

COMPARATIVE LCA OF THE USE OF BIODIESEL, DIESEL AND GASOLINE FOR TRANSPORTATION

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Abstract

The perspective of climate change, the high energy prices and the oil supplies have driven a strong interest in alternative transportation fuels. 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.

This study compares the environmental impacts of the use of gasoline, diesel and biodiesel in Greece using the scope and results of the LCA (Life Cycle Assessment) methodology. The environmental profiles of the automotive fuels are compared for the different impact categories taken into account in the study.

From the environmental point of view, biodiesel appears attractive since its use results in significant reductions of GHG emissions in comparison to gasoline and diesel. It also has lower well-to-wheel emissions of methane. However, the use of biodiesel as transportation fuel increases emissions of PM₁₀, nitrous oxide, nitrogen oxides (NO_x) as well as nutrients such as nitrogen and phosphorous; the latter are the main of agents for eutrophication.

Key words: Life Cycle Analysis; Greece; biodiesel; fossil fuels

1. Introduction

In Europe the transportation sector is responsible of the 27.4% of all greenhouse gas emissions in the EU, which contribute to the climate change [1]. In addition, the forecasted EU-25 energy consumption demands, in 2010, are estimated to be around 390 Mtoe [2]. For this reason the fulfillment of the Kyoto Protocol objective is essential to meet solutions to reduce the GHG of the transportation sector. In the Kyoto Protocol, the developed countries have committed to a reduction of their CO₂ emissions by 5% (8% in the European Union) to 1990 levels in the commitment period 2008-2012. For the year 2020, the target is set to 20% below 1990 levels for all EU-27 Member States of EU.

Towards that direction actions such as cutting energy consumption, increasing energy efficiency and carbon sequestration, the decarbonisation of energy supply by expansion of renewable energies is considered as a viable solution for a sustainable transport future. An increased usage of biofuels can contribute to reduce

CO₂ emissions in road traffic. In addition, biofuels produced from waste residues- having similar attributes to fossil fuels- can be used, using existing infrastructures and employed in the current engines not only in a mixed mode but also in pure state (especially for biodiesel). Nevertheless, a social opposition has risen, during the past years, against biofuels, bringing up concerns about environmental sustainability, energy utilization concerning the energy performance, feedstock availability and production cost.

The development of the biofuels industry in Europe has led to a lot of environmental studies and today, energy and greenhouse gases balance over their whole life cycles is well known [3-6]. In addition, a lot of comparative studies concerning comparative studies of biodiesel and fossil diesel fuel have been made [7-14] reflecting the ongoing interest in the environmental assessment of biofuels.

The United States, Brazil and China are the world's largest ethanol producers, producing 4.8, 4.5 and 1 billion gallons respectively in 2006 [15]. In Europe, more biodiesel is produced than ethanol, with rapeseed used as the primary feedstock. The total EU27 biodiesel production for 2007 was over 5.7 million metric tons, an increase of 16,8% from the 2006 figures [16]. Germany with a production of 2,890 thousand metric tons was the leader in 2007. France and Italy followed with productions of 872 thousand metric tons and 363 respectively. Biodiesel is mainly produced from oil crops (such as rapeseed and sunflower), waste cooking oils or animal fats. The extracted oils are converted by transesterification with an alcohol (usually methanol) to produce biodiesel. Biodiesel is generally accepted to be fully blendable with conventional diesel (blending up to 5-10%), except for certain considerations when using high-percentage biodiesel blends or neat biodiesel. In the case of Greece, the use of biodiesel as an alternative diesel fuel, will improve the environment, reduce imports and increase the use of renewable fuels. Biodiesel can be produced from various vegetable and/or animal oils with methanol or ethanol yielding methyl or ethyl ester with glycerol as by-product.

