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Evaluation and comparative analysis of road transport emissions evolution in different European countries: The case studies of Portugal, Romania, Spain, and Sweden.

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Abstract

Road transport is one of the most important contributing sectors of Europe's total emissions. The target of European Union (EU) road transport policy is to promote a more efficient and environmentally friendly mobility. In order to achieve its strategic goals, several measures were introduced to encourage implementation of more environmentally friendly technical engine standards. National car fleet composition can have significant impacts on emissions and energy consumption. This study aims to provide a comparative analysis of the contribution of road fleet composition in emissions and show the evolution of emissions costs on national economies for four European countries. Annual emissions of each country were estimated using official data and emission costs for various pollutants were calculated based on most updated values of damage costs. Results show a significant technological change in vehicles' engines can contribute to reduce the environmental impacts of transport.

Keywords: emissions; costs; transport externalities; road transport.

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1. Introduction

Human activities are responsible for global warming and other relative phenomena (Rattanachot et al., 2015), with transport activities being highly related to climate change (Gössling et al., 2016; Hendricks et al., 2017) and air pollution in urban areas (Cen et al., 2016; Singh et al., 2017). The improvement of air quality has been a main concern of European Union's (EU) agenda since the 1970s (Crippa et al., 2016). Road transport has been identified as a major source of air pollution, mainly in urban areas. It is one of the most significant contributors of the EU carbon dioxide's (CO_2) total emissions as it is responsible for around one-fifth of them (Avaritsioti, 2016), with 75% emitted by passenger cars (Fontaras et al., 2017). The reduction of CO_2 emissions derived from transport is a main challenge in the framework of mitigating the climate change effects (Dente and Tavasszy, 2017). Potential solutions to reduce CO_2 emissions include promotion of alternative transport modes such as cycling and walking (Tafidis et al., 2017), adoption of emission standards and technical constraints in vehicles (Cavallaro et al., 2017) and road pricing policies (e.g., taxes and tolls) (Gutiérrez et al., 2013; Cavallaro et al., 2017).

The target of EU road transport policy is to promote a more efficient, safe and environmentally friendly mobility by setting the de-carbonisation of transport sector as a priority (European Commission, 2011). For this purpose, it has introduced legislation that focus on the reduction of vehicles emissions by setting mandatory targets for new cars, while environmental policies try to reduce these emissions by encouraging the use of alternative fuels (Moro and Lonza, 2017) and implementation of more environmentally friendly technical engine standards. Among all measures, there is also regulation of the quality of motor vehicles emissions(Crippa et al., 2016) through a series of EU directives. The European emission standards or Euro standards set the acceptable exhaust emissions limits or otherwise the emission classes for new registered vehicles, and emission control technologies have to be developed in order to meet such stringent standards.

The composition of the national car fleet in terms of age, engine technology and fuel consumption can have significant impacts on emissions and energy savings (Beser Hugosson et al, 2016). In recent years, many European countries aim to reduce greenhouse gas emissions by setting limits for fuel consumption or CO_2 emissions of new automobiles (Matas et al., 2017), while the technological advances have led to improvement of the overall efficiency and fuel economy of national car fleets (Daly and Ó Gallachóir, 2011).

The main objective of this paper is to provide a comparative analysis of the role that road fleet composition has played in emissions and show the evolution of emissions costs on national economies for four European countries with different heterogeneous characteristics for a study period of 15 years (2000-2014). The authors analysed emission data in order to estimate in what extent technological changes and engine characteristics have resulted in the reduction of emissions of various pollutants and their respective costs in Portugal, Romania, Spain and Sweden. The study has been carried out in the framework of the Interreg Europe Project CISMOB (Cooperative Information Platform for Low Carbon and Sustainable Mobility) which aims to promote innovative ways to reduce carbon footprint and increase the sustainability of urban areas by improving the efficiency in the use of urban transport infrastructure. The results of this paper are of potential interest for local authorities, transport planners and policy makers to help them identifying best practices and appropriate measures to implement in order to manage transport systems more efficiently.

2. Methodology

The four case studies of this paper are the countries of Portugal (PT), Romania (RO), Spain (ES) and Sweden (SE) that are represented from respective partners in CISMOB project. Portugal, Spain and Sweden are from the EU-15 group, i.e., the number of member countries in the EU prior to the accession of ten candidate countries on 1 May 2004, while Romania is from the EU new member states that joined EU after 2004.

For the calculation of the total emissions for each year and country for several pollutants, COPERT 4 v11.4, an emission calculation tool developed by Emisia SA (Emisia SA, 2017), was used. The total emission costs and costs per km of each pollutant were calculated based on updated values of damage costs (€ per tonne, 2010) based on the Impact Pathway Approach (IPA) described in the Handbook on External Costs of Transport (Korzhenevych et al., 2014). Table 1 presents the most recent damage cost estimation per tonne for CO2, NMVOC, NO_X and PM for each study case. Because of his adverse health effects, damage costs of PM are differentiated regarding the area (Korzhenevych et al., 2014) and for their final estimation the percentage of vehicle km by road type is considered. Romania has clearly the highest damage costs for all pollutants. According the IPA methodology (Korzhenevych et al., 2014) these values are due higher exposure (population at risk exposed to emissions), and impacts (related a number of factors such as premature deaths, ill health, and ecological risk.

