ENVIRONMENTAL ASSESSMENT OF THE USE OF BIOETHANOL AND BIODIESEL IN THE AUTOMOTIVE SECTOR

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ABSTRACT

Transport is the second largest single source of greenhouse gas emissions in Europe. It is estimated that 40% of all CO_2 emissions of road transport and up to 70% of other pollutants are coming from transport. Biofuels can play a significant role in the reduction of these emissions. This study investigates the possibility of biofuels penetration into the Greek transportation sector as well as the applicability of the targets set by the European Union for the road-transport sector. The various types of biofuels currently available are examined, together with potential future conversion-technologies. The environmental impacts of the use of conventional and alternative fuels in Greece using the scope and results of the LCA methodology are estimated. The environmental profiles of the automotive fuels are compared for the different impact categories taken into account in the study.

Keywords: bioethanol;biodiesel; LCA; Greece

1. Introduction

Fossil fuels, such as diesel and gasoline, are the major energy sources for the transportation industry raising environmental concerns such as global warming and climate change. Alternative fuels are in seek due to the growing energy demand, the depletion of fossil fuels, the increasing price of petroleum and more stringent governmental regulations on exhaust emissions. In this context biofuels have been developed, during the past decades, as vehicle fuels, in order to increase transport sustainability and lessen the negative environmental impacts derived from the use of conventional fuels.

Biofuels based on biomass are categorized in first and second generation biofuels. First generation biofuels are produced from sugar, starch, vegetable oil, or animal fats using conventional technologies. The basic feedstocks are often seeds and grains such as wheat, corn, and rapeseed. The most common types of first generation biofuels are bioethanol, biodiesel, and starch-derived biogas, but also straight vegetable oils, biomethanol, and bioethers may be included in this category. 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. In Europe, more biodiesel is produced than ethanol, with rapeseed used as the primary feedstock. The total EU-27 biodiesel production for 2007 was over 5.7 million metric tones, an increase of 16,8% from the 2006 figures. Germany with a production of 2,890 thousand metric tones was the leader in 2007. France and Italy followed with productions of 872 thousand metric tones and 363 respectively [1-2].

Recently the European Commission announced a decision, which focuses especially on the sustainability criteria for biofuels to implement the Renewable Energy Directive [EC, 2009, 2010], according to which a target for 2020 of 10% renewable energy in the transport sector is set with only liquid biofuels qualifying towards the sustainability criteria given in the EU-RED for fulfillment of the targets of the Member States. Biofuels must deliver greenhouse gas savings of at least 35% compared to fossil fuels, rising to 50% in 2017 and to 60%, for biofuels from new plants, in 2018. In 2011, more than four biodiesel plants were cited in Greece. The use of sugar beets is essential for the Greek obligations within the 2009/28/EC Directive, especially taking into account the optimistic estimations of the National Renewable Energy Sources Plan for high rate of the use of biofuels in transport, i.e. from 0.11 Mtoe (2010) to 0.62 Mtoe (2020) [3]. There are many environmental studies that investigate the energy and greenhouse gases balance over the whole life cycles of biofuels [4-7]. In addition, a lot of comparative studies concerning biodiesel and fossil diesel fuel have been made [8-16], reflecting the ongoing interest in the environmental assessment of biofuels.

The objective of this study is to assess the environmental impacts from biofuels production, distribution and use, taking into account all activities from feedstock cultivation and harvest, fuel production and its use in vehicles , considering all inputs (e.g. fertilizer, auxiliary energies), and outputs (e.g. by-products, residues and waste treatment). The study employs a life cycle approach, which allows the quantification of the bioethanol and biodiesel energy as well as GHG balances resulting from bioethanol and biodiesel use alternatives to gasoline and diesel respectively. Based on a systemic description of two alternative bioethanol chains in Greece (wheat and sugar beet) as well as of two alternative biodiesel chains (rapeseed and sunflower) a Life Cycle Inventory model is build and the energy requirements for the production of abovementioned biofuels are calculated.
The Society of Environmental Toxicology and Chemistry and the International Organization for Standardization [17-20] developed in the 1990s modern LCA methodology. The main stages in the aforementioned methodology include: Goal definition and scoping, Inventory analysis, Impact assessment, Interpretation. Several guidebooks also have been published to support carrying out LCA [21-22]. The goal of this study is to evaluate the environmental performance of biofuels, based on a life cycle perspective. LCA can provide environmental performance information and works as a decision-supporting tool of environmental management or policy making. Greenhouse gas emissions are expressed in terms of CO_2 equivalents. The resulting values are then added for the whole life cycle and the impact indicators are characterized using the following equation:

$$\text{Inventory Data} \times \text{Characterization Factor} = \text{Impact Indicators} \quad (1)$$

Normalizing the calculated lifecycle emissions allows for a comparison of the different generation methods of biofuels. This procedure normalizes the impact indicator results by dividing by a selected reference value.

