Chapter 3 Biodiesel production as an alternative to reduce the environmental impact of University food courts

Capítulo 3 Producción de biodiesel como escenario alternativo para mejorar el desempeño ambiental de cafeterías universitarias

ALANIS-RAMÍREZ, Claudia Ivett†*, ÁVILA-CORDOBA, Liliana[2], ROMERO-ROMERO, Rubi[1] and NATIVIDAD, Reyna[1]

[1]Chemical Eng. Lab., Centro Conjunto de Investigación en Química Sustentable UAEM-UNAM, Universidad Autónoma del Estado de México, Toluca, Mexico, CP 50200
[2]Universidad Autónoma del Estado de México, Centro Conjunto en Química Sustentable.

ID 1st Author: *Claudia Ivett, Alanis-Ramírez* / **ORC ID**: 0000-0001-6935-1798, **CVU CONACYT ID:** 360631

ID 1st Co-author: *Liliana, Ávila-Cordoba* / **ORC ID**: 0000-0002-1073-5196, **CVU CONACYT ID:** 323060

ID 2nd Co-author: *Rubi, Romero-Romero* / **ORC ID**: 0000-0001-9163-7936, **CVU CONACYT ID:** 121454

ID 3rd Co-author: *Reyna, Natividad* / **ORC ID**: 0000-0001-8978-1066, **CVU CONACYT ID:** 87755

DOI: 10.35429/H.2021.6.37.50

C. Alanis, L. Ávila, R. Rubi and R. Natividad

*claudia.alanis.iq@gmail.com

A. Marroquín, J. Olivares, M. Ramírez and L. Cruz (Coord). Engineering and Technology. Handbooks-©ECORFAN-México, Querétaro, 2021.

Abstract

The objective of this work was to assess the environmental impacts of producing biodiesel by heterogeneous and homogeneous catalysis. The raw material for the process was the waste cooking oil (WCO) generated at 27 food courts of Autonomous University of the State of Mexico. The study was conducted by applying Life Cycle Assessment methodology and the environmental impacts were calculated with the SimaPro 9.1.0.11 PhD software with the Ecoinvent database. The method was CML-IA base line C3.06/EU25. The assessed impact categories were: Abiotic Depletion Potential (ADP, elements), Abiotic Depletion Potential (ADP, fossil fuels), Global Warming Potential (100 years) (GWP), Ozone Layer Depletion (ODP), Human Toxicity (HT), Freshwater Aquatic Ecotoxicity (FWAE), Marine Aquatic Ecotoxicity (MAE), Terrestrial Ecotoxicity (TE), Photochemical Oxidation (PO), Acidification (A) and Eutrophication (E). In addition, end point environmental indicators were also calculated (Ecosystems Quality, Human Health Damage and Resources Availability) by the method ReCiPe 2016 Endpoint (H) V1.04 / World (2010) H/A. The system boundary enclosed three main stages, WCO collection, pre-treatment and reaction (to produce biodiesel). It was concluded that the reaction stage is the one with the highest environmental impact. In this sense, the highest impact categories were ADP (fossil fuels) (105.56 MJ), GWP (8.91 kg $CO_{2\,eq}$) and MAE (2387.89 kg 1, 4-DB $_{eq}$). Nevertheless, it was also found that the GWP for the heterogeneous process is 82.52 % lower than that calculated for the homogeneous process. In addition, the human health damage of the homogeneous process is 1.77 points and is higher than the observed with the heterogeneous process.

