DECOMPOSITION ANALYSIS OF CO_2 EMISSIONS FROM PASSENGER CARS: the cases of Greece and Denmark

Katerina Papagiannaki[1], Danae Diakoulaki[2]

ABSTRACT. The paper presents a decomposition analysis of the changes in carbon dioxide (CO_2) emissions from passenger cars in Denmark and Greece, for the period 1990 – 2005. The choice of the two countries was based on the availability of detailed data used in the frame of the analysis, as well as on the challenging differences of specific economic characteristics. The developed decomposition approach relies on the Laspeyres method, which belongs to the wider family of index decomposition approaches. The particularity in road transport that justifies a profound analysis is its remarkably rapid growth during the last decades, followed by a respective increase in emissions. In both countries, passenger cars are responsible for half of the emissions from road transport as well as for their upward trend, which provokes the implementation of a decomposition analysis focused exactly on this section of road transport. The factors examined in the present decomposition analysis are related to vehicles ownership, fuel mix, engine capacity and technology of cars and to annual mileage. The comparison of the results is expected to appoint the differences in the transportation profiles of the two countries and reveal how they affect the trend of CO_2 emissions.

INTRODUCTION

Decomposition analysis is one of the most effective and widely applied tools for investigating the mechanisms influencing energy consumption and its environmental side-effects. Following a few early applications in the seventies, it has known a considerable expansion during the eighties with relevant studies focusing on changes in aggregate energy consumption in the light of the preceding energy crisis (Ang and Zhang, 2000). In the next decades, the interest of analysts was almost entirely shifted to the analysis of energy-related greenhouse gas emissions because of the growing concern for climate change. In both cases, the aim was to disentangle distinct components behind historical energy and/or emissions data in order to identify the factors that may have caused the observed changes.

Decomposition analysis has been traditionally implemented in either the entire economy level or in the manufacturing sector. However, other sectors, and especially the transport and the

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[1] PhD Candidate, School of Chemical Engineering, National Technical University of Athens, Athens, Greece, e-mail: aikaterini_211@hotmail.com

[2] Professor, School of Chemical Engineering, National Technical University of Athens, Athens, Greece, e-mail: diak@chemeng.ntua.gr

residential sector have an increasing share in the overall energy consumption and emission production. Thus, it is very important to look in more detail at these sectors too, in order to better understand the driving forces behind carbon dioxide (CO_2) emissions and accordingly establish the appropriate mitigation strategies. There is already a rich material among recent studies on transportation, focusing on the environmental aspects of fuel consumption and the examination of changes of transport energy intensity (Michaelis and Davidson, 1996; Kiang and Shipper, 1996; Kwon, 2006; Zachariadis, 2006), or analysing the link between transportation and socio-economic activity (Preston, 2001; Stead, 2001; Tapio *et al*., 2007). Furthermore, in the field of decomposition analysis, several variables affecting CO_2 emissions or carbon intensity have been examined either for freight (Shipper *et al*., 1992; Greening *et al*., 1999), or for passenger transportation (Scholl *et al.*, 1996; Shipper *et al.*, 1997), or even specifically for privately owned vehicles (Kwon, 2005).

The transport sector is one of the major sources responsible for anthropogenic CO_2 emissions. It has been constantly growing during the last 30 years and takes today a dominant position as far as the increases over time in energy use and the consequent greenhouse gases emissions are concerned. In the first 15 member countries of the European Union (EU15), transport accounts for more than 25% of total CO_2 emissions, over 90% of which are attributed to road transport. In Denmark, the increase of CO_2 emissions from road transport between 1990 and 2005 lies very close to the EU15 average, while the corresponding increase in Greece is almost twofold. In both countries, passenger cars are responsible for half, more or less, of the emissions from road transport as well as for their upward trend, which provokes the implementation of a decomposition analysis focused exactly on this section of road transport.

Both countries have a small economy size relatively to their contribution to the GDP of the EU15. However, GDP per capita in Denmark is one of the highest in the EU15, while in Greece it stands quite below average, having though a higher average annual growth in the period 1990 – 2005. The upward trend of GDP in both countries has been closely followed by a similar trend in energy consumed in road transportation. In the case of Greece, the growth of passenger cars per capita in the period 1990 – 2005 has been remarkable, surpassing by far the one of GDP. Private gasoline cars in use have been increased by 150% since 1990, while the corresponding increase in Denmark is 14%. On the other side, the share of diesel cars in private transportation in Denmark grew to 12% in 2005, while in Greece it remains negligible. Additionally, energy statistics indicate that privately owned cars are exclusively relied on petroleum, while the penetration of alternative or renewable fuels is still negligible. Recognising therefore the importance of the above mentioned facts, the present study attempts a more profound comparative analysis of the determinants behind the trends of CO_2 emissions from passenger cars in the two European countries.

The following sections present the methodological approach developed for the decomposition analysis, the trend of CO_2 emissions and parameters related to passenger cars in Greece and Denmark from 1990 to 2005, the results of the decomposition analysis followed by a discussion and the concluding remarks.

