Environmental Comparison of the Use of Bio-Diesel and Gasoline for Transportation – The Case of Athens

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Abstract: - The energy use in the Greek transport sector is in the form of gasoline consumption by automobiles, diesel oil for taxis, trucks, maritime transport and railroads and jet fuel for aircraft. The control of CO_2 emissions constitutes a major environmental issue in most countries and many authorities seek to stabilize or decrease these emissions. During the past decade biofuels in the form of blended gasoline and biodiesel have begun to find place in energy economy since a sustainable transport future requires the reduction of CO2 emissions. The Greek car market shows a remarkably low rate in the penetration of biodiesel compared to the average European Union market. In this study we try to assess and evaluate the combined effects of probable changes in biodiesel and gasoline future fuel consumption considering different scenarios of biodiesel fuel penetration.

Key words: - sustainable energy; transportation; biodiesel;

1 Introduction

The environmental repercussions of fossil fuels and concerns about petroleum supplies have spurred the search for renewable transportation biofuels. Road transport is a significant source of air pollution, particularly within urban areas. The term alternative transport fuels refers to any alternative to the conventional liquid petroleum based fuels such as biodiesel, ethanol, compressed natural gas (CNG), liquefied natural gas (LNG) as well as liquefied petroleum (LPG).

Biodiesel refers to a family of products made from vegetable oils or animal fats and alcohol, such as methanol or ethanol. The common sources of vegetable oils include soybean, rape, sunflower, coconut, palm, and used frying oil; nevertheless methods have been developed to make biodiesel from exotic materials such as oils naturally produced by certain species of algae. Biodiesel can be used neat or as a diesel additive and its typically used as a fuel additive in 20% blends (B20) with petroleum diesel in compression ignition (diesel) engines. Other blend levels can be used depending on the cost of fuel and the desired benefits. The most widely used alcohol for biodiesel is ethanol, mostly because of its ease of processing and it's relatively low cost. Blending with regular diesel allows the control of cost increases, as well as the minimization of the degree of fuel system modification that may be required in engines that were not designed for biodiesel fuelling. Therefore, biodiesel can be used in all diesel-burning vehicles, from the smallest to the largest: trucks, taxis, busses, excavators, agricultural machinery, tractors, etc. Biodiesel has been quite extensively tested in diesel engines (Graboski and McCormick, 1998) and in fact is sold at approximately 900 gas stations n Germany (www.biodiesel.org).

The quality of automotive fuels in the European Union is specified by standards developed by the European Standards Organization (CEN). The first set of standards for automotive fuels, ratified by CEN on March 19936, became mandatory in all Member States by September 1993. Three standards cover automotive fuels quality: the EN 590 for diesel fuel, the EN 228 for gasoline, and EN 589 for automotive LPG.

The standards are periodically updated to reflect changes in specifications, such as the mandatory reductions in sulfur content.

The consumption of biofuels in EU is still below 0.5% of overall diesel and petrol consumption, mainly in captive fleets that operate on pure biofuels and supported through different tax exemption schemes (European Commission, 2001). Currently, Germany, Austria and Sweden use 10% pure biodiesel in adapted vehicles. In France, biodiesel is blended at 30% in captive fleets and also used in blends of 5% in normal diesel fuel. In Italy, it is blended at 5% in normal diesel fuel.

Following the EU Directive 2003/30, the Greek government has launched in 2005 a new law L. 3423/05 (ΦΕΚ 304/A/13.12.2005) for the introduction of biofuels in the existing Greek fuel market. According to this, biodiesel will be the main biofuels for the Greek transport sector with bioethanol playing a less important role until 2008. The amount of biodiesel required to satisfy the indicative target of 5.75% (on a lower calorific basis) for the year 2010 has been estimated to be 148,000 tones, while the amount of bioethanol required to satisfy the same target for the year 2010 has been estimated to be 390,000 tones. According to the same study, sunflower oil, cotton seed oil and corn oil are defined as the immediately available resources for indigenous biodiesel production. Biodiesel today in Greece is used in a 2% blend. The market of pure biodiesel does not exist at the moment but it is expected to be developed slowly in the coming years. According to the estimated demand of diesel on 2010, the required quantities of biodiesel in 2010 are about 148.000 tones. Currently there are two plants in Greece for the biodiesel production. The first is located in Volos (in Central Greece) and is of capacity 40.000 tones of biodiesel per year, whereas the second is located in Kilkis (in North Greece) and is of the same capacity. Both of them are able to treat the used vegetable oils. The installation of anew plant for biodiesel production is under evaluation in Crete, having a capacity of 5.000 tones per year.

2 Brief overview of the Greek transport sector

Over the past decade passenger transport demand increased in the countries of European Union. Greece followed also this trend. The main underlying factor is the growth in incomes in conjunction with a tendency to spend the shame share of disposable income on transport. The passenger daily distance travelled by EU-15 citizens increased from 32 km in 1991 to 37 km in 1999, the fastest-growing modes of transport being private car and aviation (EEA, 2005). Furthermore, greenhouse gas emissions from EU Member states (emissions from international transport) represented 4% (167 million tones CO_2 equiv) of the total EU emissions in 1990 and 5% (224 million tones CO_2 equiv) in 1998. Cutting transport emissions without stifling the economic growth and development poses a steep challenge for policymakers.

