Recibido el 14 de febrero, aceptado el 25 de marzo de 2024 | ISSN: 2683-3107

01

A REVIEW ON THE LIFE CYCLE ASSESSMENT OF BIODIESEL PRODUCTION FROM WASTE FEEDSTOCKS

UNA REVISIÓN SOBRE EL ANÁLISIS DE CICLO DE VIDA DE LA PRODUCCIÓN DE BIODIÉSEL A PARTIR DE MATERIAS PRIMAS RESIDUALES

Angelica Avila Anguis
Valeria Caltzontzin Rabell
Sergio Iván Martínez Guido
Claudia Gutiérrez Antonio*

Universidad Autónoma de Querétaro, Santiago de Querétaro, México.

*claudia.gutierrez@uaq.mx

Perspectivas de la Ciencia y la Tecnología | Vol. 7 Núm. 13 | Julio-Diciembre | Facultad de Ingeniería | Universidad Autónoma de Querétaro | ISSN: 2683-3107

Abstract

Humanity is currently facing challenges such as climate change, water scarcity, inequality and hunger. In 2015, The United Nations established the 2030 Sustainable Development Goals (SDGs), with the purpose of protecting the planet and guaranteeing humanity's well-being. Among these objectives is Goal 7: affordable and non-polluting energy. One way to achieve this objective is substituting fossil diesel for biodiesel, which can be produced from various raw materials. Waste biomass is an attractive feedstock for biodiesel production due to its abundance and availability, constant generation and low price.

In recent years, the environmental impact of biofuels production has been studied through life cycle assessments (LCA), a methodological analysis that allows to objectively estimate and assess the potential environmental impacts of a service or product across its life stages. Thus, the purpose of this work is to conduct a review of the previous studies on LCAs in biodiesel production from biological waste. Thus, the benefit resulting from obtaining biodiesel from a residual raw material encompasses environmental and economic points of view.

Keywords: animal fat, biodiesel production, life cycle assessment, waste feedstocks, waste oil.

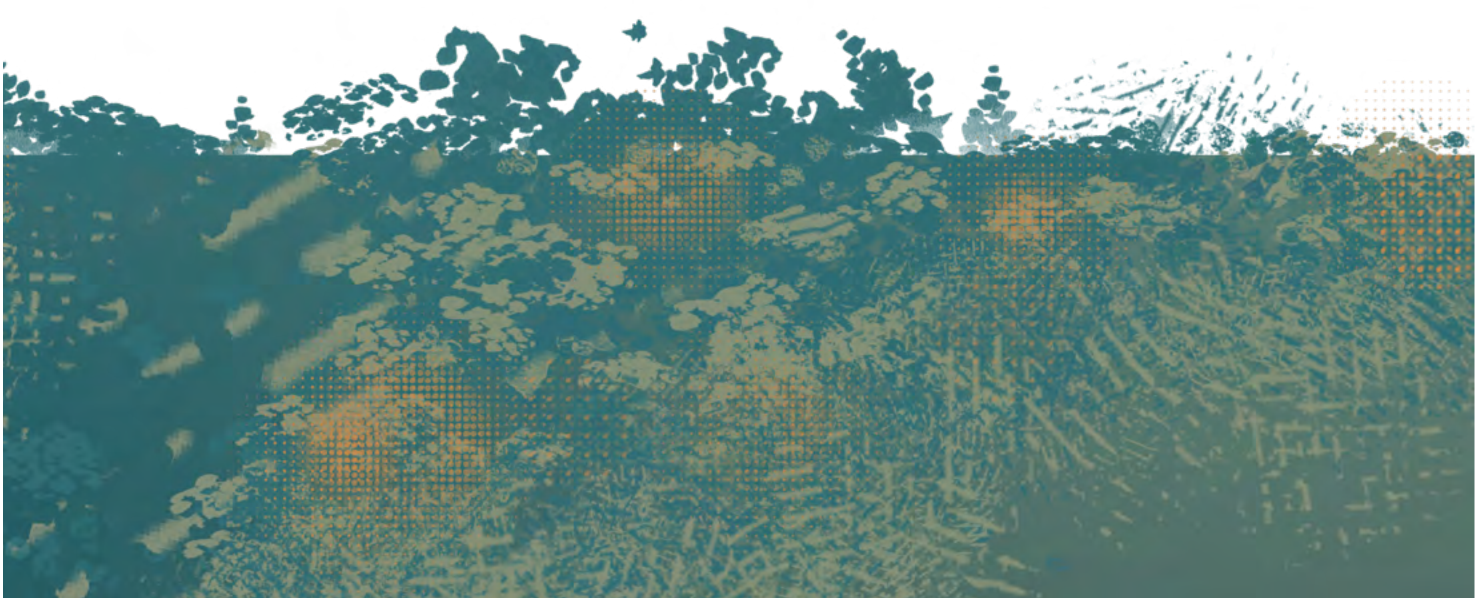
Perspectivas de la Ciencia y la Tecnología | Vol. 7 Núm. 13 | Julio-Diciembre | Facultad de Ingeniería | Universidad Autónoma de Querétaro | ISSN: 2683-3107

Resumen

Actualmente, la humanidad se enfrenta a diversos retos, tales como el cambio climático, la escasez de agua, la desigualdad, el hambre, entre otros. Debido a esto, la Organización de las Naciones Unidas en el 2015 aceptó la agenda 2030, que contiene los Objetivos de Desarrollo Sostenible (ODS), con el propósito de proteger el planeta y garantizar el bienestar de todos. Dentro de estos objetivos se encuentra el ODS7, el cual tiene como meta para el 2030 disponer de energía asequible y no contaminante. Una alternativa para alcanzar este objetivo es el reemplazo del diésel fósil por biodiésel, el cual puede producirse a partir de diversas materias primas. En particular, para la producción de biodiésel, la biomasa residual es una materia prima atractiva debido a su abundancia y elevada disponibilidad, constante generación y bajo costo.