METHODOLOGICAL APPROACH

The decomposition method applied relies on the Laspeyres model introduced by Howarth et al. (1991) and Park (1992) and extensively used in several decomposition studies, afterwards. The major problem encountered with conventional Laspeyres model was the large residual term found in most applications, leaving a significant part of the examined changes unexplained. In the present study we use the refined Laspeyres extension proposed by Sun (1998) in order to allocate the residuals on the basis of the "jointly created and equally distributed" principle. In addition, the Sun's method provides symmetric results contrary to the conventional Laspeyres method, where time reversals lead to different percentage changes (Ang, 2004). One basic drawback of the refined Laspeyres method is the complexity of the decomposition formula when the number of factors analyzed exceeds three (Ang *et al.*, 2003). Among the other index decomposition methods that have been overall proposed, the Log-Mean Divisia Index I (LDMI I) method, introduced by Ang and Liu (2001), has the most robust theoretical foundation, leading to complete and more stable decomposition results (Zhang and Ang, 2001) and having the advantage to be very easily applied. The main reasons for the choice of either the refined Laspeyres or the LDMI I method are related to the form of the results presentation and to the type of indicator decomposed. According to Ang and Zhang (2000), it is more common to use the refined Laspeyres model when a quantity indicator, like absolute energy consumption or emissions, is chosen. Furthermore, Laspeyres index is based on the use of the familiar concept of percentage changes facilitating comprehension and exploitation of results.

In the present study, the decomposition analysis, on the basis of the refined Laspeyres model, focuses on several factors which constitute the main driving forces behind the CO_2 changes from passenger cars, namely the population, the vehicles ownership, the annual mileage, the fuel mix, the engine size and the engine technology.

Decomposition model

The general equation used to calculate the amount C_t of CO_2 emissions generated in year t from the fleet of passenger cars is the following:

$$C_t = P_t \cdot V_t \cdot \sum_i (f^i \cdot D_t^i \cdot F_t^i \cdot \sum_j (S_t^{i,j} \cdot \sum_k (T_t^{i,j,k} \cdot e^{i,j,k}))) \quad (1)$$

where:

P_t: the population in year t
V_t: the number of vehicles per capita in year t
f^i: the CO_2 emission factor for fuel i
D_t^i: the distance travelled annually by car of fuel i in year t
F_t^i: the share of cars with fuel i in year t
$S_t^{i,j}$: the share of cars with fuel i and engine size j in year t
$T_t^{i,j,k}$: the share of cars with fuel i, engine size j and technology k in year t
$e^{i,j,k}$: the specific fuel consumption of cars with fuel i, engine size j and technology k

Consequently, the change in CO_2 emissions, ΔC_t, recorded in time t in comparison with their level in a base year $t=0$ is calculated as follows:

$$\Delta C_t = P_t \cdot V_t \cdot \sum_i (f^i \cdot D_t^i \cdot F_t^i \cdot \sum_j (S_t^{i,j} \cdot \sum_k (T_t^{i,j,k} \cdot e^{i,j,k}))) - \\ P_0 \cdot V_0 \cdot \sum_i (f^i \cdot D_0^i \cdot F_0^i \cdot \sum_j (S_0^{i,j} \cdot \sum_k (T_0^{i,j,k} \cdot e^{i,j,k}))) \tag{2}$$

It can be deduced from the above expression that the change in carbon emissions ΔC_t may be attributed to the following determinant factors:

- The population effect, reflecting changes in total population (ΔP) of the country
- The ownership effect, reflecting changes in the number of vehicles per capita (ΔV)
- The distance effect, reflecting changes in the average annual mileage (ΔD)
- The fuel mix effect, reflecting changes in the relative shares (ΔF) of cars using fuel type i
- The size effect, reflecting changes in the relative shares (ΔS) of cars with engine capacity j
- The technology effect, reflecting the changes in the relative shares (ΔT) of cars with engine technology k

In order to estimate the impact of each separate factor on ΔC_t, Equation 2 is solved consecutively by examining the change of the considered factor from its base year value to the level of year t, while leaving all other factors to the base year level. Thus, the difference ΔC_t is decomposed into its components as illustrated in Equation 3:

$$\Delta C_t = \Delta P_t + \Delta V_t + \Delta D_t + \Delta F_t + \Delta S_t + \Delta T_t \tag{3}$$

Each of the above factors includes not only the effect of the changes in the corresponding parameters (under the Ceteris paribus condition) but also the combined effects deriving from simultaneous changes in the examined parameters, by equally distributing them to the involved factors. According to this general definition, each explanatory factor shown in Equation 3 is calculated through Equations (4)-(9):

$$\Delta P_t = (P_t - P_0) \cdot V_0 \cdot \sum_i (f^i \cdot D_0^i \cdot F_0^i \cdot \sum_j (S_0^{i,j} \cdot \sum_k (T_0^{i,j,k} \cdot e^{i,j,k}))) \\ + \frac{1}{2} \cdot \sum R_{P,x} + \frac{1}{3} \cdot \sum R_{P,x,y} + \frac{1}{4} \cdot \sum R_{P,x,y,z} + \frac{1}{5} \cdot \sum R_{P,x,y,z,w} + \frac{1}{6} \cdot R_{P,V,D,F,S,T} \tag{4}$$

$$\Delta V_t = P_0 \cdot (V_t - V_0) \cdot \sum_i (f^i \cdot D_0^i \cdot F_0^i \cdot \sum_j (S_0^{i,j} \cdot \sum_k (T_0^{i,j,k} \cdot e^{i,j,k}))) \\ + \frac{1}{2} \cdot \sum R_{V,x} + \frac{1}{3} \cdot \sum R_{V,x,y} + \frac{1}{4} \cdot \sum R_{V,x,y,z} + \frac{1}{5} \cdot \sum R_{V,x,y,z,w} + \frac{1}{6} \cdot R_{P,V,D,F,S,T} \tag{5}$$

$$\Delta D_t = P_0 \cdot V_0 \cdot \sum_i (f^i \cdot (D_t^i - D_0^i) \cdot F_0^i \cdot \sum_j (S_0^{i,j} \cdot \sum_k (T_0^{i,j,k} \cdot e^{i,j,k}))) \\ + \frac{1}{2} \cdot \sum R_{D,x} + \frac{1}{3} \cdot \sum R_{D,x,y} + \frac{1}{4} \cdot \sum R_{D,x,y,z} + \frac{1}{5} \cdot \sum R_{D,x,y,z,w} + \frac{1}{6} \cdot R_{P,V,D,F,S,T} \tag{6}$$