The Greek transport energy consumption increased by approximately 27% between 1992 and 2003 following an annual growth rate of 2, 2% (Fig.1). Transport and energy consumption are closely linked since more transport generally consumes more energy. Given the fact that transport demand is closely linked to economic growth, it is useful to examine the trends in Greece's transport energy consumption and G.D.P. Figure 1 shows an upward trend both in transport consumption and G.D.P over the period from1992 to 2003.

Road dominates final energy consumption in transport in Greece. In 2001, road transport was responsible for 81% of transport energy consumption in comparison to 77% in 1991. The share of aviation energy consumption decreased from 22% in 1991 to 18% in 2001. The shares of rail are around 1% both in 1991 and 2001 and have remained stable over the past decade (Fig.2). It is obvious that road transport is the dominant factor regarding Greece's transport energy consumption. The transport sector in Greece is highly depended on oil products. In 2001, 99, 5% of the energy consumed in transport derived from oil products (Fig.3). Overall growth in passenger transport demand has been similar to that of GDP. The number of passenger-kilometers traveled in Greece has increased since 1970 (Fig.4). This is in accordance with the economic growth noticed for the same period. The share of the more environment friendly modes (bus, coach, rail and tram/metro) in 2002 reached 19% whereas the share of passenger cars and air transport reached 81% (Fig. 5).

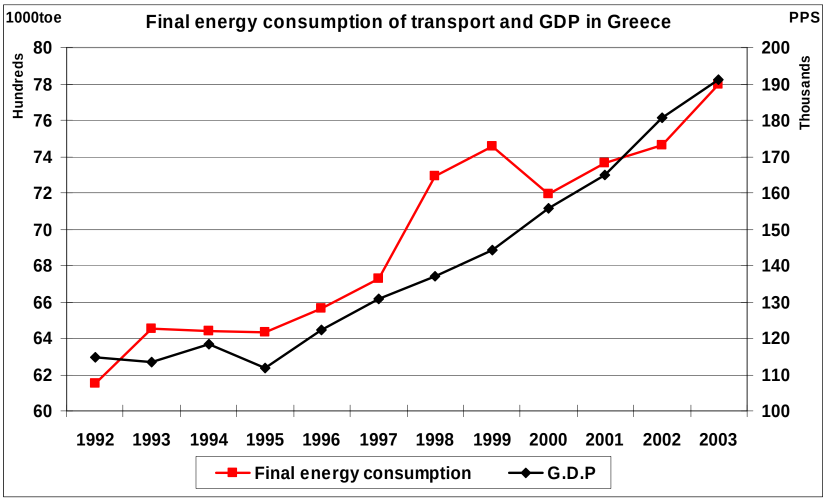


Figure 1 - Final energy consumption by transport (expressed in 1000toe) and G.D.P. (expressed in millions of purchasing power standar) in Greece over the period 1992-2003 (Eurostat-Europa, 2005).

