BIOMASS AND BIOENERGY 35 (2011) 4221–4229

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BIOMASS & BIOENERGY

Life cycle assessment of biodiesel production using alkali, soluble and immobilized enzyme catalyst processes

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ARTICLE INFO

Article history:
Received 9 November 2009
Received in revised form
13 June 2011
Accepted 7 July 2011
Available online 2 August 2011

Keywords:
Life cycle assessment
Biodiesel
Alkali catalyst
Biocatalyst
Encapsulation
Lipase

ABSTRACT

This study deals with the Life Cycle Assessment (LCA) of three different catalytic processes for biodiesel production. In the LCA study, a “cradle to gate” approach was adopted to estimate the environmental impact of different catalytic processes such as immobilized, soluble biocatalyst and alkali catalyst. The results revealed that, biodiesel production using immobilized biocatalyst has less environmental impact compared to alkali and soluble biocatalyst. The environmental impact of the immobilized biocatalyst depends on the reusability factor.

1. Introduction

Biodiesel production and its use have become mandatory due to its environmental benign characters. Transesterification of triglycerides with alcohol in the presence of chemical, biocatalyst or non-catalyst leads to the formation of alkyl ester commercially known as biodiesel. The current biodiesel production technology uses chemical catalyst. In recent years, biodiesel production using biocatalyst have drawn an increasing attention and compared to chemical approach.

Every product has a life cycle stretching from the extraction or production of raw materials to final disposal. Each of these steps will require materials and energy inputs, and may release potentially harmful output to air, water and land. LCA is a tool for categorizing and quantifying these inputs and outputs to evaluate a product’s net environmental impact [1].

Life cycle assessment of biodiesel production using various catalysts have been reported [2–4]. However, a single report exits on the LCA study, comparing with alkali and biocatalyst [2]. The biocatalyst considered in this study was a commercial immobilized enzyme and hence the raw materials and energy requirements for biocatalyst production and immobilization has not been included in the inventory analysis.

To give a complete insight on the environmental impact of a product, it is necessary to include all the energy and raw materials involved in the process. Scientific perception indicates that enzymes as catalyst could potentially bring environmental and cost improvements [5–7], However, this perception must be quantitatively substantiated through a scientifically rigorous comparison. The enzymatic catalysts do not always exhibit a marked superiority from the life cycle environmental viewpoint [8,9]. The relative environmental life

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doi:10.1016/j.biombioe.2011.07.010

cycle profiles depend not only on the biocatalytic reactions in the synthesis but more importantly on the downstream processes for the purification and isolation of the desired product. It is therefore important to not only focus on the biosynthesis performance itself but also to account for the life cycle implications of the energy and raw materials used for the biocatalyst production [10]. Thus, this work attempts to study the LCA of biodiesel production using alkali catalyst and biocatalyst (soluble and immobilized), considering the energy and raw materials involved in biodiesel production as well as in biocatalyst production.

2. Materials and methods

2.1. Materials

The LCA software tool SimaPro 7.1 (PRE consultants, The Netherlands) was used.

2.2. Methodology

2.2.1. Goal and scope

The goal of this study is to compare environmental impact of biodiesel produced using sodium hydroxide, soluble lipase and immobilized lipase. The oil source and acyl acceptor was selected to be common for all three processes. The process parameters of biodiesel production using sodium hydroxide [11], for soluble lipase [12] and immobilized lipase [13–15] were adopted respectively. The Eco-indicator 99 module was used to characterize the impact categories of the inventory data.

The scope of this LCA study was from cradle to gate, covering the raw materials and energy requirements in biodiesel production using different catalyst (Table 1). The process flow sheet for biodiesel production using alkali catalyst, soluble lipase and immobilized lipase are shown in Figs. 1–3 respectively. The process involves transesterification reaction in a stirred tank reactor with a batch mode operation followed by separation, washing and purification steps. The unit operations involved in each process are expressed as I, II, IV units in lipase production and biodiesel production.

Table 1 – Process conditions for biodiesel production.

Raw materials and process parameters	Alkali catalyst	Soluble enzyme	Immobilized enzyme
Oil used	Palm oil	Palm oil	Palm oil
Catalyst used	NaOH	Lipase PS	Encapsulated lipase PS
Mass fraction of catalyst on oil	1%	4%	5%
Alcohol used	Methanol	Methanol	Methanol
Alcohol to oil ratio ($mol\ mol^{-1}$)	7:1	7:1	7:1
FAME produced (w/w)	95%	99%	99%
Reactor temperature	60 °C	30 °C	30 °C
Reaction time	1.5 h	72 h	72 h

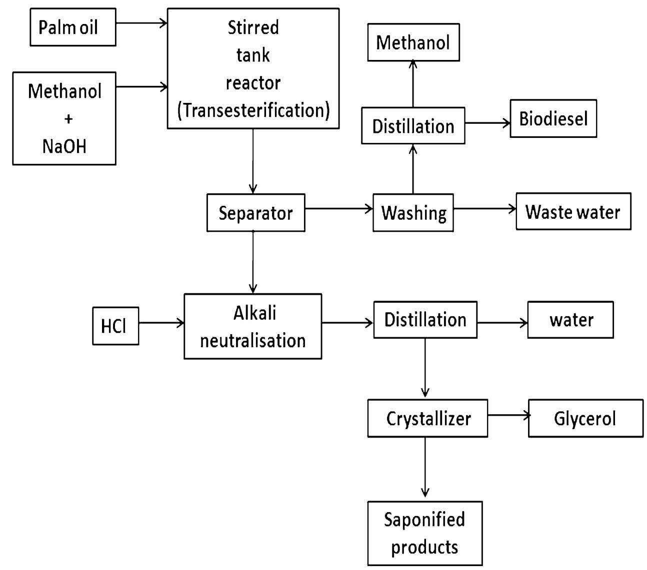

Fig. 1 – Flow chart of biodiesel production using alkali catalyst.