2. Biofuels production chains

Different biofuels types can be produced from biomass in a number of ways. Generally, biofuel conversion technologies are categorized as first and second (next/advanced) generation biofuels. First generation biofuels, ethanol from sugar and starchy crops and biodiesel from oilseed crops and animal fat, use well-established and simple conversion technologies. Second generation biofuels, from cellulosic biomass and algae, use less proven technologies. The most common types of biofuels are ethanol and biodiesel. In this context, two biofuels systems are considered. Both systems boundaries include feedstock cultivation, collection and transport, oil export (in the case of biodiesel system), feedstock conversion, refining and biofuel distribution as well as final use. Fossil energy use and GHG emissions are accounted for within the boundaries of the systems. It is noted that the GHG fluxes associated with indirect land use change (ILUC) impacts are not taken into consideration. The boundaries of the systems depict only direct effects. The GHG fluxes from ILUC are in addition to the direct GHG emissions and ILUC results do not affect the comparative environmental impact assessment of the above mentioned systems [23-26]. The lifecycle GHG emissions from the biofuels pathway are expressed in units of grams CO_2-equivalents per megajoule of energy (g CO_2-eq/MJ). The lower heating value (LHV) of ethanol is used to convert it from volumetric to energy units (MJ of energy). Using MJ instead of volumetric units makes it easy to compare ethanol with gasoline system. Ethanol is assumed to be used as a mixture of 10% ethanol with 90% gasoline by volume (termed E10); whereas biodiesel is assumed to be used as a mixture of 5% biodiesel with 95% diesel (B5).

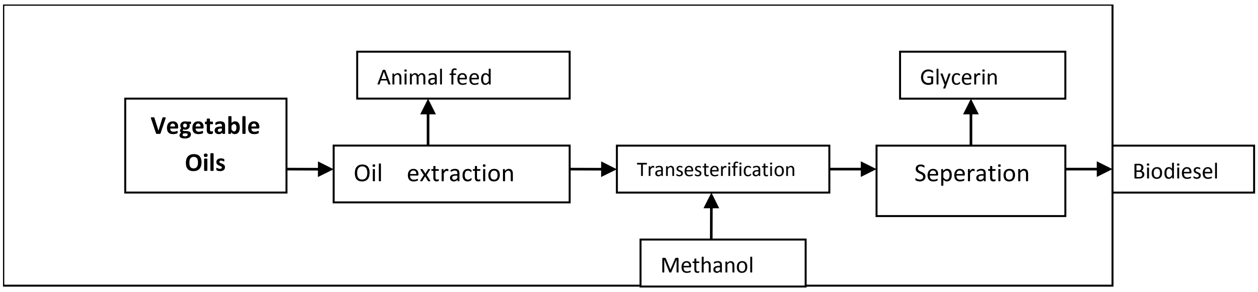
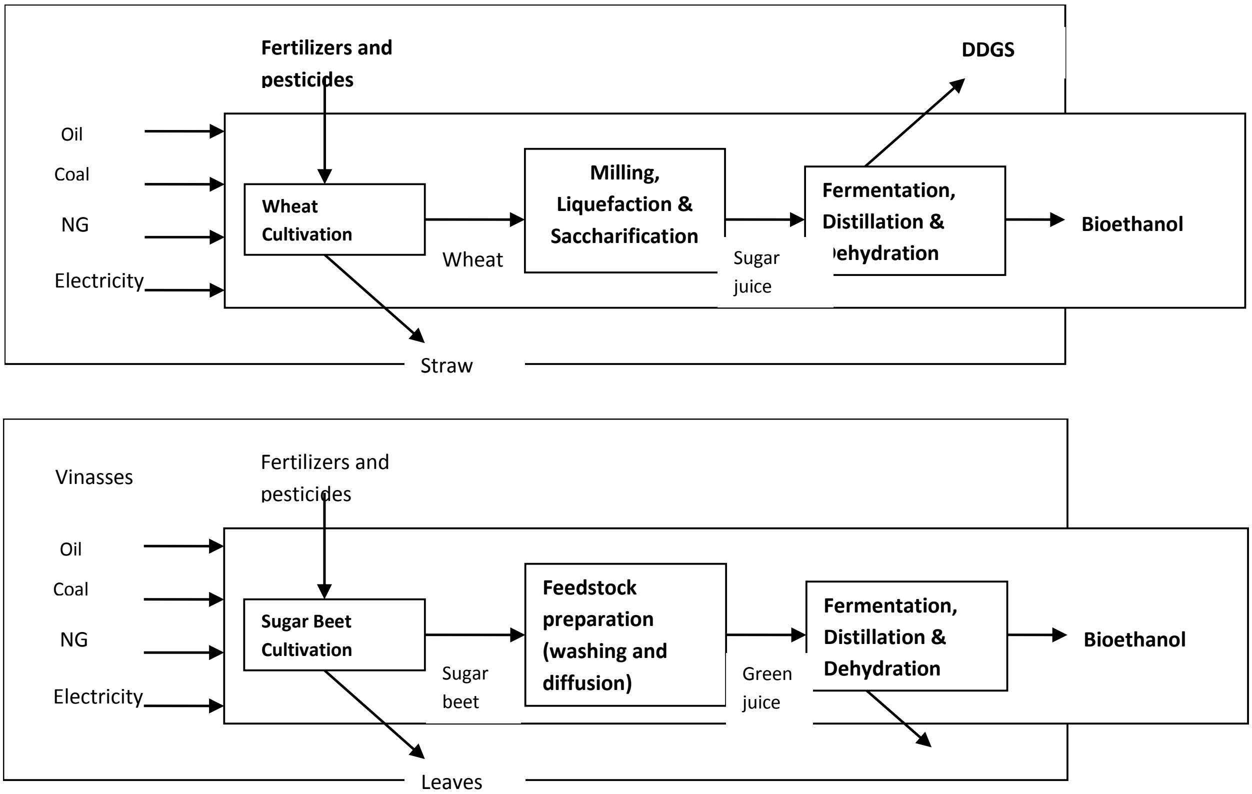