Waste cooking oil, Life cycle analysis, Heterogeneous process, Homogeneous process, Bifuntional catalyst

Resumen

El objetivo de este trabajo fue evaluar los impactos ambientales de la producción de biodiésel mediante cátalisis heterogénea y homogénenea. La materia prima para el proceso fue el aceite de cocina residual (ACR) generado en 27 cafeterías de la Universidad Autónoma del Estado de México. El estudio se realizó aplicando la metodología de Análisis de Ciclo de Vida y los impactos ambientales se calcularon con el software SimaPro 9.1.0.11 y la base de datos Ecoinvent. El método fue CML-IA C3.06/EU25. Las categorías de impacto evaluadas fueron: Agotamiento Abiótico Potencial (AAP, elementos), Agotamiento Abiótico Potential (AAP, combustibles fósiles), Potencial de Calentamiento Global (100 años) (PCG), Agotamiento Capa de Ozono (ACO), Toxicidad Humana (TH), Ecotoxicidad de Agua Dulce (EAD), Ecotoxicidad de Agua Marina (EAM), Ecotoxicidad Terrestre (ET), Oxidación Fotoquímica (OF), Acidificación (A) y Eutrofización (E). También se calcularon indicadores ambientales de punto final (Calidad de los Ecosistemas, Daño a la Salud Humana y Disponibilidad de Recursos) por el método ReCiPe 2016 Endpoint (H) V1.04 / World (2010) H/A. El sistema analizado consistió en tres etapas principales: colecta, pretratamiento y reacción del ACR para producir biodiésel. Se concluyó que la etapa de reacción es la que tiene el mayor impacto ambiental. En este sentido, las categorías de mayor impacto fueron: ACF (105.56 MJ), PCG (8.91 kg de $CO_{2\,eq}$) y EAM (2387.89 kg 1,4-DB eq). No obstante, también se constató que el PCG para el proceso heterogéneo es 82.52 % inferior al reportado proceso homogéneneo. Además, el daño a la salud humana del proceso homogéneo es 1.77 puntos mayor que en el proceso heterogéneo estudiado.

Aceite residual de cocina, Análisis de ciclo de vida, Proceso heterogéneo, Proceso homogéneo, Catalizador bifuncional

1. Introduction

The Ministry of the Environmental and Natural Resources (SEMARNAT in spanish) in its Sectoral Program 2020-2024 (SEMARNAT, 2020), suggests that for the sustainable management of organic waste, it is necessary to strengthen its comprehensive management under a circular economy approach, integrating this vision into educational processes to promote environmental management in national and international academic institutions (green schools) (SEMARNAT, 2019). For this, it is necessary to identify the stages with the greatest environmental impact and this can be achieved by applying a life cycle assessment (LCA) (Chung *et al.*, 2019). This is an approved international methodology for the evaluation of bioenergy systems using residual biomass streams from food (Antoniadou *et al.*, 2020).

Recently, Universities from the United Kingdom (Gu *et al*., 2018), India (Sangwan *et al*., 2018), China (Tsai *et al*., 2020), the United States (Clabeaux *et al*., 2020) and Mexico (Güereca *et al*., 2013), have been carried out analysis from a life cycle perspective, to reduce and avoid the waste of food, promoting pilot programs aimed at the sustainable management of its waste in University campus with the aim of reducing its environmental footprint, taking advantage of the technical and scientific capabilities of their human resources and infrastructure.

Yañez *et al*., (2020), carried out, for example, a study on carbon footprint in tonnes of carbon dioxide equivalent (tCO_{2eq}), units per student for various Latin American universities with the aim of facilitating institutional decision-making. In Mexico, studies have been reported in two universities, the Autonomous Metropolitan University (UAM) (Mendoza *et al*., 2019) and the National Autonomous University of Mexico (UNAM) (Güereca *et al*., 2013). These studies focus mainly on solid waste management.

The studies above-mentioned show that waste from coffee shops or restaurants is an environmental problem that can be remediated through proper use and management. For this, an assessment of the environmental performance of waste disposal scenarios, both solid and liquid, is essential. Among the liquid waste, one that has attracted special interest is the waste cooking oil (WCO) because one liter of WCO represents five thousand times more polluting load than that of the sewage and can contaminate up to 40 thousand liters of water, which is equivalent to the annual consumption of a person’s sanitary water (EPA, 2000), (Rincón *et al*., 2019) and (González & González, 2015).