2.2.2. Inventory analysis

The raw materials and energy requirements were taken considering the biodiesel production capacities of 1 Mg, 5 Mg, and 10 Mg using sodium hydroxide, soluble lipase and immobilized lipase for inventory analysis. The reason for

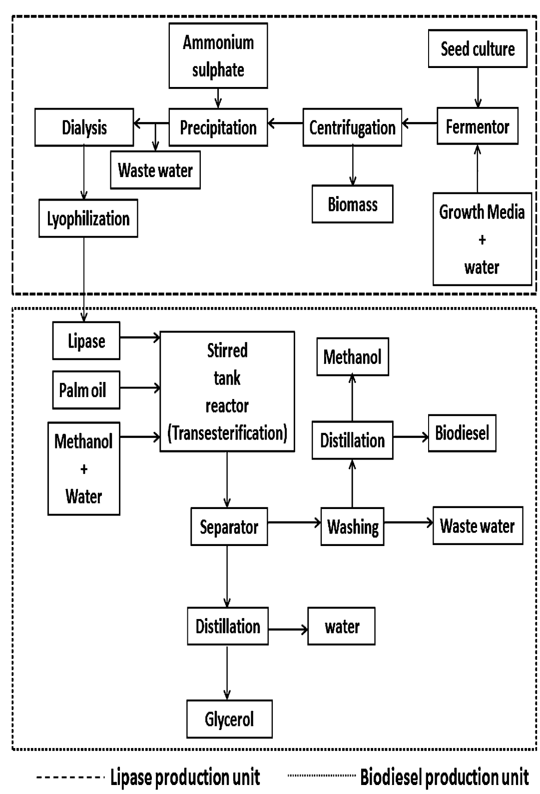

Fig. 2 – Flow chart of biodiesel production using soluble enzyme catalyst.

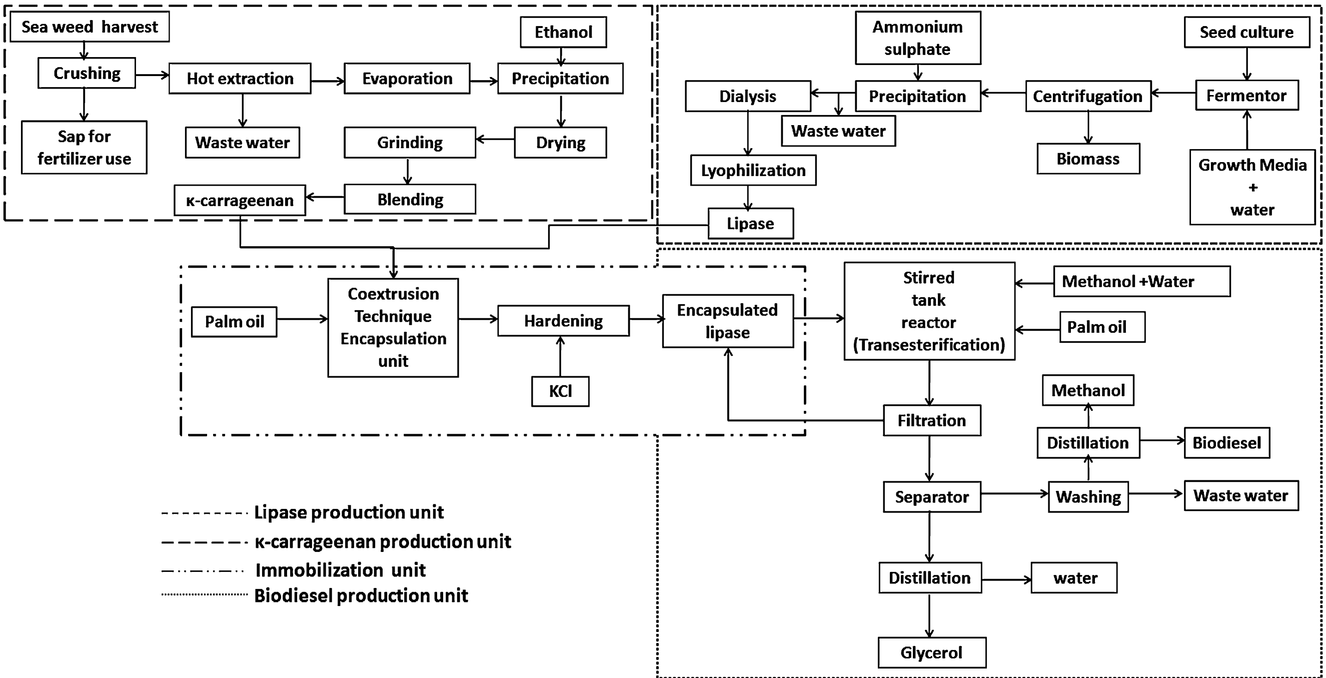

Fig. 3 – Flow chart of biodiesel production using immobilized enzyme catalyst.

Table 2 – Materials and energy used to produce biodiesel using alkali catalyst.

Production capacity	Unit	1 Mg	5 Mg	10 Mg
Materials				
Palm oil	kg	995	4975	9950
Methanol	kg	263	1315	2630
Sodium hydroxide	kg	10	50	100
Hydrochloric acid	kg	38	190	380
Water	kg	147	735	1470
Energy				
Electricity	kW h	8.6	43	86
Steam	kg	1820	9100	18200

Table 3 – Materials and energy used to produce biodiesel using soluble enzyme catalyst.