Figure 1: Biodiesel production from vegetable oils (rapeseed and sunflower)



Figures 2a – 2b: Bioethanol production from wheat and sugar beet [27]

The LCA processes for biodiesel and the fossil fuels in this study include, as presented in Fig. 1, the cultivation of the feedstock (rapeseed or sunflower). 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. LCA processes for bioethanol from wheat include (Fig. 2a): feedstock cultivation and processing (including grinding of grains), liquefaction and saccharification, where enzymes are introduced to break down the starch into sugar, fermentation of sugar juice, distillation and dehydration to obtain anhydrous ethanol. The leftover residue from the first stage (Distiller's Dried Grains with Solubles, DDGS) is the wheat equivalent of pulps from sugar beet, but with higher protein content Bioethanol production from sugar beets includes (Fig. 2b): feedstock preparation, beet slicing and diffusion to obtain diffusion juice, juice fermentation, distillation to increase concentration and dehydration to obtain anhydrous ethanol. Sugar beet pulp is recovered from the diffusion step and can be used in several alternative ways, namely in animal feed or as fuel. Vinasses, other co-product of the chain, are concentrated and spreaded on agricultural land. Data for the production of bioethanol from sugar beet and wheat have been collected from agricultural and industrial reports for Greece and from commercial databases. For bioethanol plant processing, bibliographic data were used because until now there is no bioethanol-for-transport plant cited in Greece and hence the necessary data were not available.

3. Results and discussion

The required energy for the production of conventional diesel is lower compared to the required energy for the production of biodiesel. Primary energy consumption is calculated and it is deducted that the required energy for the production of diesel is 0,99MJ lower, compared to the required energy for the production of rapeseed based biodiesel and 0,82MJ lower, compared to the required energy for the production of sunflower base biodiesel (Fig. 3) This difference is attributed to fewer stages and procedures for the production of diesel.

The total primary energy required for the production of 1 MJ of bioethanol from sugar beets is 0,42 MJ greater than the required energy for the production of the same bioethanol quantity from wheat (Fig. 4). This is attributed to the increase input of primary energy, which is required at the stage of conversion. It is noted that bioethanol production form sugar beet requires 47 MJ/kg compared to wheat, which requires 35, 7 MJ/kg.

Table 1 summarizes the calculated GHG emissions for each of the abovementioned biofuel production chain stages. Based on these data, the GHG emissions of bioethanol (sugar beet and wheat), gasoline, biodiesel (rapeseed and sunflower) and diesel are compared in Fig. 5.