An alternative that has been the subject of numerous investigations is the use of WCO as a second-generation raw material to produce biodiesel. Its use has been demonstrated to reduce the negative environmental impact inherent to the process, as it is a raw material that does not require a stage of cultivation or extraction (Foteinis *et al*., 2020), (Amaya *et al*., 2020) and (Viornery *et al*., 2020). Recycling cooking oil for biodiesel production is an example of a sustainable action that, well organized, could satisfy the criteria for green circular economic activity in the context of promoting a continuous reduction of the environmental impacts using low CO_2 emissions energy. Simultaneously, achieving the goal of employment creation, helping to benefit human health and increasing social inclusion (Sheinbaum *et al*., 2013), (Orjuela & Clark, 2020). In the European Union, 32% of biodiesel is produced exclusively from recovered WCO (Flach *et al*., 2019).

Within the sustainable processing routes of the WCO to biodiesel, there is the physico-chemical conversion (Rincón & Silva, 2015), by an esterification and transesterification treatment for the conversion of free fatty acids (FFA) and triglycerides into biodiesel (fatty acid methyl esters, FAME’s). Esterification and transesterification are the chemical reactions of an oil or fat with an alcohol, which are catalyzed by an acid catalyst or base to form esters and glycerol. The most relevant variables to carry out the reaction with an efficient conversion of WCO with high FFA content, are: temperature, alcohol and oil molar ratio, catalyst quantity and reuse, stirring speed, the type of homogeneous or heterogeneous catalyst (acid or base), and the type of WCO (source of raw material), (Narasimhan *et al*., 2021). A product of this process is glycerol and this must be separated from biodiesel. This separation is typically conducted by decantation. There are also residues of the process that can be reused and recycled, such is the case of the catalyst and methanol (Marinković *et al*., 2016).

In the context of biodiesel production from WCO, it has been reported that the heterogeneous over homogeneous catalysis has great advantages due to its lower cost, lower corrosion, reuse, and easy separation (Gaur *et al*., 2020). The generation of residues in the reaction is a variable to consider for the determination of the environmental impacts in a LCA. Carlos and Diaz (2018), report that a heterogeneous process has an emission of pollutants below 65%. Furthermore, there are bifunctional catalysts that contain both, acid and basic sites, on the same catalytic surface that allow carrying out simultaneously the esterification of free fatty acids and the transesterification of triglycerides (Enguilo *et al*., 2021) and (Al-Muhtaseb *et al*., 2021).

As described above, the production of biodiesel is an alternative scenario for the use of WCO, which improves the environmental performance of the generating sites. This improvement should be established in order to contribute to the decision making of institutions and the consequent implementation of waste management programs to promote environmental management.

In this chapter it is presented as a subject of study, the University food courts (UFC) of the Autonomous University of the State of Mexico (UAEMéx). This institution has a guide for the management of solid urban waste, which classifies the WCO as a waste of special management, coming mainly from the UFC. However, the destination remains unknown even though collection campaigns have been conducted to facilitate and ensure final disposal.

The least favorable route is one that negatively impacts the sewage system, wastewater treatment and increases the risk of contaminating the soil and water bodies (ecotoxicity) (Hartini *et al*., 2020), directly affecting biodiversity; for the UFC, is the landfill located in San Luis Mextepec, in the municipality of Zinacantepec, State of Mexico, approximately 50 kilometers from the central area, managed by the private company of Environmental Services and Maintenance S.A de C.V (MASERA). It is worth mentioning that the standard (NADF-012-AMBT-2015) was published in Mexico City, which *"envisages establishing separation as a basic strategy of environmental policy, with the aim of implementing the management and adequate disposal of waste animal and/or plant fats and oils, seeking to consider the adoption of management measures, to prevent and reduce environmental impacts and harmful health effects"* (Gaceta oficial de la Ciudad de México, 2018). Based on the above, the main objective of this work was to establish alternative scenarios to valorize the WCO generated in the UFC of the Autonomous University of the State of Mexico to biodiesel, through a heterogeneous catalyzed process and compare it with a homogeneous one.

