prod_{t=1}^{T} \frac{SE_t}{SE_{t-1}}$$

Expressions (8) and (9) are the cumulative products between 0 and T of the single-period real energy intensity and structural indices, respectively.

4.2.4. Attribution of changes in the indices by commodity groups

This subsection explains the methodology used to attribute the changes in energy intensity and its two effects, structural and real energy intensity indices, by commodity groups. The methodology described in Choi and Ang (2012) attributes the changes in the Divisia real energy intensity index to different sources associated with such changes. We apply this methodology to the real energy intensity index and the structural index. This allows us to obtain a detailed analysis of the contribution of each commodity group in the change in the two indices, taking into account that both determine the changes in energy intensity.

The methodology, both for the single-period attribution analysis and for the multi-period attribution analysis, is based on the transformation of a geometric mean index, as is the case of M-LMDI-II, into an arithmetic mean index. Following Choi and Ang (2012), the formulae for the single-period attribution of the real energy intensity index and the structural index are given by:

(10) $$\frac{IE_t}{IE_{t-1}} - 1 = \sum_{c=1}^{n} s_c^I \left(\frac{I_{c,t}}{I_{c,t-1}} - 1\right)$$

(11) $$\frac{SE_t}{SE_{t-1}} - 1 = \sum_{c=1}^{n} s_c^S \left(\frac{S_{c,t}}{S_{c,t-1}} - 1\right)$$

Thus, $s_c^I \left(\frac{I_{c,t}}{I_{c,t-1}} - 1\right)$ and $s_c^S \left(\frac{S_{c,t}}{S_{c,t-1}} - 1\right)$ correspond, respectively, to the contribution of road freight of commodity group c to the change in the real energy intensity index and to the change in the structural index between two consecutive years, where:

(12) $$s_c^I = \frac{\frac{w_c}{L\left(I_{c,t}, I_{c,t-1}\frac{IE_t}{IE_{t-1}}\right)} I_{c,t-1}}{\sum_{k=1}^{n} \frac{w_k}{L\left(I_{k,t}, I_{k,t-1}\frac{IE_t}{IE_{t-1}}\right)} I_{k,t-1}}$$

(13) $$s_c^S = \frac{\frac{w_c}{L\left(S_{c,t}, S_{c,t-1}\frac{SE_t}{SE_{t-1}}\right)} S_{c,t-1}}{\sum_{k=1}^{n} \frac{w_k}{L\left(S_{k,t}, S_{k,t-1}\frac{SE_t}{SE_{t-1}}\right)} S_{k,t-1}}$$

Following Choi and Ang (2012), for the multi-period attribution analysis, the formulae to disaggregate the real energy intensity index and the structural index are:

(14) $$\frac{IE_T}{IE_0} - 1 = \sum_{c=1}^{n} \sum_{t=1}^{T} \frac{IE_{t-1}}{IE_0} s_{c,t-1,t}^I \left(\frac{I_{c,t}}{I_{c,t-1}} - 1\right)$$

(15) $$\frac{SE_T}{SE_0} - 1 = \sum_{c=1}^{n} \sum_{t=1}^{T} \frac{SE_{t-1}}{SE_0} s_{c,t-1,t}^S \left(\frac{S_{c,t}}{S_{c,t-1}} - 1\right)$$

where:

(16) $$s_{c,t-1,t}^I = \frac{\frac{w_{c,t-1,t}}{L\left(I_{c,t}, I_{c,t-1}\frac{IE_t}{IE_{t-1}}\right)} I_{c,t-1}}{\sum_{k=1}^{n} \frac{w_{k,t-1,t}}{L\left(I_{k,t}, I_{k,t-1}\frac{IE_t}{IE_{t-1}}\right)} I_{k,t-1}}$$

(17) $$s^{S}_{c,t-1,t} = \frac{\frac{w_{c,t-1,t}}{L\left(s_{c,t}, s_{c,t-1}\frac{SE_t}{SE_{t-1}}\right)} s_{c,t-1}}{\sum_{k=1}^{n} \frac{w_{k,t-1,t}}{L\left(s_{k,t}, s_{k,t-1}\frac{SE_t}{SE_{t-1}}\right)} s_{k,t-1}}$$

Equation (14) expresses the percentage change in the real energy intensity index between 0 and T as the cumulative sum of annual percentage changes evaluated at year 0 through IE_{t-1}/IE_0. In parallel, equation (15) shows the percentage change in the structural index between 0 and T. Therefore, the contribution of road freight transport in commodity group *c* in the change of the real energy intensity index between *t-1* and *t* corresponds to the value $\frac{IE_{t-1}}{IE_0} s^{I}_{c,t-1,t}\left(\frac{I_{c,t}}{I_{c,t-1}} - 1\right)$ evaluated at year 0, while $\frac{SE_{t-1}}{SE_0} s^{S}_{c,t-1,t}\left(\frac{S_{c,t}}{S_{c,t-1}} - 1\right)$ determines the contribution of road freight transport in commodity group *c* in the change of the structural index between *t-1* and *t* and evaluated at year 0.

4.3. Results

4.3.1. Energy intensity trend

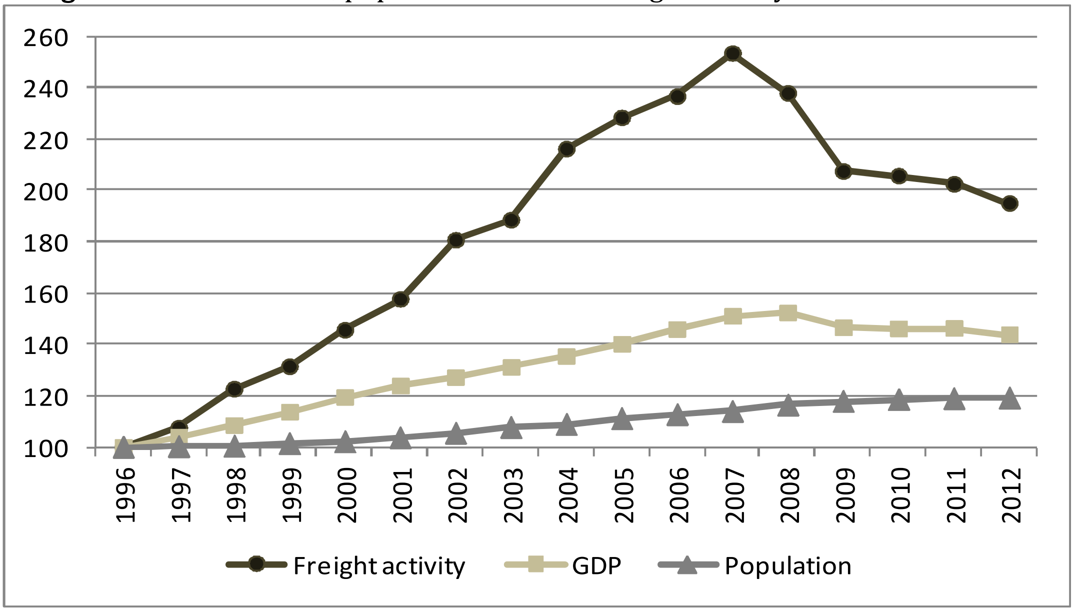
During the period 1996–2012, the strong increase in Spanish road freight energy consumption is mainly explained by the activity's significant growth, which increased by 84.7% measured in millions of tonne-kilometre (TKM). The activity also grew faster than the whole economy as GDP increased by 43.9% over the period, which explains its greater share in final energy consumption and in related emissions in Spain.

Regarding modal shares in freight transport in Spain over the period 1996–2012, it should be noted that road freight grew by 95% (199,205 millions of TKM in 2012 compared to 102,167 millions of TKM in 1996), whereas the alternative, rail transport, fell by 10.3% (from 11,100 millions of TKM in 1996 to 9,957 millions of TKM in 2012). Thus, road freight accounted for 95.2% of total freight activity in Spain in 2012.[26]

Figure 1 shows a change in the trend of road freight as a result of the beginning of the economic crisis in Spain in 2008: activity grew by 153.4% from 1996 to 2007 and decreased by 23% from 2007 to 2012. Energy consumption for road freight was also affected by the economic crisis: over the period 1996 to 2012 it rose by 89.7% while at its peak in 2007, the increase was 140.7%.

[26] In Spain, the total volume of road freight transport represented 84% of freight transport in 2007, railway transport 1% and maritime transport 15% (that includes loading and unloading), according to Eurostat (2013) data.