Nevertheless the production of biodiesel entails emissions to the environment such as fertilizers during plantation and emissions from fuel use during oil extraction, transportation, etc. Thus, the environmental implications of biodiesel production need to be addressed. Life Cycle Assessment can be used for such an evaluation. The objective of this study is to perform a comparative analysis of biodiesel from rapeseed and conventional diesel as well as petrol using the methodology of Life Cycle Assessment. This comparison has been achieved using the Eco-Indicator 99 method [17] and is throwing light into the question whether the production of biodiesel is comparable to the production of the aforementioned fossil fuels, from an environmental point of view, taking into account all stages of the life cycle of these products.

2. Legislation – Greek Experience

The Directive 2003/30/EC [18] on the promotion of the use of biofuels and other renewable fuels for transport, urges to Member States to ensure that a minimum proportion (2% in 2005 and 5.75% in biofuels and other renewable fuels is placed on their markets. Following this Directive, the Greek government has launched late in 2005 a new law L3423/05 (ΦΕΚ 304/Α 13.12.2005) for the introduction of biofuels in the existing Greek fuel market. The 1st National Report estimates that 148,000 tonnes of biodiesel would be needed to fulfill the 5.75% target by the end of 2010 [19].

The distribution of biodiesel in Greece started in December 2005 when the first batches were distributed to refineries by Hellenic Biopetroleum S.A. The blend of 2% biodiesel by volume in automotive diesel has been distributed to all final consumers since February 2006. This percentage was raised to 3.5% by volume (71,851 tonnes) by about the end of 2006, and reach 5% (97,695 tones) in 2007 [20]. It should be mentioned that the raw materials used by the biodiesel production units in 2006, comprise about 70% of imported oils – mostly rapeseed and soyabean oils- while the remaining 30% consist of domestically produced oils such as cotton-seed, sunflower and used cooking oils [21]. The cost of producing biodiesel from sunflower (0.53€/lt) and its breakdown in distinct cost components is shown in [Figure 1](#).

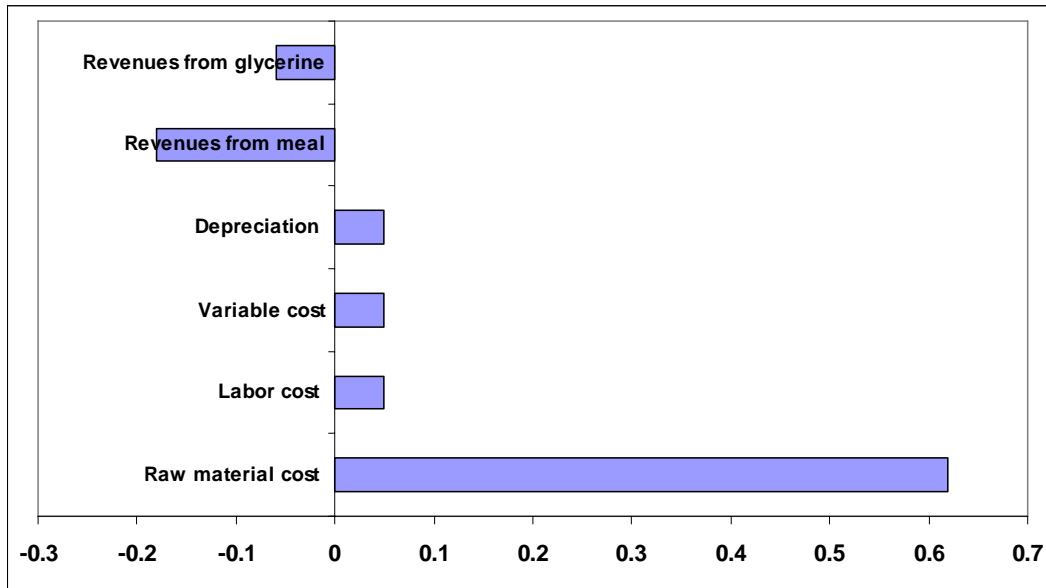


Figure 1: Costs and revenues from biodiesel production [22]

The total agricultural area of Greece is 3.8 billion ha mainly consisting of arable (56%) and tree (30%) crops [23]. The main vegetable oils produced in Greece consist of soy oil, sunflower oil and cottonseed oil with respective seeds being either domestically produced or imported –mostly in the case of soy. In 2005 most of the oilseeds produced locally were cottonseeds (720,000 tonnes), which produced 39,000 tonnes of cottonseed oil. About 26,000 tonnes of sunflowerseeds were produced in 2005; the quantity rose to 31,000 tonnes in 2006. Both soy oil and cottonseed oil have average prices around 600 €/tn, while sunflower oil price is much higher coming up to 890 €/tn in 2004 [19]. As far as the oil crops are concerned, the main existing options consist of cotton, sunflower and soy.