Production capacity	Unit	1 Mg	5 Mg	10 Mg
Materials				
Palm oil	kg	1050	5250	10500
Methanol	kg	263	1315	2630
Starch from corn	kg	30	150	300
Ammonium sulfate	kg	10	50	100
Magnesium sulfate	kg	1	5	10
Protein from corn	kg	20	100	200
Water	kg	1200	6000	12000
Energy				
Electricity	kW h	20	100	200
Steam	kg	1540	7700	15400

considering variable production capacities was to facilitate the reuse of immobilized lipase for 10 times.

The inventory analysis for biodiesel production using sodium hydroxide for different production capacities is listed in Table 2. The raw materials palm oil, methanol, sodium hydroxide were selected from the Eco-indicator 99 data library and the amount of the raw materials needed for each production capacity was entered as input. For the biocatalyst life cycle inventory, since information available to estimate environmental burden, compare the environmental impacts and footprint of biocatalyst process with chemical routes was challenging and therefore, a series of assumptions and estimations were made. However, LCA is just a model of reality, providing a snapshot of a dynamic process. In arriving at

Table 4 – Materials and energy used to produce biodiesel using immobilized enzyme catalyst.

Production capacity	Unit	1 Mg	5 Mg	10 Mg
Materials				
Palm oil	kg	1100	5080	10055
Methanol	kg	263	1315	2630
Water	kg	1300	2100	3000
Ethanol	kg	20	20	20
κ–carrageenan from sea weed	kg	100	100	100
Starch from corn	kg	30	30	30
Magnesium sulfate	kg	1	1	1
Protein from corn	kg	20	20	20
Ammonium sulfate	kg	10	10	10
Potassium chloride	kg	5	5	5
Energy				
Electricity	kW h	30	100	200
Steam	kg	1800	5000	10000

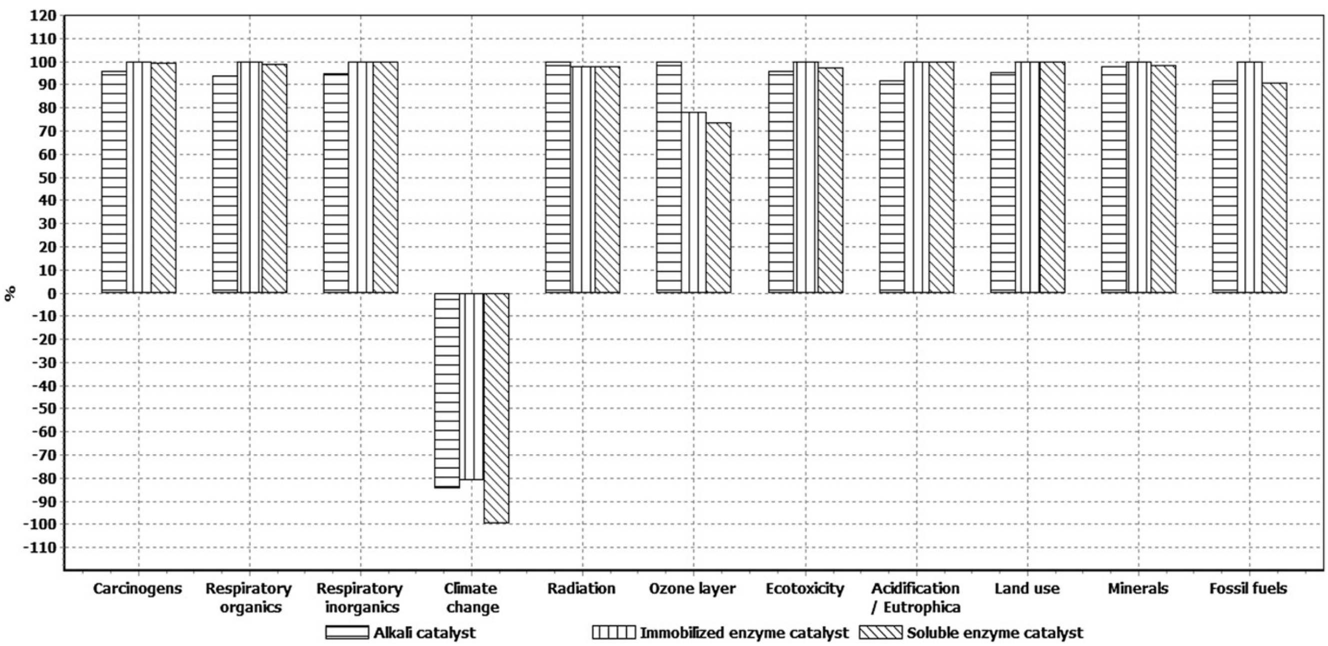

Fig. 4 – Comparison of the environmental impacts on each of the 11 environmental categories due to the production of 1 Mg palm biodiesel.

a model, one can't escape making assumptions, simplifications and subjective choices [1].

In case of soluble lipase and immobilized lipase catalytic process, some of raw materials required were not available in the Eco-indicator 99 data library. For those cases indirect inputs were used from the library. For the case of lipase production, glucose was not available in the database library. Hence the source of glucose (starch from corn) was used as the input. Similarly, in case of immobilized lipase instead of κ-carrageenan, the general raw material biopolymer available