Figure 1. Trends in GDP, population and road freight activity. SPAIN, 1996–2012

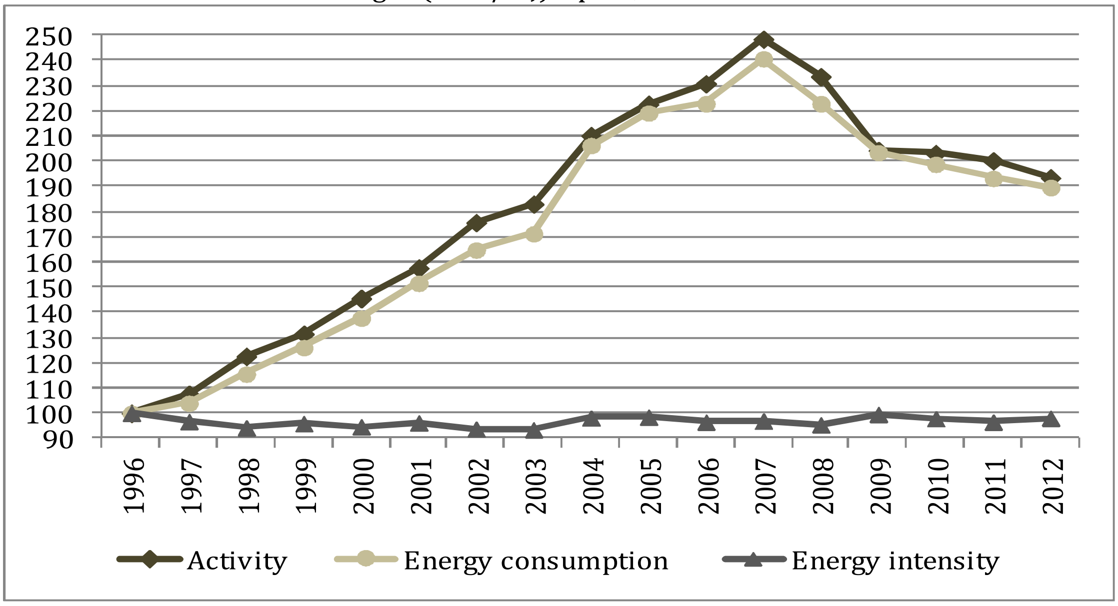


Source: the Spanish Statistical Office (Instituto Nacional de Estadística, INE, 2014) provides population (Labour Force Survey) and GDP data (National Accounts) and the EPTMC (Ministerio de Fomento, 2013) provides road freight activity data. In 1996, the population was 39,669 thousand people, tonne-kilometre transported amounted to 102,166 millions and GDP at constant prices of 2008 amounted to a total of 714,138 million Euros.

Note: If the GVA –agriculture, industry and construction– were taken as a reference, the difference in growth rates of road freight activity and the economy would be greater. For example, from 2000 to 2010, the growth rate of GVA at constant prices in the economy reached 23%, but excluding the service sector, the growth rate of GVA reached only 4%.

The energy intensity for road freight in Spain dropped by 1.9%, from 1.05 MJ/TKM in 1996 to 1.03 MJ/TKM in 2012. Figure 2 shows this variable’s behaviour over time. Its progression is somewhat erratic. During the years of economic crisis, the decrease in energy intensity was because energy consumption in road freight fell faster than road freight activity. During the period of economic expansion, energy intensity reduction was because road freight activity grew faster than energy consumption in road freight.

Figure 2. Changes in activity (TKM), energy consumption (MJ) and energy intensity of road freight (TKM/MJ). Spain, 1996–2012



Source: Prepared by the authors with data from EPTMC (Ministerio de Fomento, 2013), and IDAE (2006, 2010b).

Table 2 summarises the results of computing equation (3) for energy intensity, aggregated and by commodity group, and the share of commodity groups in road freight in Spain in the years 1996 and 2012.

These first results point to a change in energy intensity as well as in structure for road freight activity over the period 1996–2012 in Spain. In particular, the energy intensity of different commodity groups reveals a distinct pattern. Energy intensity increased considerably in the case of the transport of “Coal chemicals, tar”, “Textiles, textile articles and man-made fibres, other raw animal and vegetable materials”, and “Wood and cork”. However, it decreased especially in the case of the transport of “Paper pulp and waste paper”, “Transport equipment, machinery,…”, and “Live animals, and sugar beet”. In 2012, the disparity in energy intensities, which ranged from 0.65 MJ/TKM for “Non-ferrous ores and waste” to 1.47 MJ/TKM for “Live animals and sugar beet”, was lower than the disparity in 1996 as shown by Figure 3.

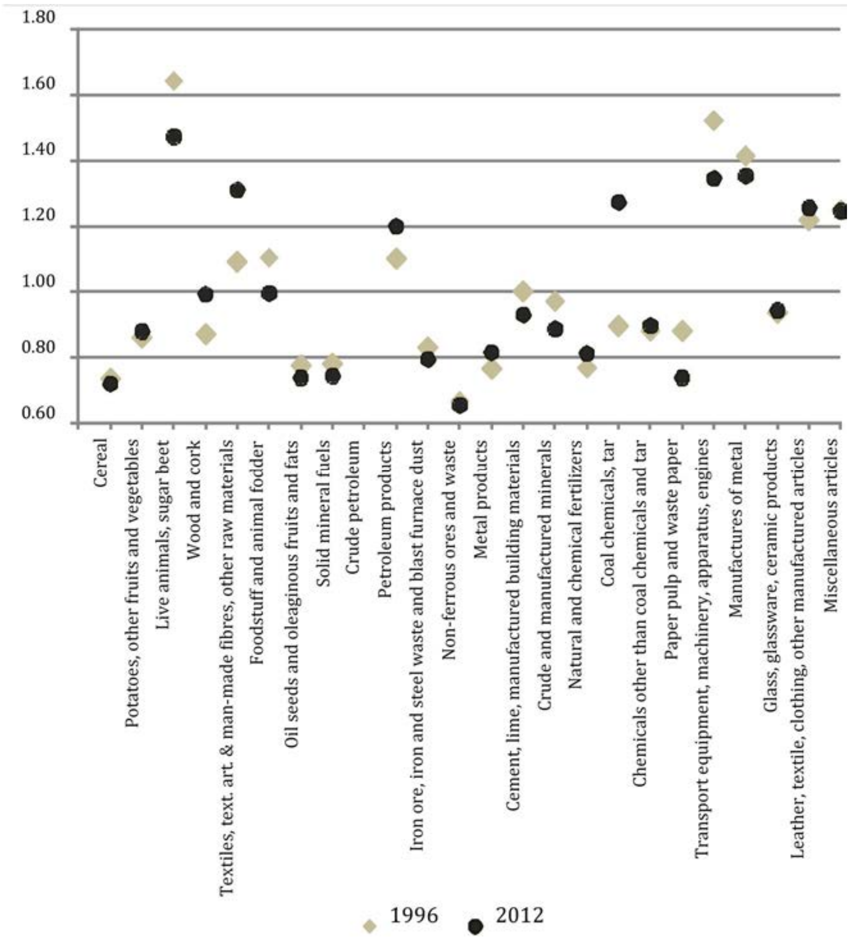
Table 2. Energy intensity (MJ/TKM) and share (TKM) of commodity groups in road freight. Spain, 1996–2012

		Energy intensity			**Share**	
		1996	**2012**	**Total change**	**1996**	**2012**
1	Cereals	0.74	0.72	-2.0%	3.2%	2.4%
2	Potatoes, other fresh or frozen fruits and vegetables	0.86	0.88	2.0%	10.0%	12.3%
3	Live animals, sugar beet	1.64	1.47	-10.4%	1.3%	0.9%
4	Wood and cork	0.87	0.99	13.8%	2.8%	1.3%
5	Textiles, textile articles and man-made fibres, other raw animal and vegetable materials	1.09	1.31	20.1%	0.7%	0.8%
6	Foodstuff and animal fodder	1.11	1.00	-9.8%	17.0%	22.0%
7	Oil seeds and oleaginous fruits and fats	0.78	0.74	-4.7%	1.1%	1.5%
8	Solid mineral fuels	0.78	0.74	-4.9%	1.1%	0.6%
9	Crude petroleum	0.40	10.62*	2540.0%	0.0%	0.0%
10	Petroleum products	1.10	1.20	8.7%	3.6%	2.6%
11	Iron ore, iron and steel waste and blast furnace dust	0.83	0.80	-4.5%	1.1%	1.6%
12	Non-ferrous ores and waste	0.67	0.65	-2.2%	0.1%	0.2%
13	Metal products	0.77	0.82	6.3%	6.4%	5.1%
14	Cement, lime, manufactured building materials	1.00	0.93	-7.0%	6.5%	5.1%
15	Crude and manufactured minerals	0.97	0.89	-8.6%	8.8%	6.1%
16	Natural and chemical fertilizers	0.77	0.81	5.7%	1.7%	1.6%
17	Coal chemicals, tar	0.90	1.27	41.9%	0.1%	0.3%
18	Chemicals other than coal chemicals and tar	0.88	0.90	1.6%	6.4%	5.1%
19	Paper pulp and waste paper	0.88	0.74	-16.1%	0.7%	1.1%
20	Transport equipment, machinery, apparatus, engines, whether or not assembled and parts thereof	1.52	1.35	-11.6%	6.0%	6.4%
21	Manufactures of metal	1.41	1.35	-4.3%	1.4%	0.9%
22	Glass, glassware, ceramic products	0.94	0.94	0.9%	1.7%	1.2%
23	Leather, textile, clothing, other manufactured articles	1.22	1.26	3.0%	8.6%	8.1%
24	Miscellaneous articles	1.25	1.25	-0.3%	9.7%	12.9%
TOTAL ACTIVITY		1.05	1.03	-1.9%	100.0%	100.0%

Source: Prepared by the authors with data from EPTMC (Ministerio de Fomento, 2013) and IDAE (2006, 2010b).
Note: The first column shows the numbering of the standard goods classification transport statistics (NST/R 24 groups) by Eurostat (2014).
*This result for *Crude petroleum* is unusual, as this commodity usually is not transported by road. Even though trucks travelled 617,666 kilometers to carry 9,733 tonnes of it, the analysis is not distorted because its share is not significant.