$$\begin{aligned}\Delta F_t &= P_0 \cdot V_0 \cdot \sum_i (f^i \cdot D_0^i \cdot (F_t^i - F_0^i) \cdot \sum_j (S_0^{i,j} \cdot \sum_k (T_0^{i,j,k} \cdot e^{i,j,k}))) \\ &+ \frac{1}{2} \cdot \sum R_{F,x} + \frac{1}{3} \cdot \sum R_{F,x,y} + \frac{1}{4} \cdot \sum R_{F,x,y,z} + \frac{1}{5} \cdot \sum R_{F,x,y,z,w} + \frac{1}{6} \cdot R_{P,V,D,F,S,T}\end{aligned} \tag{7}$$

$$\begin{aligned}\Delta S_t &= P_0 \cdot V_0 \cdot \sum_i (f^i \cdot D_0^i \cdot F_0^i \cdot \sum_j ((S_t^{i,j} - S_0^{i,j}) \cdot \sum_k (T_0^{i,j,k} \cdot e^{i,j,k}))) \\ &+ \frac{1}{2} \cdot \sum R_{S,x} + \frac{1}{3} \cdot \sum R_{S,x,y} + \frac{1}{4} \cdot \sum R_{S,x,y,z} + \frac{1}{5} \cdot \sum R_{S,x,y,z,w} + \frac{1}{6} \cdot R_{P,V,D,F,S,T}\end{aligned} \tag{8}$$

$$\begin{aligned}\Delta T_t &= P_0 \cdot V_0 \cdot \sum_i (f^i \cdot D_0^i \cdot F_0^i \cdot \sum_j (S_0^{i,j} \cdot \sum_k ((T_t^{i,j,k} - T_0^{i,j,k}) \cdot e^{i,j,k}))) \\ &+ \frac{1}{2} \cdot \sum R_{T,x} + \frac{1}{3} \cdot \sum R_{T,x,y} + \frac{1}{4} \cdot \sum R_{T,x,y,z} + \frac{1}{5} \cdot \sum R_{T,x,y,z,w} + \frac{1}{6} \cdot R_{P,V,D,F,S,T}\end{aligned} \tag{9}$$

For the set U of the examined determinant factors *(U= P, V, D, S, T, F)*, residual terms $R_{Q,x}$, $R_{Q,x,y}$, $R_{Q,x,y,z}$, $R_{Q,x,y,z,\mathrm{w}}$, $R_{P,V,D,F,S,T}$ denote the synergetic effects of 2, 3, 4, 5 and 6 factors. Factor Q corresponds to the examined effect $(Q \in U)$ and factors $(x, y, z, w) \in (U - \{Q\})$, $x \neq y \neq z \neq w$.

As an example for $Q=P$, the residual terms $R_{P,x}$ summed up in Equation 4 are the following:

$$R_{P,V} = (P_t - P_0) \cdot (V_t - V_0) \cdot \sum_i (f^i \cdot D_0^i \cdot F_0^i \cdot \sum_j (S_0^{i,j} \cdot \sum_k (T_0^{i,j,k} \cdot e^{i,j,k}))) \tag{4i}$$

$$R_{P,D} = (P_t - P_0) \cdot V_0 \cdot \sum_i (f^i \cdot (D_t^i - D_0^i) \cdot F_0^i \cdot \sum_j (S_0^{i,j} \cdot \sum_k (T_0^{i,j,k} \cdot e^{i,j,k}))) \tag{4ii}$$

$$R_{P,F} = (P_t - P_0) \cdot V_0 \cdot \sum_i (f^i \cdot D_0^i \cdot (F_t^i - F_0^i) \cdot \sum_j (S_0^{i,j} \cdot \sum_k (T_0^{i,j,k} \cdot e^{i,j,k}))) \tag{4iii}$$

$$R_{P,S} = (P_t - P_0) \cdot V_0 \cdot \sum_i (f^i \cdot D_0^i \cdot F_0^i \cdot \sum_j ((S_t^{i,j} - S_0^{i,j}) \cdot \sum_k (T_0^{i,j,k} \cdot e^{i,j,k}))) \tag{4iv}$$

$$R_{P,T} = (P_t - P_0) \cdot V_0 \cdot \sum_i (f^i \cdot D_0^i \cdot F_0^i \cdot \sum_j (S_0^{i,j} \cdot \sum_k ((T_t^{i,j,k} - T_0^{i,j,k}) \cdot e^{i,j,k}))) \tag{4v}$$

What is mostly important is that a complete decomposition model has been developed in order to avoid unexplained residuals that could obscure the real causes behind the upward emission trends and reduce the comparability of the obtained results.

FLEET PROFILE AND CO_2 EMISSIONS

The transport sector has a particularly aggravating role regarding the anthropogenic CO_2 emitted in the atmosphere and the consequent Greenhouse Gas (GHG) effect. Road transportation is responsible for over 90% of these emissions. According to the Annual European Community GHG Inventory Report prepared from the European Environmental Agency (EAA, 2007), when emissions of carbon dioxide EU15 increased by 4% in 2005 compared to 1990, CO_2 from transport increased by 24%, with an average annual rate of increase at 1.5%. Similar is the trend of CO_2 from transportation in Denmark (Denmark's National Inventory Report (NIR), National Environmental Research Institute, 2007), while in Greece the rate of increase lies well above the EU15 average, at 46% (Greek National Inventory Report (NIR), MEPPPW, 2007). Road transportation in Greece evolves in an impressive rate leading to an increase of CO_2 emissions by 59% in 2005 compared to 1990 levels, while quite lower are the increases for EU15 and Denmark, by 25% and 32% respectively.