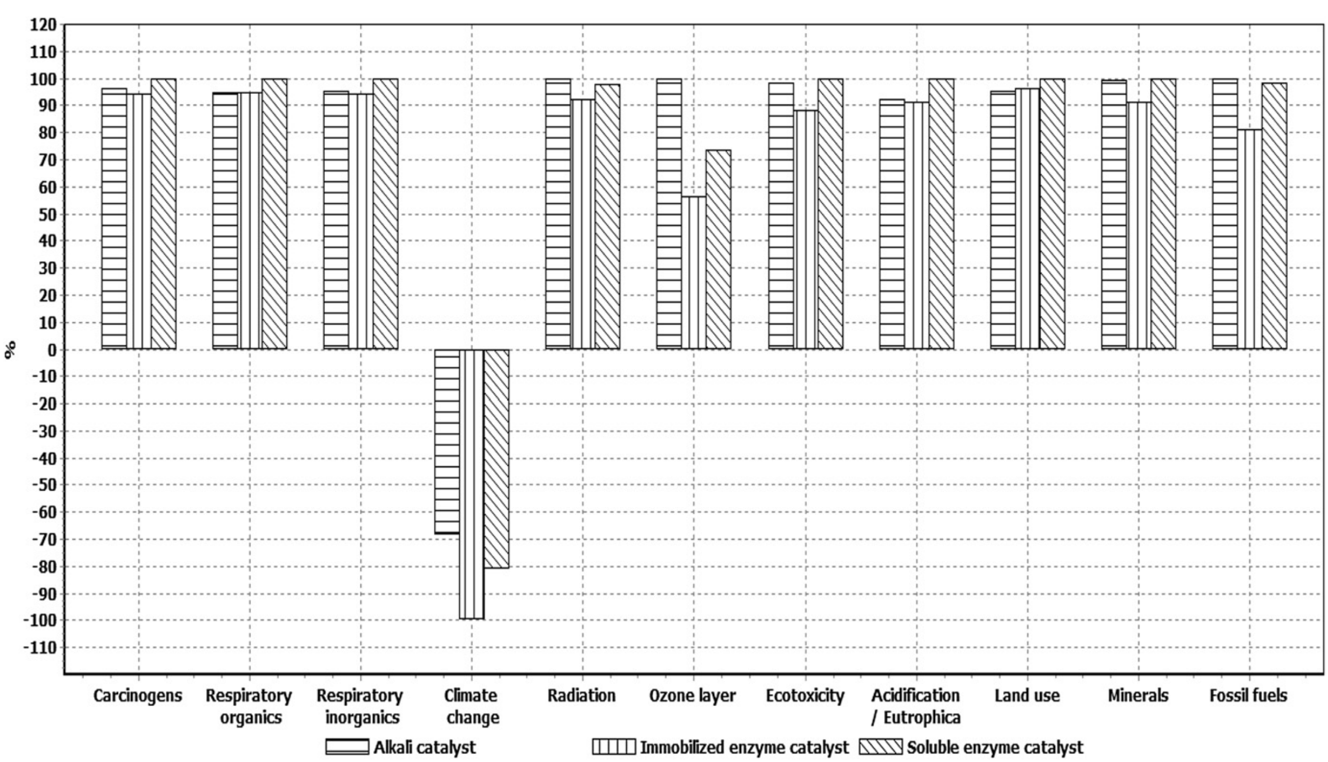

Fig. 5 – Comparison of the environmental impacts biodiesel on each of the 11 environmental categories due to the production of 5 Mg palm biodiesel.

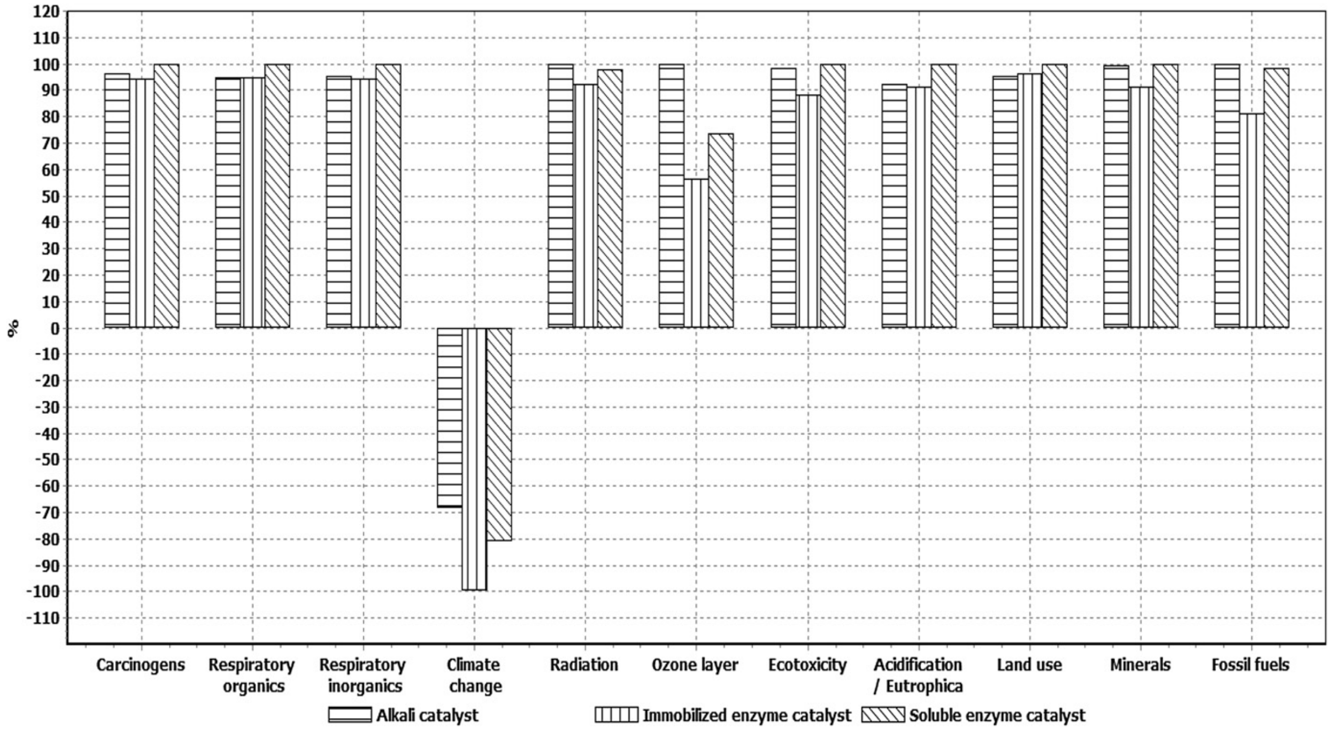

Fig. 6 – Comparison of the environmental impacts on each of the 11 environmental categories due to the production of 10 Mg palm biodiesel.

in the database library was used as input. The details of the inputs in the inventory analysis for biodiesel production using soluble lipase and immobilized lipase catalyst for each production capacity are listed in the Tables 3 and 4. In the context of immobilized lipase catalyst, the raw materials for lipase and immobilization were repeated for production capacities of 1 Mg, 5 Mg (5 reuse) and 10 Mg (10 reuses) due to its reusable capability.