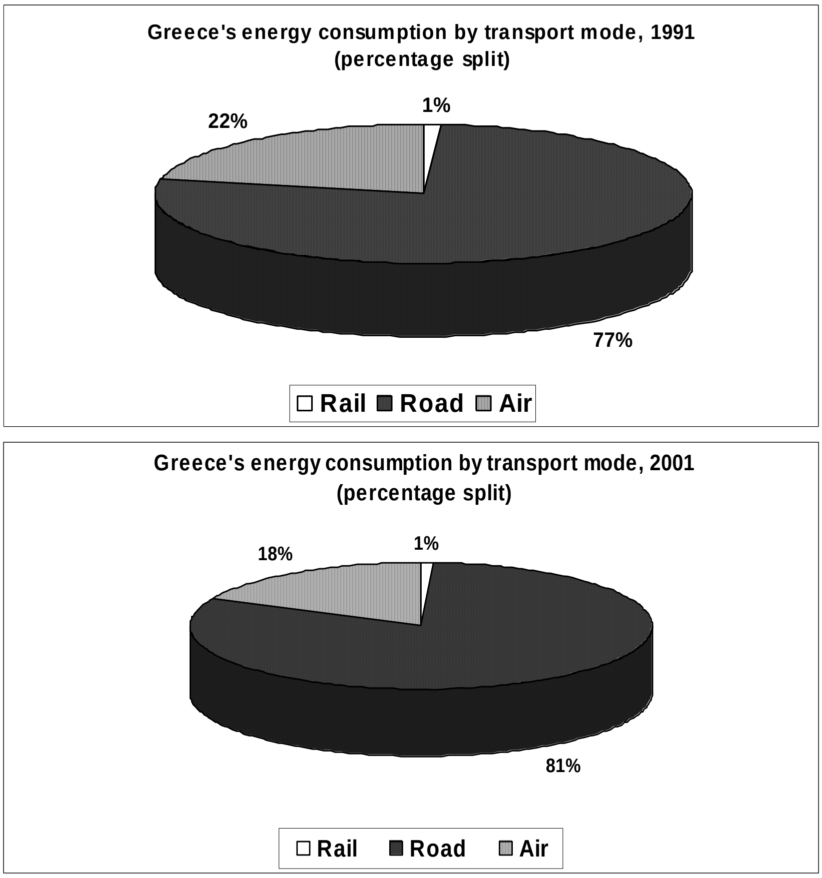
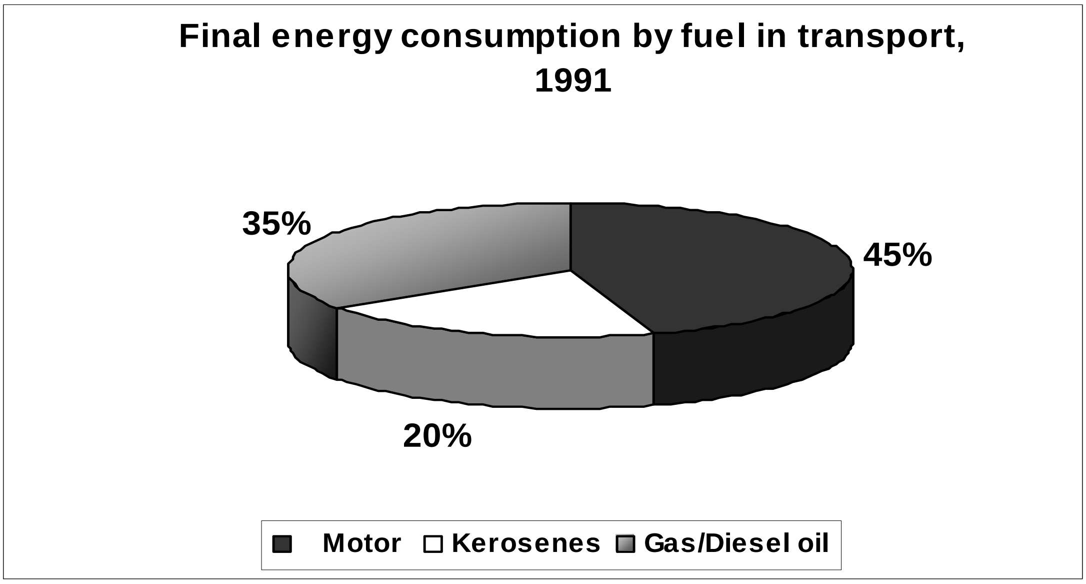


Figure 2: Greece's distribution of energy consumption by transport mode (in ktoe) in1991 and in 2001 (Eurostat-Europa, 2005).



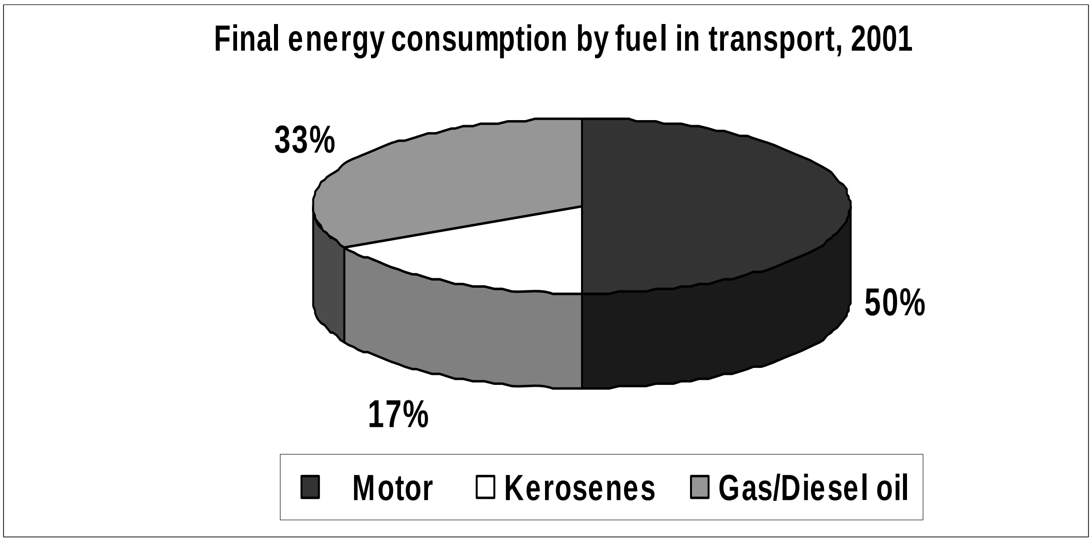


Figure 3: Greece's final energy consumption (in ktoe) by fuel in transport in 1991 and 2001.

