ROAD TRANSPORT EMISSIONS AND THE EFFECT OF DIESELIZATION OF PASSENGER CARS ON THE AIR QUALITY OF THE GREATER ATHENS AREA (GAA), GREECE

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Abstract: The Greater Athens Area (GAA) being the largest conurbation of Greece faces severe air pollution problems due to the combination of high road traffic emissions and its complex topography. Unfavourable meteorological conditions (e.g. sea breeze) often inhibit the pollutants' dispersion and lead to the development of pollution episodes. Towards air pollution abatement, the Greek authorities cancelled the ban on movement for Passenger Cars (PCs) with diesel engines in Athens as experts argue that diesel vehicles produce lower CO_2, and HCs emissions. The present work aims to estimate road emissions in Greece, the potential benefits of replacing gasoline PCs with diesel and examine the current state of air quality above the GAA based solely on road traffic emissions.

The program COPERT 4 was used to calculate the annual total emissions from the road transport sector for the period 2006-2010. The results revealed that the major part of CO_2 emissions is due to passenger cars (37.3% in 2009) while Heavy Duty Vehicles (HDVs) were connected with 57% of the total $PM_{2.5}$ emissions. Part of gasoline PCs were then replaced by diesel PCs based on scenarios that correspond to different percentage of diesel penetration concerning new registrations and total fleet. The comparison showed that reduction of about 4.6% was achieved for CO_2 emissions when diesel penetration was 75% of the total PCs fleet. The benefit on passenger cars emissions was insignificant for smaller values of diesel penetration.

Based on the above an emission inventory for the GAA was developed with a spatial allocation (2x2 km^2) of the COPERT annual emission data with the help of Geographic Information System (GIS). Results revealed that the benefit from dieselization in the Greater Athens Area was about 9% in CO_2 urban emissions while NOx and particles emissions increased.

Key words: *emission inventory, road transport, dieselisation, Athens.*

INTRODUCTION

The concentration of people and activities (transportation, central heating and industries) in and around cities has lead to their rapid expansion and as a result the down spiral of air quality. Road transport is characterised by researchers as a large contributor to urban air pollution, while it is responsible for approximately 4% of global fossil fuel CO_2 emissions. For this reason, many countries have encouraged a shift to diesel fuelled cars in an effort to reduce GHG emissions (Sullivan et al. 2004, Zachariadis 2006, Zervas et al. 2006, Zervas 2006). In this respect, the Greek authorities cancelled the ban on movement from passenger cars with diesel engines. However, diesel fuelled cars are sources of NOx, fine particulates and CO and have been recently blamed by researchers for maintaining high pollution levels in urban areas (Gonzalez et al. 2012). According to the European Environmental Agency the percentage of diesel passenger cars among new registrations increased from 2% in 2006 to 4% in 2010 for Greece which is very low compared with other European countries- about 70% in France, Spain, Belgium, Portugal, Luxemburg and about 50% in Italy, UK, Austria, Denmark, Finland and Ireland.

The GAA being the largest conurbation of Greece faces severe air pollution problems due to the combination of high traffic emissions, complex topography and unfavourable meteorological conditions, (e.g. sea breeze, winter temperature inversions) that lead to the development of severe pollution episodes (Progiou and Ziomas 2011). Within that frame, the purpose of the present work is to a) construct an emission inventory in order to examine the road traffic emission trend in Greece and the GAA for the period 2006-2010, b) estimate the possible benefits of increased diesel penetration where part of gasoline passenger cars are replaced by diesel (reduction of CO_2) in Greece and the GAA, c) examine the effects from increasing the percentage of diesel passenger cars on total road emissions and on the local emission profiles of all other pollutants in Greece and the G.A.A.

METHODOLOGY

Emission inventories are important tools for the definition of emission sources, the formulation of mitigation strategies and the application of local/regional pollution models (Progiou and Ziomas 2012; Markakis et al. 2010). In the European Union the EMEP/CORINAIR methodology is applied for compiling emission inventories, while the program COPERT IV (EMEP/CORINAIR 2009, Ntziachristos et al. 2009) is used for the calculation of road transport emissions. In the present work the COPERT IV code was applied to calculate the annual total emissions from the road transport sector for the period 2006-2010. The methodology allows the estimation of emissions for five main vehicle classes: passenger cars, light duty vehicles, heavy duty vehicles, urban buses and coaches and two wheelers, which are then distinguished according to the fuel type (gasoline, diesel, LPG, CNG), the EU Directives to which they conform in terms of emissions (PRE ECE, ECE 15/00-01, EURO 1, EURO 2, etc.) and the cylinder capacity (e.g. <1.4lt, 1.4-2.0lt, >2.0lt for passenger cars, <3.5t or >3.5t for commercial vehicles).

