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Environmental impact assessment of olive pomace oil biodiesel production and consumption: A comparative lifecycle assessment

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The well-to-wheel environmental impacts of olive pomace oil biodiesel (B20 and B100) and conventional petroleum diesel were compared using life cycle assessment. Moreover, energy and economic analyses of olive pomace oil biodiesel production was conducted throughout its life cycle. Human Health, Ecosystem Quality, Climate Change and Resources were the selected end-point impact categories. Comparing biodiesel with petroleum diesel, significant environmental tradeoffs exist between the Climate Change and Resources damage categories. Moreover, biodiesel was found to require some corrective practices (in the view of agricultural and combustion stages) in order to be more eco-friendly in all the mentioned damage categories. Having pursued the suggestions of this study, for the B100, the minimum reduction rates of 30–32% and 24–26% in the Human Health and Ecosystem Quality damage categories could be expected, respectively. While for the B20, these reduction rates would be at least 19–22% and 14–16%, respectively. This could be promising especially for the B20 blend as a good alternative for petroleum diesel. On the other hand, lifecycle energy assessment revealed promising energy indices (e.g., fossil energy ratio of 1.22–1.33). Finally, economic analysis showed a benefit-to-cost ratio of 1.45 revealing the economic viability of olive pomace oil biodiesel production.

1. Introduction

Given the growing limitation of the existing oil reserves and the fact that the global peak in oil production (1996–2030) will be over soon, it is becoming increasingly clear that the fossil resources are deemed to eventually run out. On the other hand, negative social, political, and environmental impacts of fossil fuels utilization have made governments, industrial players, and general public keen on developing environmental-friendly, renewable, and domestically-available energy sources [1,2].

Among the various renewable energy sources, biomass-derived biofuels have gained more interests due to 1) their capability to be used as transportation fuels, 2) the energy security provided by their diversified supply, 3) creation of new job opportunities, and finally 4) improving the economic aspects of the agriculture sector [3,4]. Moreover, using biomass as fuel could help mitigate GHG (greenhouse gas) emissions [5] due to the fact that the CO_2 released (through combustion or conversion of biomass into chemicals) is biogenic and is chemically identical to the CO_2 removed from the environment by photosynthesis during the production of biomass [1].

Biodiesel is the most promising biofuel to substitute petro-diesel and can be produced from a variety of vegetable oils and animal fats [6–10]. More specifically, biodiesel is a mixture of mono-alkyl esters of fatty acids, most often originated from available, abundant, and renewable feedstocks, such as vegetable oils

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Nomenclature

Definition

ASTM	American Society for Testing and Materials
BCR	Benefit to cost ratio
BSFC	Brake specific fuel consumption
B100	100% Biodiesel
B20	20% Biodiesel& 80% Diesel
CH_4	Methane
CN	Cetane number
CO_2	Carbon dioxide
DALY	Disability-Adjusted Life Years
DU	Degree of unsaturation
EA	Energy-based allocation
EGR	Exhaust gas recirculation
EPS	Expanded polystyrene
FAMEs	Fatty acid methyl esters
FER	Fossil energy ratio
FFA	Free fatty acid
FID	Flame ionization detector
GC	Gas chromatography
GHGs	Greenhouse gases
HFU	High-frequency ultrasound
HHVs	Higher heating values
ICEs	Internal combustion engines
ISO	International Organization for Standardization
IV	Iodine value
LCA	Life cycle assessment
LCEA	Life Cycle Energy Assessment
LCI	Life cycle inventory
LCIA	Life Cycle Impact Assessment
LCSF	Long-chain saturated factor
LFU	Low-frequency ultrasound
LUC	Land use change
MA	Mass-based allocation
MVA	Market value-based allocation
N_2O	Dinitrogen monoxide
NER	Net energy ratio
NEV	Net energy value
NO	Nitrous oxide
NO_x	Nitrogen oxides
OH	hydroxyl
OP	Olive pomace
OPO	Olive pomace oil
PAs	poly-aromatics
$PDF_{m^2 \times y}$	Potentially Disappeared Fraction of species over a certain amount of area (m^2) during a certain amount of time (year)
PM	Particular matters
SCR	Selective catalytic reduction
SNCR	Selective non-catalytic reduction
SO_2	Sulfur dioxide
SO_x	Oxides of sulfur
SV	Saponification value
UA	Ultrasound-assisted
UHCs	Unburned hydrocarbons

and animal fats. Olive (Olea *europaea)* is one of the Mediterranean crops whose cultivation generates two key products, i.e., olive and olive oil, and one by-product, i.e., OP (olive pomace). The oil is extracted from OP also known as OPO, is a non-edible inexpensive feedstock which has been previously used for biodiesel production [11].

There are four primary methodologies for biodiesel production and utilization including transesterification, direct use and blending, microemulsions, and thermal cracking (pyrolysis) [12–14]. Among these processes, transesterification is the most adopted one for commercial production scale due to the simplicity of the process, and the ease of operation [15]. The transesterification reaction could be described as a chemical reaction between natural triacilglycerols and short-chain alcohols in the presence of a catalyst to produce mono-alkyl esters also known as biodiesel [16]. Due to the fact that the chemical reaction between triglycerides and alcohol would happen at the interfacial surface area, the conventional mixing methods for biodiesel production are time- and energy-consuming. Thus, state-of-the-art methods are implemented in order to optimize the transesterification reaction. Recently, developments in sonochemistry made the use of ultrasonic irradiations in transesterification viable. The advantages of the LFU (low-frequency ultrasound) method over the classical synthesis methodologies include maximizing the interfacial surface area between the immiscible reactants. i.e., triglycerides and alcohol (through the cavitation phenomenon), lower energy inputs, higher efficiency, saving time, and improved economic viability of the process [17].

Moreover, in order to establish sustainable biodiesel production scenarios, they should be assessed from different sustainable development aspects and be compared with the conventional petroleum-derived energy carriers, e.g., diesel. In fact, the true renewability of renewable energy production scenarios depend on their energy balance, as well as environmental, social, political, and economic aspects which are essential elements of sustainable development. LCA (Life cycle assessment) is a tool that can help decision makers evaluate the environmental impacts of a specific product and/or service throughout its life cycle on a cradle to grave basis [18]. LCA has been frequently used to evaluate and compare the environmental, energy, and economic aspects of biodiesel production from different feedstocks around the world. Table 1 summarizes a variety of LCA studies conducted on biodiesel production. More specifically, the geographical scales of the studies, feedstock used for biodiesel, functional unit, lifecycle energy and economic assessment, as well as the impacts used in these studies are presented. However, it is worth mentioning that LCA studies reported vary and sometimes offer contradictory conclusions mostly due to 1) difference in the methodologies used for calculating soil emissions (i.e., excluding N_2O, overestimating N_2O or using deterministic values of N_2O in the calculation), 2) inclusion/exclusion of carbon associated with LUC (land use change), 3) truncated impact coverage, and 4) disregarding parameter uncertainty for certain key inputs (e.g., carbon emissions from soil and N_2O) and scenarios. Moreover, to the best of our knowledge, to date, no study has been reported on the LCA of biodiesel production and consumption from OPO. Therefore, the goals of the present LCA study was placed at 1) assessing the environmental pollution, energy balance, and economic viability of biodiesel production from OPO throughout its life cycle, and 2) comparing the environmental impacts of OPO biodiesel and conventional petroleum diesel No. 2.