The objective described in the previous paragraph was achieved through applying the LCA methodology under ISO 14044 (Environmental management, life cycle analysis, requirements, and guidelines), which is described in detail in Section 2. In defining the scope, the following aspects were considered: intended application, reasons for carrying out the study, benefited sector of society, comparative and individual description of the process under study, functional unit definition, reference flow and system boundaries. In addition, an inventory was integrated from the data collection, with the application of surveys to the UFC managers, defining the general characteristics of the WCO generated in the UFC in the current waste management system. In the analysis of the inventory, inputs and outputs in the production of biodiesel were quantified, with the experimental information generated in the Chemical Engineering Laboratory of the Joint Research Center on Sustainable Chemistry UAEM-UNAM (CCIQS) triglycerides (Enguilo *et a*l., 2021).

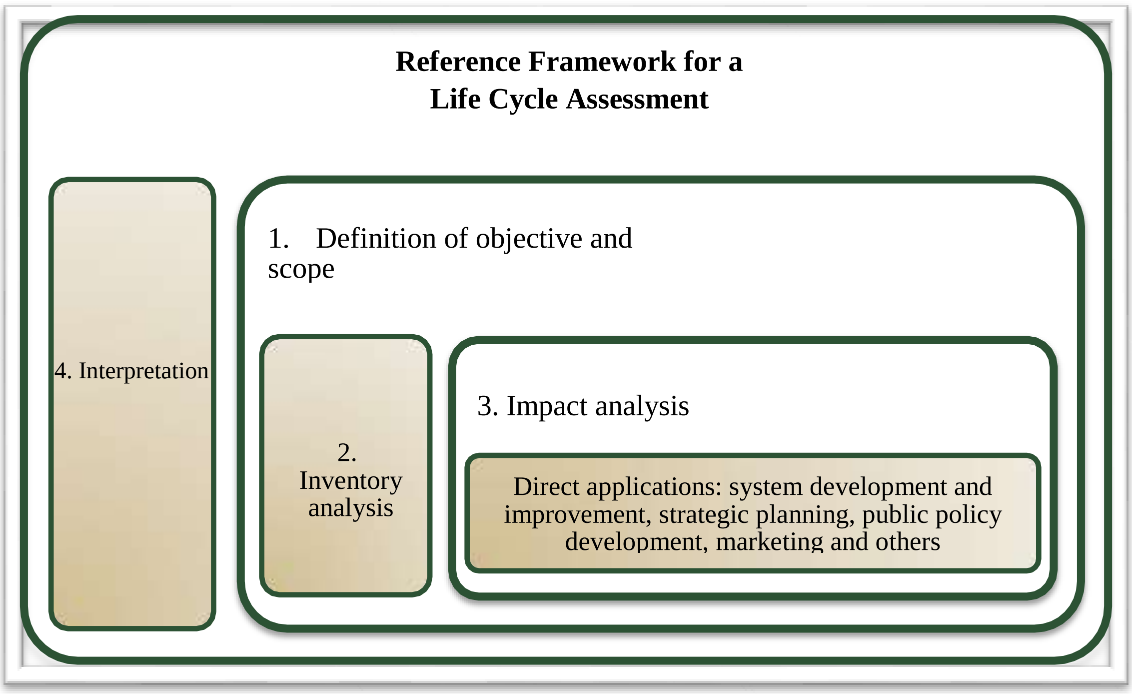
For the homogeneous process, theoretical data were obtained from documentary information (Talens *et al*., 2010). The results are reported in Section 3, where data for the assessment of mid-point environmental impacts for the WCO are analyzed, as well as weighting and grouping of those directly related to life cycle impacts (characterization and classification) for the heterogeneous process. In addition, the mid-point and end-point environmental impacts for alternative esterification and transesterification scenarios are compared using homogeneous and heterogeneous catalysis. Finally, the conclusions section establishes the magnitude of the environmental impacts of the current management of WCO in the UFC and the feasibility of its reduction, through the production and use of biodiesel in mobile transport.