Indicative of the situation in the road transport sector in Greece is the fact that despite the accelerated increase of CO_2 emissions, the per capita CO_2 emitted per day, reaching 4.7 kg/cap/day in 2005, is still below the EU15 average of 5.6 kg/cap/day. Evidently, it is expected for a low per capita emitter, like Greece, to have a faster growth in per capita emissions (Scholl *et al.*, 1996), especially when considering also the high rate of economic growth over the same period. By contrast, the respective index in Denmark is 9% higher than the EU15 average, at 6.2 kg/cap/day, with a quite lower, however, change, between 1990 and 2005, compared to Greece. Looking alongside at the modal structure of road passenger transportation, even though public modes still cover over 30% of passenger-kilometers (pkm) in Greece, which constitutes the higher percentage among the 15 EU member countries, a clear shift to privately owned cars has been taken place (European Commission, 2006). The level of car ownership has climbed up to 391 passenger cars for every 1000 inhabitants, increased by 128% since 1990. On the other side, the respective ownership rate for Denmark is 372, increased by only 17% since 1990, while the share of cars in road pkm has remained stable at 80%.

The relationship between economic growth and transport activity, transport intensity or car ownership has been presented in several studies (Scholl *et al.*, 1996; Stead, 2001) and further examined relatively to the suitability of the economic measures available (Banister and Stead, 2003). Following the reasoning of Paravantis and Georgakellos (2007), GDP per capita (in constant 2000 US$) has been correlated to car ownership in order to compare the effect the growth of income has upon the cars market in the two countries examined. In the case of Denmark, as shown in Figure 1, ownership follows closely the economic growth, but a clear decoupling has taken place, although the gap between the two indicators does not seam to continue increasing significantly. On the contrary, in Greece the trend of ownership exceeds by far the one of GDP, with the absolute figures of ownership running after the levels of the most developed European countries.

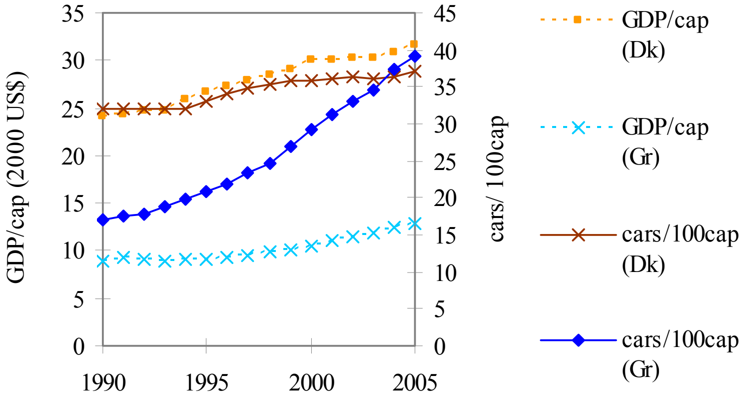

Figure 1. Trends in GDP per capita and car ownership in Greece and Denmark

Sources of primary data

Detailed databases with the number of vehicles in use by fuel type, engine capacity and technology have been taken by the annual National Inventory Reports of the two countries, and additional data have been collected from the Hellenic Ministry of Transport and Communications (HMTC), the Hellenic Association of Motor Vehicle Importers-Representatives (AMVIR, 2007) and the European Automobile Manufacturers' Association (ACEA, 2007). The categorisation of cars by engine size and technology follows the one introduced in COPERT model (Computer Program to calculate Emissions from Road Transport), which has been developed by Ntziachristos and Samaras (2000) on behalf of the EEA. Specific fuel consumption data used are the default ones included in the database of the most recently updated version of the model, COPERT IV. Fuel consumption per vehicle type is given for three different road categories, rural, urban and highways, while appropriate mileage contribution by road category for each country has been used for the estimation of weighted average fuel consumption by vehicle type (Denmark's NIR, 2007; Greek NIR, 2007).

Fuel intensity

The exploitation of specific fuel consumption data, as they are provided by COPERT IV model, in combination with the relevant vehicles fleet data, produced the aggregated figures of fuel consumption (expressed in liters per 100 km) presented in Table 1. It must be noticed, though, that for the purpose of the decomposition model's CO_2 calculation, fuel consumption default figures have been adjusted in order to represent better the real road driving conditions. Growing congestion, intense driving style and the penetration of additional electric devices are the main factors which affect in an aggravating way the final energy consumption. There has been a lot of discussion on this particular issue in the recent studies on road transportation (Shipper and Tax, 1994; Zachariadis, 2006; Kwon, 2005; Fontaras and Samaras, 2007), suggesting a gap, between the official and the 'on road' fuel consumption rate, which varies according to the survey from 7% to 25%. An adjustment factor of 15% has been finally assumed in this case study and implemented in every vehicle type and road category in both countries.

