Life cycle assessment of biorefinery with waste treatment

Rafael de Freitas Moura[1*], Bettina Susanne Hoffmann[1] and Yordanka Reyes Cruz[1]

[1] Programa de Engenharia Ambiental, UFRJ, Universidade Federal do Rio de Janeiro, Rio de Janeiro, 21941-901, Brazil.

rafael.moura@poli.ufrj.br; susanne@eq.ufrj.br; yordanka@eq.ufrj.br
* Corresponding author

Abstract:
Climate change and fossil fuel depletion have increased attention on the development of multiproduct biorefineries. Life cycle assessment has been considered a crucial tool to determine the environmental benefits of biorefineries over petroleum refineries and confirm the achievement of the expected energy and environmental benefits. This work performs a life cycle screening study of a biorefinery for oil extraction from microalgae biomass, integrating waste treatment processes in algae and hydrogen production. The life cycle inventory was built on secondary data taken from the literature and the ecoinvent database. Eighteen categories of environmental impact of the Recipe 2016 Midpoint (H) method were analyzed. Results show that of the eleven steps that make up the preliminary proposal for the biorefinery, extracting oil from microalgae biomass and removing acidic gases in hydrogen production represent hotspots.

Keywords:
wastewater treatment, life cycle assessment, microalgae, municipal solid waste, green diesel

1 Introduction

Since the 18th century, a period marked by the Industrial Revolution, in which western societies established a new model of economic development, the Earth's average temperature has increased significantly due to the burning of fossil fuels (IPCC, 2007; EPA, 2020; IEA, 2020). Between 1750 and 2021, the main gases that contribute to the greenhouse effect increased in their concentrations in the atmosphere: CO_2 by 47%, methane (CH_4) by 156%, and nitrous oxide (N_2O) by 23% (IPCC, 2021).

An alternative to the use of fossil fuels are biofuels generated from renewable sources, for example, microalgae biomass. Microalgae produce lipids, an energy-rich substance that can be used for the production of different liquid biofuels, such as green diesel, biodiesel, biokerosene (Soares *et al.*, 2019). An important advantage of this primary material is that it does not generate direct competition with food production (Shuba; Kifle, 2018; Singh *et al.* 2015).

Currently, low-carbon policies have clearly motivated the use of residual raw materials to produce biofuels (Capaz *et al.*, 2021b). In this sense, ANP Resolution No. 842 of May 14, 2021, establishes specifications for the commercialization of green diesel in the national territory. The National Petroleum Agency (ANP) proposal complies with the National Biofuels Policy (RenovaBio), established by Law 13.576 of 2017 (ANP, 2020).

The present study is in line with current research trends in the biofuel sector, mainly regarding the production of green diesel from microalgae. As a way of contributing to the social and scientific spheres, the research is aimed at investigating the environmental impacts of the green diesel production chain through the life cycle assessment.

2 Research Methodology

The research uses the life cycle assessment method recommended by ABNT NBR ISO 14040 and 14044 (ABNT NBR, 2006) to assess the potential environmental impacts generated by the production of green diesel. The production of biofuel occurs through the hydrotreatment route of microalgae oil, extracted from biomass cultivated during the bioremediation of urban sanitary effluent, and the use of hydrogen produced by the gasification of urban solid waste.

The data used for the preliminary proposal for the biorefinery is based on the literature and the ecoinvent database. These secondary data serve to determine the mass balance and energy balance of the processes and consolidate the life cycle inventory. After defining the inventory using the software OpenLCA, the same software is used to calculate the environmental impacts in the eighteen categories of the Recipe 2016 Midpoint (H) method. The ReCiPe Midpoint (H) methodology was used for being the most representative method on a global scale with a focus on environmental issues, making it the most qualified method for this study (Prè, 2013).

Finally, the interpretation of the results obtained in the inventory analysis and life cycle impact assessment phases was carried out. In this phase, the consistency of the model results was verified, and the inconsistencies of the previous stages were reviewed and adjusted, as defined in ISO 14040 and 14044 (ABNT NBR, 2006).

3 Findings and Discussion

When analyzing the results of the contribution tree of the eighteen impact categories of the biorefinery supply chain, only two categories were selected, namely: global warming, and scarcity of fossil resources. The choice occurred because both represent sensitive points for biorefinery and sustainability, given the context of the proposal (Ubando *et al.*, 2022).

The greatest contributions to observed environmental impacts come from the stages of extracting oil from microalgae biomass (extraction), with contributions above 92%, followed by the hydrodeoxygenation stage, represented by the nickel markets with contributions varying between 1.03% and 3,35% and the molybdenum market emitting between 0.84% and 3,33%, and finally, the hydrogen sulfide (H_2S) removal stage (Selexol), with emissions lower than 1%.

The extraction process uses hexane and ethyl acetate solvents to remove oil from microalgae biomass. According to the literature, it is possible to recover 95% of these compounds, however, this study does not consider the extraction process's recovery. The same occurs with nickel, molybdenum, and Selexol, both are subject to recovery.

Table 1. Summary of total supply chain contribution tree results.

Global warming			
Contribution	**Process**	**Amount**	**Unit**
92.90%	Extraction - BR	8,07E+13	kg CO2 eq.
03.35%	market for nickel, class 1 | nickel, class 1 | Cutoff, U - GLO	2,91E+12	kg CO2 eq.
03.33%	market for molybdenum | molybdenum | Cutoff, U - GLO	2,90E+12	kg CO2 eq.
00.33%	Selexol - BR	2,85E+11	kg CO2 eq.
Fossil resource scarcity			
Contribution	**Process**	**Amount**	**Unit**
97.90%	Extraction - BR	8,01E+13	kg oil eq.
01.03%	market for nickel, class 1 | nickel, class 1 | Cutoff, U - GLO	8,44E+11	kg oil eq.

00.84%	market for molybdenum | molybdenum | Cutoff, U - GLO	6,83E+11	kg oil eq.
00.21%	Selexol - BR	1,75E+11	kg oil eq.

Source: Author, 2023

4 Conclusion

The identification of the extraction, hydrodeoxygenation and Selexol processes as hotspots paves the way for testing other solvents and catalysts. Through the results obtained, it was possible to conclude that improvement opportunities fit in the proposal, such as modelling the processes in a virtual environment to have more accurate input and output data about the processes and to test new technological routes from this study to make the best use of inputs and waste generated in the biorefinery.

Even with limitations and opportunities for improvement, the research can serve as a basis for the development of new studies related to the theme. The use of secondary data helped in the development of the work; however, most of the data has the global north as a reference, which does not reflect the reality of Brazil and, consequently, generates greater inconsistencies in the results and their interpretations. In other words, having a robust database for the reality of Brazil can help improve studies.

5 Acknowledgment

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