On the other hand, shifts in the share of commodity groups mark a significant structural change in transport activity. In fact, the importance of the transport of the commodities "Foodstuff and animal fodder" and "Potatoes, other fresh or frozen fruits and vegetables" increased notably, whereas the weight of "Crude and manufactured minerals", "Cement, lime and manufactured building materials", "Metal products", and "Chemicals other than coal chemicals and tar" was reduced in overall activity (Table 3).

Figure 3. Disparity in energy intensity (MJ/TKM) of commodity groups in road freight. Spain, years 1996 and 2012



Source: Prepared by the authors with data from EPTMC (Ministerio de Fomento, 2013) and IDAE (2006, 2010b).

Table 3. Changes in energy intensity and share of commodity groups in road freight

		ENERGY INTENSITY	
		Decrease	**Increase**
SHARE	**Decrease**	Cereals Live animals, sugar beet Solid mineral fuels Cement, lime, manufactured building materials Crude and manufactured minerals Manufactures of metal	Wood and cork Crude petroleum Petroleum products Metal products Natural and chemical fertilizers Chemicals other than coal chemicals and tar Glass, glassware, ceramic products Leather, textile, clothing, other manufactured articles
	Increase	Foodstuff and animal fodder Oil seeds and oleaginous fruits and fats Iron ore, iron and steel waste and blast furnace dust Non-ferrous ores and waste Paper pulp and waste paper Transport equipment, machinery, apparatus, engines, whether or not assembled and parts thereof Miscellaneous articles	Potatoes, other fresh or frozen fruits and vegetables Textiles, textile articles and man-made fibres, other raw animal and vegetable materials Coal chemicals, tar

Source: Prepared by the authors with data from EPTMC (Ministerio de Fomento, 2013) and IDAE (2006, 2010b).

Taking into account the structural change, the data obtained from the EPTMC indicate that the amount of empty running with respect to total distance travelled decreased over the period considered, which represented a relative improvement in the logistics of the activity. In short, 29.1% of the total distance travelled by heavy goods vehicles corresponded to empty running in 1996, whereas this was reduced to 22.9% in 2012. That is, whereas empty running increased by 53.9%, the loaded distance travelled increased by 99.0% over the period.

4.3.2. Decomposition analysis results

4.3.2.1. M-LMDI-II decomposition

The M-LMDI–II decomposition results are summarised in Table 4, which shows the results of computing equations (4), (5) and (6) for the yearly single-period decomposition and equations (7), (8) and (9) for the chained multi-period decomposition. Through the single-period decomposition, it can be seen that the progression of energy intensity of road freight activity was somewhat erratic over the period considered. In some years it increased, as illustrated by the positive contribution to this increase of both the energy intensity index and structural index for the years 1999, 2001, 2005, 2007, 2009 and 2012. However, in other years (1997, 1998, 2006, 2008 and 2011), energy intensity decreased as both indices contributed to this decrease.

However, through the multi-period decomposition analysis, it can be seen that the real energy intensity index contributed to energy intensity reduction by 3.0% over the period. In contrast, the structural index contributed to increasing energy intensity by 1.1% during the same period. The combination of these two effects led to a 1.9% decrease in energy intensity from 1996 to 2012.

Table 4. M-LMDI-II decomposition of road freight energy intensity changes. 1996–2012

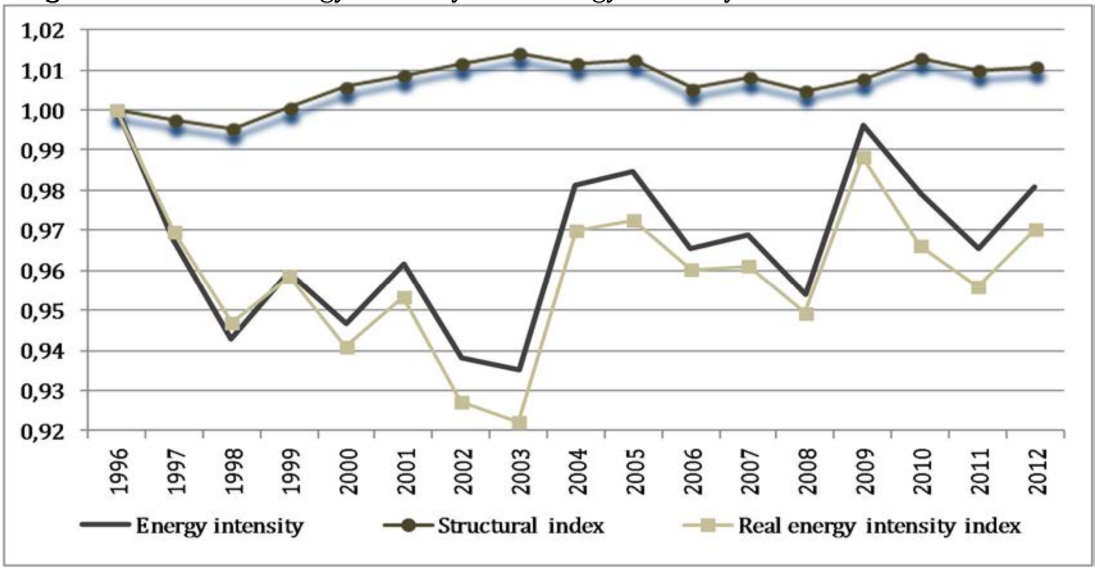
	Single-period annual analysis				Multi-period analysis (1996 is the base)		
	Energy intensity	Real energy intensity index	Structural index		Energy intensity	Real energy intensity index	Structural index
1997	-3.3%	-3.0%	-0.2%		-3.3%	-3.0%	-0.2%
1998	-2.6%	-2.3%	-0.2%		-5.7%	-5.3%	-0.4%
1999	1.8%	1.2%	0.5%		-4.1%	-4.2%	0.1%
2000	-1.3%	-1.8%	0.5%		-5.4%	-5.9%	0.6%
2001	1.6%	1.3%	0.3%		-3.8%	-4.7%	0.9%
2002	-2.5%	-2.7%	0.3%		-6.2%	-7.3%	1.2%
2003	-0.3%	-0.5%	0.3%		-6.5%	-7.8%	1.4%
2004	4.9%	5.2%	-0.2%		-1.9%	-3.0%	1.2%
2005	0.3%	0.3%	0.1%		-1.5%	-2.7%	1.3%
2006	-1.9%	-1.3%	-0.7%		-3.4%	-4.0%	0.6%
2007	0.3%	0.1%	0.3%		-3.1%	-3.9%	0.8%
2008	-1.5%	-1.2%	-0.3%		-4.6%	-5.1%	0.5%
2009	4.4%	4.1%	0.3%		-0.4%	-1.2%	0.8%
2010	-1.7%	-2.2%	0.5%		-2.1%	-3.4%	1.3%
2011	-1.4%	-1.1%	-0.3%		-3.5%	-4.4%	1.0%
2012	1.6%	1.5%	0.1%		-1.9%	-3.0%	1.1%

Source: Prepared by the authors with data from EPTMC (Ministerio de Fomento, 2013) and IDAE (2006, 2010b).

The implications of the results are immediate. The energy intensity reduction in road freight in Spain is the result of the positive contribution of the real energy intensity index. That is, greater apparent energy efficiency in road freight (lower fuel consumption per tonne-kilometre). However, this was partially offset by the negative contribution of the structural index: the commodity groups which are more energy intensive in their transportation increase their share in the activity. Thus, the multi-period decomposition analysis shows that the real energy intensity index has negative cumulative growth rates, which translate into an improvement in energy efficiency. Similarly, except for the years 1997 and 1998, the structural index has positive cumulative growth rates which contributed, in turn, to worsening energy efficiency. As the negative growth rates of the real energy intensity index were superior to the positive growth rates of the structural index, energy intensity decreased over the period.