Actualmente, se ha estudiado el impacto ambiental de la producción de biocombustibles mediante el análisis del ciclo de vida, el cual es una metodología que permite, de manera objetiva, cuantificar los impactos que puede tener un producto o servicio en el medio ambiente en todas las etapas de su vida. Por lo tanto, el objetivo del presente trabajo es llevar a cabo una revisión de la literatura existente acerca de la evaluación del análisis de ciclo de vida para la producción de biodiésel utilizando materia prima residual. Así, el beneficio resultante de obtener biodiésel a partir de esta puede abarcar aspectos económicos y medioambientales.

Palabras clave: grasa animal, producción de biodiésel, análisis de ciclo de vida, materias primas residuales, aceite residual.



Perspectivas de la Ciencia y la Tecnología | Vol. 7 Núm. 13 | Julio-Diciembre | Facultad de Ingeniería | Universidad Autónoma de Querétaro | ISSN: 2683-3107

Introduction

In 2015, the United Nations authorized the 2030 Agenda on Sustainable Development, that contains 17 Sustainable Development Goals (SDGs); they represent a global call to action to address the social, economic and environmental challenges facing the world. The 17 SDGs are: no poverty, zero hunger, good health and well-being, quality education, gender equality, clean water and sanitation, affordable and clean energy, decent work and economic growth, industry innovation and infrastructure, reduced inequality, sustainable cities and communities, responsible consumption and production, climate action, life below water, life on land, strong institutions and partnerships for the goals [1]. Altogether, these goals seek to improve people's quality of life, promote equity, safeguard the environment and ensure economic development that is sustainable and beneficial for all people and the planet.

Figure 1 shows all the 17 sustainable development goals; specifically, SDG 7 includes the generation of affordable and clean energy; the purpose is to guarantee access to affordable, high quality, sustainable and modern energy for all [2]. One target for 2030 is to achieve a considerable increase in the proportion of renewable and sustainable energy in the repertoire of energy sources. One strategy to achieve this contemplates the production and consumption of biofuels, especially for this work, biodiesel.

Figure 1. Sustainable development goals. Own elaboration based on [3].

Perspectivas de la Ciencia y la Tecnología | Vol. 7 Núm. 13 | Julio-Diciembre | Facultad de Ingeniería | Universidad Autónoma de Querétaro | ISSN: 2683-3107

Petroleum derived fuels currently dominate over the transportation sector around the world [2]. However, this type of fuels are produced from a non-renewable source. Another problem is that they release toxic and greenhouse gases (GHG) into the atmosphere when burned, contributing to global warming, climate change and environmental pollution [4], [5].

In order to mitigate the difficulties mentioned above, biofuels are considered a cleaner and renewable replacement for fossil fuels. Among the most ecological ones developed to date is biodiesel, a liquid obtained from oils of organic materials [6]. There are four generations of feedstocks for biodiesel production [7]:

— Food crops.

— Non-edible feedstock, for example: waste cooking oil, animal fat residues and vegetable oils.

— Algae biomass.

— Genetically modified algae, electrofuels and photobiological solar fuels.

Biodiesel is obtained through transesterification, a catalyzed chemical reaction involving a vegetable oil or fat and an alcohol that produces alkyl esters of fatty acids (or biodiesel) and glycerol [8]. With the potential to decrease emissions of GHG [10], it is useful not only in the transportation sector, but also in the generation of energy and heat, either as a full or partial replacement of fossil diesel [9]. In addition, it is biodegradable, renewable, non-toxic and has a high cetane rating, and flash point, which favors immediate combustion [11].

> ... As the risk of climate change, water scarcity and hunger increase, life cycle assessments become more and more important for the industrial sectors. This work provides an insight on the research done so far respecting lcas in order to remark their importance for the sustainable development of humanity towards the future.

In the last few years, several studies have been carried out to evaluate the environmental impacts of the biodiesel production from different feedstocks [10]. One methodology to evaluate the environmental impact attributed to the biodiesel production process is the life cycle assessment (LCA), which provides insight for decision making towards sustainable options [5].

LCA is a global systematic methodology to evaluate the environmental aspects and potential impacts associated with a service or product. In LCA the relevant inputs and outputs of the product system are collected, and the potential environmental effects attached to those inputs and outputs are evaluated; finally, the results of the inventory analysis as well as impact assessment phases are interpreted [12]. This methodology effectively captures the diverse impacts on natural resources, human health and ecosystem quality [6].