Among the required input data are the mean vehicle speed for three main road types (urban, rural, highway), the mean annual mileage driven from each vehicle, the share of annual driven condition from each vehicle class to these road types (e.g. for gasoline passenger cars this share is 44%, 42% and 14% for urban, rural and highway driving conditions respectively). Moreover, the minimum and maximum monthly mean temperature for Greece and the annual fuel consumption for each fuel type are required. The fleet composition data for the year 2006 were provided by the Greek Ministry of Transport (vehicle type, cylinder capacity, fuel type), while data concerning vehicle new registrations were obtained from the Association of European Automobile Manufactures (ACEA), the Association of Motor Vehicle Importers Representatives (AMVIR), the National Statistical Service of Greece and the European Union in order to complement the annual fleet. For annual mileage driven from each vehicle type, it was considered that older vehicles travel fewer kilometres (Symeonidis et al. 2003) so different mileage was used for each vehicle category. The Hellenic National Meteorological Service provided the necessary temperature data while the annual total fuel consumption for each fuel type was provided by the Greek Ministry of Environment. The yearly fleet composition at national level is reported in Table 1.

Emissions were calculated for pollutants CO, VOCs, NOx, $PM_{2.5}$, PM_{10}, CO_2, NMVOCs, CH_4, NH_3 and heavy metals for the years 2006 to 2010. In order to estimate the possible benefits due to the increased diesel penetration three scenarios were then constructed where part of gasoline passenger cars was replaced by diesel. The base year of the emission inventory was 2006 so the vehicle fleet composition remained unchanged for 2006.
More specifically, the three scenarios are:

- ***Scenario A***: 70% of new passenger cars registrations were considered to be diesel vehicles.
- ***Scenario B***: scenario A and 50% of gasoline passenger cars were replaced by diesel vehicles with cylinder capacity < 1.4 lt.
- ***Scenario C***: scenario A and 70% gasoline passenger cars were replaced by diesel vehicles with cylinder capacity < 1.4 lt.

The annual total emissions were then spatially allocated in gridded form covering the Greater Athens Area (2x2 km^2) with the use of a Geographic Information System (GIS) representing the driving conditions on three main road types (urban, rural, highway).The allocation was based on EMEP/CORINAIR methodology using road length, road traffic flow data and population data as proxy values.

Table 1. Temporal variation of the vehicle fleet composition (national level).

population	**2006**	**2007**	**2008**	**2009**	**2010**
PCs total	4610282	4798530	5016210	5131960	5216873
PCs gasoline	4550856	4735631	4945897	5059189	5140712
PCs diesel	58354	60651	65659	66359	68618
Light Commercial Vehicles	991234	1016906	1040892	1046397	1056963
Heavy Duty Trucks	228555	238939	248466	255866	261170
Buses	26938	27102	27186	27324	27311
Two wheelers	1179719	1295217	2768607	1448851	1499133

