Journal of Environmental Sciences Studies
Journal home page: www.jess.ir

Investigating the role of life cycle assessment of biodiesel production from algae

Gholamhossein Jafari [a], Farzad Naseri-Moghanlou[b*]
[a] Computer engineering, faculty of art and engineering, Islamic Azad University, Science and Research Branch, Tehran, Iran
[b]Departement of biosystem engineering, university of Tabriz, Tabriz, Iran
Email Address: Naseri.farzad2023@gmail.com
Received (5-4-2023)
Accepted (6-3-2023)

Abstract

The existing problems in using fossil energy sources have caused significant progress in producing Biodiesel from different raw materials. The high price of edible vegetable oils, followed by the high cost of product production, leads the biodiesel industry to use cheap raw materials derived from waste. Also, due to the existence of different stages of production, the amount of environmental effects of each production route differs. This study aims to evaluate the cycle of Biodiesel obtained from waste oil, algae oil, and microalgae and to investigate its environmental and economic effects. In this regard, recent sources published evaluating waste oil, and microalgae biodiesel cycles were studied and analyzed. The present study collected the study database using systematic review guidelines from Scopus, web of science (WoS), and google scholar. About 890 research articles have cooperated in the review process. The results showed that microalgae biodiesel production using wastewater and biocatalyst significantly reduce environmental effects. The production system of biofuels from microalgae requires a high investment, which includes 47-86% of the total production costs. Biodiesel from WCO produces less CO2 compared to first-generation Biodiesel. The added value of WCO is preventing water pollution through its release. Using eggshell CaO biocatalysts in WCO biodiesel production shows better environmental effects than KOH alkaline catalysts. In the WCO life cycle assessment, the waste collection stage and the details of this stage should also be considered. The following study tries to report the policies for obtaining sustainable biodiesel production from algae.

Keywords: Algae; Biodiesel; life cycle assessment; clean energy; renewable energy

Introduction

Rapid industrialization, demographic changes, improving human living standards, and growing populations are the main drivers of increasing energy demand [1, 2]. Dwindling fossil fuel reserves and growing concerns about increasing greenhouse gases have necessitated the exploration of alternative sustainable fuels to meet the growing order in the transportation sector and mitigate global warming and climate change. Among the environmentally friendly fuels that have been developed to date, fatty acid methyl or ethyl ester (biodiesel) obtained from vegetable oils, animal fats, and waste oils, which are considered due to their similarities in physiochemical properties to petrodiesel fuels. have been noticed [3-5]. Regardless of the renewable, carbon-neutrality, and biodegradability of biomass-derived fuels such as biodiesel [6], its use in pure or mixed form can significantly reduce the emission of toxic pollutants [7].Although considerable progress has been made in producing Biodiesel from different raw materials. Its impact on the price of edible vegetable oils and the high cost of the product obtained using these sources has pushed the biodiesel industry towards the use of low-cost raw materials derived from leads to waste [8, 9]. Also, due to the different stages in the production of raw materials, biodiesel production, and product supply stages, each production path's environmental effects have differences [10, 11].Due to the variety of raw materials and the different methods of biodiesel production, it is felt necessary to research and study to evaluate the cheap and more environmentally friendly production path to provide the most optimal product to replace fossil fuels.

This study aims to evaluate the biodiesel cycle obtained from waste oil, algae oil, and microalgae to investigate its environmental and economic effects.To the best of our knowledge, the present study is one of the pioneer systematic reviews for evaluating biodiesel production from algae from the environmental point of view. Preparing periodic review papers on a particular scientific subject might consider and recommend policy changes. Several survey studies have recently been conducted to evaluate the role of life cycle assessment in biodiesel production from algae. Table 1 covers notable review studies.

Table 1. Notable surveys

Ref.	Systematic review	Technical evaluation	Technical policies
[12]	☒	☒	☒
[13]	☒	☒	☑
[14]	☒	☒	☑
[15]	☒	☒	☒
[16]	☒	☒	☑
[17]	☒	☒	☒
Present study	☑	☑	☑

According to Table 1, several review papers analyzed biodiesel production from algae and other resources from the viewpoint of life cycle assessment. No systematic design study in the literature evaluates biodiesel production from algae regarding life cycle performance and taxonomy. This weakness can be considered a primary deficiency in this specialized field because there is no basic mapping for the desired aim. We decided to cover this weakness by doing a systematic review. We applied the PRISMA guidelines to investigate and assess the biodiesel production scenarios. The research was conducted in three stages. The first step is to collect the database, then analyze that data, and the final step is to report the study's primary findings.