The consumption of automotive diesel fuel used in transport in Greece for year 2002 amounted to 1,925,000 tons [19]. It is noted that the biodiesel distributed in the Greek market meets the EN 14214 specifications. The end products under the specifications of EN 14214 for bio-auto fuels have valuable energy content representing a good degree of replacement relative to fossil-fuels (Table 1). Nevertheless, Greece has one of the lowest EU Hydrocarbon Tax for fossil fuels which makes the competitive position of biofuels more difficult: Greece (30 €/liter), Spain (40.3 €/ liter), Germany (66.5 €/liter), UK (68 €/liter), France (59 €/liter).

Fuel	Energy content (MJ/l)	Energy content ratio
Bioethanol (BE)	21.2	1.472 (BE/FG)
Fossil Gasoline (FG)	31.2	0.679 (FG/BE)
Biodiesel	32.8	1.088 (BD/FD)
Fossil Diesel (FD)	35.7	0.919 (FD/BD)

Table 1: Properties of fossil fuels and biodiesel [24]

3. Methodology

Life Cycle Assessment has been chosen as the methodology to qualitatively evaluate the environmental loads of the studied fuels. The Society of Environmental Toxicology and Chemistry and the International Organization for Standardization [25-28] developed in the 1990s modern LCA methodology. The methodology used falls under the international standards series ISO 14040. The main stages in the

forementioned methodology include: Goal definition and scoping, Inventory analysis, Impact assessment, Interpretation. The goal of this study is to evaluate the environmental performance of biodiesel, based on a life cycle perspective. The assessment includes the extraction of primary raw materials as well as the combustion of the fuels in the car engine. The system boundaries do not include the production of capital goods, risks and human labour. Final transportation to the fuel station is not considered as the average distance as well as the means of transportation are assumed to be the same for the aforementioned fuels. Greece is considered to be the geographical reference area for the fuels life cycle. As far as the functional unit is concerned, this is defined in the ISO standard as a “quantified performance of a product system for use as a reference unit in a life cycle assessment”. In this study, 100 km -covered with a middle-size and recent car- is chosen as the functional unit. Life Cycle Assessment is conducted using the Eco-Indicator 99 method, in the hierchist perspective.

Biodiesel is assumed to be rapeseed methyl ester (RME), which is produced by transesterification of rapeseed oil [29]. The LCA processes for biodiesel and the fossil fuels in this study start with the cultivation of the rapeseed grains. After the growth and harvest of plants, the grains are dried and then oil is extracted in two steps, followed by an extraction with an organic solvent (hexane). The solvent is separated and recycled, while a small quantity is lost (emission to air). Oil and rapeseed meal are generated. Transesterification of the oil produces methyl esters (biodiesel) and glycerol, which is purified and then used in chemical industry.

The production of the fertilizers and pesticides, soils emissions of N₂O, the consumption and emissions of the tractors (fertilizing, tillage, sowing, harvesting, and transport) as well as the valorization of by-products are taken into consideration. The aforementioned data are listed in Table 2 [19; 30-31]. It is noticed that all transportation steps are taken into consideration. Table 3 presents the energetic and chemical consumptions of the rapeseed processes [31]. As far as the final use is concerned, it is noted that the exhaust emissions and fuel consumptions of the vehicles were calculated on the basis of those of the fossil fuel vehicles. It is assumed that the efficiencies of the motors (in MJ/km) and the greenhouse-gas emissions (g/km)- with the exception of fossil carbon dioxide- to be the same for the biodiesel and the fossil fuels [5;32]. According to EPA [33], the use of biodiesel leads to a decrease of the emissions of particulates (47%) and VOC (67%), but also to an increase of NO_x emissions (10%). Based on the aforementioned data and the emissions of fossil fuels the emissions of a middle sized car running on biodiesel were calculated (Table 4).