Table 1. Specific fuel consumption per vehicle category

l / 100 km[1]	1990	1995	2000	2005
Denmark - fleet	**8.1**	**7.9**	**7.8**	**7.7**
Gasoline Cars	8.1	8.0	7.9	7.9
Diesel Cars	6.7	6.6	6.6	6.6
Gasoline <1.4 l	7.6	7.4	7.1	6.9
Gasoline 1.4-2.0 l	8.7	8.4	8.1	8.1
Gasoline >2.0 l	10.2	10.3	10.4	10.1
Diesel < 2.0 l	6.7	6.6	6.5	6.4
Diesel > 2.0 l	6.7	7.3	8.0	8.3
Greece - fleet	**8.1**	**7.8**	**7.6**	**7.5**
Gasoline Cars	8.1	7.8	7.6	7.5
Diesel Cars	6.9	6.8	7.3	7.7
Gasoline <1.4 l	7.9	7.6	7.2	7.0
Gasoline 1.4-2.0 l	9.0	8.6	8.3	8.3
Gasoline >2.0 l	10.6	10.3	10.5	10.3
Diesel < 2.0 l	6.9	6.7	6.6	6.6
Diesel > 2.0 l	6.9	7.0	8.0	8.4

[1] 'on road' fuel consumptions

Higher specific fuel consumption rates for gasoline cars of all engine sizes are observed in Greece, reflecting the higher share of cars with older technological standards. In Denmark there has been a greater penetration of new cars, the share of which complying with EURO standards has reached 80% in 2005. The picture changes, however, when comparing the aggregated fuel consumption for the amount of gasoline cars, due to the higher and continuously growing share of bigger gasoline cars in Denmark (Figure 2).

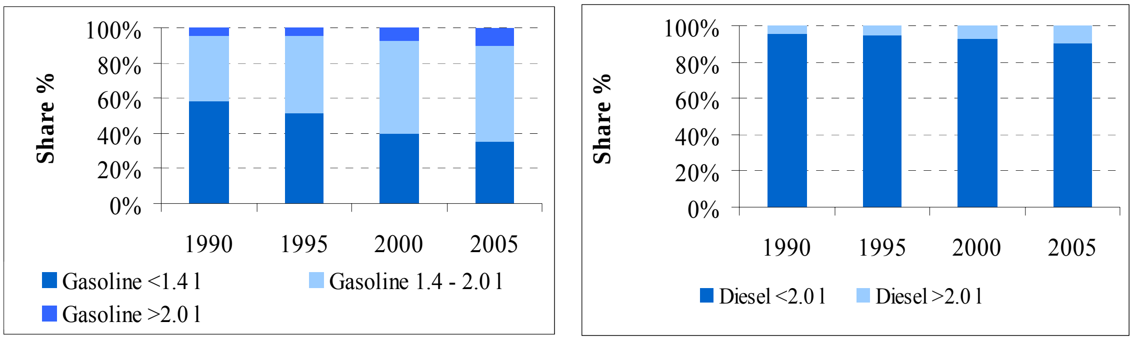

Figure 2. Shares of gasoline and diesel cars by engine capacity, in Denmark

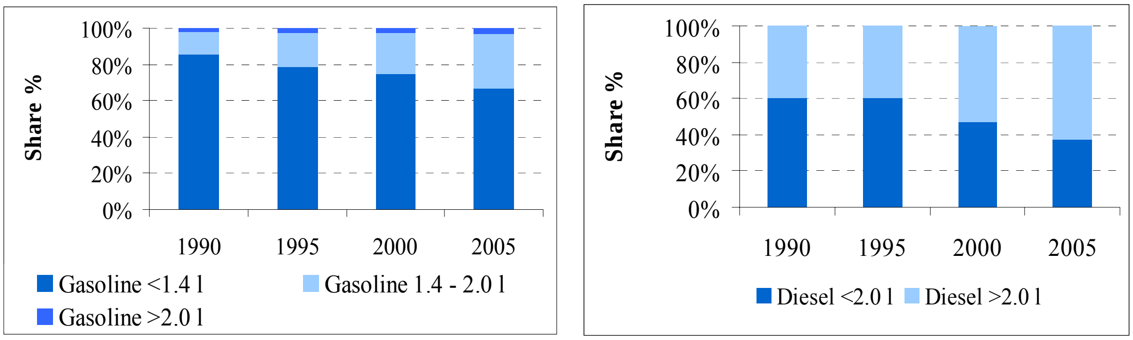

Figure 3. Shares of gasoline and diesel cars by engine capacity, in Greece

On the contrary, diesel cars with greater engine capacity constitute the majority in Greece since the end of nineties (Figure 3), influencing, thus, the specific consumption of the entire category of diesel passenger cars, which has an upward trend between 1995 and 2005.

Examining further, in Figures 4 and 5, the renewal in gasoline and diesel cars, from a technological point of view, one can easily observe the delay in the replacement of older cars with pre EURO standards, which have not yet been withdrawn from the market in 2005. In Greece, the most considerable renewal has been realized in the early nineties, due to the incentives given then by the Ministry for the Environment for the old cars withdrawal.