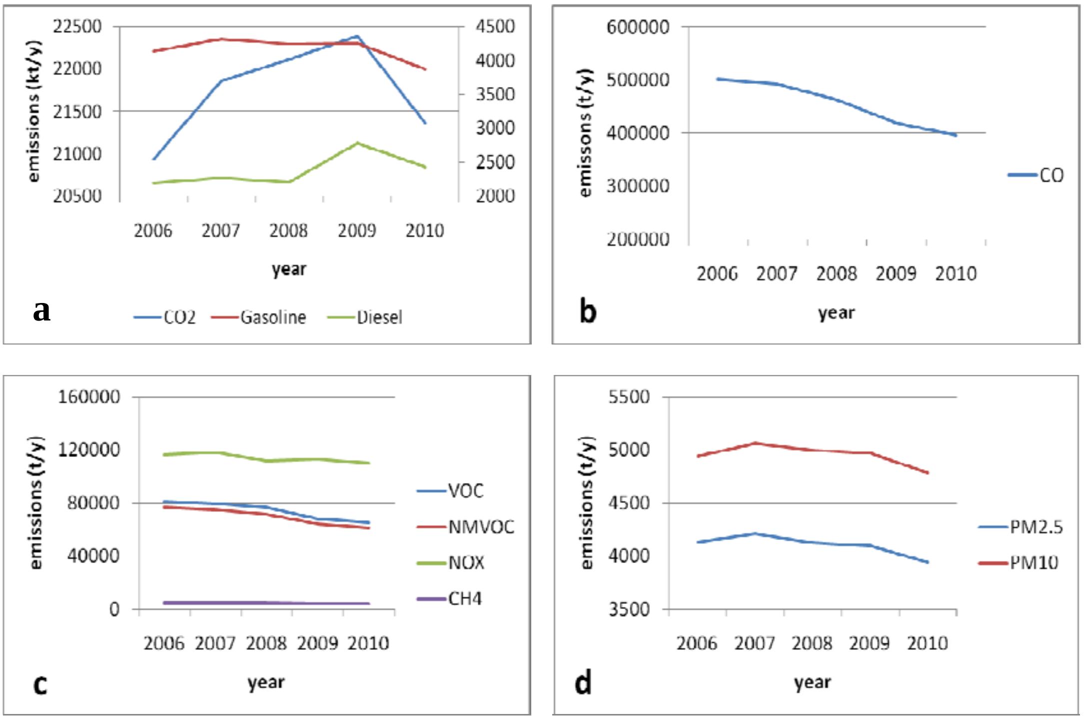

Figure 1. Temporal variation of (a) CO_2, (b) CO, (c) VOC, NMVOC, NOx, CH_4 and (d) $PM_{2.5}$, PM_{10} emissions (t/y), national level.

RESULTS

Emission inventory for the road transport sector in Greece

The annual total emissions variation for the period 2006-2010 is presented in Figure 1. The CO_2 emissions were positively related to the annual fuel consumption (Figure 1a) presenting an increase for the first 3 years while in 2010 a decrease of 4.6% was observed for CO_2 coupled with a 8.9% reduction in gasoline consumption and 12.5% in diesel. NOx, CH_4, $PM_{2.5}$ and PM_{10} remained rather stable with the latter two showing a slight decrease in 2010 (3.7% for both pollutants). Moreover, the continuous decrease in CO, VOCs and NMVOCs emissions reflects the import of new engine anti-pollution technologies. Especially from 2008 to 2009 when EURO 5 and 6 passenger cars entered the Greek market the decrease was 9.4%, 10.5%, 10.3% for CO, VOCs and NMVOCs respectively. The contribution of each vehicle category to CO_2 emissions for Greece is given in Table 2. It can be seen that passenger cars contribute most to the total road traffic emissions of CO_2, while approximately 20% of emissions come from gas passenger cars with cylinder capacity 1.4-2.0lt ssince this group is the most populated of the three categories it is responsible for the highest emissions of all pollutants. It is worth mentioning that the total contribution of passenger cars to $PM_{2.5}$ national emissions is very low (8.9% in 2010). The vehicle category that dominates in $PM_{2.5}$ emissions is Heavy Duty Vehicles with 57%, which may be attributed to the diesel engines.

Table 2. Contribution of each vehicle category to CO_2 national emissions.

Vehicle category	2006	2007	2008	2009	2010
PC	8125283 (38.8%)	8591406 (39.3%)	8245127 (37.3%)	8343151 (37.3%)	7133086 (33.4%)
LDV	5419751 (25.9%)	5539538 (25.3%)	5721025 (25.9%)	5718978 (25.5%)	5763071 (27.0%)
HDV	5473934 (26.2%)	5753510 (26.3%)	6133354 (27.7%)	6411508 (28.6%)	6586217 (30.8%)
Buses	1083991 (5.2%)	1090396 (5.0%)	596617 (2.7%)	981825 (4.4%)	827597 (3.9%)
Two wheelers	828981 (4.0%)	880693 (4.0%)	1415000 (6.4%)	932728 (4.2%)	1050431 (4.9%)