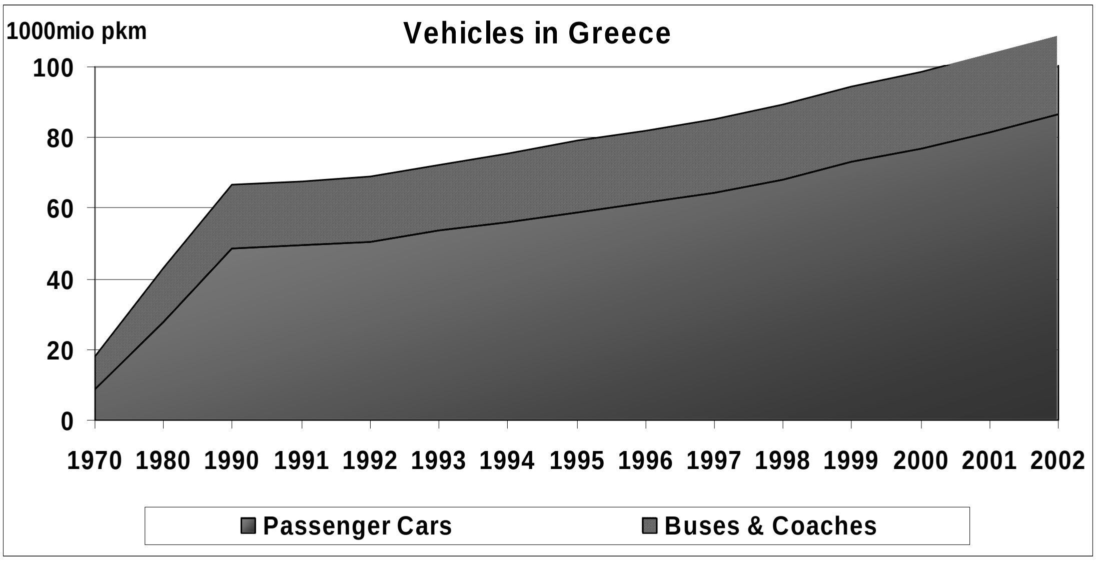


Figure 4: Passenger transport by cars, buses and coaches for Greece (Eurostat Statistics, 2004).

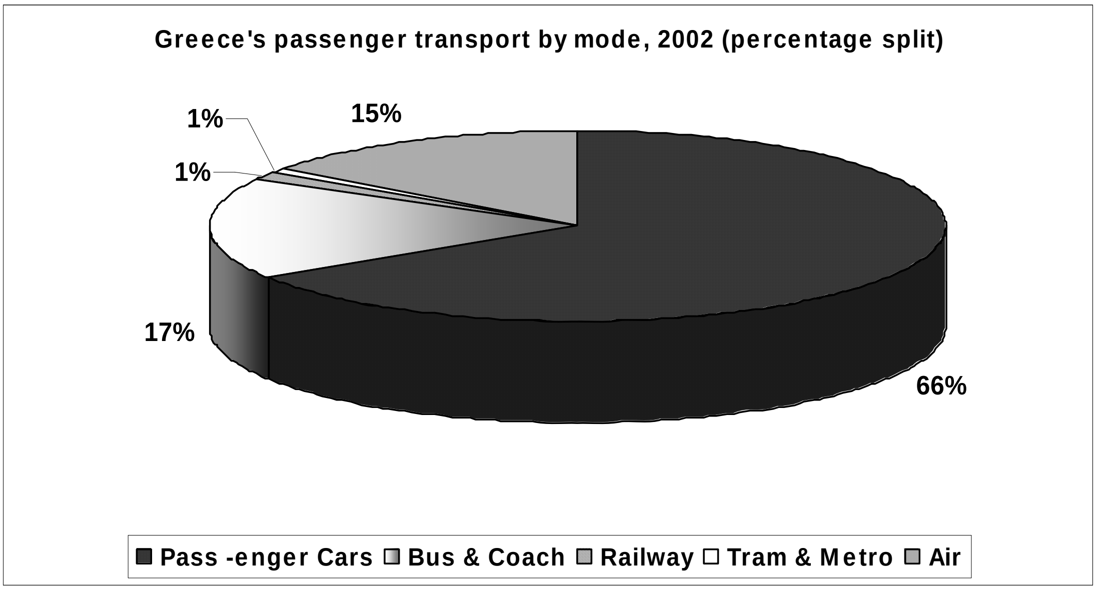


Figure 5: Greece's passenger transport by mode in 2002 –passenger –km in %-

3 Environmental Impacts

Poor air quality has a negative effect on health, ecosystems, crops and buildings. The primary pollutants from internal combustion engines are oxides of nitrogen (NOx), Total Organic Compounds (TOC), carbon monoxide (CO) and particulates, which include both visible (smoke) and non visible compounds. Nitrogen oxide formation is directly related to high pressures and temperatures during the combustion process and to the nitrogen content of the fuel. The other pollutants, namely HC, CO and smoke are primarily the result of incomplete combustion. Ash and metallic additives in the fuel also contribute to the particulate content of the exhaust. Furthermore, sulphur compounds, mainly sulfur dioxide are directly related to the sulfur content of the fuel (EPA, 1979). Switching to more environment-friendly fuels, e.g. biofuels contributes to lowering the environmental pressure from fuel consumption; though the impact on the environment of biofuels use is still being debated. A main problem could be the impact of fertilizer and pesticide use, which could in some production systems balance the positive effect of fossil fuel substitution., due to the fact that some biofuels crops are "fertilizer- and pesticide- intensive" crops.