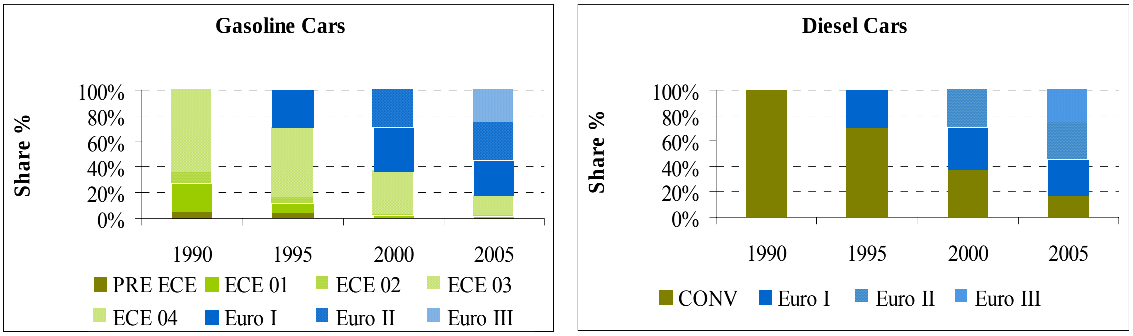

Figure 4. Shares of gasoline and diesel cars by engine technology, in Denmark

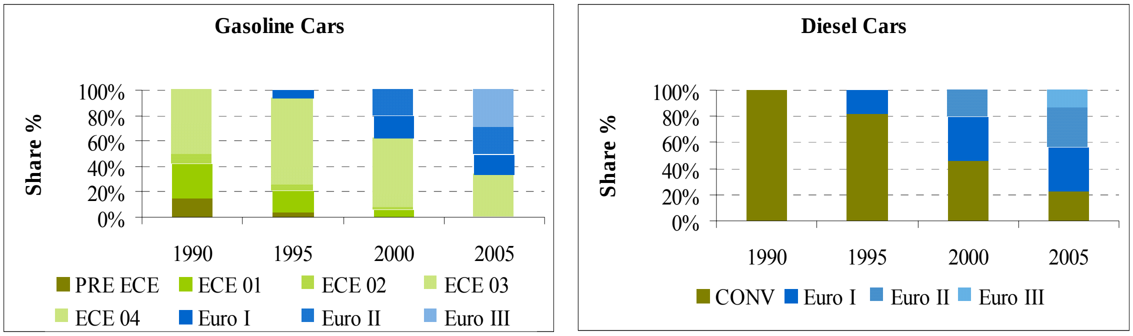

Figure 5. Shares of gasoline and diesel cars by engine technology, in Greece

The aggregated energy intensity by fuel type and the way it evolves are basically affected by the preference of the market in cars with bigger engine size and the technological renewal of the fleet. Aggregated fuel consumption for the entire fleet has decreased in both Denmark and Greece, by 4% and 7% respectively. In the case of Greece, the similarity in the trends of specific fuel consumption for gasoline cars and the entire passenger cars fleet is naturally predictable considering the almost negligible fraction of diesel cars. There is of course an increasing penetration of bigger cars, in terms of engine size, however the share of cars with engine size more than 2.0 l is still less than 4% and slightly increased since 1990, while the respective fraction in Denmark is close to 10%, increased by 6 percentage units since 1990. This clear shift to bigger cars in Denmark is the basic factor responsible for the lower reduction in the average fuel intensity of the passenger cars fleet.

Annual mileage

The main uncertainty associated with the primary data used in the model for the estimation of CO_2 emissions from passenger cars in Greece derives from the lack of reliable data on the average distance traveled annually by cars. Only few references, related to the mileage driven by the amount of passenger cars for certain years, have been reported (MEPPPW; Yannis, 2007; Zachariadis and Samaras, 2001), without offering the possibility to produce a time series or a trend of distance traveled per car of different fuel types. The existing information, along with the impressive average annual rate of increase for passenger cars ownership, have been considered so as to assume an annual decrease in the distance traveled by gasoline and diesel cars of 1% and 0.5% respectively. Our estimate is that a 1% decrease produces a reasonable trend of gasoline consumption, rationalizing in a way the exaggerated trend of ownership. Plus, the total decrease of distance travelled by gasoline cars by 13% in 2004 compared to 1990 coincides with the respective decrease introduced in the COPERT III model for the calculation of CO_2 emissions for passenger gasoline cars in Greece (MEPPPW, 2007). The particularity in the case of diesel cars in Greece is that over 90% are taxis, because of the interdiction of diesel- fueled private cars in the two major cities, Athens and Thessaloniki. As a consequence, the share of diesel cars in the country is about 1%, when the respective rate for EU15 is about 44%, while the average distance traveled by diesel cars is at least 6 times above the respective figures for gasoline cars.

All necessary data regarding annual mileage by each vehicle category in Denmark are provided by the Danish Road Directorate and have been explicitly reported in the country's NIR (2007). According to these data, annual average distance driven by diesel cars is double compared to mileage attributed to gasoline cars, while the average annual mileage of a Danish car, regardless the fuel type, has been increased by 15% in the 1990 – 1995 period and it keeps decreasing afterwards.

RESULTS OF THE DECOMPOSITION ANALYSIS

The number of vehicles corresponding to every thousand inhabitants, the average distance travelled annually and total CO_2 emissions, as they are calculated by general Equation 1, are presented in Table 2 for Denmark and Greece and for the years defining the time periods examined.

Table 2. Ownership, average distance travelled and CO_2 emissions for the entire fleet, gasoline and diesel cars

	Fleet			Gasoline Cars			Diesel Cars		
	CO_2 (kt)	Vehicles/ 1000cap	Distance (km)	CO_2 (kt)	Vehicles/ 1000cap	Distance (km)	CO_2 (kt)	Vehicles/ 1000cap	Distance (km)
Denmark									
1990	4,919	319	16,656	4,434	303	15,834	485	16.2	31,981
1995	5,853	332	19,113	5,334	315	18,360	520	16.8	33,184
2000	6,286	360	18,829	5,577	337	17,884	709	23.0	32,694
2005	6,423	372	18,262	5,076	329	16,385	1,347	43.4	32,484
Greece									
1990	4,573	171	14,688	4,112	168	13,490	462	3.0	80,940
1995	5,381	209	13,977	4,823	205	12,829	558	3.6	78,937
2000	7,014	292	13,005	6,411	288	12,200	603	3.6	76,983
2005	8,985	391	12,276	8,267	387	11,602	718	4.1	75,078

Figures 6(a) and 6(b) present the CO_2 emissions induced by the change of each one of the factors examined, during the periods 1990 – 1995, 1995 – 2000 and 2000 – 2005. Starting with total CO_2 changes, they follow an upward trend in the case of Greece, where actual CO_2 emissions from passenger have been increased by 96% in 2005 compared to 1990 levels. The respective growth for Denmark has been calculated at 31%, with the greater increase taken place during the first five years, by 19%, falling at rather lower rates afterwards. The primal reason for this differentiation is the remarkable growth of vehicles per capita in Greece, straightly pointed at the decomposition results. Therefore, the ownership effect, ΔV, is growing with time, while the contribution in total CO_2 changes is around 120% in all the three 5-year periods. Indicative of the excessive trend of cars sales in Greece is the fact that new registrations per capita have increased by 135% since 1990, when the respective increase for Denmark is about 73% and for the average of the EU15 is around 1.5% (ACEA, 2007). It should be stressed, however, that new registrations per capita in 2005 are still by 25% lower in Greece compared to the average of the EU15. Emissions changes in Denmark are definitely less affected by ΔV, with the exception of time period 1995 – 2000, when a greater increase in car ownership is observed.