Table 1. Damage costs of main pollutants from road transport, in € per tonne (Korzhenevych et al., 2014).

Country	CO_2	NMVOC	NO_X	PM 2.5		
				highway	rural	urban
Portugal	90	1048	1957	18371	49095	196335
Romania		1796	22893	56405	84380	231620
Spain		1135	4964	14429	48012	195252
Sweden		974	5247	14578	50210	197450

3. Analysis of the vehicle fleet data

In this section, an overview of the data that was used for this study is presented trying to identify the main trends in vehicle fleet of each study case. Table 2 provides information regarding the evolution of the population of each country as well as the size of the vehicle fleet and total annual vehicle mileages during the study period.

Table 2. General overview of characteristics of national vehicle fleets (Pordata,2017) (Emisia SA, 2017). Absolute values are provided for the baseline year 2000 and relative values for the remaining years.

Year	Population (in millions of individuals)				Vehicle fleet							
					Size (in millions of vehicles)				Mileage (in millions of km)			
	PT	RO	ES	SW	PT	RO	ES	SW	PT	RO	ES	SW
2000	10.29	22.44	40.57	8.87	5.78	3.35	24.62	4.65	79010.3	24623.0	279727.4	72720.8
2001	10.36	22.13	40.85	8.90	5.91	3.46	25.58	4.72	79786.2	31998.7	294395.6	73842.7
2002	10.42	21.73	41.43	8.93	5.95	3.55	27.22	4.79	82723.6	33205.6	307126.7	76363.2
2003	10.46	21.57	42.19	8.96	6.05	3.68	26.76	4.90	83032.0	35930.1	318371.2	77823.0
2004	10.48	21.45	42.92	8.99	6.09	3.84	28.05	4.93	83231.3	38631.3	331396.0	79843.4
2005	10.50	21.32	43.65	9.03	6.12	3.98	29.27	5.04	82838.6	37102.0	345303.6	81616.7
2006	10.52	21.19	44.40	9.08	6.18	4.42	30.10	5.14	84400.5	37537.3	361091.1	82928.2
2007	10.54	20.88	45.23	9.15	6.27	4.56	31.91	5.25	84181.8	40099.7	373552.5	86241.1
2008	10.56	20.54	45.95	9.22	6.30	5.27	32.52	5.29	83818.3	45420.7	361224.5	85766.6
2009	10.57	20.37	46.36	9.30	6.35	5.79	32.34	5.32	85523.4	48045.9	346412.0	85774.8
2010	10.57	20.25	46.58	9.38	6.54	6.33	32.50	5.35	86605.2	44112.9	346317.9	87646.4
2011	10.56	20.15	46.74	9.45	6.54	6.38	32.47	5.43	79796.1	45096.3	337916.7	87845.0
2012	10.56	20.06	46.77	9.52	6.53	6.55	32.63	5.48	76904.4	47229.3	323422.8	85508.7
2013	10.46	19.98	46.62	9.60	6.52	6.72	32.08	5.53	75900.5	45498.2	322736.4	86281.4
2014	10.40	19.91	46.48	9.70	6.51	6.89	32.97	5.63	76081.5	45516.5	323417.4	87364.6

According to table 2 the percentage of people owning a car in each country ranged during the study period from 56.1% to 61.9% in Portugal, from 14.9% to 34.6% in Romania, from 60.7% to 70.9% in Spain and from 52.4% to 58% in Sweden. Romania is still presenting the lowest ratio of vehicles per inhabitant reflecting mainly the low purchasing power of the country. The lower percentage in Sweden is maybe explained by the strong public transport system and due higher use of active modes such as cycling (EC, 2017).

The most compelling feature of the table is that while the population of Romania has been decreased by almost 11% in 2014 compared to 2000, the number of the registered vehicles has almost been doubled during that period. In the other countries, the ratio between the evolution of the population and the number of vehicles during the studied period is 1:0.7 in Portugal, 1:1.2 in Sweden and 1:1.4 in Spain.

Another interesting finding from the analysis of the table is that in Portugal, it can be observed a reduction in the mileage after the year 2010, possible explained by the financial crisis that took place in the country between 2010-2014, and the highest average annual crude oil prices in the same period (EEA, 2017). In the other 3 studied areas, an increase in the total travelled kilometres were noticed. The evolution of the travel activity in the studied areas is in accordance with the EU Transport Statistics (EU, 2016).

Figure 1 illustrates the national vehicle fleet composition of each country in terms of type of vehicle (columns) and by type of engine fuel (lines). The percentages of passenger cars in each study area are the highest. In Portugal and Spain, there is also a significant percentage of Light Commercial Vehicles and Mopeds, while in Romania is observed an important percentage of Heavy Duty Trucks over 5% during the study period.

