



Comparative environmental assessment of Athens urban buses—Diesel, CNG and biofuel powered



E.A. Nanaki^{a,*}, C.J. Koroneos^b, G.A. Xydis^c, D. Rovas^b

^a University of Western Macedonia, Department of Mechanical Engineering, Bakola and Sialvera, 50100 Kozani, Greece

^b Laboratory of Heat Transfer and Environmental Engineering, Aristotle University of Thessaloniki, PO Box 483, 54124 Thessaloniki, Greece

^c Centre for Research and Technology Hellas, Institute for Research & Technology of Thessaly Technology Park of Thessaly, 1st Industrial Area, 38500 Volos, Greece

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ABSTRACT

Greenhouse gases (GHGs) emitted by road transport vehicles as a direct result of fossil fuel combustion and other environmental pollutants released throughout the life cycle of petroleum based fuels, encourage a shift towards alternative transport fuels. Within this frame, an environmental assessment was performed so as to evaluate the environmental implications of alternative fuels (natural gas and biofuels) penetration in the city buses of the city of Athens. The results are evaluated in terms of CO₂, CO, HC, PM and NO_x emissions. The findings show that CO₂ emissions are significantly reduced in CNG buses compared to diesel powered buses. CO₂ emissions can also be reduced by 7.85% in B10 blends and 78.45% in B100 blends, compared to diesel. The environmental assessment can be considered as a basis so as to investigate the viability of replacement of petroleum- based diesel with natural gas and biofuels in city transport buses. Concepts for sustainable bus transportation can be incorporated using the methodology defined in this study, in order to promote a sustainable transportation system and mitigate the climate change.

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1. Introduction

Energy-related CO₂ emissions, resulting from burning fossil fuels, represent the major part of recent human-made greenhouse gas emissions (GHG). Emissions from the transport sector are an important source of CO₂ in many countries. Public transportation systems providing mobility and access to most activities play a crucial role to cities; nevertheless the shift to a low carbon public transportation system is challenging. In this context, cities have a key role to play in the global agenda for addressing the challenge of CO₂ emissions mitigation. Especially in the case of European cities that face problems caused by transport and traffic, the challenge is to enhance mobility while at the same time reducing congestion and air pollution. Despite the fact that improvements have been made in the energy efficiency of various transport modes and non-fossil fuels have been introduced, increased transport demand is outweighing these benefits (European Environment Energy (EEA), 2007).

In 2007, the transport sector accounted for 18% of total 2007 GHG, reaching a total of 24 million tones of CO₂ equivalents (an increase of 33% on 1997 levels) (<http://www.epp.eurostat.ec.europa.eu>). Road transport is a significant source of air pollution in Greece, particularly within urban areas. To be more specific, road transport contributed to approximately 80% of these CO₂ emissions highlighting the very real challenge in restructuring a sector which is intensive in energy demand, environmental impacts and continues to grow. The split between road transport oil in Greece from 1978 onwards is approximately 37% diesel and 63% gasoline, with the majority of the gasoline demand being for private car use (Papagiannaki and Diakoulaki, 2009). Based on our previous study (Koroneos and Nanaki, 2007) it is shown that a number of elements influenced the increased demand for private transportation. The increasing GDP, and therefore income of households, allowed householders to travel in more “luxury” benefiting from faster and more accessible private transportation as well as being a symbol of wealth. Additionally, distances travelled to work, shopping and leisure activities increased ensuring that total distance travelled by private cars measured in 1000 mio pkm also continued to increase. Nevertheless, Greece's economic crisis has led an increasing number of motorists in urban areas such as Athens to resort to the capital's various forms of public transport as higher gasoline prices and

* Corresponding author.

E-mail addresses: evananaki@gmail.com (E.A. Nanaki), koroneos@aix.meng.auth.gr (C.J. Koroneos), gydis@mail.iireth.certh.gr (G.A. Xydis), drovas@aix.meng.auth.gr (D. Rovas).

the unprecedented economic crisis dent the attraction of private vehicle use (http://archive.ekathimerini.com/4dcgi/_w_articles_politics_0_28/05/2010_117332). Public transportation plays a vital role in the transportation system of an area and it also helps to minimize traffic congestion and other traffic-related externalities. Transportation problems are among the most pressing strategic development problems in many cities and are often considered as a major constraint for long-term urban development. In addition, transportation problems are very closely related to land development, economic structure, energy policies, and environmental quality. Since all citizens are either enjoying the transportation system or, and often at the same time, suffering from it, it is an important element of the urban quality of life.

The public transportation system of Athens consists of buses, trolley buses, a subway system (metro) as well as tram. On the demand side, the daily traffic is of 2650,000 passengers. The average bus speed in the city centre is 7 km/h; whereas in areas outside the city centre the average speed increases to 13 km/h. The use of public transport in the whole metropolitan area of Athens in 2004 came up to 31.7%, whereas 68.3% represented private vehicles. As far as the main city is concerned 45% represented the use of public transport, whereas 55% represented the use of private vehicles ([Website of European Metropolitan Transport Authorities, 2007](#)). The strong gap between modal share in the main city and in the whole metropolitan area, where public transport accounts, in average, for 30% of motorized trips, illustrates one of the main challenges facing public transport authorities: developing public transport in the suburbs and the less dense parts of the metropolitan areas.