It should also be noted that the somewhat erratic behaviour of energy intensity corresponds to the development shown by the real energy intensity index throughout the period, while the structural index shows less variability. In particular, the negative real energy intensity index for the years 2004 and 2009 changed the progression of energy intensity (Figure 4). To obtain more clues to the factors behind the contribution of both effects and to establish which policies could improve energy intensity for road freight in the future, we proceed to decompose these effects into the contribution of each commodity group.

Figure 4. Trends in energy intensity: real energy intensity index and structural index



Source: Prepared by the authors with data from EPTMC (Ministerio de Fomento, 2013) and IDAE (2006, 2010b).

4.3.2.2. Results of attribution of changes in Divisia to the real energy intensity index and the structural index

Table 5 summarises the results of multi-period attribution analysis of energy intensity for the real energy intensity index and the structural index in the period 1996–2012, obtained from the computation of equations (14) and (15). The last row of the table shows the contribution to the cumulative percentage change in energy intensity of the real energy intensity index and the structural index over the period. The method attributes this change quantitatively to the transportation of each of the 24 commodity groups. Regarding the real energy intensity index, it can be said that the commodity groups "Foodstuff and animal fodder", and "Transport equipment, machinery, …" determine almost entirely the positive development of the real energy intensity index between 1996 and 2012.

Regarding the structural index, it can be seen that the worsening in energy intensity derived from this index is mainly due to the following commodity groups: "Potatoes, other fresh or frozen fruits and vegetables", "Foodstuff and animal fodder", and "Miscellaneous articles".

This is despite the positive contribution of the commodity groups “Crude and manufactured minerals”, and “Cement, lime and manufactured building materials”.

Table 5. Attribution of M-LMDI-II of energy intensity to real energy intensity and structural indexes by chain method in percent change (base = 1996). 1996–2012

	Energy intensity	**Real energy intensity index**	**Structural index**
Cereals	-0.6	0.0	-0.6
Potatoes, other fresh or frozen fruits and vegetables	2.1	0.2	2.0
Live animals, sugar beet	-0.8	-0.2	-0.6
Wood and cork	-1.2	0.1	-1.3
Textiles, textile articles and man-made fibres, other raw animal and vegetable materials	0.3	0.1	0.1
Foodstuff and animal fodder	3.1	-1.7	4.8
Oil seeds and oleaginous fruits and fats	0.3	0.0	0.3
Solid mineral fuels	-0.5	0.0	-0.4
Crude petroleum	0.0	0.0	0.0
Petroleum products	-1.0	0.2	-1.2
Iron ore, iron and steel waste and blast furnace dust	0.4	0.0	0.4
Non-ferrous ores and waste	0.1	0.0	0.1
Metal products	-0.8	0.3	-1.1
Cement, lime, manufactured building materials	-1.8	-0.4	-1.4
Crude and manufactured minerals	-3.1	-0.6	-2.4
Natural and chemical fertilizers	0.0	0.0	0.0
Coal chemicals, tar	0.3	0.0	0.3
Chemicals other than coal chemicals and tar	-1.1	0.0	-1.1
Paper pulp and waste paper	0.3	-0.1	0.4
Transport equipment, machinery, apparatus, engines, whether or not assembled and parts thereof	-0.5	-1.1	0.6
Manufactures of metal	-0.8	-0.1	-0.7
Glass, glassware, ceramic products	-0.5	0.0	-0.5
Leather, textile, clothing, other manufactured articles	-0.4	0.2	-0.5
Miscellaneous articles	4.0	0.1	3.9
Activity	**-1.9%**	**-3.0%**	**1.1%**

Source: Prepared by the authors with data from EPTMC (Ministerio de Fomento, 2013) and IDAE (2006, 2010b).

The combination of both indices provides the contribution of each commodity group to the progression of energy intensity in road freight in the period 1996–2012. Thus, the commodity groups “Cement, lime and manufactured building materials”, and “Crude and manufactured minerals” contribute significantly to the reduction of energy intensity in road freight.

However, three commodity groups with a significant share in total activity, “Potatoes, fresh or frozen fruits and vegetables”, “Foodstuff and animal fodder”, and “Miscellaneous articles”, prevented further contraction in energy intensity over the period analysed. In the first case, “Foodstuff and animal fodder”, despite having reduced real energy intensity in the period considered (positive real energy intensity index), increased its relative weight in total activity (negative structural index) in such a way that the second index dominates the first. In the second two cases, “Potatoes, fresh or frozen fruits and vegetables” and “Miscellaneous articles”, both increased in terms of real energy intensity and their relative weight in total activity.

Taking into account the above and in relation to the study of the somewhat erratic behaviour of energy intensity, the high variability of the real energy intensity index may be explained by the commodity groups “Foodstuff and animal fodder” and “Miscellaneous articles”. Specifically, both experienced a strong growth in the real energy intensity index in 2004 and 2009. Moreover, a more detailed analysis of the progression of the real energy intensity index in 2004 and 2009 reveals that the commodity groups “Potatoes, fresh or frozen fruits and vegetables”, and “Leather, textiles, clothing and other manufactured articles” should also be considered. Similarly, the commodity group “Transport equipment, machinery, …” should also be taken into account for 2009 (Table 8) .

Table 6. Performance of key factors in road freight activity

		2003/2004	2008/2009
Transport content	Potatoes, other fresh or frozen fruits and vegetables	11.0%	-5.6%
	Foodstuff and animal fodder	6.9%	8.0%
	Transport equipment, machinery, apparatus, engines, whether or not assembled and parts thereof	-	8.8%
	Leather, textile, clothing, other manufactured articles	18.5%	-0.8%
	Miscellaneous articles	-3.0%	3.5%
Transport efficiency	Potatoes, other fresh or frozen fruits and vegetables	-12.9%	-6.6%
	Foodstuff and animal fodder	-4.4%	-1.0%
	Transport equipment, machinery, apparatus, engines, whether or not assembled and parts thereof	-	-7.5%
	Leather, textile, clothing, other manufactured articles	-15.4%	-6.7%
	Miscellaneous articles	-3.3%	-1.0%

Source: Prepared by the authors with data from EPTMC (Ministerio de Fomento, 2013) and IDAE (2006, 2010b).

To examine what factors explain the results of the real energy intensity index for the commodity groups indicated in years 2004 and 2009, two key performance factors of the activity were analysed: transport content and transport efficiency. In 2004 and 2009, both key factors, transport content (distance travelled per tonne transported) and transport efficiency (tonnes carried per vehicle) worsened considerably.[27] In short, the negative development of the real energy intensity index in 2004 and 2009 is explained because in transporting these commodity groups, heavy goods vehicles carried fewer tonnes and travelled more kilometres per tonne transported (Table 6).

4.4. Discussion

The energy intensity of road freight transport of heavy goods vehicles dropped by 1.9% in Spain over the period 1996–2012. The improvement in energy efficiency was very modest in relation to the 89.7% increase in the energy consumption of road freight transportation in the same period. This poor improvement in energy intensity of road freight transport of heavy goods vehicles is in consonance with the findings of Pérez Martínez (2009) and Mendiluce and Schipper (2011).

The decomposition analysis of energy intensity change shows that the positive result in energy intensity progression was due to the behaviour of the real energy intensity index, due to the lower energy consumption per tonne-kilometre. This was partially offset by the bad behaviour of the structural index, as more energy intensive commodity groups increased their relative share in total activity. Moreover, the results of the decomposition analysis show that the decrease in energy intensity over the period was not constant but somewhat erratic. This behaviour was due to the instability shown by the real energy intensity index, whereas the structural index presented little variability.

The attribution analysis of energy intensity shows that not all commodity groups participated positively in the reduction nor to the same degree over the period of time analysed. Thus, the commodity groups that contributed significantly to the reduction of energy intensity in road freight were “Crude and manufactured minerals”, and “Cement, lime and manufactured building materials”. An important remark is that these two commodity groups are directly related to construction, a sector seriously affected by the economic crisis in Spain. In contrast, “Foodstuff and animal fodder”, “Potatoes, fresh or frozen fruits and vegetables”, and “Miscellaneous articles” were the commodity groups that prevented greater contraction in energy intensity over the period. It is worth to note that the commodity groups “Foodstuff and animal fodder”, and “Potatoes, fresh or frozen fruits and vegetables” are directly related

[27] Regarding the transport content factor, the commodity group “Miscellaneous articles” is an exception in 2004 and the commodity groups “Potatoes, other fresh or frozen fruits and vegetables” and “Leather, textiles, clothing and other manufactured articles” are the exceptions in 2009.

to the food industry. The analysis has shown that heavy goods vehicles, when transporting these commodity groups, carried fewer tonnes and travelled more kilometres per tonne transported, i.e. the logistics seem to not work correctly. Furthermore, the trend in the three last commodity groups also helps to explain to a great extent the somewhat erratic movement of the real energy intensity index.

Lastly, our estimation of empty running disaggregated by commodity group (explained in Subsection 4.2.1) could have affected somehow the results obtained. In the same way, the allocation of vehicle fuel consumption according to the guidelines of efficiency provided by IDAE (2010a) could also have influenced the results.