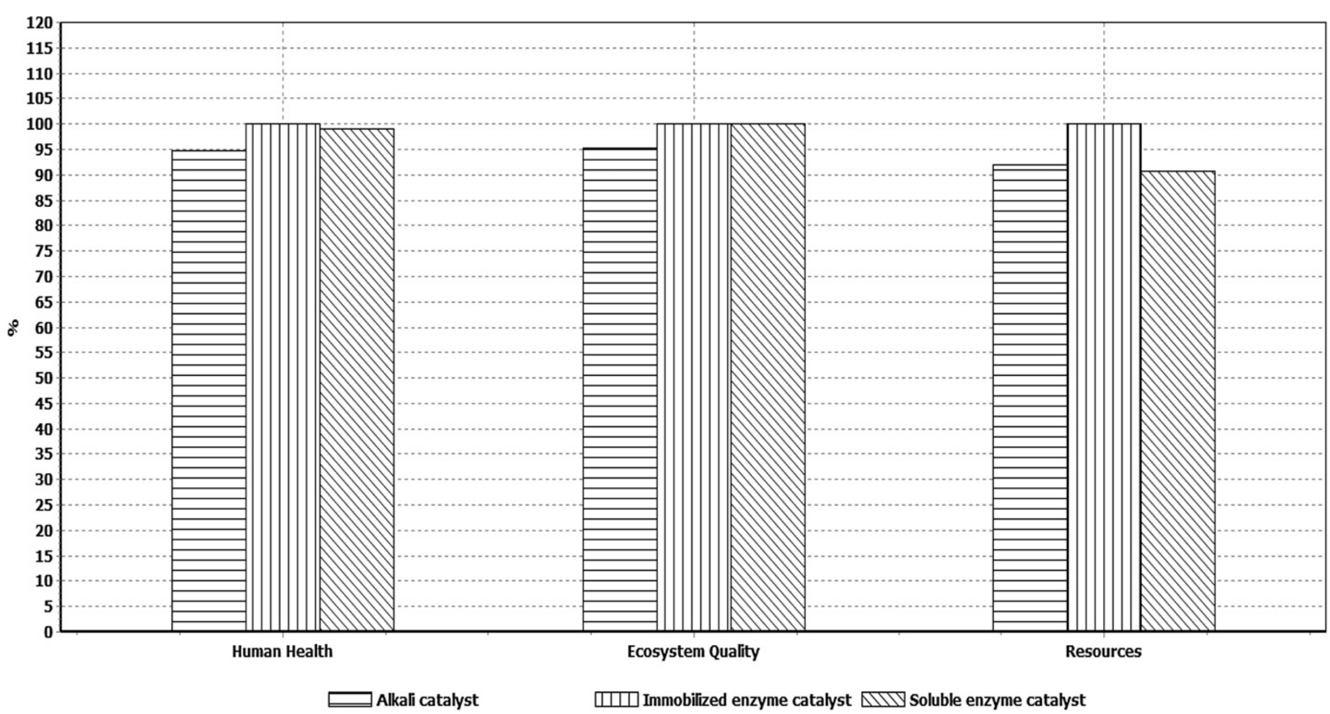

Fig. 7 – Comparison of the environmental impacts on human health, ecosystem and resources due to the production of 1 Mg palm biodiesel.