Dieselization

Regarding Scenario A, slightly lower CO_2 emissions (1.4%) were estimated compared with the base case for 2010 (Table 3). The influence of replacing also part of gasoline passenger cars with diesel ones having cylinder capacity < 2.0 on pollutants emissions was more obvious. When the ratio of gasoline/diesel passenger cars was about 1:1 (scenario B) a decrease of 4.2% on CO_2 emissions from passenger cars appeared while a higher diesel penetration (scenario C) only moderated that decrease (- 4.6%). However, dieselization had negative impacts on NOx and particles emissions. As shown in table 3 NOx emissions were 81% higher in scenario C while $PM_{2.5}$ increased at about 197% from 2006. The spatial allocation of annual emissions to gridded form for the GAA revealed that emissions representing low speed driving conditions (characterized as "urban emissions" in COPERT IV) prevailed among emissions from the other driving conditions. 15% of annual total CO_2 is emitted under urban driving conditions from passenger cars in the G.A.A. (demarcated by the black square in figure 3) where the traffic flow is higher. In figure 3 the difference in CO_2 and NOx gridded emissions between 2006 and 2010_scenarioC is illustrated as it was considered to be representative of the greater influence of dieselization. The benefit from dieselization in the Greater Athens Area amounted to a reduction of about 9% in CO_2 emissions (667.542 ton in 2010- 608.630 ton in 2010_scenarioC) as illustrated by the negative values in the left figure 3.The major decrease appeared in cells covering the most populated areas. Concerning NOx emissions they were about 95% higher in 2010_scenario C than in 2006 (6.194 t in 2006-11.965 in scenario C). This increase was found to be almost 5t in urban cells.

Table 3. Pollutants emissions (t/y) from passenger cars.

	2006	2010	2010_scenarioA	2010_scenarioB	2010_scenarioC
CO_2	8.125.283	7.133.086	7.036.125	6.835.173	6.803.899
NOx	11.682	6.083	9.069	17.684	21.153
VOCs	25.632	16.811	14.870	7.929	5.143
$PM_{2.5}$	438	373	563	1.089	1.301
PM_{10}	737	638	839	1.370	1.587
CO	113.109	60.566	53.206	29.507	20.002
NMVOCs	24.460	16.009	14.183	7.555	4.897

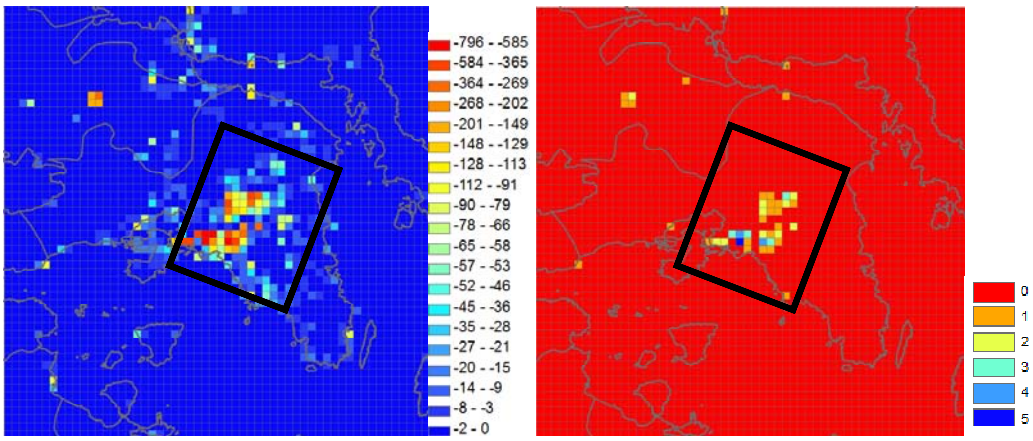

Figure 3. Difference between 2006 and scenario C emissions (t/y) under urban driving conditions CO_2 –left figure- and NOx –right figure- in the Greater Attica Area.

CONCLUSIONS

Since road traffic is responsible for the majority of air pollutant emissions, a comprehensive emission inventory for the road transport sector was created for Greece for the period 2006-2010 according to EMEP/CORINAIR methodology. The results of this study indicated that:

- A decrease in CO, VOCs and MNVOCs emissions took place after 2009 due to the import of new engine anti-pollution technologies.
- CO_2 emissions are positively related to fuel consumption and in fact decreased by 4.6% in 2010.

- Passenger cars contributed most to the total CO_2 emissions while Heavy Duty Vehicles dominated the $PM_{2.5}$ emissions.
- When diesel penetration among passenger cars fleet reached 70% the benefit in CO_2 emissions was 4.6% in 2010 for Greece and 9% for the Greater Athens Area.
- On the other hand dieselization had negative effects on NOx and particles emissions which increased quite considerably (95% and 200% increase in NOx and $PM_{2.5}$ emissions respectively from 2006 till 2010_scenarioC for the GAA).

Concluding, dieselization has different impacts on pollutants emissions which should not be neglected in order to make proper policy decisions. Further work to complete the new emission inventory at national level and for the G.A.A. will shed light on the contribution of all sources to the pollutant levels. Moreover, modeling of the pollutants' dispersion and chemical transformations will be possible, leading to the assessment of different mitigation strategies on the local and regional air quality.

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