The aforementioned opens a window of opportunity, to reduce the environmental footprint of the University through the implementation of sustainable actions aimed at evaluating environmental performance indicators such as the reduction of the volume of organic waste for special management discharged to landfills, extending the lifetime of universities towards a circular economy and promoting sustainable consumption patterns, and waste management among the University community and subsequently in other social sectors, within the local level.

2. Methodology

The methodology was developed under the Mexican Standard of Life Cycle Assessment, Requirements and Guidelines (ISO 14044, 2006) and (UNEP/SETAC Life cycle Initiative, 2005), as shown in Figure 3.1.

Figure 3.1 Stages of a LCA according to the ISO 14040 series of standards



Source: (ISO 14044, 2006)

This study was conducted in the municipality of Toluca, State of Mexico, considering 27 UFC, which are classified into four collection routes (Colón-Espacios Deportivos "R1", Centro-Cerrillo "R2", Ciudad Universitaria "R3" and Remolques "R4") by the Department of Services of the UAEMéx, see Table 3.1. The data collection was carried out by means of a survey that was answered by the UFC managers as well as identifying the alternative scenarios of the WCO, see Figure 3.2, with information by route, management capacity from the institution, mobile infrastructure and management options with a scientific approach that is developed within the same University spaces.

Table 3.1 WCO collection routes generated in the University food courts of the UAEMéx

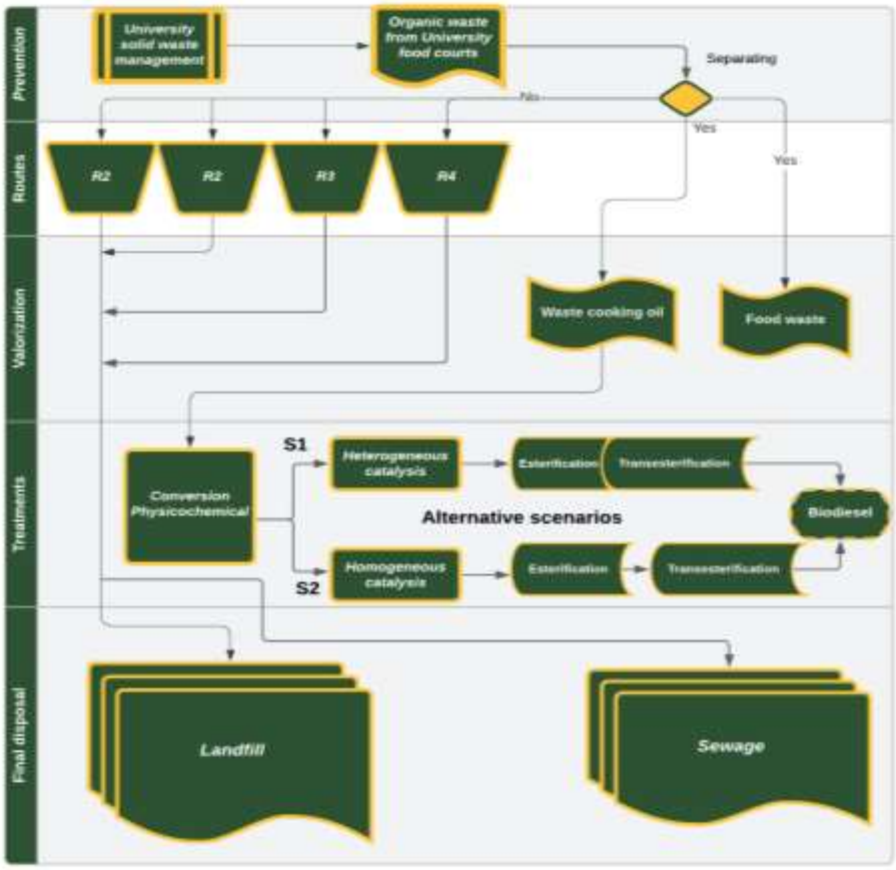
Collection route	University in academic spaces
R1	Faculty of Medicine Faculty of Urban Planning Faculty of Nursing Faculty of Chemistry Faculty of Anthropology Faculty of Languages Faculty of Dentistry
R2	San Cayetano Faculty of Gastronomy and Tourism Administrative Building Faculty of Agricultural Sciences Cerrillo piedras blancas El Rosedal
R3	International Centre for Language and Culture (CILC) Faculty of Tourism and Gastronomy University Town Faculty of Performing Arts Faculty of Economics Faculty of Geography Faculty of Engineering
R4	Campus No. 2 of the Preparatory School "Nezahualcóyotl" Faculty of Accounting and Administration UAEM "Unidad Los Uribe" Santa Cruz Azcapotzaltongo Central Library Faculty of Psychology Preparatory 3 "Cuauhtémoc" Center of Sustainable Chemistry UNAM-UAEM Campus no. 4 of the Preparatory School "Lic. Ignacio Ramírez Calzada" Campus no. 1 of the "Lic. Adolfo López Mateos" Campus No. 5 of the Preparatory School "Dr. Angel Ma. Garibay Kintana "