2. Materials and Methods

The present study employs PRISMA guidelines for the dataset-collecting process [22, 23]. PRISMA guidelines are responsible for locating and organizing records (Figure 1, Phase I). The Thomson Reuters Web-of-Science (WoS) and the Elsevier Scopus databases contributed 1105 of the papers, while the remaining 135 came from external sources. The screening looked for instances of duplication as well as specific cases (Figure 1, Phase II).115 records were eliminated due to duplicates. The analysis of the titles and abstracts excluded 75 records. Phase III, which determined eligibility, chose 160 papers. The authors researched the selected records during the election monitoring process and picked the most pertinent samples. There was a censoring of the documents. As a direct result of this, 890 papers were looked into.

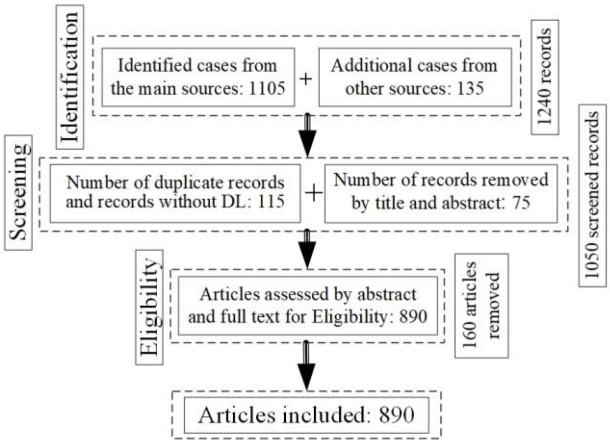

Figure 1. PRISMA guideline

2.1. Review

Saranya et al. performed a comparative evaluation for microalgae cultivation considering different nutrient inputs, no nutrient input (scenario 1), wastewater as nutrient input (scenario 2), and fertilizer input (scenario 3). Acid catalyst and biocatalysts were used to convert microalgae oil into Biodiesel. The scenarios' environmental impacts were evaluated using OpenLCA v1.10.3, which highlights the further release of eutrophication and photochemical oxidation related to the fertilizer input scenario with acid catalyst transesterification [18].Amid et al. conducted a study for the environmental analysis of an ultrasonic system that converts waste cooking oil (WCO) into Biodiesel. Twenty-seven different experiments (scenarios) have been conducted at three levels of methanol content, methanolysis temperature, and reaction time and compared using the 2002 Plus life cycle impact assessment approach from an environmental point of view. The effects of different scenarios on four endpoint impact categories, including human health, ecosystem quality, climate change, and resource consumption, were quantitatively evaluated and comprehensively discussed. The effects of material and energy flow on endpoint impact categories were also assessed through sensitivity analysis [19].Foteinis et al. conducted a study with the aim of investigating the environmental sustainability of waste cooking oil on an industrial scale. Environmental highlights include energy inputs to drive this process, followed by methanol (CH_3OH) and potassium methoxide (CH_3KO) consumption. Glycerol ($C_3H_8O_3$) and potassium sulfate (K_2SO_4), both process products, lead to the avoidance of environmental burdens [20].

Wu et al. compared two chains of microalgae to diesel and microalgae to butanol conversion through process integration and design. According to the bio-cycle assessment standards, two proposed chains were compared in terms of 17 categories of bio-cycle assessment effects and sensitivity analysis of bio-cycle assessment effects on two chains with different fat or carbohydrate content in microalgae cells was performed [21].