Since biodiesel is made entirely from vegetable oil, it does not contain any sulphur, aromatic hydrocarbons, metals or crude oil residues. The absence of sulphur means a reduction in the formation of acid rain by sulphate emissions which generate sulphuric acid in atmosphere. The reduced sulphur in the blend will also decrease the levels of corrosive sulphuric acid accumulating in the engine crankcase oil over time.

The fuel properties of petroleum diesel and biodiesel are summarized in Table 1. The high cetane rating of biodiesel (ranges from 49 to 62) is another measure of the additive's ability to improve combustion efficiency, since the cetane number of the fuel is a measure of its ignition quality. The flash point is a measure of the temperature to which a fuel must be heated such that a mixture of the vapor and air above can be ignited. The flash point of neat biodiesel is typically greater than 93^{o}C; out of this reason biodiesel and blends of biodiesel with petroleum diesel are safer to store, handle and use than conventional diesel fuel.

As far as the energy balance is concerned, it should be noted that biodiesel yields 3.2 units of fuel product energy for every unit of fossil energy consumed in its life cycle. On the other hand, petroleum diesel's life cycle yields only 0.83 units of fuel energy per unit of fossil energy consumed. The energy yield of biodiesel is 280 percent greater than petroleum diesel fuel (USDA, 1998). Table 2 summarizes the aforementioned. The positive energy ratio displayed by ethanol and biodiesel is attributed to the contribution of solar energy collected by the crop from which the fuel is made. This energy is considered "renewable" because a new crop is raised each year. Fossil fuels, on the other hand, originate from fossilized plants and animals stored beneath the earth's surface in a process that took million of years.

Table 1: Fuel properties of diesel and biodiesel **(**www.doe.gov, 2000**)**

Fuel property	*Diesel*	*Biodiesel*
Fuel Standard	ASTM D975	ASTM PS121
Fuel Composition	C10-C21 HC	C12-C22 FAME
Lower Heating Value, Btu/lb	130,250	120,910
Kin.Viscosity, @ 40^{o}C	1.3-4.1	1.9-6.0
Specific Gravity kg/l @60^{o}F	0.85	0.88
Water, ppm by wt.	161	.05% max.
Carbon, wt%	87	77
Hydrogen, wt%	13	12
Oxygen, by dif. wt%	0	11
Sulphur, wt%	.05 max	0
Boiling Point ^{o}C	188 to 343	182 to 338
Flash Point ^{o}C	60 to 80	100 to 170
Cloud Point ^{o}C	-15 to 5	-3 to 12
Pour Point ^{o}C	-35 to -15	-15 to 16
Cetane Number	40 to 55	48 to 60
Autoignition Temperature ^{o}C	316	
Stoichiometric Air/Fuel Ratio, wt./wt.	15	13.8
BOCLE Scuff., grams	3,600	>7,000
HFRR, microns	685	314

Table 2: Energy balance/Energy Life Cycle Inventory (USDA,1998)

Fuel	*Energy yield*	*Net Energy (loss) or gain*
Gasoline	0.805	(19.5 percent)
Diesel	0.843	(15.7 percent)
Ethanol	1.34	34 percent
Biodiesel	3.20	220 percent

Comparison of emissions

Table 3: Average biodiesel emissions compared to conventional diesel (www.epa.gov)

Emission Type	*B100*	*B20*
Regulated		
Total Unburned Hydrocarbons	-67%	-20%
Carbon Monoxide	-48%	-12%
Particulate Matter	-47%	-12%
Nitrous Oxides	+10%	+2% to -2%
Non- Regulated		
Sulfates	-100%	-20%
PAH (Polycyclic Aromatic Hydrocarbons)	-80%	-13%
Nitrated PAH's	-90%	-50%
Ozone potential of speciated HC	-50%	-10%

It is pointed out that:

- Due to better combustion, its exhausts contain less smoke
- It does not contain sulphur. Thus, sulphur dioxide is not produced during combustion.
- It is biodegradable. Biodiesel leaks do not pollute the ground, underground, water table, seas and lakes. A 10% biodiesel mixture is biodegraded 4 times as fast as petroleum diesel.
- The carbon dioxide produced by combustion is equal to that previously absorbed from the atmosphere by the plants used to produce biodiesel.