Source: Author´s Own Creation

To carry out the inventory analysis indicated by the LCA methodology, the unit processes in the production of biodiesel were determined, see Figure 3.3, establishing the system boundary for the management of WCO, from the WCO collection in the UFC, transport to the CCIQS for pretreatment was subsequently considered. In the laboratory, once the oil has been purified, esterification and transesterification reaction are carried out with a heterogeneous process, to finally produce biodiesel; it should be mentioned that glycerol is part of the coproducts. Methanol is reused as a reagent in the heterogeneous process stage, as well as a bifunctional catalyst. The functional unit of the experimental process is 1L of biodiesel produced, the reference flow is 150L per week of biodiesel, with a mass allocation of 100 % for its production.

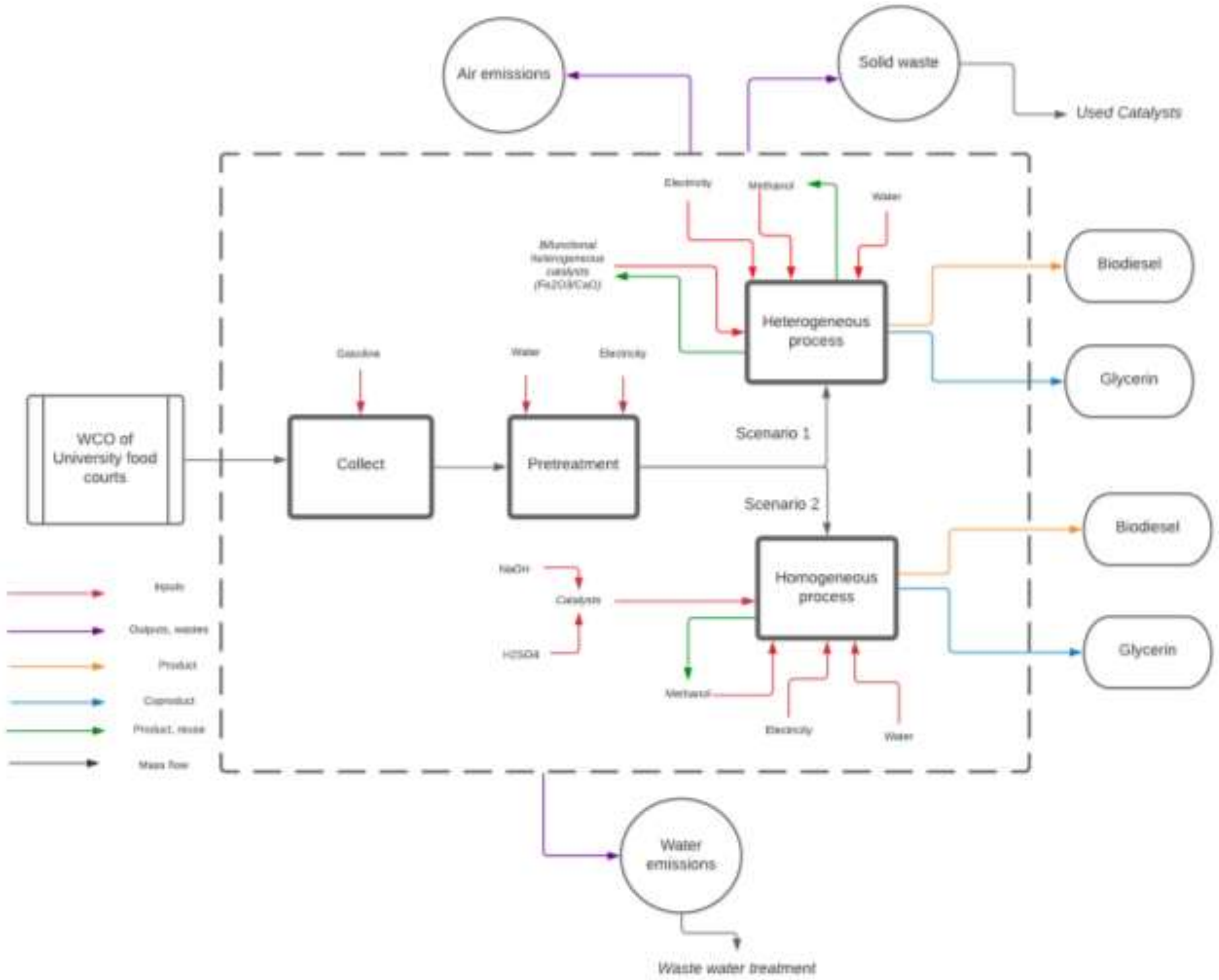
The evaluation was performed using SimaPro 9.1.0.11 PhD software and the Ecoinvent database. The method was CML-IA baseline C3.06/EU25 with impact categories: Abiotic Depletion Potencial (ADP, elements), Abiotic Depletion Potential (ADP, fossil fuels), Global Warming Potential (100 years) (GWP), Ozone Layer Depletion (ODP), Human Toxicity (HT), Freshwater Aquatic Ecotoxicity (FWAE), Marine Aquatic Ecotoxicity (MAE), Terrestrial Ecotoxicity (TE), Photochemical Oxidation (PO), Acidification (A) and Eutrophication (E). In the interpretation, a heterogeneous process (scenario 1) was compared with a homogeneous process (scenario 2), the results are shown in Figure 3.3. Data reported by (Talens *et al;* 2010), were used for the homogeneous process. The assessment of end-point environmental indicators (Ecosystem Quality, Human Health Damage and Resource Availability) was carried out using the ReCiPe 2016 Endpoint (H) V1.04 / World (2010) H/A.

Figure 3.2. Integral Management System of Organic Waste of the UAEMéx, with alternative scenarios



Source: Author´s Own Creation
Diagramming software: Ludichart Web 2.0

Figure 3.3 System boundary for the management of WCO in the University food courts of the UAEMéx, through a heterogeneous process (scenario 1) or homogeneous process (scenario 2)