Perspectivas de la Ciencia y la Tecnología | Vol. 7 Núm. 13 | Julio-Diciembre | Facultad de Ingeniería | Universidad Autónoma de Querétaro | ISSN: 2683-3107

In 2016, Mu [13] used LCA to assess the environmental impacts for the transformation of scum (generated at a sewage treatment plant) into biodiesel. The results indicated that all reviewed impacts were below zero; thus, significant environmental benefits can be attained. The study highlights the feasibility and advantages of implementing scum-to-biodiesel technology in sewage treatment facilities. Also in 2016, Tu [14] presented an LCA to estimate the energy expenditure and GHG emission of biodiesel production from fats and oils contained in a grease trap. The outcomes demonstrated that the waste contained in the grease trap is potentially a more energy-efficient raw material with lower GHG emissions, compared to other feedstocks, such as soybean and algae oil. Later, Foteinis [15] examined through LCA the sustainability of biodiesel produced from waste cooking oil (WCO); then, results were compared with first-generation biodiesel. It was found that the total environmental and carbon footprint of biodiesel production from residual cooking oil were 40% less than the impacts generated by the production of first generation biodiesel. Additionally, a three-fold decrease in environmental impacts compared to petroleum diesel was observed. In the same year, Vargas-Ibáñes [11] carried out an LCA to estimate the potential environmental impacts of ternary blends of diesel and biodiesel from beef tallow with additives as a biofuel used in diesel engines. In 2022, Corral-Bobadilla [16] carried out an LCA to evaluate different input process parameters that generate the greatest environmental WCO derived biodiesel impact; these studied parameters included reaction temperature, methanol to oil molar ratio, reaction time, catalyst dosage and agitation rate. Recently, Kiehbadroudinezhad [17] evaluated the environmental sustainability of the biodiesel production process from fish waste using LCA. The results showed that biodiesel from fish oil has approximately 76% lower environmental impact, compared to biodiesel from vegetable oils.

Residual oils as raw material for the production of biodiesel are a promising solution, not only because they do not compete with food for human consumption [18], but also because the use of this type of feedstock aligns with the circular economy approach [19]; this model seeks to reduce the environmental impact of a process by reusing, recycling and recovering the waste generated in the process [17]. However, further research is required to improve the visualization of inventory data, investigate other residual feedstocks such as animal fats, agricultural waste and sewage sludge, and compare the environmental performance of different biodiesel production systems [12].

This literature review analyzes the LCA studies that have been carried out to evaluate the production of biodiesel using exclusively residual raw materials. The aim is to understand in depth the various types of waste

Perspectivas de la Ciencia y la Tecnología | Vol. 7 Núm. 13 | Julio-Diciembre | Facultad de Ingeniería | Universidad Autónoma de Querétaro | ISSN: 2683-3107

that have been evaluated for biodiesel production, as well as to identify and analyze the main findings and methodologies used in those studies. Furthermore, this study is intended to highlight the importance of knowing the types of waste evaluated, since this significantly influences the environmental performance and sustainability of the biodiesel production process. As a consequence, possible areas of opportunity are shown as a guide for future studies.

Methodology

To accomplish the purpose of this work, a review of the literature was carried out using Google Scholar, which is a tool that enables the search of academic documents. Indexed scientific articles were located firstly using the following keywords: "life cycle assessment" and "biodiesel production" and "animal fat" and "waste feedstocks". Subsequently, the word "animal fat" was replaced with "waste oil." In addition, the Elsevier platform named ScienceDirect was also used with the following keywords: "life cycle assessment" and "biodiesel" and "waste biomass." Another search was conducted replacing "waste biomass" with "waste feedstock," "waste triglyceride." The aforementioned terms were defined in order to find all the works that have been done using LCA regarding the production of biodiesel solely from residual raw materials.

Based on the results of the search process, three inclusion criteria were used for the selection of the relevant literature:

- Search period, where only articles published from 2010 to the current year were selected.
- Only articles published in indexed journals were considered, which means that they are high-quality journals and are listed in a global consultation database. In this case, to verify this inclusion criterion, the Web of Science database was used.

Finally, there were additional criteria for the removal of articles, which are presented next:

- Removal of repeated articles: Repeated articles were found several times in the search engines.
- Removal due to content: The articles do not include an LCA focused on biodiesel production from waste feedstock.
- Removal of items that were not available.

Perspectivas de la Ciencia y la Tecnología | Vol. 7 Núm. 13 | Julio-Diciembre | Facultad de Ingeniería | Universidad Autónoma de Querétaro | ISSN: 2683-3107

Selection of literature

The keywords: "life cycle assessment" and "biodiesel production" and "animal fat" and "waste feedstocks" were entered in the Google Scholar search engine; 94 documents were obtained. After criterion 1 was applied, the number of articles decreased to 82, while the application of criteria 2 and 3 reduced the number to 6. Later, the same procedure was carried out with the following keywords: *"life cycle assessment"* and *"biodiesel production"* and *"waste oil"* and *"waste feedstocks;"* 88 documents were obtained. When inclusion criterion 1 was applied, the number of articles decreased to 76; then, criteria 2 and 3 were applied and the number of articles was reduced to 3. It was observed that from the results, two articles were already included when using the keywords in the previous paragraph, so, they were removed. A similar procedure was carried out with the search in Elsevier Platform: 13 more references after applying all the criteria previously described were found.

Finally, the articles selected in both search engines amounted to a total of 20. Figure 2 presents a flowchart that shows the process for the search and selection of the literature present in this study.