Greenhouse Gas Emissions

Table 4 lists full fuel-cycle CO_2 emissions for a range of transport fuels expressed in g CO_2/ MJ. From this table, it is obvious that reductions in greenhouse gases per MJ result from the substitution of CNG and LNG with diesel. The reductions are more apparent when biofuels are utilized, whereas for LSD and ULSD there is a small penalty due to higher production overheads. In terms of emissions reductions, different blends percentages contribute to different levels of emissions reductions when compared to diesel (Figures 6, 7).

Table 4: Full fuel-cycle CO_2 emissions for a range of transport fuels - g CO_2/ MJ (Beer et al, 2000; Sheehan et al., 1998).

Process	*Fuel production*	*Combustion*	*Total*	*Reduction in emissions cf. stnd diesel (%)*
Diesel	11	69	80	0
LS[1] diesel	12	69	81	+1.25
ULS[2] diesel	13	69	82	+2.5
LPG	11	69	80	0
CNG	6	54	60	-25
LNG	9	55	64	-20
E95[3]	-29	65	36	-55
BD20[4]	2	73	75	-6.25
BD100[5]	-41	89	48	-40

Note: LS[1] diesel = low sulphur diesel; ULS[2] diesel -= ultra low sulphur diesel ; E95[3] = hydrated ethanol (95% ethanol, 5% water) ; BD20[4] =80% diesel/ 20% biodiesel; BD100[5] = 100% biodiesel.