Regarding the type of fuel, only in Sweden and Romania there is a mentionable percentage of vehicles using alternative fuels in the end of the study period of 4.83% and 2.82% respectively. The most important raise is in Sweden and took place after the 2007 mainly because of a series of policies and measures that promote their use as: i) the taxation strategy for alternative fuels, ii) the CO2-based vehicle tax, iii) a vehicle tax based on CO2 that was introduced in 2006 which encouraging the purchase of energy-efficient vehicles, iv) a new legal act that obligates gas stations to offer renewable fuels, v) the environmental policy for State-owned vehicles, where vehicles purchased by the State must as a rule be eco-friendly and finally, vi) the eco-friendly car subsidy that encourage the use of fuel-efficient cars and vehicles using environmentally friendly fuels (Swedish Government, 2007).

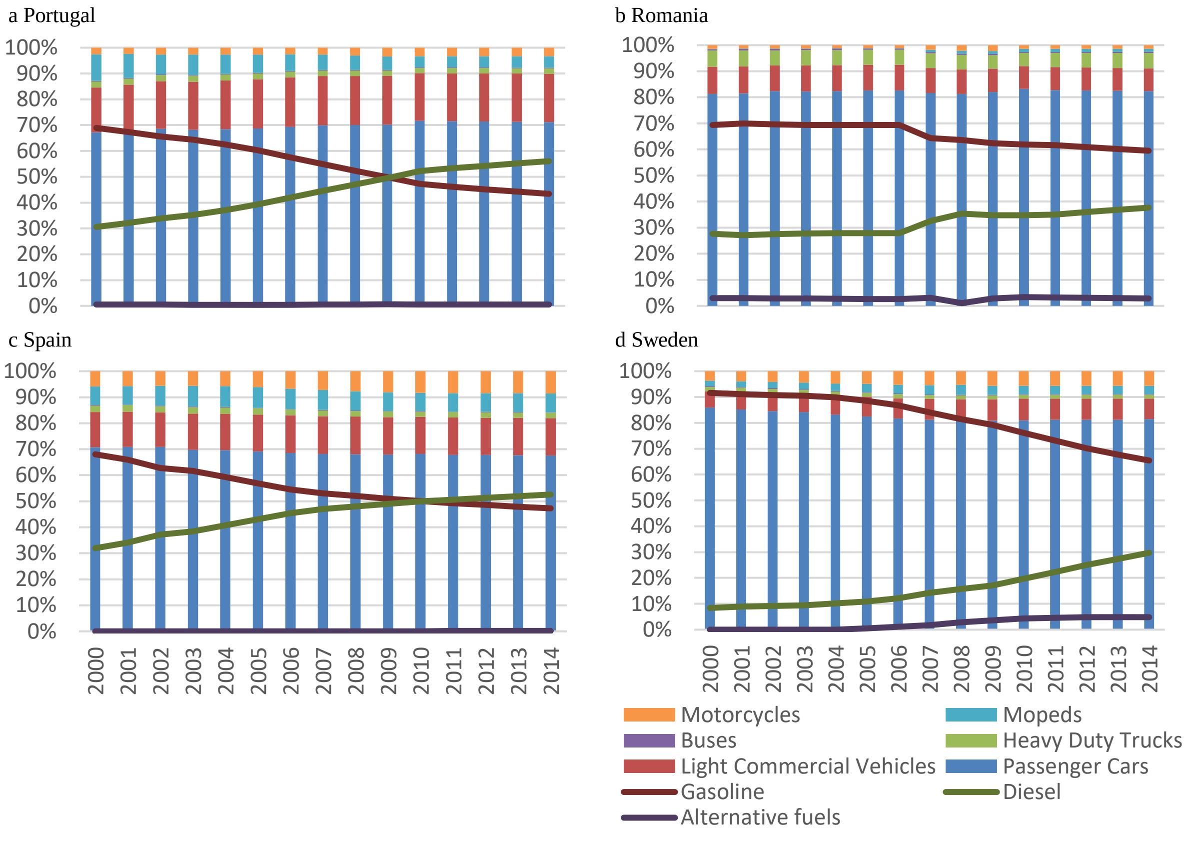

Fig. 1. National car fleet compositions in terms of vehicle (columns) and fuel (lines) type for a) Portugal, b) Romania, c) Spain, and d) Sweden.

In Figure 2, the national passenger car fleet composition of each country in terms of engine technology (columns) and by type of engine fuel (lines) is presented.

The share of passenger gasoline cars has been slightly floating over the years in Romania with values clearly above 80%. Between 2007 and 2009, there was an oscillating period, where it can be observed a clear minimum point in the alternative-fuel passenger cars in 2008, when values fall until almost 1.3%. During the studied period, there has been in average 3.4% passenger cars powered by alternative fuels. However, since its highest value in 2010, such value has been decreasing. Concerning passenger cars powered by gasoline, reduction is more evident since 2006, dropping from 77% to 65.7% in 2014. This value is very close to that of Sweden, but clearly higher than that registered in Portugal or Spain.