	<i>Rapeseed (kg/ha)</i>
Energy consumed (MJ/kg)	110.3
N fertilizer	144
K ₂ O	74
P ₂ O ₅	74
Pesticides	2.2
Rapeseed produced	1300

Table 2: Energy used for the production of oilseed rape [19; 30-31]

	<i>Heat (MJ/ t RME)</i>	<i>Electricity (kWh/t RME)</i>	<i>Chemicals (kg/t RME)</i>	<i>By-products (kg/t RME)</i>
Drying	812	33	-	
Extraction	2317	106	Hexane:2.7	Meal: 1582
Refining	162	11	-	-
Esterification	947	37	Methanol: 109	Glycerin: 100

Table 3: Mass and energy balance of biodiesel production [31]

	<i>Petrol</i>	<i>Diesel</i>	<i>Biodiesel</i>
Consumption (MJ/100KM)	223.5	183.1	183.1
CO₂-fossil (kg/100km)	16.6	13.4	0.74
CH₄ (mg/100km)	2.4	7.6	7.6
N₂O (mg/100km)	0.129	0.0645	0.0645
NO_x (mg/100km)	10.2	25.6	28.2
Particulates (mg/100km)	0.5	3.56	1.89
NM VOC (mg/100km)	2.53	9.59	3.17

Table 4: Energetic consumption and exhaust emissions of vehicles [33; 35]

Finally, the life cycle of gasoline and diesel is established using the SimaPro 5.0 [34] databases. Greenhouse gases emissions as well as fuel consumptions data came from the comparison of literature sources [5; 32]. Calculations concerning NO_x, VOC and particulate emissions from the car are based on the Annual certification test results, 2005, of the US Environmental Protection Agency [35].

4. Environmental impacts

The biofuels environmental impact depends on different factors. The raw materials used to obtain the biofuels, the different production processes and the final use can determine the environmental balance of biofuels introduction. Biofuels' supply chain follows the typical approach of biomass production, biofuel processing, distribution and consumption. Several climatology factors (type of soil, weather etc) have a strong influence on environmental impact. Additionally, other significant factors are the past land-use, the production or not of by-products, the technological process path as well as the relative use of the end fuel either in a mixed or in a pure mode.

Comparative LCA has been carried out between biodiesel versus gasoline and diesel. The results about fossil energy consumption and GHG emissions along the whole chain show the environmental benefits of biodiesel use in Greece. Environmental impacts associated with air emissions and fossil fuel usage is shown in Figure 2, where the environmental profiles of the three automotive fuels are compared for the different impact categories taken into account in this study. The environmental impacts taken into consideration include: organic respiratory effects, inorganic respiratory effects, fossil fuels, acidification - eutrophication, greenhouse effect, ecotoxicity and carcinogenic effects. The fuel with the highest contribution to a particular environmental effect is indicated with 100% bar. The use of biodiesel instead of fossil diesel fuel produces environmental advantages as well as disadvantages. Biodiesel is beneficial with respect to the saving of fossil energy and to the greenhouse effect; nevertheless is detrimental regarding acidification, inorganic respiratory effects and ecotoxicity. The better environmental score for the greenhouse effect can be attributed to the fact that rapeseed assimilates CO₂ during its growth. It is estimated that every ton of fossil diesel adds about 2.8 tons of CO₂ to the atmosphere. The specific carbon content of 1 ton bio-diesel is slightly lower, about 2.4 tons of CO₂. As far as the category of inorganic respiratory effects is concerned, it is noticed that biodiesel has a significant impact, mainly due to the increase of the exhaust emissions of NO_x of the vehicle. It is obvious that the impacts of biodiesel are significantly lower than those of gasoline and diesel, primarily due to sharp reductions in CO₂.