Dasan et al. used a critical-to-gate approach to provide insight into the impact of different cultivation systems and biomass productivity on life cycle energy (LCEA), carbon balance (LCCO2), and economic (LCC) microalgae biodiesel production pathways. In addition, the co-production of bioethanol from microalgae residues is suggested to improve the financial sustainability of the whole system [22].Chung et al. conducted a bio cycle evaluation of biodiesel production of waste cooking oil with eggshell CaO catalyst. Comparative studies were conducted to evaluate the difference in the environmental effects of cooking oil waste, the production of WCO biodiesel by CaO catalyst derived from eggshell with two different production processes using jatropha oil as the raw material of oil and potassium hydroxide as the homogeneous catalyst [23].Viornery et al. compared the environmental impacts of the production and use of Biodiesel B25 and ultra-low sulfur diesel in a 33 kW power generator at 100% rated load and used the life cycle method to describe the derived impacts based on primary data for the process steps [24].Caldeira et al. performed a life cycle assessment (LCA) of the impact of the waste cooking oil collection stage on the overall effects of Biodiesel. Characterization and composition of changes associated with WCO collection systems, parameter uncertainty, variability, and modeling options were performed [25].Yano et al. performed an uncertainty analysis to determine the environmental benefits of hydrogenated Biodiesel produced from cooking oil by catalytic cracking and hydrogenation compared to diesel or FAME-type Biodiesel. A combined functional unit consisting of "waste cooking oil treatment" and "diesel vehicle for household waste collection" was established in Kyoto, Japan. The characteristics, damage, and integration factors identified by LIME2 were used in the calculation based on the endpoint modeling method [26].Gnansounou et al. performed a life cycle assessment of algae biorefining considering several selected products (Biodiesel, protein, and succinic acid) to estimate the environmental impacts compared to a reference system [27].

3. Results & Discussion

Based on a study [18], it was determined that using wastewater for algae cultivation and transesterification through biocatalysts significantly reduces environmental impacts with minimal greenhouse gas emissions. The LCA of all three scenarios showed that the required range of fossil energy is between 3.6 and 5.7 MJ/kg, and the amount of greenhouse gas emissions (in kilograms equivalent to CO2 emissions) is 0.85-1.46 kg/kg of Biodiesel. The reduction of the fossil energy requirement is about 87.3% in the microalgae bioreactor based on the experimental bed. The wastewater-biocatalyst scenario has the highest net energy ratio of 18.8, with the added benefit of low-cost wastewater treatment. According to the study [19], methanol content had the most significant effect on the studied effect categories, while methanolysis temperature had the most negligible impact on these environmental indicators. In general, the molar ratio of methanol to oil is 1:6, a methanolysis temperature is 60°C, and a reaction time of 10 minutes can be recommended as the most appropriate operating conditions from the technical and environmental point of view. The sensitivity analysis showed that the electrical power used in this process had the greatest impact on the categories of human health and climate change damage. Phosphoric acid used to neutralize crude glycerol was the most influential input on ecosystem quality damage, while methanol consumed in this process significantly affected the resource use damage category.Based on study [20], it was determined that the total carbon footprint per ton of Biodiesel produced was 0.55 tons of CO2eq (i.e. 14 gCO2eq/MJ) and 58.37 Pt, respectively. Which is 40% less than first-generation Biodiesel. A three-fold reduction in environmental effects was observed compared to petrodiesel. In addition, the added value of cooking oil for biodiesel production can eliminate water pollution from its disposal to the sewage system.