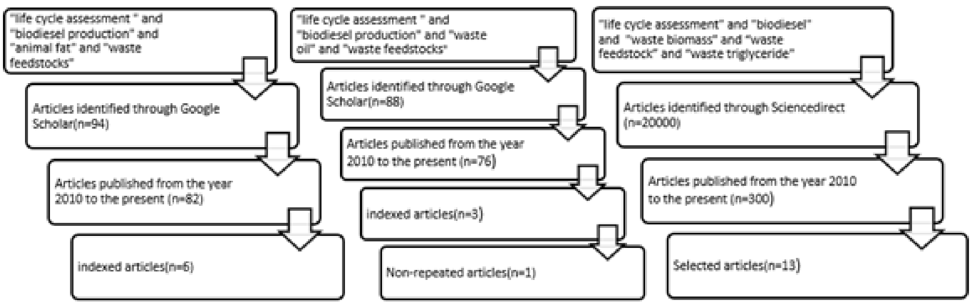


FIGURE 2. Flowchart of literature selection process

Results and discussion

This section presents the literature analysis regarding the LCA for the production of biodiesel from waste feedstocks.

First, waste cooking oil emerges as the most extensively researched waste feedstock, constituting 41.7% of the selected studies. Following WCO, research focuses on animal fats as residual raw material, comprising 20.83% of the reviewed studies. Finally, a variety of other residual raw materials are explored in less proportion. These include agricultural waste, waste oil obtained from wastewater treatment, fats and oils contained in grease traps, ground coffee residues and insect oil, which correspond to 16.66%, 8.33%, 4.16%, 4.16% and 4.16%, respectively. Table 1 lists the residual raw materials used in the reviewed literature.

Perspectivas de la Ciencia y la Tecnología | Vol. 7 Núm. 13 | Julio-Diciembre | Facultad de Ingeniería | Universidad Autónoma de Querétaro | ISSN: 2683-3107

As for the LCA type, it can be seen from Table 1 that the total of the reviewed literature mentions the system boundaries, which are divided into five categories. The most widely used boundary system in the literature is the limit called *from the cradle to the gate*, which represents 50%; this boundary covers the process of extraction of the feedstock until the production of biodiesel to assess its environmental impact, but the use and disposal of the product is excluded [20]. The other four boundaries mentioned are *from gate to gate, from the well to the wheels, from the cradle to the grave* and *from waste to electricity*, which represent 30%, 10%, 5% and 5%, respectively.

With respect to the software used to calculate the environmental impact assessment, it was observed that 60% of the works relied on SimaPro; also, other softwares were used, such as Aspen Plus, GREET, GaBi, which represent 10% each one, as well as Python and NR, which represent 5% each one. Table 2 displays the type of biodiesel production process and the operating conditions that were carried out in each study reviewed.

Table 1. Feedstocks, system boundaries and software used in life cycle assessment.

Author	Waste feedstock	System boundary	Software
[8]	Residual vegetable oil	Cradle to grave	Aspen Plus
[13]	Scum	Gate to gate	GREET
[6]	WCO		SimaPro
[21]	WCO		SimaPro
[16]	WCO		SimaPro
[14]	Oils and fats contained in grease traps		Python 2.7
[9]	WCO		GaBi Software
[5]	WCO	Cradle to gate	Green Delta
[15]	WCO		SimaPro
[18]	Waste date seed oil		NR
[19]	Waste Prunus Armeniaca seeds		SimaPro
[17]	Fish waste		SimaPro
[11]	Beef tallow		SimaPro
[4]	Loquat kernel oil residues		SimaPro
[10]	WCO		SimaPro and Aspen Plus
[24]	Spent ground coffee		GaBi Software
[25]	BSFL		SimaPro
[12]	WCO, beef tallow, poultry fat and sewage sludge	Well to the wheels	SimaPro
[23]	WCO and pork tallow		GREET
[22]	WCO	Waste to electricity	NR

Perspectivas de la Ciencia y la Tecnología | Vol. 7 Núm. 13 | Julio-Diciembre | Facultad de Ingeniería | Universidad Autónoma de Querétaro | ISSN: 2683-3107

In 80% of the studies, biodiesel is obtained from conventional transesterification. Moreover, esterification process is reported in 5% of the articles for biodiesel production, while 15% of the studies reported new techniques in the transesterification process. Morais [8], for instance, obtained biodiesel from residual vegetable oils through the transesterification process with supercritical methanol using propane as co-solvent; this process was carried out at a temperature of 280 °C for 12.6 minutes. The data were compared to those obtained via a transesterification process utilizing alkaline and acid catalysts. The results demonstrated that the supercritical methanol process is the most favorable alternative for the environment, contrary to the acid catalyzed process that shows the highest potential environmental impacts.

In order to address the problems of mechanical agitation in the transesterification process, Aghbashlo [6] analyzed an ultrasound-assisted system; in this study, the objective was to provide the initial reaction energy and decrease the conversion time of WCO into biodiesel. The results showed that the most environmentally friendly transesterification conditions were a methanol to oil molar ratio of 6, temperature of 60 °C and a reaction time of 10 minutes; the yield under these conditions was 97.12%. The environmental impacts of biodiesel produced under the conditions mentioned above, such as damage to human health, ecosystem quality, climate change and resource categories were significantly lower than those of conventional diesel fuel.