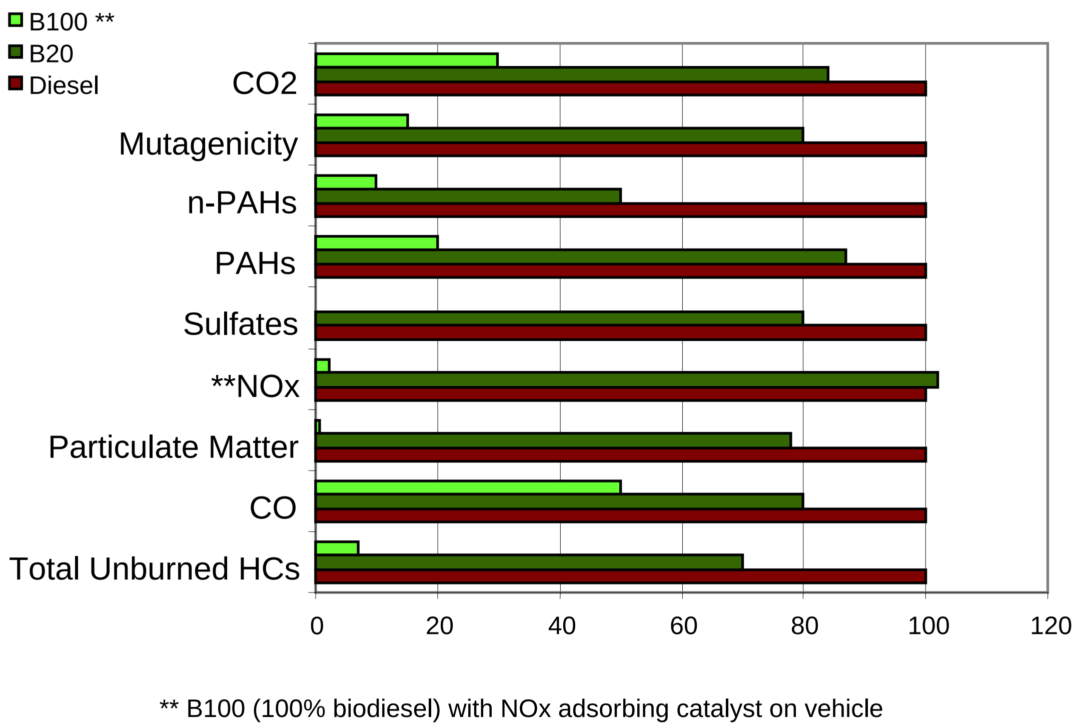


Figure 6: Relative emissions of diesel and biodiesel

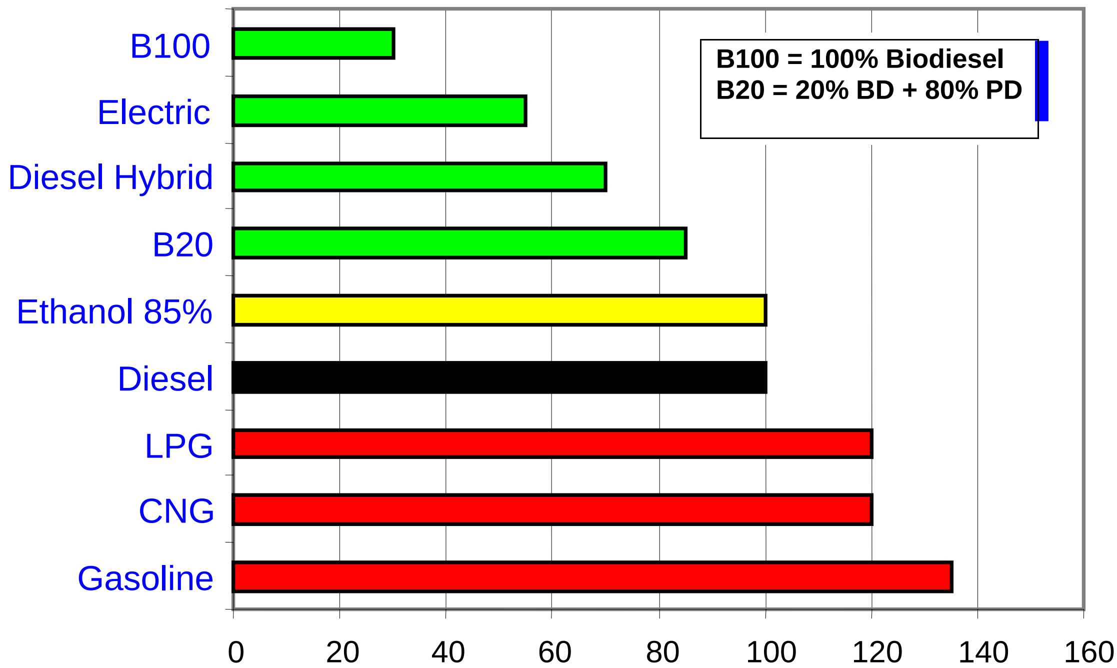


Figure 7: Relative greenhouse gas emissions

Human Health Impacts of Pollutants

The lack of toxic and carcinogenic aromatics (benzene, toluene and xylene) in biodiesel means the fuel mixture combustion gases will have reduced impact on human health and the environment. The ozone (smog) forming potential of biodiesel hydrocarbons is less than diesel fuels.

Air pollutants such as particulate matter, ozone and NO_2 constitute a serious respiratory risk. Hydrocarbons and oxides of nitrogen combine under certain conditions to form photochemical smog, which exacerbates respiratory illness and leads to asthma attacks, acute respiratory symptoms, restricted activity and premature mortality. Carbon monoxide can affect the performance of the lungs, brain and blood circulation. Particulate emissions can cause amenity problems due to smoke, odor and the staining and deterioration of buildings. Particulates the size of 10μm and smaller (PM $_{10)}$ are thought to contribute to cancer in some cases.

The valuation of the aforementioned externalities is still developing. The average health cost savings associated with hydrocarbon emissions are listed in Table 5.

Table 5: Average capital health cost savings per tone of emission (Coffey Geosciences, 2003).

Emission Type	*Air Quality Impact*	*Health Savings ($/tone)*
CO	Carbon monoxide	$12.90/ € 9.6
NO_X	Nitrogen dioxide	$58.70/ € 43.6
NO_X	Ozone	$8,500/ € 6,310
Particulates (PM_{10})	Particulates	$232,000/ € 172,270
HC	Air toxic emissions	$2,200/ € 1,634

Note: Health savings associated with hydrocarbon emissions based on US EPA (2003) values

4 The case study of Athens

Athens metropolitan region is the most populous area in Greece with 3.7 million people. The region covers an area of 1,450 $km^{2,}$ 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 (5,882 people per square kilometer).

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.

More than 75% of the population of the European Union lives in urban areas. Out of this reason urban transport accounts for a significant part of total mobility ans en even greater proportion of damage to public health and to buildings. Public transport accounts for more than 50% of all motorized trips in the densest parts of most European metropolitan areas. Public transport in Athens accounts for 13% of passenger-kilometers travelled.

Public transport in Athens consists of buses, a subway system (metro) as well as tram. ETHEL is the company that operates the buses that serve the capital. The bus network consists of 311 bus lines, for a total network length of about 7,000 km. The 2,000 buses in operation make a total of about 16,000 trips per day (www.oasa.gr). On the demand side, the daily traffic is of 1,300,000 passengers. The average bus speed in the city centre is 7km/h; whereas in areas outside the city centre the average speed increases to 13km/h. To be more specific the bus line network in Athens is composed of the following lines:

- 40 core lines that connect the city centers of Athens and Piraeus with the centers of the peripheral municipalities.
- 20 inter-municipal lines that connect the municipalities of the Attica basin without crossing the city centers of Athens and Piraeus.
- 123 local lines that operate within the limits of one or a group of neighboring municipalities and act as suppliers to the core lines.
- 19 express lines
- 7 school lines

Currently there are 1,822 buses in operation during peek hours, against 1,490 buses in peak hour circulation in 1997. Within the bus fleet in Athens 416 buses run on natural gas, 656 buses are of average age and 1,443 utilize modern environmentally- friendly technology.

The trolley bus network has 22 lines, for a total network length of about 360 km. A total of 2,500 daily trips are made by a fleet of 366 trolley buses. The passenger traffic is of about 300,000 passengers per day. As far as the metro is concerned, there are three lines in total while there are 45 stations for a total network length of about 50 kilometers. On the demand side, there are about one million passengers per day. It should be mentioned that new subway lines are under construction.

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 (www.emta.com, 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.