4.5. Conclusions and policy implications

The substantial increase in the energy consumption of freight transport in Spain during the period 1996–2012 is explained by the strong growth in activity. Road freight activity was clearly primarily responsible for this increase, accounting for between 90% and 95% of domestic freight transport over the period.

Investigating the energy intensity of transport, its trend and its determinant factors, the real energy intensity index and the structural index, helps to understand the behaviour of one key component of energy consumption. This article aims to contribute to a better understanding of the factors behind the change in energy intensity in relation to road freight, which can inform the design of measures to achieve greater energy efficiency in the sector. The use of the M-LMDI-II decomposition analysis to examine energy intensity complements the literature that to date has focused mainly on the study of energy consumption in road freight. Similarly, expanding the study through considering the attribution of changes in the Divisia index probes the results in greater depth and shows how each commodity group has participated in changes in energy intensity.

The greater importance of the real energy intensity index in explaining changes in energy intensity and the fact that the structural index depends on the specialization of the economy, reinforces the idea that the policies should aim to implement measures leading to a further reduction in the real energy intensity index. These measures should not only consist of the gradual replacement of the fleet with more energy efficient vehicles, and/or the introduction of higher quality fuels, or more generally, of adequate infrastructure and efficient driving. The Spanish Government applied two plans according to these measures during the last decade: the Strategic Plan for Road Freight Transport (Plan Estratégico para el Transporte de Mercancías por Carretera, PETRA) (Ministerio de Fomento, 2001) in the period 2001–

2006 and the Strategic Action Plan for Road Freight Transport (Plan Estratégico de Actuación para el Transporte de Mercancías por Carretera, PETRA II) (Ministerio de Fomento, 2008) in 2006–2011. The moderate decrease in energy intensity over the period shows the limited success of these two plans. Therefore, other factors should also be considered to achieve greater energy efficiency.

The change in the structural index shows how the success of measures to achieve more efficient energy use in road freight transport depends on the extent to which the composition of commodity groups is properly taken into account. Thus, measures designed to achieve greater energy efficiency are even more necessary in a context in which the more energy intensive commodity groups increase their share in transport activity, as was the case in Spain during the period 1996–2012. In this context, and under a scenario where road freight activity has taken advantage over other transport modes over the period, it would be advisable that authorities promote the use of alternative modes of freight transport as rail. This seems to be the strategy carried out recently by the Spanish Government, which has set up the Strategic Plan for the Promotion of Rail Freight in Spain (Plan Estratégico para el Impulso del Transporte Ferroviario de Mercancías en España, Ministerio de Fomento, 2010b) for the period 2010–2020. The objective of this plan is to promote a greater rail use in the Spanish freight transport, increasing its share (measured in tonnes kilometres) from 4.1% in 2010 to 8%–10% in 2020.

The results of the attribution of the real energy intensity index and of the structural index by commodity group suggest the need to design measures that take into account the commodity group being transported. This research has demonstrated the relevance to take this into account, as each commodity group is involved to a different degree and with different sign in the reduction of energy intensity. Regarding the real energy intensity index, it is important to improve the logistics, i.e. to reduce empty running, get better transport content and transport efficiency, and to achieve the suitable mix of vehicles used, in line with the measures suggested by Kamakaté and Schipper (2009) and Vanek and Campbell (1999). We also agree, as suggested by Vanek and Morlok (2000), that authorities should develop these measures paying special attention to those commodity groups that have revealed bad behaviours in the real energy intensity index. In relation to the structural index, the commodity groups which are more energy intensive in their transport should reduce their share in road freight. Policy makers should design policies aimed to achieve a greater use of alternative transport modes such as rail, particularly in the case of the transport of these commodity groups.

Finally, the real energy intensity index does not to show a clear trend, due to its somewhat erratic evolution, specially because of its trend change in years 2004 and 2009. It is worth to note that there are not official data of fuel consumption. The methodology used to estimate fuel consumption was to assign an average consumption by vehicle type (a fixed value over the period provided by IDAE, 2006, and Ministerio de Fomento, 2010a), as it was the only data available for this purpose. Therefore, results do not include energy efficiency improvements resulting from technological improvements in vehicles or fuels, but they include energy efficiency improvements resulting from suitable choices of vehicle type and a better logistics and, of course, those resulting from improvements in infrastructures and driving. Moreover, in relation to the trend change in the progression of energy intensity in 2004, according to the database used, the EPTMC, there is a greater use in road freight activity of higher power vehicles since 2004. Along with the activity increase, the share in fuel consumption of articulated vehicles of a gross vehicle weight superior to 40 tonnes was 0% until 2004 and 2% thereafter. As a result, there was a significant increase in energy intensity, which would explain the trend change in energy intensity in 2004. Lastly, the trend change in energy intensity in 2009 may be linked to the decline in the fuel prices, which dropped by 20.1% in 2009 with respect to 2008.

Future research should focus on studying in greater detail different factors related to logistics that have influenced the progression of the real energy intensity index, and thus find mechanisms that could lead to improvements, specially through designing policies aimed to commodity groups that have revealed a bad behaviour. If an energy intensive commodity group such as “Transport equipment, machinery, …” has managed to achieve greater energy efficiency in its transport, it is conceivable that this could also be achieved in the transport of other commodity groups. Nevertheless, policies should be systematically adjusted to take into account possible significant changes in this behaviour over time. Similarly, the analysis should be extended by including another important mode of freight transport, namely rail. The analysis could then be carried out by disaggregating by commodity group and by mode of transport. To make possible this analysis, official data should provide information on tonnes-kilometre by commodity group carried by rail (classified as in EPTMC) and related energy consumption, which is not yet available. Thus, once we know more precisely which are the improvements of energy intensity in freight transport that could be achieved through a larger participation of rail at the expense of road, policy makers could then design measures aimed to improve energy intensity. For example, by increasing specially the share of rail in freight transport in the commodity groups which are more energy intensive in its transport by road. Finally, this later research could also be extended to study the trend in the intensity of greenhouse gas emissions of freight transport and its drivers. The identification of the role played by structural and real emission intensity effects, and the examination of the magnitude of the changes observed by commodity group and its causes (changes in transport modes, use of fuels, and the extension of good practices, among other aspects), will orientate the design of the appropriate policies to help the mitigation of emissions in the sector.

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Appendix

Table 7. Average fuel consumption
(litres / 100km)

Year	Estimated average consumption
1996	29.75
1997	30.04
1998	30.27
1999	30.23
2000	30.43
2001	30.44
2002	30.60
2003	30.72
2004	30.85
2005	30.90
2006	30.94
2007	30.92
2008	31.03
2009	31.10
2010	31.22
2011	31.28
2012	31.33

Source: Prepared by the authors with data from EPTMC (Ministerio de Fomento, 2013) and (IDAE, 2006, 2010a)

Table 8. Attribution of M-LMDI-II real energy intensity index. Single-period analysis (base = previous year)