Bhonsle [21] produced biodiesel from WCO via two approaches: transesterification by conventional method and transesterification at room temperature. Regarding the second process, no heating was required; in order to achieve this reaction a novel solvent was added to the reaction mixture of WCO with alkaline catalyst potassium hydroxide in methanol. No significant differences in biodiesel yield were observed in both cases, and a yield of about 85% was achieved. The results showed that biodiesel at ambient temperature produced about 425 kg CO_2eq, while conventional

TABLE 2. Type of biodiesel production process and operating conditions.

Author	Waste Feedstock	Production process	Alcohol	Catalyst	Temperature	Time
[8]	Residual vegetable oil	Transesterification with supercritical methanol	Propane as co-solvent		280 °C	12.6 min
[12]	WCO	Transesterification	Methanol	NaOH	nr	nr
	Beef tallow	Transesterification	Methanol	NaOH	nr	nr
	Poultry fat	Transesterification	Methanol	NaOH	nr	nr
	Waste water sludge	Transesterification	Methanol	H_2SO_4	nr	nr
[13]	Scum	Transesterification	Methanol	CH_3KO	60 °C	1 h
[5]	WCO	Transesterification	Methanol	CaO derived from chicken eggs shells	65 °C	2 h
[6]	WCO	Ultrasound-assisted Transesterification	Methanol	KOH	60 °C	10 min
[15]	WCO	Transesterification	Methanol	CH_3KO	nr	nr

Perspectivas de la Ciencia y la Tecnología | Vol. 7 Núm. 13 | Julio-Diciembre | Facultad de Ingeniería | Universidad Autónoma de Querétaro | ISSN: 2683-3107

Author	Waste Feedstock	Production process	Alcohol	Catalyst	Temperature	Time
[18]	Waste date seed oil	Transesterification	Methanol	Magnetic catalyst	55 °C	47 min
[19]	Waste *Prunus Armeniaca* seeds	Transesterification	Methanol	$SrO–La_2O_3$	70 °C	90 min
[21]	WCO	Transesterification at room temperature	Methanol	koh	nr	nr
[16]	WCO	Transesterification	Methanol	Naoh	nr	nr
[17]	Fish waste	Transesterification	Methanol	koh	nr	25 min
[11]	Beef tallow	Transesterification	Methanol	Naoh	nr	nr
[4]	Loquat kernel oil residues	Transesterification	Methanol	Bifunctional catalytic system based on CaO loaded on ceria oxide support	70 °C	90 min
[14]	Oils and fats contained in grease traps	Transesterification	Methanol	$Naoch_3$	65 °C	nr
[10]	WCO	Transesterification	Methanol	Naoh	66 °C	nr
[22]	WCO	Transesterification	Methanol	koh	NR	13 h
[23]	WCO	Transesterification	NR	NR	NR	NR
	Pig tallow	Transesterification	NR	NR	NR	NR
[9]	WCO	Transesterification	Methanol	Naoh	NR	NR
[24]	Spent ground coffee	Transesterification	Methanol	Naoh	NR	NR
[25]	BSFL	Transesterification	Methanol	H_2so_4	NR	NR

In the literature review, it was found that 70% of the studies used a basic catalyst in the transesterification process, while only 10% used an acid catalyst; this may be due to the fact that acid catalysis needs a higher molar ratio of methanol to oil, which in turn causes high energy requirements associated with methanol recovery operations. The remaining 20% of the studies carried out the transesterification process making use of novel catalysts. Chung [5] performed an LCA of biodiesel production from WCO using CaO derived from chicken eggshell as catalyst. The results obtained were compared using potassium hydroxide (KOH) as catalyst. It was found that the CaO catalyst derived from chicken eggshell has a lower contribution to climate change impact, with 27.2 kg co_2eq, while KOH obtained a value of 300 kg co_2eq.

Al-Mawali [18] synthesized a novel magnetic solid acid catalyst that can be reused five consecutive times, without significant degradation in its catalytic activity, for the esterification of residual date seed oil. The magnetic catalyst demonstrated high catalytic performance with a biodiesel yield of 91.4% with optimum residence time, catalyst loading and temperature conditions of 47 min, 1.5 wt% and 55 °C, respectively. An LCA was carried out, and a global warming potential value of 1114 kg co_2eq and human health toxicity as 633 kg 1.4-DBeq were obtained.

Perspectivas de la Ciencia y la Tecnología | Vol. 7 Núm. 13 | Julio-Diciembre | Facultad de Ingeniería | Universidad Autónoma de Querétaro | ISSN: 2683-3107

Al-Muhtaseb [19] developed a novel SrO-La_2O_3 catalyst for biodiesel production from *Prunus Armeniaca* seed oil waste. The analysis showed an optimal yield of biodiesel of 97.28%, with a reaction temperature of 65 °C, a residence time of 75 min, a catalyst charge of 3% by weight, and a molar ratio of methanol to oil of 9. LCA showed that the global warming potential during the entire biodiesel production process reached 1150 kg CO_2eq.