As far as the cost of urban transport is concerned, it should be noticed that the price of a single ticket valid for one bus trip in centre of the metropolitan area of Athens reaches 0.50 euros, whereas the price of a single ticket valid for one metro trip is 0.70 euros. The price of monthly pass in centre of the metropolitan area of Athens comes up to 35euros.

The speeds follow a spatial distribution. Therefore, in Athens the average speed is 18km/h in the central area, 22km/h within a 4km radius of the central area and 30 km/h in the rest of Greater Athens and 48 km/h outside this area in the Attica Region (NTUA, 2001).

Tailpipe emissions analysis by United States Department of Energy and the USDA, entitled, “Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus” shows that the overall lifecycle emissions carbon dioxide from biodiesel are 78% lower than the overall carbon dioxide emissions from petroleum diesel. Moreover, the overall lifecycle emissions of carbon monoxide emissions from biodiesel are 35% lower than overall carbon monoxide emissions from diesel. The study also finds that the overall lifecycle emissions of particulate matter from biodiesel are 32% lower than overall particulate matter emissions from diesel. It is noticed that biodiesel reduces the total amount of particulate matter soot in bus tailpipe exhaust by 83.6%. Soot is the heavy black smoke portion of the exhaust that is essentially 100% carbon that forms as a result of pyrolisis reactions during fuel combustion. The emissions of hydrocarbons are 37% lower for biodiesel than diesel fuel. However, the overall lifecycle emissions of hydrocarbons from biodiesel are 35% greater than overall hydrocarbon emissions from diesel. Nevertheless it is noted that emissions of hydrocarbons have localized effects. The overall lifecycle emissions of sulphur oxides from biodiesel are 8% lower than overall sulphur oxides emissions from diesel. Furthermore, it is stated that an urban bus that runs on biodiesel has tailpipe emissions of nitrogen oxides that are only 8.89% higher than a bus operated n petroleum diesel. Additionally, in urban bus engines, biodiesel and B20 exhibits similar fuel economy to diesel fuel (based on a comparison of the volumetric energy density of the two fuels); thus, the use of biodiesel in a part of the bus fleet of Athens, would be a challenge in improving the air quality.

Based on the aforementioned, the options- concerning the bus fleet- for the reduction of emissions in the metropolitan area of Athens include:

Retrofitting of buses using one of the following methodologies : **a)** Diesel Oxidation Catalyst (open channel devices installed in exhaust line), **b)** Continuous Regeneration Diesel Particle Filters – CRDPF (wall flow devices installed in the exhaust line combined with a DOC to enable NO_2 – based regeneration, **c)** Fuel-Borne Catalyst Diesel Particle FILTERS –FBDPF (wall flow devices installed in the exhaust line, it requires a fuel-borne catalyst to facilitate soot combustion, **d)** Exhaust Gas Recirculation (recycling of exhaust gas in the cylinder to reduce flame temperature and thus NO production), **e)** Selective Catalytic Reduction (open channel devices with urea injection for the reduction of NO_x to nitrogen and water.

- Using Ultra Low Sulphur Diesel in buses
- Using Ultra Low Sulphur Diesel and retrofitting
- Using B20 (refueling) in buses and retrofitting
- Using B100 in buses in summer months

The use of biodiesel in a fleet of diesel engine vehicles in the region of Athens as well as the acceptance of using biodiesel by the purchasing public as its sale in some service stations of fuels is of great significance. The assessment of these alternatives concerning the metropolitan area of Athens could be achieved with multi – criteria decision aid method.

5 Discussion-Conclusions

The imperative to reduce greenhouse gas emissions and minimize the possibility of destructive global warming - stemming from a city's transport system - it is likely to be felt more acutely in the next years throughout the world. In order to find the best alternatives it is important to understand how a city runs its transport system, how it produces different levels of CO_2 emissions and some of the underlying reasons for these patterns. In addition, the European's Commission's White Paper "Energy for the Future: Renewable source of energy "sets out the objective to raise the share of renewable energy sources to 12% of the Union's gross domestic energy consumption by 2010. With respect to fuels, the objectives of a 7% use f biofuels in 2010, and a target of 20% for all fuel substitutes for 2020 is also included.

Greece has a large number of crops, which can be made available for the production of biodiesel, of which sunflower oil and cotton-seed oil are expected to play an important role, along with rape-seed oil. Sweet sorghum, which has a higher bioethanol yield per hectare than sugar beet, is expected to play an important role in the production of bioethanol.

The challenge for future urban transport systems will be to meet the demand for accessibility for people, while at the same time minimizing the impacts on the environment with safeguarding the quality of life. This is particularly true, in the field of public transport, where decisions affect the daily lives of millions of people and where the investment and operation costs of complex systems often amount to millions of euros. They also have a determinant impact on the economic dynamism and environmental quality of urban areas. The implementation of a sustainable transport strategy in the metropolitan area of Athens is of great importance; nevertheless further analysis and research is required, in order to find the best solution in terms of sustainability.

This study can be considered as an opportunity for further research to resolve these concerns and evaluate the available options.

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