A study by [21] indicated that, based on the specifications and prescribed conditions for microalgae cultivation, pre-treatment, and product purity level, LCA analysis showed that the final annual ReCiPe score of producing 1 kg of biobutanol is less than 1 kg of Biodiesel by 54.4%. The microalgae to butanol conversion chain can reduce the final annual ReCiPe rating of producing 100 megajoules of diesel/gasoline from crude oil by 5-10%. The microalgae-to-butanol conversion chain is more environmentally friendly than the microalgae-to-diesel conversion chain due to low LCA impacts such as climate change, human health, climate change ecosystems, and fossil fuel reduction.A study by [22] showed that traditional microalgae biofuel processing routes lead to several deficiencies such as dehydration, and microalgae lipid extraction requires high energy and consumes approximately 21-30% and 39-57% of the total energy required, respectively. The microalgae biofuel production system requires high investment, which includes 47-86% of the total production costs, which subsequently leads to poor technological performance. Furthermore, current analysis of environmental aspects of algal biorefining showed a negative CO2 balance in microalgae biofuel production. A study by [23] showed that using WCO as an oil raw material for biodiesel production has fewer environmental effects than jatropha oil; Because WCO biodiesel production does not include the agricultural stage. Likewise, the use of eggshell CaO catalyst (heterogeneous catalyst) contributes less to the overall categories than KOH (homogeneous alkaline catalyst), because KOH production requires adding chemicals and additives, plus complex purification and complex purification and neutralization processes. The results showed that the best environmental performance of CaO obtained from eggshell was 1.17 Pt on traditional KOH catalysts and using jatropha oil.A study by [24] indicated that the reduction of the significant effect related to the decrease of abiotic factors, the potential of human toxicity, the possibility of eutrophication, the prospect of acidification, and the potential of global warming was 39.48, 39.44, 39.24, 38.73, and 35.77%, respectively. Experimental measurements of exhaust gas emissions showed increased CO (52%) and reduced NOx (41.54%) for B25 compared to low-carbon diesel.A study by [25] indicated that two factors have the greatest influence on the observed changes: WCO collection efficiency and characteristics of the collection system (eg sector, type of collection and population density). WCO collection step cannot be ignored when evaluating the overall environmental performance of Biodiesel produced from WCO.A study by [26] showed that if diesel vehicles complying with Japan's new long-term emission standard are used in the future, the advantage of FAME-type Biodiesel will be relatively limited. Furthermore, the scenario introducing hydrogenated Biodiesel was more effective in reducing total environmental impacts, implying that switching from FAME-type Biodiesel to hydrogenated Biodiesel would be more beneficial.A study by [27] indicated less CO2 emission and land use for the Biodiesel, protein, and succinic acid production system than for algae's biodiesel and protein production system. The impact reduction was more significant than conventional diesel, soy protein, and fossil-based succinic acid systems. A higher carbohydrate composition in algae reduces CO2 emissions and fossil fuel consumption of the algae system compared to the reference system.The results of various research in the field of evaluation of the biodiesel cycle obtained from algae oil, microalgae and waste oil were described. In converting microalgae into biofuel, paying attention to the comparative assessment of the life cycle can introduce the most appropriate product regarding environmental compatibility. In this context, biobutanol is more environmentally friendly than biodiesel [9]. If supplied from inappropriate sources, especially fossil sources, the electrical energy used in the WCO biodiesel production process dramatically impacts human health and climate change. The production of Biodiesel from WCO by removing or reducing waste disposal can play an influential role in preventing and reducing water pollution by eliminating wastewater containing WCO.

To reduce the environmental impact, it is essential to pay attention to the WCO collection stage; Because the collection efficiency and the collection system's characteristics have the most significant impact. The energy spent on collection should lead to a suitable collection efficiency. In this regard, it is essential to pay attention to the type of system and population density of the region from which WCO is collected.

4. Conclusions

The present study investigated the impact of the life cycle assessment method on the production of Biodiesel from algae compared to other biomass. The results showed that:

- The production of microalgae biodiesel using wastewater and biocatalyst significantly reduces environmental effects.
- The production system of biofuels from microalgae requires a high investment, which includes 47-86% of the total production costs.
- WCO biodiesel produces less CO2 compared to first-generation Biodiesel. The added value of WCO is preventing water pollution through its release.
- Using eggshell CaO biocatalyst in WCO biodiesel production shows better environmental effects than KOH alkaline catalyst.

In the WCO life cycle assessment, the waste collection stage and the details of this stage should also be considered.

Paying attention to the stage of waste oil collection in the evaluation of the life cycle of the resulting Biodiesel will lead to the recognition and correct decision regarding its environmental effects; Therefore, it is appropriate to pay more attention to this issue in future studies.

The production of Biodiesel from microalgae oil has the problem of high initial investment to establish a cultivation site, extract oil from it, and convert it into Biodiesel; Therefore, it will be appropriate to pay more attention to the reduction of these costs in future studies.

Acknowledgments

We want to thank the university of Mohaghegh Ardabili for their contribution to providing laboratory uses.

References

1. Ramachandra, T., et al., GHG footprint of major cities in India. 2015. **44**: p. 473-495.
2. Faizollahzadeh Ardabili, S., et al., Fuzzy logic method for the prediction of cetane number using carbon number, double bounds, iodic,