Al-Muhtaseb [4] used loquat seed oil as a waste feedstock to produce biodiesel on a new CaO-based bifunctional catalyst system, loaded on a ceria oxide support. The optimal yield of biodiesel obtained through the parametric study was 90.14%. The optimal parameters of the process were established at a reaction temperature of 70 °C, methanol to oil ratio of 9, reaction time of 90 minutes, and 4 wt% of catalyst. The LCA estimated a global warming potential during the entire biodiesel production process of 1129 kg CO_2eq to produce 1000 kg of biodiesel.

It is important to mention that 10% of the literature reviewed corresponds to studies in which combinations of biodiesel with conventional diesel are analyzed. In this type of research, Viornery-Portillo [9], through LCA, evaluated the environmental impacts related to the use of the biodiesel B25 mixture and ultra-low sulfur diesel in a power generator; the feedstock used was WCO. Significant impact reductions were found for the categories of abiotic depletion, human toxicity potential, eutrophication potential, acidification potential and global warming potential.

Finally, 25% of the literature compares biodiesel produced from residual feedstock with different types of feedstocks; such is the case of the study of Dufour [12], who performed a comparison between the biodiesel production process from 4 residual oils (WCO, beef tallow, poultry fat and sludge from wastewater treatment) with 2 vegetable oils (soybean oil, rapeseed oil) and low sulfur diesel. The results showed that biodiesel from residual vegetable oils potentially presents the most favorable environmental performance. Sajid [10] studied and compared the environmental impacts of biodiesel from *Jatropha* oil and WCO through LCA. The results showed a 74% lower total environmental impact in case of using WCO as feedstock compared to *Jatropha* oil. In addition, Xu [23] compared the LCA of GHG emissions from biodiesel production from corn oil distilleries, oilseed crops, WCO and pig tallow. The results showed that the GHG emissions from residual feedstocks are lower than those of first-generation biodiesel.

Perspectivas de la Ciencia y la Tecnología | Vol. 7 Núm. 13 | Julio-Diciembre | Facultad de Ingeniería | Universidad Autónoma de Querétaro | ISSN: 2683-3107

Perspectives

The revision of the literature shows that there is scarce research regarding the LCA using residual feedstock for biodiesel production. WCO is the residual raw material that has been most evaluated in LCAs in the biodiesel production process. Moreover, there is a wide field of research on other types of waste feedstocks, such as bio-oil derived from agricultural waste, animal fats, fats and oils contained in grease traps and wastes generated in wastewater treatment. Indeed, recently the conversion of organic residues through microorganisms and insects to generate oil and then biodiesel has been reported.

Bathia carried out and published some studies realated to the aforementioned [26], where lipids were obtained by *Rhodococcus* sp. YHY0 using WCO as a carbon source to subsequently produce biodiesel; the results showed that the biodiesel produced met international standards. Carmona-Cabello [27] produced microbial oil using the oleaginous yeast *Rhodosporidium toruloides* Y-27012 and residues from the food industry of the hospitality sector as an organic residue for the production of biodiesel, obtaining favorable results. Sitepu [28] carried out a direct transesterification assisted by a controlled crushing device of black soldier larvae. The biodiesel obtained complied with the international standard regulations except for the ester content and viscosity. Feng [29] used insect shells to synthesize a biocarbon-based heterogeneous catalyst for the conversion of insect lipid into biodiesel. The outcomes showed that a high-yield biodiesel can be obtained from insect oil.

These recent advances must also be studied considering the complete supply chain and also the LCA. As previous studies suggest, the use of waste biomass for biodiesel production significantly reduces the environmental impact; however, the recollection of this waste biomass must also be considered, since the carbon dioxide emissions associated with this task can limit the benefits.

Also, it was observed that the most used type of boundary in LCA found in the literature review is the *cradle to gate*, which does not evaluate the effects of the use and disposal of biodiesel. In the literature reviewed, very few studies were found that used the *cradle to grave* limit, which would be favorable to implement in the LCA. This limit takes into account the environmental impact from the extraction of the raw material, transportation, processing of materials, biodiesel production, distribution, use and final disposal. An important aspect in this context is also the use and disposal of glycerol, which is a sub-product of the biodiesel production.

Perspectivas de la Ciencia y la Tecnología | Vol. 7 Núm. 13 | Julio-Diciembre | Facultad de Ingeniería | Universidad Autónoma de Querétaro | ISSN: 2683-3107

Conclusions

In this work, a review of the literature pertaining to the LCA of biodiesel generation from waste triglyceride feedstock has been presented. The production cost as well as the environmental impact of the destilation and use of this biofuel depends on many factors, among which the choice of raw material stands out. In this context, the use of waste feedstock is attractive due to its high availability and abundance.

The literature review has shown that from all LCA works reported for biodiesel production from waste feedstocks, the conversion of waste cooking oil to biodiesel is the most studied. Derived from the life cycle assessment, it was found that the use of this residue presents many benefits, which include reducing the amount of arable land required, lowering the price of biodiesel production and mitigating waste management challenges. This finding reinforces the relevance of LCA studies focused on evaluating the sustainability of biodiesel production using exclusively residual raw materials.