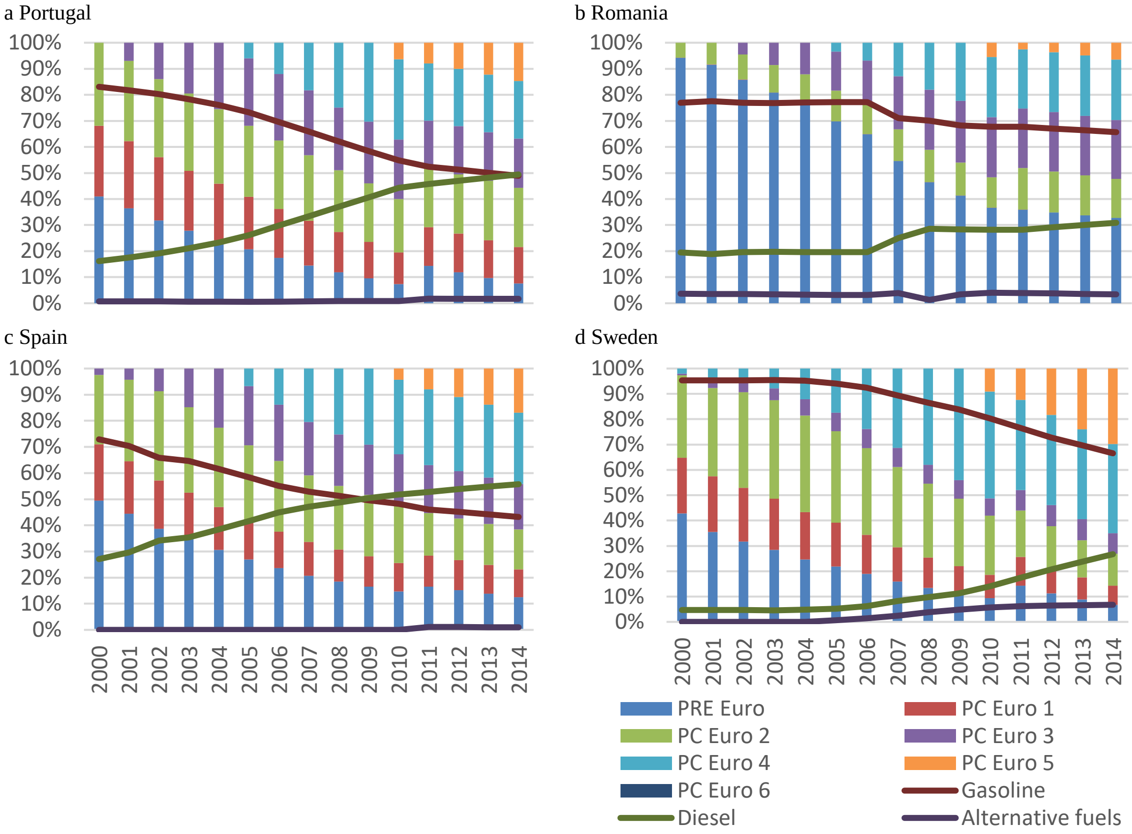

Fig. 2. National passenger car fleet compositions in terms of engine technology (columns) and fuel type (lines) for a) Portugal, b) Romania, c) Spain, and d) Sweden.

Another interesting finding of the analysis is that in Spain during the last years, the share of passenger cars using diesel is higher compared to the ones using gasoline, while in Portugal there are almost equal, partially explained because diesel is most favoured by the tax system which is related to CO2 emissions per km. In Spain, the share of diesel-driven passenger cars has been increased, rising from 27% in 2000 to almost 56% in 2014. It can also be observed a reversed moment in 2009, where diesel vehicles overlap gasoline vehicles.

4. Analysis of the results

4.1. Total emissions

Figure 3 presents the total annual emissions of CO, CO_2, VOC, NMVOC, NO_X and PM2.5 for the fleet of passenger cars of Portugal, Romania, Spain and Sweden. Due to the size of the fleet Spain is naturally the country which produce the most emissions from road transport. It can be observed an important reduction during the studied period in terms of CO, VOC, NMVOC and NOx emissions in all the studied areas which can be associated with the higher share of cars with new engine technologies. In Spain, there is a significant decrease in CO, VOC and NMVOC emissions during the studied period of approximately 75%.