Table 1: Calculation of life cycle GHG emissions for each biofuel chain

	Biodiesel		**Bioethanol**	
gr. eq. CO_2/MJ biofuels	**Rapeseed**	**Sunflower**	**Wheat**	**Sugar Beet**
Cultivation	-26.84	-48.44	-40.61	-51.61
Conversion	-4.95	-2.02	16.22	31.69
Transportation & Distribution	1.2	1.2	1.5	1.5
Final Use	76.23	76.23	71.38	71.38

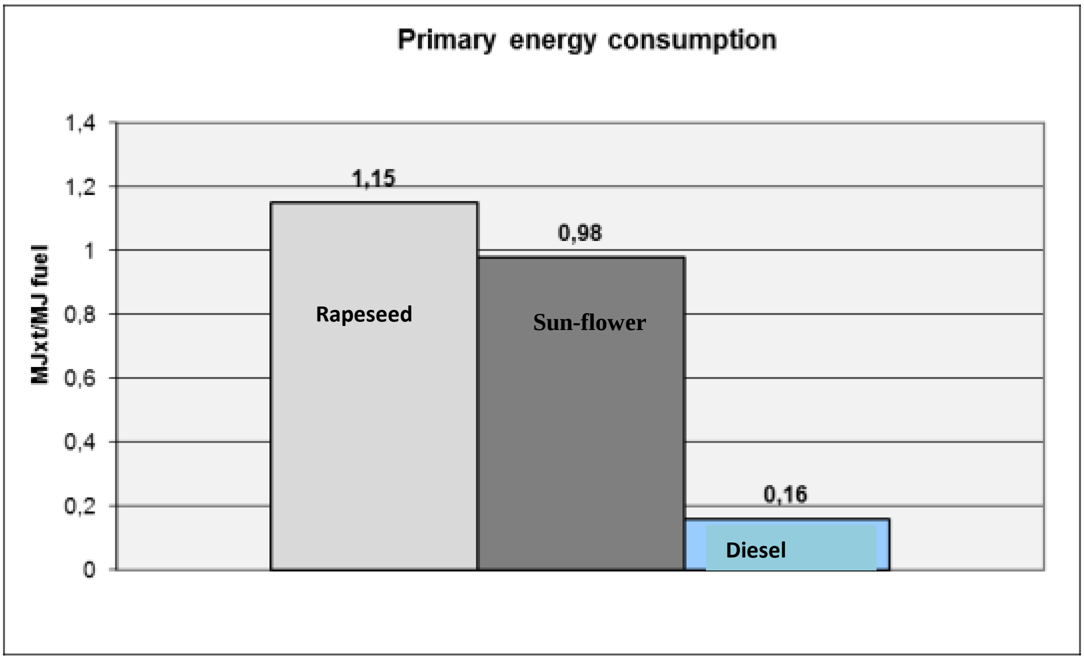


Figure 3: Primary energy consumption for the production of biodiesel and diesel

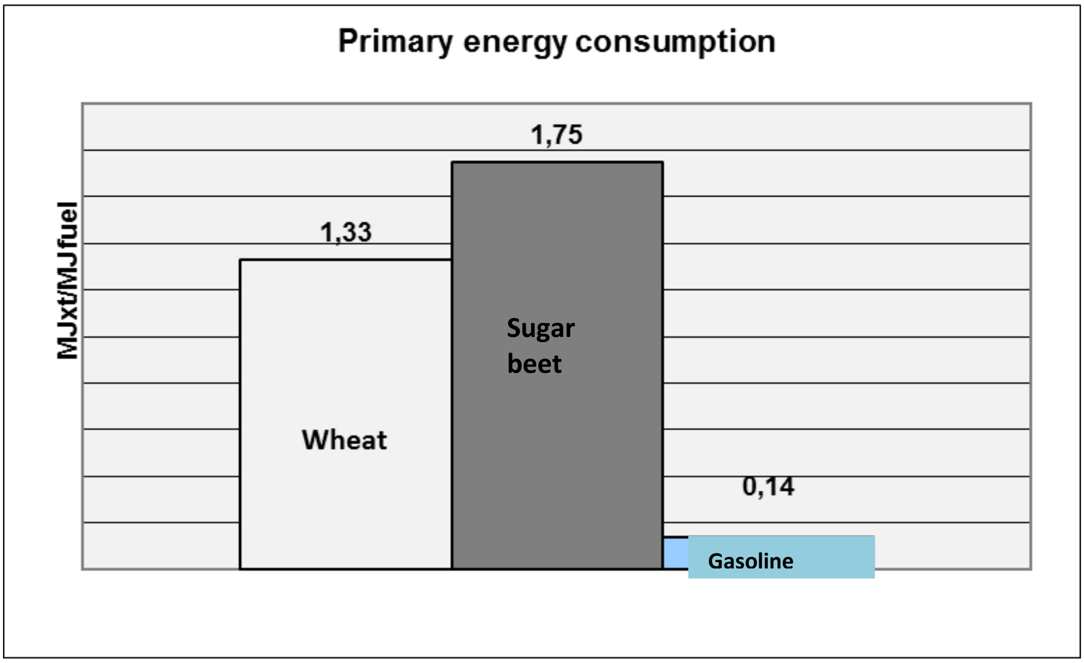


Figure 4: Primary energy consumption for the production of bioethanol and gasoline.