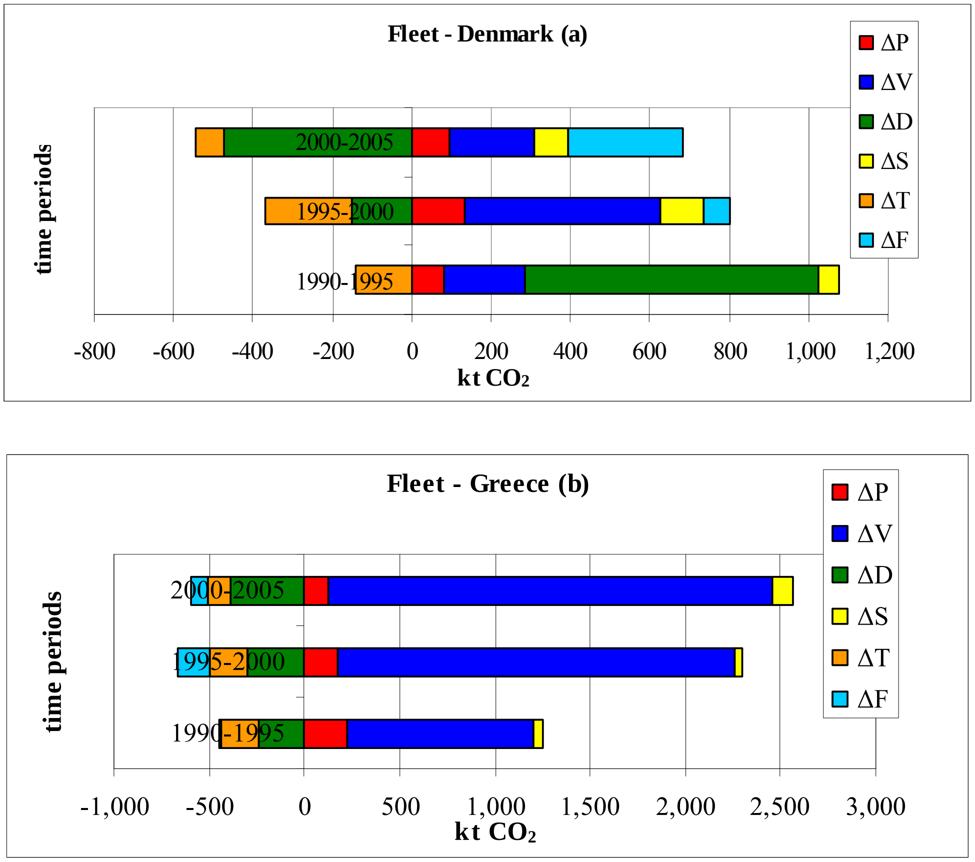

Figure 6. Contribution of population (ΔP), vehicles per 1000 capita (ΔV), distance traveled annually (ΔD), engine size (ΔS), technology (ΔT) and fuel mix (ΔF) effects at CO_2 change by passenger cars in (a) Denmark and (b) Greece

Population and engine size have also, together with vehicles ownership, a positive effect in the increase of CO_2 levels. The contribution of population effect, ΔP, to the increase of CO_2 emissions is in general restrained, following directly the changes in population in each country. Relative to the engine capacity, the shares of gasoline cars with medium and big engine size are gradually increasing (Figures 2 and 3) and so is their impact, ΔS, in CO_2 emissions. The role of ΔS is more significant in the case of Denmark, especially for the periods following 1995, since the share of cars with engine size bigger than 1.4 l constitute the majority. In Greece, small cars still dominate in the market of gasoline cars, while the share of more powerful diesel cars is strengthened only after 2000, without having any remarkable effect in total CO_2 emissions change due to their small relative number.

What has been previously mentioned about the penetration of new technologies and their energy intensities can now be confirmed by observing the contributions of engine technology effect, ΔT, in each of the periods examined. The replacement of engines with pre ECE and early ECE standards for gasoline cars during 1990 – 2000 is obvious in Figures 4 and 5, while the improvement in energy efficiency seems restrained in the period 2000 – 2005, since there is no major change in specific fuel consumption from the fleet of gasoline cars (Table 1). Diesel cars with conventional technologies are mostly replaced during 1990 – 2000, and they keep reducing afterwards. We should notice here, however, that default specific fuel consumptions given by COPERT IV for diesel cars with greater capacity are higher when EURO standards have been implemented. This partly explains the restrained benefits related to technological improvements during the last years for both countries. In Greece, where the penetration of gasoline cars with EURO standards is generally smaller over time, the greater CO_2 reduction attributed to technology took place in the first time period, through the replacement of cars with PRE ECE standards, which were particularly fuel consuming and represented a 15% of total gasoline cars in 1990.