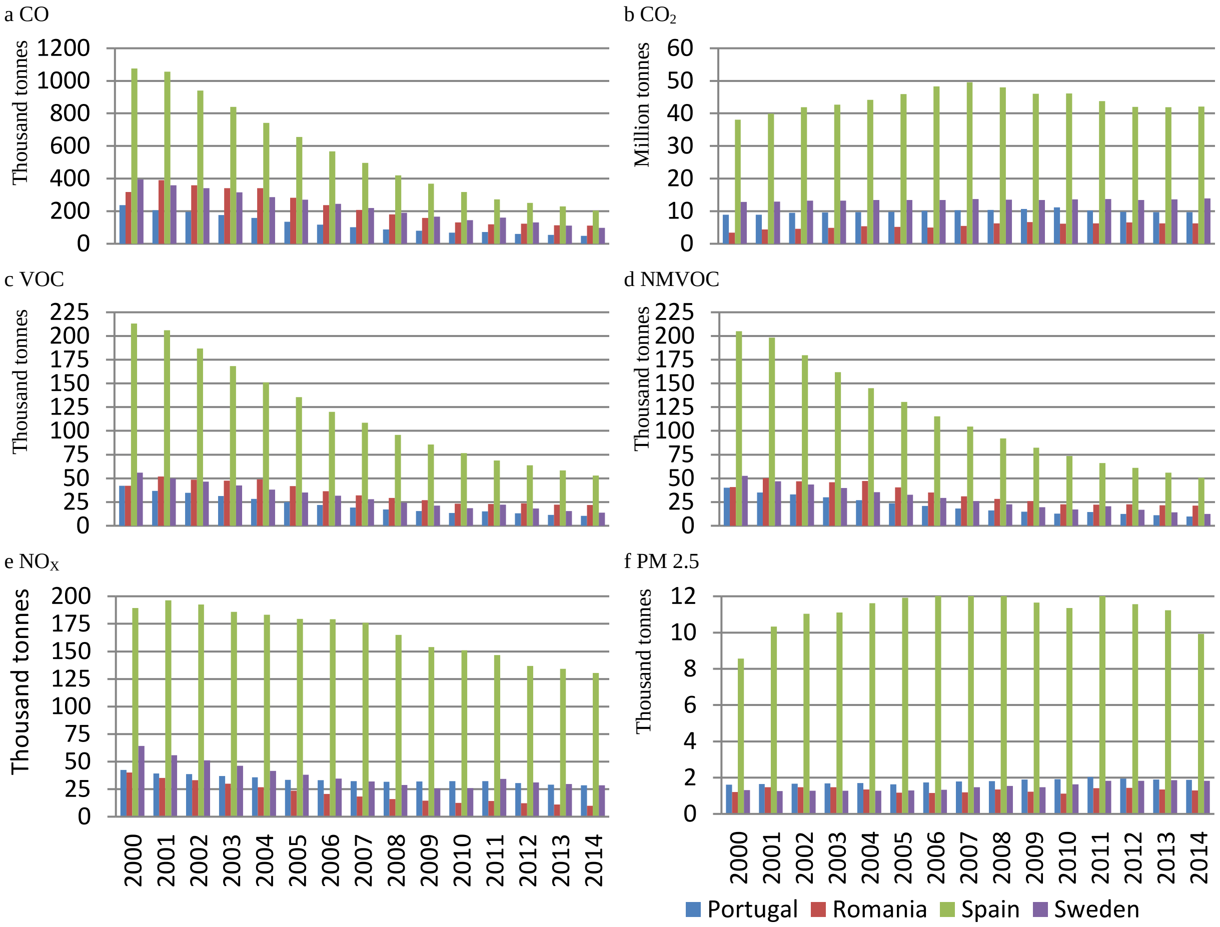

Fig. 3. Total annual passenger car emissions of: a) CO, b) CO_2, c) VOC, d) NMVOC, e) NO_X and d) PM 2.5 for Portugal, Romania, Spain and Sweden.

By examining the passenger car fleet composition during these years in each country, it should be highlighted the significant reduction of vehicles with older emission standards (PRE Euro and PC Euro 1) and that in 2014, almost 1 out of 3 passenger cars comply with PC Euro 4 or 5 emission standards in each country, while in Sweden the respective percentage is over 60%. In terms of CO2 and PM 2.5 emissions, it can be observed that there is a slight raise in the end of 2014 compared to the respective levels of 2000. This can be partially justified because of the increase of the total kilometers travelled and by the growing market penetration of diesel vehicles, which have higher PM emissions factors compared to gasoline vehicles.

4.2. Costs per km

Figure 4 shows the associated costs per kilometre of each pollutant for each country. Romania presents the highest values for all pollutants. In Portugal, CO2 costs have been decreasing, nonetheless above 0.02 €/km, until 2010, when the lowest value was achieved. Since then, they remained below the 0.02 line, representing a reduction around 6%. PM 2.5 costs were dropped from over than 0.01€ in 2000 to 0.0059 €/km in 2010, when the lowest value was achieved, representing a reduction of 41%. NMVOC costs have been exhibiting a decreasing tendency under 0.0009 €/km, while NO_X costs have been decreasing until 2010 with a value around 0.00167 €/km, raising up to 0.0018 €/km in 2011, showing in general a decreasing trend since then.