The results of global environmental impacts after weighting are presented in Figure 3. Nevertheless, it should be interpreted with caution, due to their subjective aspect. The benefit of biodiesel in comparison to other fossil fuels is obvious.

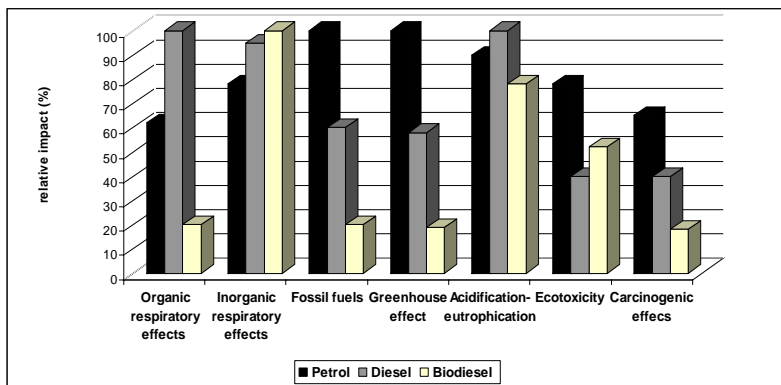


Figure 2: Comparison of the environmental impacts of the automotive fuels

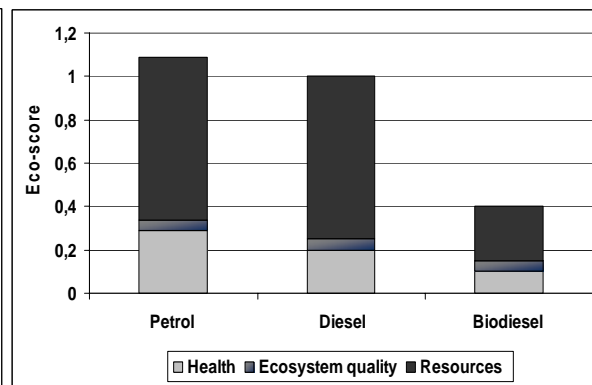


Figure 3: Environmental impacts after weighting

5. Discussion – Conclusions

The results of the present study can be used as an input to the strategic decision-making process for future transport energy policy and also to identify key areas of interest for further technology research and development of the Greek transport system. Biofuels Life Cycle Analysis can be considered as a valuable tool, offering flexibility to the system parameterization and to the integrated evaluation of their environmental impacts and their performance in general. Furthermore, it can be a useful tool in the process of strategic and integrated transportation planning, since it takes into account environmental, technical and cost considerations. It is obvious that the use of LCA can result in a shift of the way planners make strategic and operational decisions, through being more effective in identifying improvement opportunities that may not have been previously obvious.

Taken into consideration the fact that the biodiesel is suitable for use in standard compression-ignition (diesel) engines designed to operate on petroleum-based diesel fuel, it is obvious that it can be easily used in existing diesel engines either in its pure form (B100) or in virtually any blend ratio with conventional diesel fuels. Additionally, biodiesel can be strongly promoted through captive and private fleets (bus, taxi, car driver, municipal fleets etc). Moreover, the development of biodiesel production in Greece is expected to reduce costs of raw materials for biodiesel production, thus further increasing their competitiveness in the Hellenic fuel market.

A strategic and integrated transportation planning can evaluate the results of a comparative fossil fuel and biofuel Life Cycle Assessment in conjunction with a set of measures such as the organization of training campaigns for fleet owners and operators, based on dissemination of experiences from other countries/cities in relation to biodiesel; as well as the presentation of information regarding fuel and investment costs, maintenance and operational safety issues. It should be also mentioned that a green public transport fleet can be an excellent example for motivating citizens to switch to alternative energy

The use of biodiesel in a fleet of diesel engine vehicles in the region of Athens -or other urban areas- 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 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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