A lower proportion of research was found in the literature on the environmental impact of biodiesel production from other residual feedstocks, such as animal fats, agro-industrial wastes, grease trap wastes and wastewater treatment material. Because these feedstocks are wastes, they can reduce biodiesel production costs. Also, the use of microbial and insect oil was found to be a promising alternative for biodiesel production; in particular, microbial oils exhibit many advantages, such as less dependency on weather and season, and less labor required. The use of insect oil also has many advantages, such as the availability of insects and higher production of fat content, which can range between 2 and 50%. The use of microorganisms and insects to produce biodiesel shares the advantage that they can use a variety of organic residue such as food waste, animal manure, agricultural waste, thus assuming the role of waste management. In this context, these insects and microorganisms can be used as pretreatment in order to employ organic residue for biodiesel production. However, these biological methods have not been studied comprehensively; therefore, there is a large area of opportunity to evaluate the environmental impact through LCA, and the performance of the conversion of waste feedstocks into biodiesel through the transesterification process.

Acknowledgments

We express our gratitude to CONAHCYT for the financial support through the maintenance grant (835894) for Angelica Avila Anguis' graduate studies.

Data availability

Data is available upon request.

References

[1] United Nations, "Sustainable Development Goals." [Online]. Available: https://www.un.org/sustainabledevelopment/es/ [Accessed: May 4, 2023]

[2] United Nations, "Energy." [Online]. Available: https://www.un.org/sustainabledevelopment/es/energy/ [Accessed: May 18, 2023]

[3] United Nations. "Sustainable Development Goals." [Online]. Available: https://sdgs.un.org/goals

[4] A. H. Al-Muhtaseb *et al.*, "Circular economy approach of enhanced bifunctional catalytic system of CaO/CeO_2 for biodiesel production from waste loquat seed oil with life cycle assessment study," *Energy Conversion and Management*, vol. 236, p. 114040, 2021, DOI: 10.1016/j.enconman.2021.114040

[5] Z. L. Chung *et al.*, "Life cycle assessment of waste cooking oil for biodiesel production using waste chicken eggshell derived CaO as catalyst via transesterification," *Biocatalysis and Agricultural Biotechnology*, vol. 21, p. 101317, 2019, DOI: 10.1016/j.bcab.2019.101317

[6] M. Aghbashlo, M. Tabatabaei, S. Amid, H. Hosseinzadeh-Bandbafha, B. Khoshnevisan, and G. Kianian, "Life cycle assessment analysis of an ultrasound-assisted system converting waste cooking oil into biodiesel," *Renewable Energy*, vol. 151, pp. 1352-1364, 2020, DOI: 10.1016/j.renene.2019.11.144

[7] M. N. B. Mohiddin *et al.*, "Evaluation on feedstock, technologies, catalyst and reactor for sustainable biodiesel production: A review," *Engineering Chemistry*, vol. 98, pp. 60-81, 2021, DOI: 10.1016/j.jiec.2021.03.036

[8] S. Morais, T. M. Mata, A. A. Martins, G. A. Pinto, and C. A. V. Costa, "Simulation and life cycle assessment of process design alternatives for bio-

diesel production from waste vegetable oils," *Journal of Cleaner Production*, vol. 18, n.° 13, pp. 1251-1259, 2010, DOI: 10.1016/j.jclepro.2010.04.014

[9] E. A. Viornery-Portillo, B. Bravo-Díaz, and V. Y. Mena-Cervantes, "Life cycle assessment and emission analysis of waste cooking oil biodiesel blend and fossil diesel used in a power generator," *Fuel*, vol. 281, p. 118739, 2020, DOI: 10.1016/j.fuel.2020.118739

[10] Z. Sajid, F. Khan, and Y. Zhang, "Process simulation and life cycle analysis of biodiesel production," *Renewable Energy*, vol. 85, pp. 945-952, 2016, DOI: 10.1016/j.renene.2015.07.046

[11] L. T. Vargas-Ibáñez, J. J. Cano-Gómez, P. Zwolinski, and D. Evrard, "Environmental assessment of an animal fat based biodiesel: Defining goal, scope and life cycle inventory," *Procedia* CIRP, vol. 90, pp. 215-219, 2020, DOI: 10.1016/j.procir.2020.02.053

[12] J. Dufour y D. Iribarren, "Life cycle assessment of biodiesel production from free fatty acid-rich wastes," *Renewable Energy*, vol. 38, n.° 1, pp. 155-162, 2012, DOI: 10.1016/j.renene.2011.07.016

[13] D. Mu, M. Addy, E. Anderson, P. Chen, and R. Ruan, "A life cycle assessment and economic analysis of the Scum-to-Biodiesel technology in wastewater treatment plants," *Bioresource Technology*, vol. 204, pp. 89-97, 2016, DOI: 10.1016/j.biortech.2015.12.063.

[14] Q. Tu y B. E. McDonnell, "Monte Carlo analysis of life cycle energy consumption and greenhouse gas (GHG) emission for biodiesel production from trap grease," *Journal of Cleaner Production*, vol. 112, pp. 2674-2683, 2016, DOI: 10.1016/j.jclepro.2015.10.028

[15] S. Foteinis, E. Chatzisymeon, A. Litinas, and T. Tsoutsos, "Used-cooking-oil biodiesel: Life cycle assessment and comparison with first- and third-generation biofuel," *Renewable Energy*, vol. 153, pp. 588-600, 2020, DOI: 10.1016/j.renene.2020.02.022