and saponification values of biodiesel fuels. 2019. **38**(2): p. 584-599.
3. Hosseinzadeh-Bandbafha, H., et al., Exergetic, economic, and environmental life cycle assessment analyses of a heavy-duty tractor diesel engine fueled with diesel–biodiesel-bioethanol blends. 2021. **241**: p. 114300.
4. Ardabili, S.F., et al., Performance and emission analysis of a dual-fuel engine operating on high natural gas substitution rates ignited by aqueous carbon nanoparticles-laden diesel/biodiesel emulsions. Fuel, 2021. **294**: p. 120246.
5. Faizollahzadeh Ardabili, S., et al., Using SVM-RSM and ELM-RSM approaches for optimizing the production process of methyl and ethyl esters. 2018. **11**(11): p. 2889.
6. Mateus, M.M., J.C. Bordado, and RGJF dos Santos, Potential biofuel from liquefied cork–Higher heating value comparison. 2016. **174**: p. 114-117.
7. Dias, A.P.S., et al., Effect of the oil acidity on the methanolysis performances of lime catalyst biodiesel from waste frying oils (WFO). 2013. **116**: p. 94-100.
8. Najafi, B., et al., Application of ANNs, ANFIS and RSM to estimating and optimizing the parameters that affect the yield and cost of biodiesel production. Engineering Applications of Computational Fluid Mechanics, 2018. **12**(1): p. 611-624.
9. Tabatabaei, M., et al., Environmental impact assessment of the mechanical shaft work produced in a diesel engine running on diesel/biodiesel blends containing glycerol-derived triacetin. 2019. **223**: p. 466-486.
10. Faizollahzadeh Ardabili, S., Improving the combustion process of Biodiesel using additives, in Biosystem Engineering. 2021, University of Mohaghegh Ardabili: Ardabil, Iran. p. 120.
11. Akbarian, E., et al., Experimental and computational fluid dynamics-based numerical simulation of using natural gas in a dual-fueled diesel engine. 2018. **12**(1): p. 517-534.
12. Rathore, D., et al., Bioengineering to Accelerate Biodiesel Production for a Sustainable Biorefinery. 2022. **9**(11): p. 618.
13. Kim, J.Y., et al., Biodiesel from microalgae: Recent progress and key challenges. 2022. **93**: p. 101020.
14. Kumar, AJCA, Current and future perspective of microalgae for simultaneous wastewater treatment and feedstock for biofuels production. 2021. **4**: p. 249-275.
15. Karpagam, R., K. Jawaharraj, and R.J.S.o.T.T.E. Gnanam, Review on integrated biofuel production from microalgal biomass through the outset of transesterification route: a cascade approach for sustainable bioenergy. 2021. **766**: p. 144236.
16. Chamkalani, A., et al., A critical review on life cycle analysis of algae biodiesel: current challenges and future prospects. 2020. **134**: p. 110143.
17. Kumar, D., B.J.B. Singh, and Bioenergy, Algal biorefinery: An integrated approach for sustainable biodiesel production. 2019. **131**: p. 105398.
18. Saranya, G., TJEC Ramachandra, and M. X, Life cycle assessment of Biodiesel from estuarine microalgae. 2020. **8**: p. 100065.
19. Amid, S., et al., Effects of waste-derived ethylene glycol diacetate as a novel oxygenated additive on performance and emission characteristics of a diesel engine fueled with diesel/biodiesel blends. Energy Conversion Management, 2020. **203**: p. 112245.
20. Foteinis, S., et al., Used-cooking-oil Biodiesel: Life cycle assessment and comparison with first-and third-generation biofuel. 2020. **153**: p. 588-600.
21. Wu, W., Y.-C. Lei, and J.-S.J.B.t. Chang, Life cycle assessment of upgraded microalgae-to-biofuel chains. 2019. **288**: p. 121492.
22. Dasan, Y.K., et al., Life cycle evaluation of microalgae biofuels production: Effect of cultivation system on energy, carbon emission and cost balance analysis. 2019. **688**: p. 112-128.
23. Chung, Z.L., et al., Life cycle assessment of waste cooking oil for biodiesel production using waste chicken eggshell derived CaO as catalyst via transesterification. 2019. **21**: p. 101317.
24. Viornery-Portillo, E.A., B. Bravo-Díaz, and VYJF Mena-Cervantes, Life cycle assessment and emission analysis of waste cooking oil biodiesel blend and fossil diesel used in a power generator. 2020. **281**: p. 118739.
25. Caldeira, C., et al., Incorporating uncertainty in the life cycle assessment of Biodiesel from waste cooking oil addressing different collection systems. 2016. **112**: p. 83-92.
26. Yano, J., et al., Life cycle assessment of hydrogenated biodiesel production from waste cooking oil using the catalytic cracking and hydrogenation method. 2015. **38**: p. 409-423.
27. Gnansounou, E. and J.K.J.A.e. Raman, Life cycle assessment of algae biodiesel and its co-products. 2016. **161**: p. 300-308.