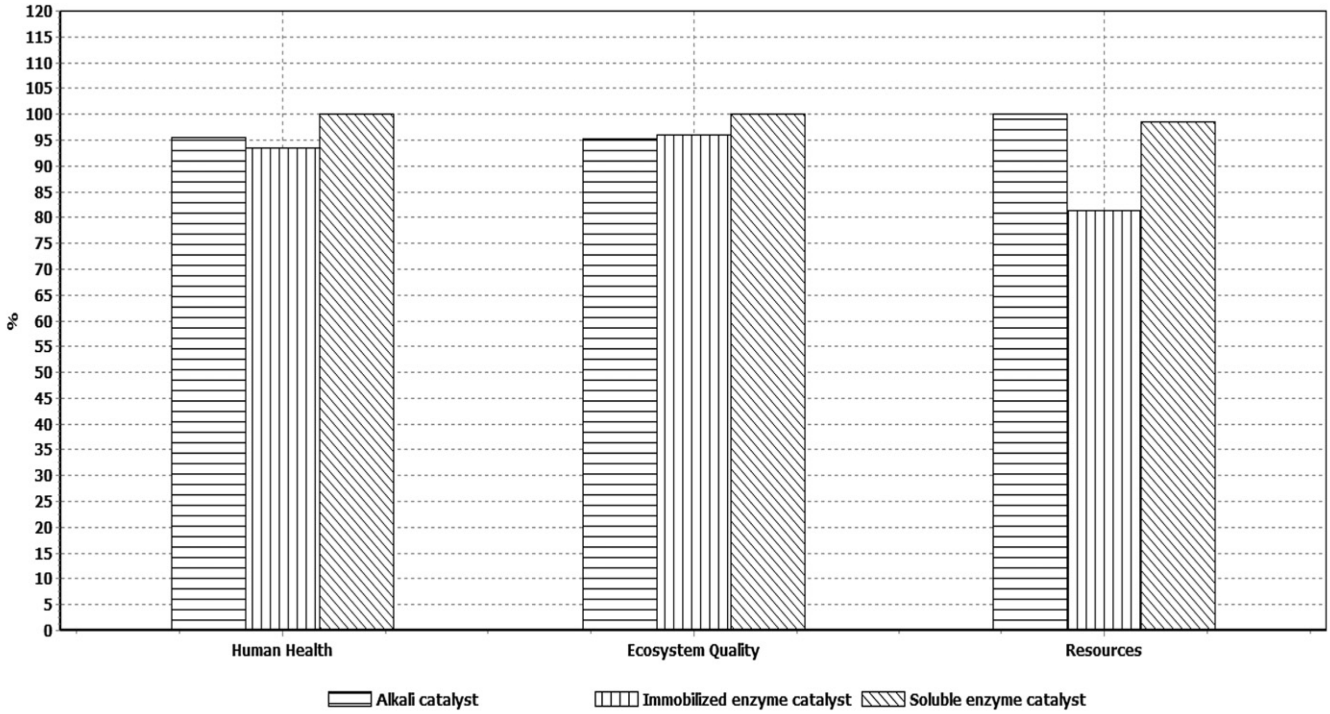

Fig. 8 – Comparison of the environmental impacts on human health, ecosystem and resources due to the production of 5 Mg palm biodiesel.

2.2.3. *Impact assessment*

Environmental impact for biodiesel production process with different capacities was estimated for eleven categories. The categories include climate change, carcinogens, respiratory organics, inorganic, ozone layer depletion, eco-toxicity, acidification/eutrophication, minerals, radiation, land use and fossil fuels. Further, the environmental impact on human health, ecosystem and resources along with their single

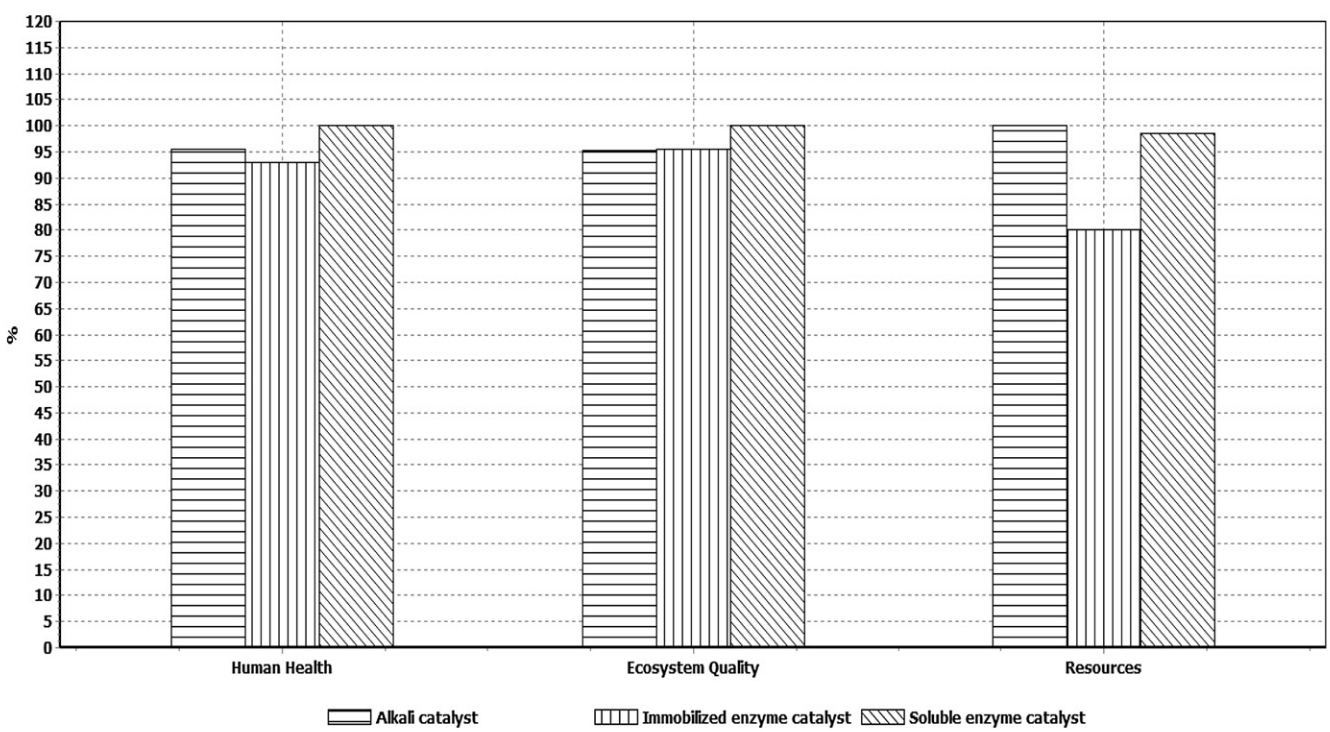

Fig. 9 – Comparison of the environmental impacts on human health, ecosystem and resources due to the production of 10 Mg palm biodiesel.