[16] M. Corral-Bobadilla, R. Lostado-Lorza, F. Somovilla-Gómez, and S. Íñiguez-Macedo, "Life cycle assessment multi-objective optimization for eco-efficient biodiesel production using waste cooking oil," *Journal of Cleaner Production*, vol. 359, p. 132113, 2022, DOI: 10.1016/j.jclepro.2022.132113

[17] M. Kiehbadroudinezhad, A. Merabet, and H. Hosseinzadeh-Bandbafha,"A life cycle assessment perspective on biodiesel production from

fish wastes for green micro-grids in a circular bioeconomy," *Bioresource Technology Reports*, vol. 21, p. 101303, 2023, DOI: 10.1016/j.biteb.2022.101303

[18] K. S. Al-Mawali *et al.*, "Life cycle assessment of biodiesel production utilising waste date seed oil and a novel magnetic catalyst: A circular bioeconomy approach," *Renewable Energy*, vol. 170, pp. 832-846, 2021, DOI: 10.1016/j.renene.2021.02.027

[19] A. H. Al-Muhtaseb *et al.*, "Integrating life cycle assessment and characterisation techniques: A case study of biodiesel production utilising waste Prunus Armeniaca seeds (PAS) and a novel catalyst," *Journal of Environmental Management*, vol. 304, p. 114319, 2022, DOI: 10.1016/j.jenvman.2021.114319.

[20] K. K. C. Cárdenas, A. G. Romero-Izquierdo, S. I. Martínez-Guido, and C. Gutiérrez-Antonio, "Análisis de ciclo de vida: una herramienta para contribuir a la producción sustentable de biocombustibles de aviación," *Naturaleza y Tecnología*, Sep. 2022, Available: http://quimica.ugto.mx/index.php/nyt/article/view/427

[21] A. K. Bhonsle, J. Singh, J. Trivedi, and N. Atray, "Comparative LCA studies of biodiesel produced from used cooking oil using conventional and novel room temperature processes," *Bioresource Technology Reports*, vol. 18, p. 101072, 2022, DOI: 10.1016/j.biteb.2022.101072

[22] J. Lin, C. W. Babbitt, and T. A. Trabold, "Life cycle assessment integrated with thermodynamic analysis of bio-fuel options for solid oxide fuel cells," *Bioresource Technology*, vol. 128, pp. 495-504, 2013, DOI: 10.1016/j.biortech.2012.10.074

[23] H. Xu, L. Ou, Y. Li, T. R. Hawkins, and M. Wang, "Life Cycle Greenhouse Gas Emissions of Biodiesel and Renewable Diesel Production in the United States," *Environ. Sci. Technol.*, vol. 56, n.° 12, pp. 7512-7521, 2022, DOI: 10.1021/acs.est.2c00289

[24] A. Forcina, A. Petrillo, M. Travaglioni, S. di Chiara, and F. De Felice, "A comparative life cycle assessment of different spent coffee ground reuse strategies and a sensitivity analysis for verifying the environmental convenience based on the location of sites," *Journal of Cleaner Production*, vol. 385, p. 135727, 2023, DOI: 10.1016/j.jclepro.2022.135727

[25] C. Seng Liew *et al.*, "Life cycle assessment: Sustainability of biodiesel production from black soldier fly larvae feed-

Perspectivas de la Ciencia y la Tecnología | Vol. 7 Núm. 13 | Julio-Diciembre | Facultad de Ingeniería | Universidad Autónoma de Querétaro | ISSN: 2683-3107

ing on thermally pre-treated sewage sludge under a tropical country setting," *Waste Management*, vol. 164, pp. 238-249, 2023, DOI: 10.1016/j.wasman.2023.04.013

[26] S. K. Bhatia *et al.*, "Rhodococcus sp. yhy01 a microbial cell factory for the valorization of waste cooking oil into lipids a feedstock for biodiesel production," *Fuel*, vol. 301, p. 121070, 2021, DOI: 10.1016/j.fuel.2021.121070

[27] M. Carmona-Cabello, I. L. García, A. Papadaki, E. Tsouko, A. Koutinas, and M. P. Dorado, "Biodiesel production using microbial lipids derived from food waste discarded by catering services," *Bioresource Technology*, vol. 323, p. 124597, 2021, DOI: 10.1016/j.biortech.2020.124597

[28] E. K. Sitepu, S. Perangin-angin, G. J. Ginting, S. Machmudah, R. N. Sari, and J. B. Tarigan, "Controlled crushing device-intensified direct biodiesel production of Black Soldier Fly larvae," *Heliyon*, vol. 9, n.° 6, 2023, DOI: 10.1016/j.heliyon.2023.e16402

[29] W. Feng *et al.*, "Polymer functionalization of biochar-based heterogeneous catalyst with acid-base bifunctional catalytic activity for conversion of the insect lipid into biodiesel," *Arabian Journal of Chemistry*, vol. 16, n.° 7, p. 104814, 2023, DOI: 10.1016/j.arabjc.2023.104814

[30] G. M. Mathew *et al.*, "Recent advances in biodiesel production: Challenges and solutions," *Science of The Total Environment*, vol. 794, p. 148751, 2021, DOI: 10.1016/j.scitotenv.2021.148751

[31] F. Akram *et al.*, "Current trends in biodiesel production technologies and future progressions: A possible displacement of the petro-diesel," *Journal of Cleaner Production*, vol. 370, p. 133479, 2022, DOI: 10.1016/j.jclepro.2022.133479