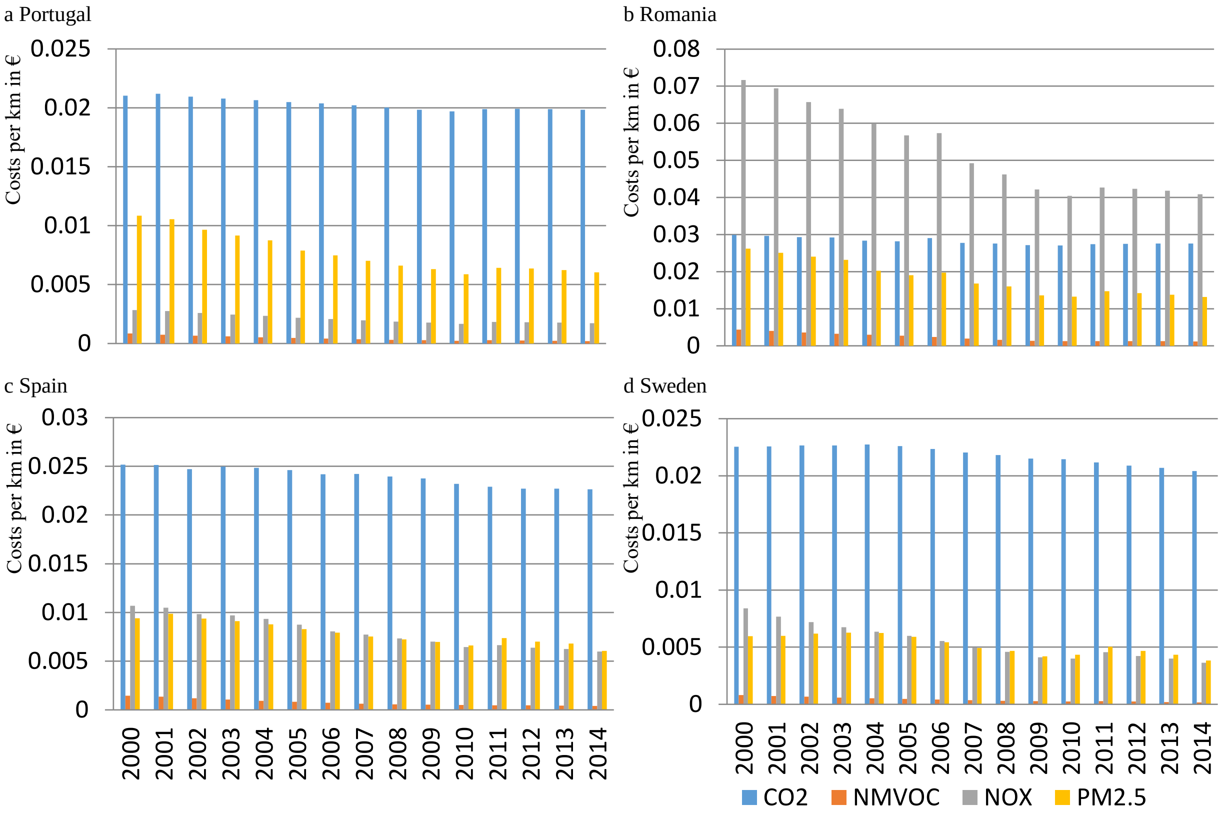

Fig. 4. Annual estimated costs per km of each pollutant CO_2, NMVOC, NO_X and PM 2.5 for each country: a) Portugal, b) Romania, c) Spain and d) Sweden.

During the studied period, in Romania, CO2 costs varied from 0.027 to 0.03 €/km, presenting a reduction around 8%. PM 2.5 costs have in general a decreasing tendency until 2010. In 2014, such value was approximately of 0.0132€/km. Between 2000 and 2010, NMVOC costs showed a reduction of approximately 71%. In 2014, PM 2.5 costs were around 0.0012€/km. NOx costs were in general decreased, with some variations, but always presenting values above 0.04€/km that is considerable higher compared to the rest countries. However, Romania was able to reduce these costs in 43% due to the market penetration of less pollutant vehicles.

Spain presents the second highest CO costs per kilometre, with values ranging between 0.0226 and 0.02517€/km. The country reduced its CO_2 costs per kilometre in 1%. PM 2.5 costs has in general been decreasing until 2010, with a slight augment in 2011. Since then, a decreasing trend can be observed, reaching in 2014 a value around 0.0061€/km, representing a reduction of approximately 36%. NMVOC costs presented a decreasing trend, dropping from 0.0015€/km in 2000 to 0.00042 €/km in 2014, which represents a reduction around 72%. In case of Sweden, CO_2 costs per kilometre has been in general decreasing, presenting during the studied period a reduction of 9%. NMVOC cost has been decreasing, dropping from approximately 0.00082€/km in 2000 to 0.00018 in 2014, which represents a reduction around 78%. Between 2000 and 2010, NO_X costs reduced more than a half. Since 2011, it has been decreasing, reaching in 2014 a value very close to 0.0036€/km. Facing 2000 values, this represents a reduction of almost 57%. Values of PM 2.5 costs have been swinging during the studied period, with a more pronounced peak of almost 0.0063€/km in 2003, but since 2011 a decreasing trend can be observed, ending up with a global reduction of 36%.

4.3. Costs by vehicle technology

In Figure 5, we can see the contribution of each technology in the CO2 annual emissions. Although, as it has been already mentioned, there is an increase in the market share of vehicles with new emission standards, it can be seen an increase in CO2 costs in each country. This can be explained by and the greater difficulty of the automotive industry to make engines more energy efficient when compared to the evolution of emission control systems of other pollutants.