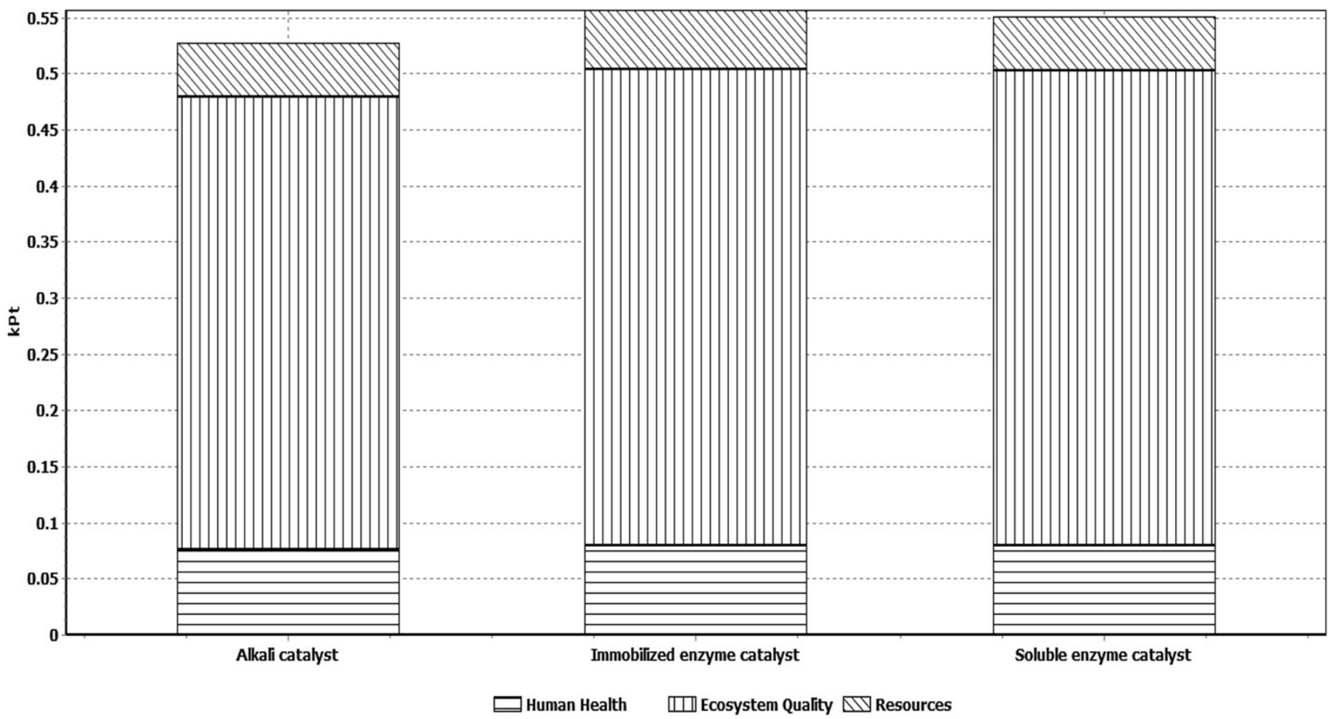

Fig. 10 – Comparison of the environmental impacts on each environmental category based on a single cumulative score due to the production of 1 Mg palm biodiesel.

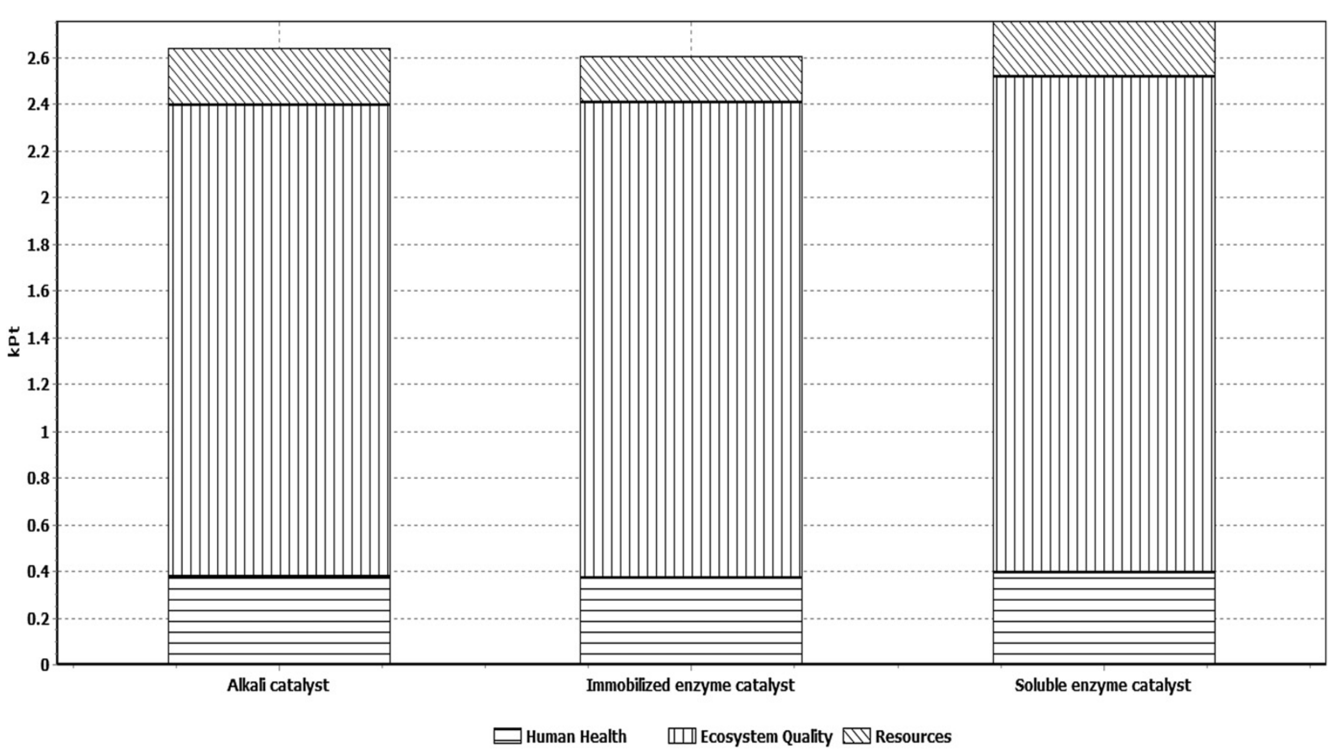

Fig. 11 – Comparison of the environmental impacts on each environmental category based on a single cumulative score due to the production of 5 Mg palm biodiesel.