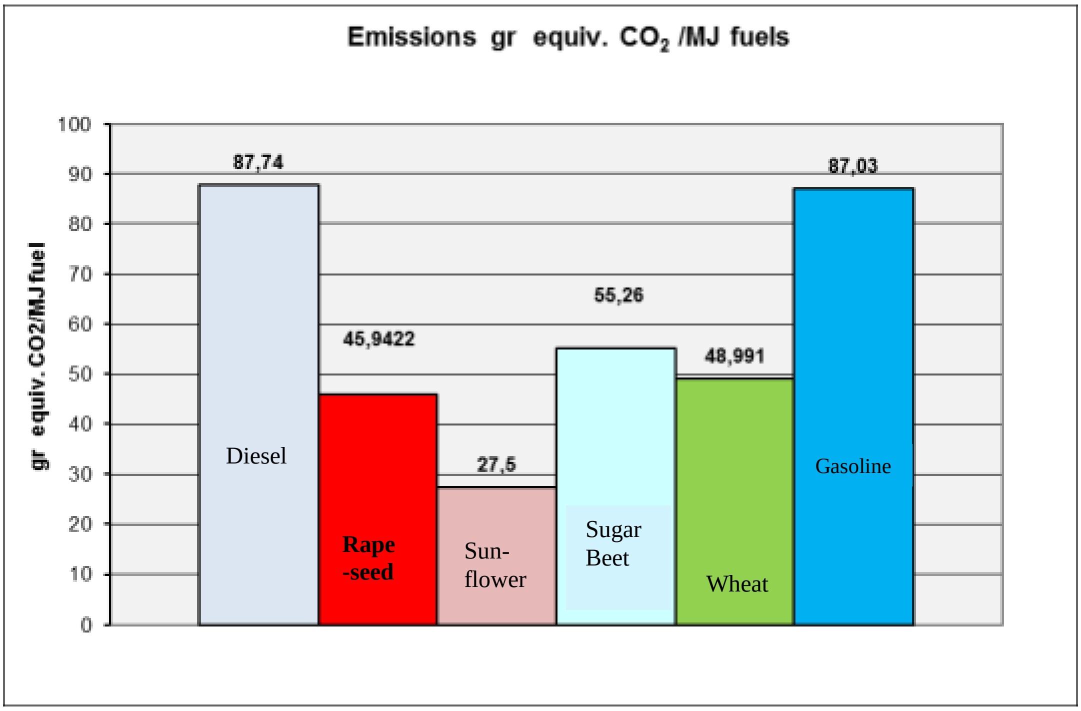


Figure 5: Life cycle GHG emissions of bioethanol, gasoline, biodiesel and diesel

Ethanol from wheat has a lower environmental impact to the global warming than sugar beet based ethanol. Results obtained for the abovementioned chains exhibit higher values than gasoline, which clearly indicates that considerable reductions in fossil fuel depletion would be achieved by replacing gasoline with bioethanol. GHG emissions are calculated as 55,26 and 48,99 g CO2eq for sugar beet and wheat, respectively, which are considerably low than gasoline emissions, which are reaching 87,03 g CO2eq. The production of biodiesel from rapeseed contributes more to the global warming effect, whereas the production of biodiesel from sunflower has lower environmental impact. GHG emissions are calculated as 45,94 and 27,5 g CO2eq for rapeseed and sunflower, respectively, which are considerably lower compared to diesel emissions (87,74) g CO2eq.Despite the increased primary energy consumption for the production of biofuels, the life cycle GHG emissions are significant lower compared to these of conventional fuels.

4. Conclusion

A life cycle approach was used to calculate avoided greenhouse gas emissions as well as primary energy consumption for biodiesel (rapeseed and sunflower) replacing diesel and bioethanol (sugar beet and wheat) replacing gasoline. The LCA results for these biofuels in general shows that bioethanol and biodiesel present better environmental performance than fossil fuel for the important environmental category of global warming, The study presents some clear environmental advantages of bioethanol and biodiesel over fossil fuels, such as conserving fossil energy sources and reducing global warming potential.

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