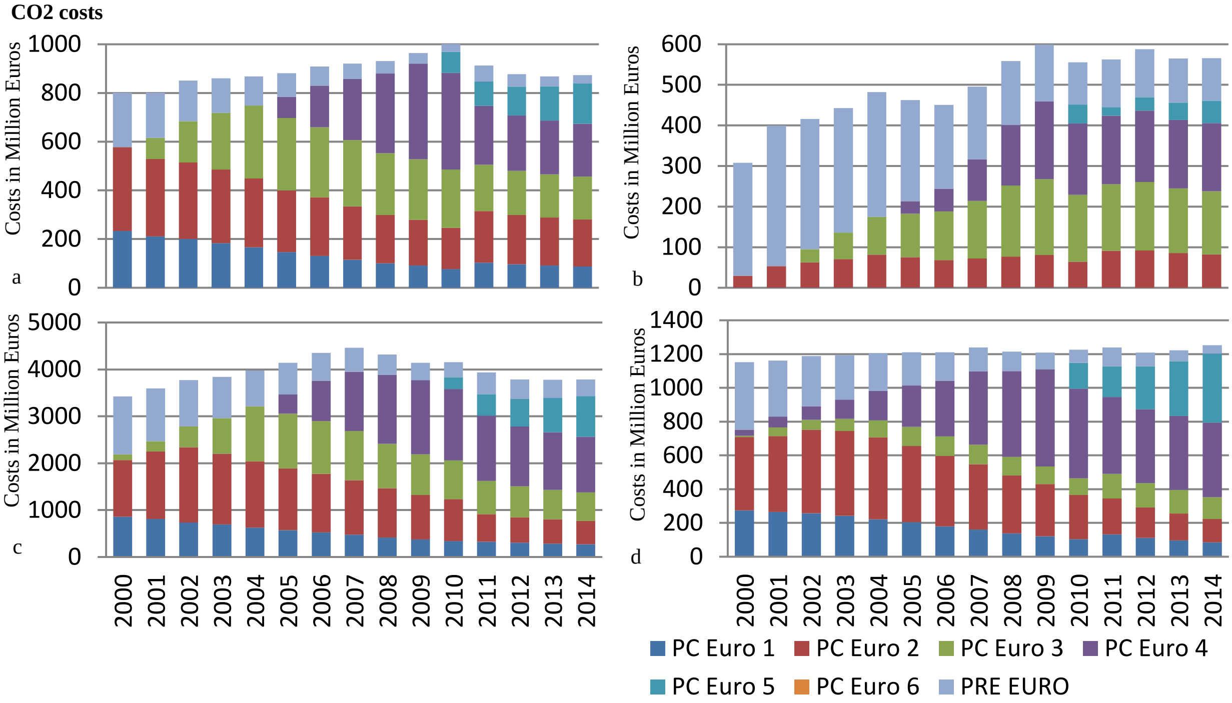

Fig. 5. Costs of CO_2 emissions by vehicle technology for a) Portugal, b) Romania, c) Spain and d) Sweden, in M€.

In Figure 6, the respective costs of NOx emissions are presented. An overall trend of reduction in each country can be noticed showing that the changes in the national fleet composition in terms of engine technologies contributed in costs savings, although the increase in the number of cars and kilometers travelled.