The main objective of this study is to evaluate and analyse the environmental impacts from public transportation vehicles in urban areas and especially in the city of Athens and recognize possible routes for achieving the ambitious EU targets of 20–20–20 on energy and climate. Furthermore, this study aims to determine the CO₂ emissions reduction that could be achieved due to penetration of alternative transport fuels in urban bus fleet. The data used for this analysis were taken from the databases of [Athens Urban Transport Organization](#).

2. Methodology

The emission estimation methodology covers the exhaust emissions of CO, NO_x, CO₂, PM and HC for each vehicle technology of Athens's bus fleet. PM mass emissions in vehicle exhaust mainly fall in the PM_{2.5} size range. Therefore, all PM mass emission factors are assumed to correspond to PM_{2.5}. The methodology used considers the fuel used by different vehicle categories and their emission standards. In this respect, the vehicle category of buses includes urban CNG buses and urban diesel buses according to emission-control legislation categories (EURO I, II, III, IV, V, VI).

The technical data used take into account national variations. The variations may include parameters such as the fuel consumption, the composition of vehicle park, vehicle age, driving patterns, some fuel parameters and climatic conditions. Other variations which may exist, e.g. variations in vehicle maintenance, are not accounted for, because there is not enough data available to do so. The calculation is based on the following main types of input parameters: total fuel consumption, vehicle technology, vehicle park, driving condition, emission factors.

The emission factors are stated in units of grammars per vehicle-kilometer for each vehicle technology. These average European emission factors are determined using typical values for driving speeds, ambient temperatures, highway-rural-urban mode mix, trip length, etc. ([Ntziachristos and Samaras, 2009](#)). Based on the above and in order to calculate the emissions of each

vehicle technology, the following equation was used:

$$E_{i,j} = \sum k(N_j, k \times M_j, k \times EF_{i,j}, k) \quad (1)$$

where, j are the vehicle categories of diesel and CNG buses, k is the technology of each category (i.e. EURO I, EURO II, etc.), N_j, k is the number of vehicles in the city's under study bus fleet of category j and technology k , M_j, k represents the average annual distance driven per vehicle of category j and technology k , $EF_{i,j}, k$ represents the technology-specific emission factor of pollutant i for vehicle category j and technology k .

From the above mentioned it is obvious that it is necessary to have data regarding the number of vehicles and the annual number of vehicle-km per technology. These vehicle-km data are then multiplied by the emission factors. Data concerning Athens's bus fleet (number of vehicles, categories, engine type as well as annual distance driven) were obtained from [Athens Urban Transport Organization](#). The emissions factors used, are obtained from the studies of [Ntziachristos and Samaras \(2009\)](#), [Nylund et al. \(2004\)](#), [Beer et al. \(2000\)](#); [Table 1](#) presents the emissions factors used for the diesel bus fleet; whereas [Table 2](#) presents the emissions factors used for the CNG bus fleet.

3. Athens public transportation system

Athens metropolitan area is the most populous area in Greece with 4.0 million people. The region covers an area of 1450 km² encompassing 83 local authorities (municipalities) in 3 counties. Athens belongs to the Attica region and covers 35% of its surface area, with the Athens urban administrative area covering a total of 544 km². Athens in terms of both surface area and population is densely populated (5882 people per square kilometre). The Athens Metropolitan area is surrounded by mountains from West to East and by the Aegean Sea from the South. Within the central urban area, the existence of several hills has an influence upon the transport in the city, causing local roads to have steep gradients. The Athens urban area has spread rapidly in recent decades and continues to expand, mainly to the East and the North.

The transport infrastructure in Athens consists of a road network with a total length of 8000 km. The main road network covers 1826 km. The center of the city is the area bounded by the inner ring road (an area of 9.2 km²). There is also a (middle) ring road system surrounding an area of 111 km². The road traffic in Athens—both in private and public modes— involves significant traffic delays and low traffic speeds.

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Table 1
Emissions factors for diesel bus fleet.

Engine type	CO ₂ (g/km)	CO (g/km)	HC (g/km)	PM (g/km)	NO _x (g/km)
EURO I	1.397	1.50	0.3	0.45	16
EURO II	1.386	1.35	0.2	0.2	14
EURO III	1.351	1.00	0.15	0.18	9
EURO IV	1.343	0.95	0.09	0.06	6.38
EURO V	1.330	0.74	0.06	0.01	3.83

Table 2
Emissions factors for CNG bus fleet.

Engine type	CO ₂ (g/km)	CO (g/km)	HC (g/km)	PM (g/km)	NO _x (g/km)
EURO II	1.100	2.70	4.7	0.01	15
EURO III	1.250	1.00	1.33	0.01	10

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