	Δ % IE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1997	-3.04	-0.05	-0.20	-0.17	0.06	-0.11	-0.89	0.04	0.00	0.00	-0.06	-0.06	0.00	-0.19	-0.36	0.02	0.00	0.00	-0.04	0.00	-0.52	-0.09	0.11	-0.27	-0.26
1998	-2.35	0.08	-0.51	-0.04	-0.24	0.04	-0.59	-0.05	-0.02	0.00	-0.12	0.02	0.00	-0.01	-0.09	-0.40	-0.02	0.00	-0.03	-0.15	-0.32	-0.09	-0.19	0.55	-0.17
1999	1.23	-0.08	0.20	0.13	0.13	0.03	0.18	-0.02	0.03	0.00	0.14	-0.03	0.00	0.00	0.05	0.21	-0.06	0.00	0.03	0.03	-0.05	0.19	0.10	0.08	-0.06
2000	-1.84	0.02	-0.14	-0.05	0.02	0.04	-0.46	0.01	-0.01	0.00	-0.12	-0.01	0.00	0.00	0.01	0.09	-0.02	-0.01	-0.11	-0.05	0.07	-0.13	-0.01	-0.59	-0.39
2001	1.33	0.02	0.03	-0.03	0.00	0.02	0.08	-0.02	0.01	0.00	0.12	-0.01	0.00	0.12	0.02	-0.06	0.01	0.01	0.16	0.07	0.13	0.11	-0.01	0.75	-0.19
2002	-2.74	-0.01	-0.25	-0.04	0.04	0.03	-0.53	0.01	0.00	0.00	-0.17	0.03	0.00	-0.07	0.11	0.30	0.08	0.00	-0.09	-0.02	-0.30	-0.04	-0.10	-1.09	-0.63
2003	-0.54	-0.01	-0.03	-0.01	0.04	-0.05	-0.04	0.01	0.00	0.00	0.00	-0.02	0.00	-0.09	-0.12	-0.30	-0.05	0.00	0.09	-0.02	-0.28	-0.14	0.07	0.11	0.29
2004	5.18	0.08	1.24	0.07	-0.08	0.07	0.77	0.00	-0.01	0.00	0.25	0.00	0.00	0.43	0.13	0.07	0.07	0.01	-0.09	0.11	-0.41	0.15	0.17	1.60	0.57
2005	0.27	-0.03	-0.48	0.11	-0.02	0.12	-0.51	-0.02	0.01	0.00	-0.02	0.04	0.00	0.09	0.03	0.03	0.00	0.01	-0.09	-0.03	0.13	0.01	-0.07	-0.01	0.96
2006	-1.26	0.02	-0.36	-0.16	0.10	-0.10	0.46	-0.01	-0.01	0.00	0.01	-0.02	0.00	-0.10	0.15	-0.02	0.05	0.02	0.08	0.02	-0.03	-0.04	-0.01	-0.86	-0.46
2007	0.09	-0.05	0.29	0.02	0.02	0.06	-0.40	0.01	-0.03	0.00	0.09	-0.05	-0.01	-0.02	-0.07	-0.23	-0.04	0.00	-0.06	-0.03	0.10	-0.03	0.05	0.11	0.35
2008	-1.24	0.03	-0.33	-0.01	-0.08	0.02	0.24	-0.02	0.00	0.00	-0.20	-0.05	0.00	-0.21	-0.18	0.04	0.05	0.02	-0.15	-0.03	-0.14	-0.06	-0.08	-0.33	0.24
2009	4.12	-0.01	0.60	0.04	0.08	0.09	0.27	0.07	0.04	0.00	0.16	0.09	0.00	0.30	0.13	0.03	-0.02	-0.01	0.20	0.04	0.67	0.25	0.04	0.78	0.30
2010	-2.24	0.01	0.37	0.01	0.01	-0.14	-0.15	-0.03	-0.01	0.00	-0.01	-0.01	-0.01	0.04	-0.06	-0.19	-0.09	-0.03	0.00	-0.07	-0.42	-0.17	-0.02	-0.64	-0.64
2011	-1.06	-0.06	-0.50	-0.01	-0.03	0.02	-0.58	0.00	0.01	0.00	0.05	0.00	0.01	-0.13	-0.01	-0.10	-0.02	0.00	-0.02	0.06	0.12	0.09	0.02	0.19	-0.17
2012	1.50	0.01	0.31	-0.04	0.11	0.01	0.44	-0.02	-0.04	0.00	0.11	0.06	0.00	0.13	-0.11	-0.15	0.12	0.02	0.17	0.00	0.15	-0.08	-0.03	-0.04	0.39
Mean	-0.15	0.00	0.01	-0.01	0.01	0.01	-0.10	0.00	0.00	0.00	0.01	0.00	0.00	0.02	-0.02	-0.04	0.00	0.00	0.00	-0.01	-0.07	0.00	0.00	0.02	0.01

Source: Prepared by the authors with data from EPTMC survey (Ministerio de Fomento, 2013) and IDAE (2006, 2010a).

Note: The percentage change of energy intensity in year t over the preceding year derived from the real energy intensity index is presented in the first column of the table. The remaining columns show quantitatively the responsibility of each commodity group for that percentage change, so that their sum is equal to the first column. In the last row, the average annual percentage change of energy intensity due to the real energy intensity index shows the average annual percentage change for each commodity group between 1996 and 2012. The correspondence between numbers and names of sectors is given in Table 2.

Table 9. Attribution of M-LMDI-II structural index. Single period analysis (base = previous year)

	Δ % SE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1997	-0.23	-0.14	0.94	0.10	0.14	0.24	0.15	0.06	-0.29	0.00	0.07	0.04	-0.04	0.11	-0.01	-0.27	-0.28	-0.04	-0.08	0.04	-0.71	-0.07	0.10	-0.46	0.16
1998	-0.21	-0.12	-0.47	-0.37	0.28	0.07	-0.88	-0.04	0.02	0.00	-0.19	-0.01	0.00	0.36	0.45	0.14	0.12	0.03	0.41	0.01	1.04	-0.20	-0.12	-2.15	1.41
1999	0.53	0.10	-0.25	-0.05	-0.45	-0.09	-0.93	-0.22	0.03	0.00	-0.32	0.00	-0.03	0.15	0.58	0.79	0.08	0.06	-1.06	-0.12	0.25	-0.31	0.11	0.90	1.33
2000	0.51	-0.15	-0.26	-0.11	-0.01	-0.12	-0.64	0.05	-0.08	0.00	0.24	0.09	0.02	-0.10	0.30	0.04	-0.16	-0.02	-0.09	0.03	0.62	0.14	-0.17	0.56	0.32
2001	0.29	-0.15	0.28	0.01	-0.26	0.10	-0.18	-0.02	-0.09	0.00	-0.17	-0.07	-0.01	-0.06	-0.30	0.68	-0.02	0.02	-0.34	0.01	0.00	0.09	0.04	0.44	0.30
2002	0.28	-0.05	0.23	-0.30	-0.46	-0.12	-1.15	0.00	0.12	0.00	-0.19	0.06	0.01	-0.14	0.10	0.19	-0.21	-0.03	0.05	0.02	0.06	-0.09	-0.03	0.92	1.30
2003	0.25	0.03	-0.80	0.10	-0.11	-0.11	-0.03	-0.08	-0.10	0.00	-0.13	-0.05	-0.03	0.37	0.13	0.51	0.23	0.01	-0.16	0.04	0.66	0.13	-0.02	-0.28	-0.06
2004	-0.25	-0.46	0.43	-0.11	0.47	-0.02	0.62	0.39	0.12	0.01	-0.32	0.10	0.11	-0.70	0.61	-0.57	-0.03	-0.01	0.63	-0.10	1.06	-0.39	-0.48	-1.21	-0.38
2005	0.08	0.07	-0.47	-0.30	-0.24	-0.13	0.00	-0.11	0.01	-0.01	-0.22	-0.05	0.05	-0.41	0.53	1.13	-0.18	0.00	0.07	0.06	-0.04	0.10	0.03	0.22	-0.02
2006	-0.69	0.01	0.83	0.10	-0.43	0.13	1.94	0.06	0.07	0.00	-0.06	0.00	-0.07	0.62	0.36	-0.29	-0.15	0.08	-0.39	-0.15	-0.81	-0.02	0.06	0.85	-3.42
2007	0.26	0.07	-0.79	0.04	-0.29	-0.10	0.23	-0.15	-0.13	0.00	-0.02	0.15	0.12	0.07	0.13	0.27	0.26	0.01	-0.50	0.17	0.95	-0.11	-0.08	-0.03	-0.01
2008	-0.31	0.11	0.31	0.13	0.02	0.08	1.27	0.25	-0.09	0.00	0.36	0.23	0.05	-0.29	-1.10	-1.38	0.13	0.04	0.24	0.18	-2.46	0.21	0.03	0.76	0.60
2009	0.28	0.05	1.03	-0.05	-0.01	0.02	2.65	0.03	-0.04	0.00	0.06	-0.25	-0.16	-0.67	-0.73	-1.04	-0.05	0.10	-0.35	-0.06	-0.16	0.01	0.08	-0.86	0.66
2010	0.53	-0.10	-1.19	-0.12	-0.07	0.02	0.02	0.06	-0.12	0.00	0.08	0.21	0.05	0.50	-1.08	-0.94	0.01	0.13	0.47	0.11	0.55	-0.01	0.02	0.63	1.29
2011	-0.32	0.28	0.99	0.16	0.18	0.19	0.07	0.00	0.13	0.00	-0.25	-0.09	0.03	-0.31	-0.71	-0.48	0.16	-0.10	0.03	0.11	-0.14	-0.07	-0.07	-0.68	0.25
2012	0.09	-0.14	1.16	0.19	-0.09	-0.02	1.63	0.01	0.01	0.00	-0.10	0.05	-0.02	-0.54	-0.61	-1.16	0.06	0.06	-0.06	0.01	-0.25	-0.09	0.01	-0.16	0.14
Mean	0.06	-0.04	0.11	-0.03	-0.08	0.01	0.28	0.02	-0.03	0.00	-0.07	0.02	0.01	-0.06	-0.08	-0.14	0.00	0.02	-0.07	0.02	0.04	-0.04	-0.03	-0.03	0.23

Source: Prepared by the authors with data from EPTMC survey (Ministerio de Fomento, 2013) and IDAE (2006, 2010a).