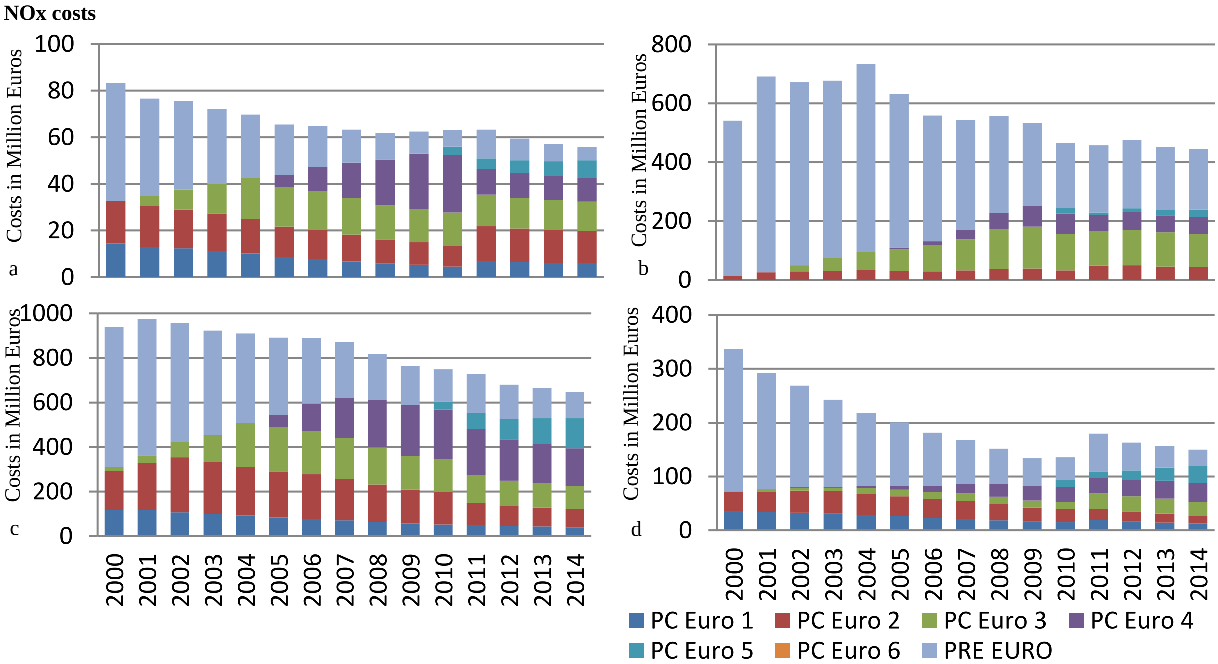

Fig. 6. Costs of NO_X emissions by vehicle technology for a) Portugal, b) Romania, c) Spain and d) Sweden, in M€.

4.4. Total costs

Figure 7 shows the evolution of the ratio between total traffic-related air pollution costs (NO_X, NMVOC, PM2) and gross domestic product (GDP), and CO_2 emission costs per unit of GDP.

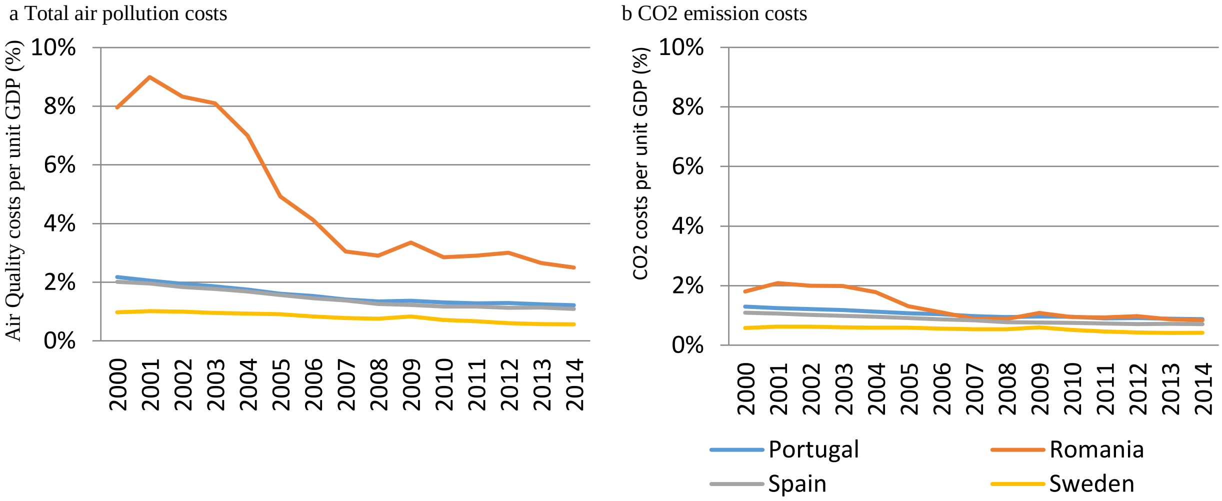

Fig. 7. Air quality costs per unit GDP (a) and CO2 costs per unit GDP (b) for Portugal, Romania, Spain and Sweden.

A first observation is that air pollution costs ratio has drastically decreased between 2003 and 2008 in Romania. This development is particularly noteworthy in Romania, where despite the doubling of vehicle kilometers travelled (VKT) the percentage decreases from 9% to 3%. However, since then, all countries have slowed the rate at which the emission costs intensity of their economy increases. Although the presented ratios can seem surprisingly high, mainly in Romania, they are in line with the world health organization report, which shows the economic cost of premature

deaths in Romania from Air pollution represents 26% GDP) in 2005 (WHO, 2015). This is also consistent to the fact the transport sector accounts for about 39%, 6% and 3,5% of emissions of NO_X, NMVOC and PM2,5 respectively (OECD, 2017).

In Portugal, the level of CO2 emission costs per unit of GDP was approximately 33% lower in 2014 than in 2000, while in Spain the reduction was around 35% and in Sweden it was 29%. Romania presented the highest decrease over the studied period, reducing its level of CO2 emission costs per unit of GDP by almost 54%.

5. Conclusions

In this study, a comparative analysis of the contribution of road fleet composition in air emissions and the evolution of emissions costs on national economies for four European countries is presented. Results show that a significant technological change in vehicles' engines can contribute in reducing the environmental impacts of transport by contributing in emission and cost savings for specific pollutants.

More specifically, an important reduction during the studied period in terms of CO, VOC, NMVOC and NOx emissions in all the studied areas was noticed. During that period, the share of vehicles with new emission standards were increased in each country, although the absence of standards regarding CO2 emissions resulted in the increase of the respective costs. This can be justified based on the increase in the number of total kilometers travelled that happened almost in every study area. Given this increase, and the fact that environmental transport costs (excluding noise) are still representing important costs the European countries economy, other measures for more sustainable use of infrastructures are needed, from modal transfer or eco-navigation systems focused on the most critical pollutants. Future work will focus on assessing the impact future market penetration trends of the various technologies and different traffic management measures.

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