Annual average mileage covered by passenger cars in Denmark has been increased by 15% between 1990 and 1995 and kept decreasing since then. Consequently, the effect of distance is positive and the main factor responsible for the CO_2 emissions increase during the first period examined, while it turns to be negative afterwards. Specifically in the last five years, mileage reduction plays a determinant role in restraining the increase of CO_2 emissions. The effect of the average distance traveled by passenger cars in Greece is negative throughout the period 1990 – 2005, since they are presumed based on the assumption that distances are normally reduced through time.

As long as the major part of diesel cars in Greece is represented by taxis, which travel at least six times more than privately owned gasoline cars, the fuel mix effect, ΔF, in CO_2 reduction is increasing when the share of diesel cars is reduced, as shown in Figure 6(b). This is actually aggravated by the fact that carbon intensity, measured as CO_2 per unit of distance traveled, is estimated to be from 5% to 25% higher for diesel cars in respect to gasoline ones during 1990 – 2005. In Denmark, the respective difference is limited to 1% - 2% and it grows excessively when we compare intensity measured as CO_2 per vehicle, due to mileage differences between diesel and gasoline cars, as in the case of Greece. In Denmark, the advantage of the energy intensity of diesel cars, which is by 17% lower compared to gasoline cars, is thereby counteracted by the distance factor as well as by the higher CO_2 intensity of diesel fuel (Timmermans et al., 2006).

CONCLUSIONS

The continuous growth of energy consumption and CO_2 emissions from privately owned vehicles raises the need for a more comprehensive examination of basic key drivers affecting the emissions changes. This paper presents a decomposition analysis of the changes in CO_2 emissions from passenger cars in Denmark and Greece for the period 1990 – 2005. This period is divided into three time intervals, 1990 – 1995, 1995 – 2000 and 2000 – 2005. The developed decomposition approach relies on the Laspeyres method, which belongs to the wider family of index decomposition approaches. The analysis examines the implication of six factors in CO_2 levels, namely the population (P), the vehicles in use per capita (V), the average distance traveled by car (D) and the shares of cars by fuel type used (F), engine size (S) and engine technology (T).

In the case of Greece, decomposition analysis leads to very clear conclusions. Among the factors examined, ownership of passenger cars is by far the most influential one, presenting an average annual rate of increase by 5.6%, six times higher compared to the corresponding rate for Denmark and four times compared to the same rate for the average EU15. The relative contributions of the remaining factors are quite lower. A shift to bigger and more powerful cars with greater energy consumption is observed to a certain degree, while the advantage of the improvement in engine technologies is offset partly by a certain delay regarding the renewal of the fleet. On the other side, a regular reduction of the annual mileage has been assumed, so as to counterbalance the remarkable increase of new car registrations. Diesel cars constitute only a small fraction of the fleet of passenger cars, mainly used for taxis which travel at least six times more than gasoline cars. This great difference in the mileage is the primal reason for the positive effect of fuel mix in CO_2 reduction in cases where the share of diesel cars decreases.

Vehicles ownership in Denmark tends to increase at a much lower pace than in Greece, affecting thus accordingly total emissions. Therefore, CO_2 emission increases are found to be restrained in respect to the Greek case, except for the period 1990 – 1995 which is marked by the particular increase of the average annual distance covered by passenger cars. In the next two 5-year periods, the upward trend of emissions is restricted by the continually reduction of mileage and by the engine technology effect, related mostly with the faster, compared to Greece, penetration of cars with EURO standards, especially from year 1995 to 2000. Quite important is also the contribution of the growing diesel cars share, which is responsible for the largest part of CO_2 increase between 2000 and 2005, because of the higher CO_2 intensity attributed to diesel cars. Finally, the turn in cars with greater cylinder capacity is much more intense in the case of Denmark and, therefore, the consequent size effect has a higher contribution in total CO_2 changes.

In the frame of the Kyoto Protocol, EU countries develop strategies to help implementing measures in order to meet the targets for restricting GHG emissions. The findings of the decomposition analysis suggest that a number of actions could be undertaken in both countries towards a more sustainable road transport system, including policy measures and technological support. The major problem Greece has to deal with straightway is the continuous growth in passenger cars volumes. In the level of total passenger road transportation, the promotion of the less intensive modes is surely one of the most essential and effective measures. Public and alternative transport like bicycling, should be promoted along with the strengthening of rail transport, the share of which in total passenger travels is still very low (EC statistics, 2006). Moreover, in Greece, annual mileage driven has been decreasing the last decade (Zachariadis, 2001), but the same applies for car occupancy, which has not been considered yet in policies regarding the restriction of emissions from vehicles (Paravantis and Georgakellos, 2007).

In what concerns the energy intensity of cars, the ACEA has already been committed to further reduce CO_2 emissions from new passenger cars, which will naturally affect the whole fleet as well. The trend of the market for more powerful cars, which have also become heavier due to the regulations on safety and air quality, needs to be moreover taken into account. Directed to the improvement of fuel efficiency, a green owner tax in motor vehicles has been already introduced in Denmark since 1997, differentiated according to fuel consumption and fuel type, while eco-driving principles have been incorporated into driving courses (Denmark's Fourth National Communication). Greece introduced in 1992 the exhaust emissions control card, which is likely to slightly improve on-road fuel efficiency of cars through better maintenance. Additionally, biodiesel and ethanol are exempt from fuel excise, in both countries, in order to promote the purchase of cleaner cars. In Greece, where the average age of cars is rather high in comparison with most of the developed European countries, financial incentives should be furthermore given to encourage withdrawal of old cars, a measure which was successfully promoted in the early nineties. Finally, the effectiveness of cleaner cars has to be strengthened by a well studied traffic management, since growing congestion has become one of the major problems in city areas, increasing dramatically the energy efficiency of cars.

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