Table 10. Attribution of M-LMDI-II real energy intensity index. Multi-period analysis (base =1996)

	Δ % IE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1997	-3.04	-0.05	-0.20	-0.17	0.06	-0.11	-0.89	0.04	0.00	0.00	-0.06	-0.06	0.00	-0.19	-0.36	0.02	0.00	0.00	-0.04	0.00	-0.52	-0.09	0.11	-0.27	-0.26
1998	-5.31	0.03	-0.69	-0.22	-0.17	-0.07	-1.46	-0.01	-0.03	0.00	-0.18	-0.04	0.01	-0.20	-0.45	-0.36	-0.02	0.00	-0.07	-0.14	-0.83	-0.18	-0.07	0.26	-0.43
1999	-4.15	-0.05	-0.50	-0.09	-0.05	-0.04	-1.29	-0.03	0.01	0.00	-0.04	-0.06	0.01	-0.20	-0.40	-0.17	-0.08	0.00	-0.04	-0.12	-0.88	0.00	0.02	0.33	-0.48
2000	-5.91	-0.02	-0.63	-0.14	-0.03	0.00	-1.73	-0.02	-0.01	0.00	-0.16	-0.07	0.00	-0.20	-0.39	-0.08	-0.10	-0.01	-0.14	-0.17	-0.82	-0.13	0.01	-0.23	-0.86
2001	-4.67	-0.01	-0.60	-0.16	-0.03	0.02	-1.66	-0.04	0.00	0.00	-0.04	-0.08	0.01	-0.08	-0.37	-0.14	-0.09	-0.01	0.01	-0.10	-0.69	-0.02	0.00	0.47	-1.03
2002	-7.28	-0.02	-0.84	-0.20	0.00	0.05	-2.17	-0.03	0.01	0.00	-0.21	-0.05	0.01	-0.15	-0.26	0.15	-0.02	-0.01	-0.08	-0.13	-0.98	-0.06	-0.10	-0.57	-1.63
2003	-7.78	-0.03	-0.87	-0.20	0.04	0.01	-2.20	-0.01	0.01	0.00	-0.21	-0.07	0.01	-0.23	-0.38	-0.13	-0.06	-0.01	0.01	-0.15	-1.24	-0.19	-0.04	-0.47	-1.37
2004	-3.00	0.04	0.28	-0.14	-0.04	0.07	-1.49	-0.01	-0.01	0.00	0.03	-0.07	0.00	0.17	-0.26	-0.07	0.00	0.00	-0.07	-0.05	-1.61	-0.05	0.12	1.00	-0.84
2005	-2.75	0.02	-0.19	-0.04	-0.06	0.19	-1.98	-0.03	0.01	0.01	0.01	-0.04	0.00	0.25	-0.23	-0.04	0.01	0.01	-0.16	-0.08	-1.49	-0.04	0.06	0.99	0.09
2006	-3.97	0.04	-0.54	-0.20	0.04	0.09	-1.54	-0.04	0.00	0.01	0.02	-0.06	0.00	0.15	-0.08	-0.06	0.05	0.03	-0.08	-0.06	-1.51	-0.07	0.04	0.16	-0.36
2007	-3.89	-0.02	-0.25	-0.18	0.06	0.15	-1.92	-0.03	-0.03	0.01	0.11	-0.11	0.00	0.14	-0.16	-0.29	0.01	0.04	-0.14	-0.09	-1.41	-0.11	0.09	0.26	-0.02
2008	-5.08	0.02	-0.57	-0.18	-0.02	0.17	-1.69	-0.05	-0.04	0.01	-0.09	-0.16	-0.01	-0.06	-0.33	-0.25	0.06	0.06	-0.29	-0.12	-1.55	-0.16	0.02	-0.05	0.21
2009	-1.17	0.01	0.00	-0.15	0.06	0.25	-1.43	0.01	0.00	0.01	0.07	-0.07	-0.01	0.22	-0.20	-0.22	0.04	0.04	-0.10	-0.08	-0.92	0.08	0.06	0.68	0.49
2010	-3.38	0.01	0.37	-0.14	0.07	0.12	-1.58	-0.02	-0.01	0.01	0.06	-0.08	-0.02	0.26	-0.26	-0.41	-0.05	0.01	-0.10	-0.15	-1.33	-0.09	0.04	0.05	-0.13
2011	-4.41	-0.05	-0.12	-0.15	0.04	0.14	-2.14	-0.02	0.01	0.01	0.11	-0.08	-0.01	0.14	-0.28	-0.51	-0.07	0.01	-0.12	-0.10	-1.22	0.00	0.06	0.23	-0.29
2012	-2.97	-0.04	0.17	-0.18	0.14	0.14	-1.72	-0.05	-0.03	0.01	0.21	-0.02	-0.01	0.27	-0.39	-0.65	0.05	0.02	0.05	-0.10	-1.08	-0.08	0.02	0.19	0.08

Source: Prepared by the authors with data from EPTMC survey (Ministerio de Fomento, 2013) and IDAE (2006, 2010a).

Table 11. Attribution of M-LMDI-II structural index. Multi-period analysis (base = 1996)

	Δ % SE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1997	-0.23	-0.14	0.94	0.10	0.14	0.24	0.15	0.06	-0.29	0.00	0.07	0.04	-0.04	0.11	-0.01	-0.27	-0.28	-0.04	-0.08	0.04	-0.71	-0.07	0.10	-0.46	0.16
1998	-0.45	-0.26	0.47	-0.27	0.42	0.30	-0.73	0.01	-0.27	0.00	-0.12	0.03	-0.04	0.47	0.44	-0.13	-0.16	-0.02	0.34	0.05	0.33	-0.28	-0.02	-2.61	1.57
1999	0.08	-0.16	0.22	-0.32	-0.02	0.21	-1.65	-0.21	-0.24	0.00	-0.44	0.03	-0.07	0.62	1.03	0.65	-0.09	0.05	-0.71	-0.07	0.58	-0.58	0.09	-1.71	2.90
2000	0.60	-0.32	-0.04	-0.43	-0.03	0.09	-2.30	-0.15	-0.32	0.00	-0.20	0.12	-0.05	0.52	1.33	0.69	-0.25	0.02	-0.81	-0.04	1.20	-0.45	-0.08	-1.15	3.22
2001	0.89	-0.47	0.24	-0.42	-0.29	0.19	-2.47	-0.17	-0.41	0.00	-0.37	0.05	-0.05	0.46	1.03	1.37	-0.27	0.04	-1.14	-0.03	1.20	-0.36	-0.04	-0.70	3.52
2002	1.17	-0.52	0.47	-0.72	-0.76	0.07	-3.64	-0.17	-0.29	0.00	-0.56	0.11	-0.05	0.32	1.12	1.56	-0.49	0.01	-1.10	-0.01	1.26	-0.45	-0.07	0.23	4.83
2003	1.42	-0.49	-0.34	-0.62	-0.87	-0.04	-3.67	-0.24	-0.39	0.00	-0.69	0.05	-0.07	0.69	1.25	2.08	-0.26	0.02	-1.25	0.03	1.93	-0.32	-0.09	-0.05	4.77
2004	1.17	-0.96	0.10	-0.73	-0.40	-0.06	-3.04	0.15	-0.27	0.01	-1.02	0.15	0.04	-0.03	1.87	1.50	-0.28	0.01	-0.62	-0.08	3.00	-0.72	-0.58	-1.28	4.39
2005	1.25	-0.89	-0.38	-1.03	-0.64	-0.19	-3.04	0.04	-0.26	0.00	-1.24	0.10	0.09	-0.44	2.41	2.64	-0.46	0.01	-0.55	-0.01	2.97	-0.62	-0.55	-1.06	4.37
2006	0.56	-0.88	0.46	-0.93	-1.07	-0.06	-1.08	0.09	-0.19	-0.01	-1.30	0.10	0.02	0.19	2.77	2.35	-0.62	0.09	-0.95	-0.17	2.14	-0.64	-0.49	-0.20	0.91
2007	0.81	-0.81	-0.34	-0.89	-1.36	-0.16	-0.85	-0.05	-0.32	-0.01	-1.32	0.25	0.14	0.26	2.90	2.62	-0.36	0.10	-1.45	0.01	3.10	-0.74	-0.57	-0.23	0.90
2008	0.50	-0.70	-0.03	-0.76	-1.34	-0.08	0.43	0.20	-0.41	-0.01	-0.96	0.48	0.19	-0.03	1.79	1.23	-0.22	0.14	-1.20	0.19	0.62	-0.53	-0.54	0.54	1.50
2009	0.78	-0.65	1.01	-0.81	-1.35	-0.06	3.10	0.23	-0.45	-0.01	-0.90	0.23	0.03	-0.71	1.06	0.18	-0.27	0.24	-1.55	0.13	0.46	-0.52	-0.46	-0.33	2.17
2010	1.32	-0.74	-0.19	-0.92	-1.41	-0.03	3.12	0.29	-0.57	0.00	-0.82	0.45	0.08	-0.21	-0.03	-0.76	-0.26	0.37	-1.08	0.23	1.01	-0.53	-0.44	0.30	3.47
2011	0.99	-0.46	0.81	-0.76	-1.23	0.16	3.19	0.29	-0.44	-0.01	-1.07	0.35	0.11	-0.52	-0.75	-1.25	-0.09	0.27	-1.05	0.35	0.87	-0.60	-0.51	-0.39	3.73
2012	1.07	-0.60	1.97	-0.57	-1.33	0.14	4.84	0.30	-0.43	-0.01	-1.17	0.40	0.10	-1.06	-1.37	-2.42	-0.03	0.32	-1.11	0.36	0.62	-0.70	-0.50	-0.55	3.87

Source: Prepared by the authors with data from EPTMC survey (Ministerio de Fomento, 2013) and IDAE (2006,

Chapter 5

Conclusions

This dissertation analyzes the topic of transport and environmental pressure through three closely related issues —transport greenhouse gas emissions, transport activity, and transport energy intensity—, and from three different approaches. It studies the driving factors and their contribution on the direct greenhouse gas emissions of transport activity (Chapter 2); the direct and total greenhouse gas emissions of transportation and storage activities given the economic structure (Chapter 3); and, finally, the energy intensity trend and its explanatory factors for road freight transport of heavy goods vehicles (Chapter 4).