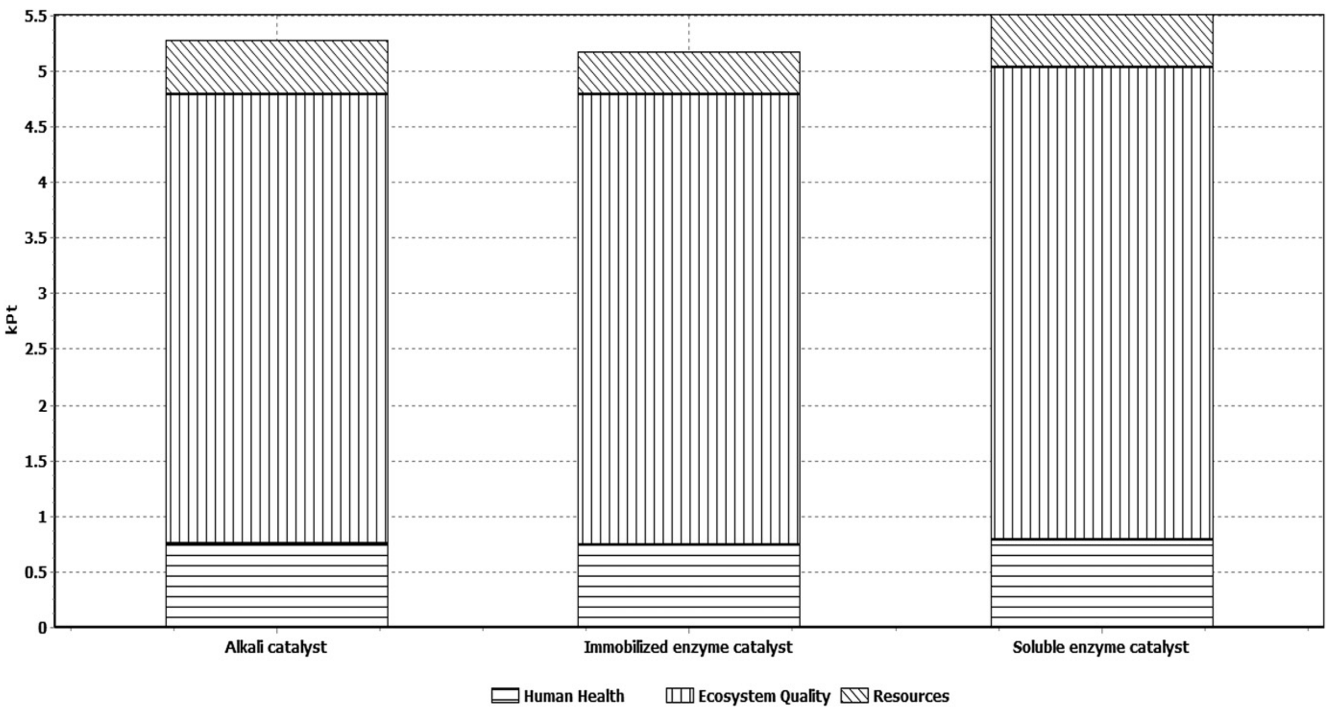

Fig. 12 – Comparison of the environmental impacts on each environmental category based on a single cumulative score due to the production of 10 Mg palm biodiesel.

cumulative score were also estimated. The comparative results of environmental impacts are represented in graphical form.

3. Results and discussion

The results and discussion of LCA for biodiesel production using various catalytic processes are reported in the interpretation section.

3.1. *Interpretation*

The environmental impact of biodiesel production from palm oil and methanol using sodium hydroxide, soluble lipase and immobilized lipase catalyst for 1 Mg, 5 Mg, and 10 Mg capacity are shown in the Figs. 4–6. The results reveals that for a 1 Mg, biodiesel production capacity, immobilized catalyst process showed higher environmental impact (9 out of 11 categories) compared to sodium hydroxide (2 out of 11 categories) and soluble lipase catalyst (3 out of 11 categories). The reason could be higher number (IV) of unit operations involved in immobilized lipase production leading to more quantity requirements of raw materials and energy usage. As the production capacity increased, the environmental impact of immobilized lipase catalyst process decreased compared to the other two processes. For 5 Mg and 10 Mg capacity the environmental impact of immobilized lipase catalyst decreased for all the 11 categories compared to the other two processes. Because, the immobilized lipase catalyst is reused for 5 and 10 times respectively, indicating the less environmental impact.

In case of soluble lipase catalyst, increase in biodiesel production capacity increased the environmental impact compared to the sodium hydroxide and immobilized lipase catalyst. For 10 Mg biodiesel production capacity, the soluble lipase catalyst process showed high environmental impact compared to the other two processes. This was due to the higher raw material and energy needs.

The environmental impact of biodiesel production using sodium hydroxide, soluble lipase and immobilized lipase on health, ecosystem and resources is shown in the Figs. 7–9 respectively. For immobilized lipase catalyst process the environmental impacts gradually decreased upon increasing the production capacity. This trend was opposite for the alkali and soluble lipase catalyst. Similar trend was followed for the environmental impacts of biodiesel production from various catalytic processes on each environmental category based on a single cumulative score (Figs. 10–12).

4. Conclusion

Based on the LCA study on biodiesel production using different catalyst, it is concluded that, the environmental impact of biodiesel production using immobilized catalyst decreases upon reuse compared to alkali and soluble enzyme catalyst. The degree of environmental impact depends strongly on the number of reuses. It should be also noted that the immobilization matrix and immobilization process also plays a role in environmental impact and it is suggested to use immobilization matrix with environmental benign characters and a milder immobilization process conditions.

Acknowledgment

The authors wish to thank PRE consultants for providing SimaPro software.

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