The three investigations carried out in this dissertation delve into the following questions: What are the determinants and what is the impact of these determinants on direct greenhouse gas emissions of transport activity? How does the economic structure, in particular, productive specialization, affect direct and total greenhouse gas emissions of transport activity? How has the energy intensity of road freight transport changed and to what extent has each commodity contributed to explaining it? What are the implications of our results in terms of environmental policies?

In Chapter 2, an innovative extension of the STIRPAT model (Dietz and Rosa, 1994, 1997) allows us to determine that the population, real per capita GDP, transport volume, transport energy intensity, and changes in modal share and in energy source mix are driving factors of greenhouse gas emissions in the European Union transport sector in the period 1990–2014. In particular, transport energy intensity, together with the population, is especially meaningful in explaining European Union transport emissions. Considering that the main objective of the 2011 White Transport Paper in environmental terms consists of a 60% reduction in the transport sector emissions by 2050 in relation to 1990 (European Commission, 2011), the outcomes obtained in this research have something to say in relation to the four proposals aimed at diminishing transport emissions it suggested. Firstly, the proposal of gradual elimination of conventionally fueled cars in cities will effectively decrease European Union transport emissions, given that our results show that switching from oil products to alternative sources of energy leads to a significant reduction in transport emissions, although electricity should be the preferred alternative source due to its larger impact on the reduction of European Union transport emissions. Secondly, our empirical analysis points out that the proposal of substitution of rail or waterborne transport for 50% of road transport will, in effect, lessen the European Union transport emissions, as the shift from road to rail or waterborne transport cut them, but rail should be the favored alternative mode of transport given that its impact on reducing emissions is greater than that of waterborne transport. Thirdly, the proposal related to the promotion of low-carbon fuels in aviation will also work, given that our results show that an increase in aviation activity at the expense of roads will bring to an increase in the European Union transport emissions. Therefore, the only effective measure for reducing aviation emissions will be precisely to draw on low-carbon fuels and, when possible, switch to other transport modes. Finally, reduction in shipping needs by improving logistics, in addition to the above suggested measures, i.e. shifting from oil products to other sources of energy, encouraging the use of sustainable low-carbon fuels, and improving energy efficiency are measures that our empirical analysis indicate will contribute to the proposal of cutting shipping emissions by at least 40%.

Given that Chapter 2 only analyzes direct transport emissions, Chapter 3 provides a different insight by focusing the study on direct and total (direct and indirect) transport emissions using a novel approach, based on the Ghosh model (Ghosh, 1958) of the input–output subsystems analysis (Sraffa, 1960; Alcántara, 1995). We define transportation and storage sector as a subsystem and we use data of Spain in 2014 to get empirical outcomes. The data point out that direct emissions from the subsystem amounted to 34,419.7 thousand tons of CO_2 equivalent, accounting for 10.6% of the overall direct greenhouse gas emissions generated by the whole economy. Meanwhile, the input–output analysis shows that the direct and indirect greenhouse gas emissions of the subsystem reached 29,628.3 thousand tons of CO_2 equivalent, accounting for 9.1% of total greenhouse gas emissions generated in the whole economy. These results indicate that there were some subsectors of the subsystem —land transport and transport via pipelines, water transport, and air transport— whose direct emissions were higher than total emissions, or rather, the production they had to carry out for the rest of the sectors of the economy was significant. In particular, the main sectors responsible for these indirect transport emissions were the construction sector and the activities of the service subsystem not related to transport activities and, especially, retail trade activity, real estate activity —with a direct relationship with the construction sector—, and rental of transport vehicles activity. The implications of these outcomes in terms of promoting adequate environmental measures in transport activity in order to reduce its emissions are immediate. The adoption of common measures to diminish transport emissions, which are sometimes too general or simplistic, such as the continuous introduction of new improvements in transport logistics, should take into account the economic structure of the economy and to promote environmental measures that were more specific and concrete when considering the productive specialization of the economy. In the case of Spain in 2014, our empirical analysis reveals that advances in transportation and storage associated with certain sectors or economic activities, in particular transportation and storage associated with the construction sector and retail trade activity, would significantly help to reduce greenhouse gas emissions of the transportation and storage sector.

Chapter 4 considers the outcomes achieved in the two previous chapters. In view of the significance of energy intensity in Chapter 2 and of productive specialization in Chapter 3, and given that these two previous chapters stress the importance of road transport, in Chapter 4 we perform a study of energy intensity focused on road transport through commodity approach using decomposition analysis —LMDI-II decomposition analysis (Ang, 2004) and the attribution of changes in Divisia indices (Choi and Ang, 2012)— in an original way and we apply it to the Spanish road freight transport of heavy goods vehicles over the period 1996–2012. The results show that the energy intensity for road freight in Spain dropped by 1.9%, from 1.05 MJ/TKM in 1996 to 1.03 MJ/TKM in 2012. The decomposition analysis reveals that the real energy intensity index —lower energy consumption per ton-kilometer transported— contributed to energy intensity reduction by 3.0% over the period. Meanwhile the structural index contributed to increasing energy intensity by 1.1% during the same period, i.e. greater share in freight transport of those commodities of which the transportation is more energy intensive. Moreover, the energy intensity of different commodity groups shows a distinct pattern. The commodity groups that contributed significantly to the reduction of energy intensity in road freight —“Crude and manufactured minerals” and “Cement, lime and manufactured Building materials”— were commodity groups that were directly related to the construction sector, a sector that was seriously affected by the economic crisis in Spain. In contrast, the commodity groups that prevented greater contraction in energy intensity over the period —“Food stuff and animal fodder”, “Potatoes, fresh or frozen fruits and vegetables” and “Miscellaneous articles”— were commodity groups closely related to retail trade activity, and our empirical analysis shows that the logistics of these commodity groups seem to not work correctly. These outcomes of Chapter 4 corroborate the results achieved in Chapter 2 and, especially, in Chapter 3. Thus, once again, the construction sector and retail trade activity are economic activities that must be considered when designing environmental measures aimed at cutting transport emissions.

In short, these results could be used to find mechanisms that could lead to a greener transport. This dissertation stands up for the great importance of introducing environmental measures in order to reduce energy intensity and, at the same time, improving transport logistics paying attention to the specialization of the economy, so that these lead to significant reductions in greenhouse gas emissions of transport activity. Notwithstanding, these environmental measures should be systematically adjusted to contemplate possible meaningful changes in the productive specialization of the economy.

To conclude, it is worth noting that the three main chapters of this dissertation open new lines of research. Chapter 2 via the extension of an ecological model, the STIRPAT model, applied to transport activity emissions. Chapter 3 via the development of a new methodology of input–output subsystem analysis from a supply-side perspective, with an empirical application to transport activity emissions. Chapter 4 via the application in a novel way of two methodologies related to decomposition analysis, LMDI, and the attribution of changes in Divisia indices, to energy intensity of road freight transport activity. Therefore, future investigations can be developed on the basis of the research lines started in these three chapters. Firstly, the interdependencies among different economies were not included in the analysis in these chapters. Nevertheless, transport emissions of an economy partially depend on the economic activity of other countries. Thus, future research could enrich the analysis by taking into account such interdependencies. Secondly, future research should focus on analyzing in greater detail transport logistics, particularly in the case of transport activity related to certain commodity groups or economic activities that are identified as having the main responsibility for transport emissions (see Chapter 3 and Chapter 4). In addition, the analysis should consider that the transport of a particular commodity may involve one or more modes of transport; therefore, the inclusion of intermodal transport in the analysis would provide a broader point of view of freight transport. Thirdly, future research should consider studying in depth the factors that are identified in this dissertation as having the main responsibility for transport emissions (see Chapter 2). In the case of transport energy intensity, the analysis could be extended to other modes of transport that are different from road, or to passenger transport, or focusing on heavy goods vehicle fleets instead of on commodity groups. Fourthly, future research could include comparative analysis of the transport activity of different economies in order to figure out how the similarities and differences in the productive structure impact on transport emissions. Lastly, future research could also consider new applications of the method proposed in Chapter 3.

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