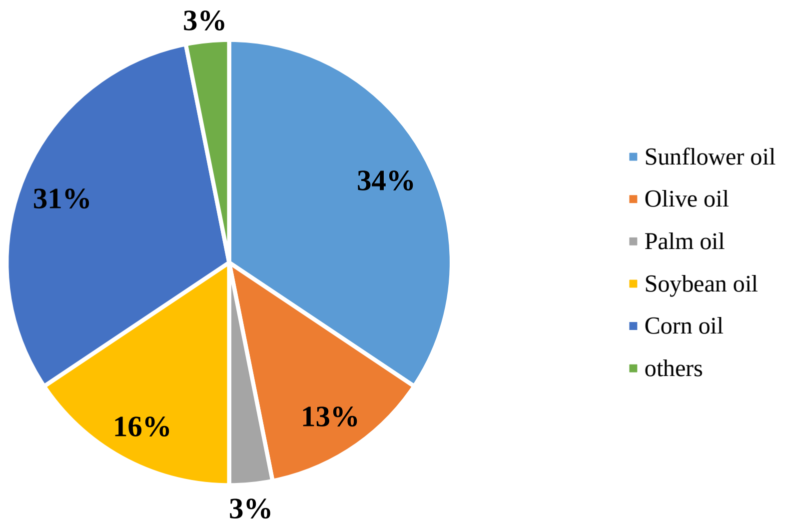


Source: Author´s Own Creation
Diagramming software: Ludichart Web 2.0

3. Results

From the survey of UFC managers, it appears that from the type of oil used for food preparation and/or cooking, see Graph 3.1, the responses showed that 34% is sunflower oil, 31% corn, 16% soy, 13% olive and 3% palm oil. It was also concluded that 85% of the UFC surveyed use a fryer and the consumption of oil varies in a range of 0 to 5 L and from 12 to 20 L in 30% of the total spaces under study, 10 to 15 L and 5 to 10 L in 19% and 4% reported that none. The 27 UFC managers were also questioned whether or not the oil was reused, a *negative* response was obtained in 74% of the answers, *affirmative* in 11% and *perhaps* reached a percentage of 15%. Regarding the use and disposal of labelled containers, 93 per cent answered that WCO is placed in labelled containers. The arrangement of these containers varies according to the UFC as follows: monthly (37%), weekly (33%), daily (19%) and not collected (7%). Only 4% is reused. This allows us to identify the lack of a well-established policy for the management of the WCO in the UFC of the UAEMéx, a behavior that has now occurred in households in other countries (Hartini *et al*., 2020).

Graph 3.1 Percentage of consumption by type of oil in the University food courts of the UAEMéx



Source: Author´s Own Creation

Regarding the information on the generation of WCO (L/week), it was classified by collection route to the landfill and the distance traveled by the four units of transport with gasoline engine. The route that collects the most WCO is the R4 (80 L/week), the UFC of the Preparatory 5 "Dr. Angel Ma. Garibay Kintana" has a participation of 50% regarding the academic spaces included in the route. In second place, there is the RI (44 L/week) with 7 UFC, like the R3, generating 31 L/week and finally the R2 with 10 L/week. It is important to note that this route is the one that travels the longest towards the filling, 65 km and only includes 4 UFC.

Based on the results described above, for the analysis of the LCA inventory, see Table 3.2, we considered the total WCO reported as generated (165 L/week) and the total distance traveled per week (138.1 km), in a 1.5-ton van with an approximate yield of 2.5 L/km. The functional unit to produce biodiesel in the heterogeneous process was 1L. For the homogeneous process, the inputs, and outputs of (Talens *et al*., 2010) were considered in the same calculation base, it should be noted that in their inventory analysis they do not specify the stages and only one electricity consumption was reported.

Table 3.2 Inventory analysis according to the functional unit (1 L) in biodiesel production with a heterogeneous process

Stage	**Input**				**Output**			
	Flow	**Parameter**	**Amount**	**Unit**	**Flow**	**Parameter**	**Amount**	**Unit**
Collect	Energy	Gasoline	0.128	tkm	Middle flow	WCO	1.100	L
	Raw material	WCO	1.100	L				
Pre treatment	Energy	Electricity consumption	0.722	kWh	Middle flow	WCO	1.100	L
	Raw material	Potable water	0.745	L	Residue	Waste water	0.745	L
		WCO	1.100	L				
Reaction	Energy	Electricity consumption	11.20	kWh	Product	Biodiesel	1.000	L
	Raw material	WCO	1.100	L				
		Pig iron (Fe_2O_3)	0.005	kg	Co-product	Glycero	0.100	L
		Hydraulic lime (CaO)	0.079	kg	Residue	Waste water	0.819	L
					Recyclable product	Methanol	0.209	L
		Water, deionized	0.819	L	Reusable product	Bifuntional catalysts (Fe_2O_3/CaO)	0.084	kg
		Methanol	0.232	L				

Source: Author´s Own Creation

The assessment of the environmental impacts of each stage, using the CML-IA baseline method C3.06/EU25, includes 11 impact categories, see Table 3.3.

In the LCA of biodiesel production, the WCO has a zero initial environmental charge at the collection stage. This is because it is a waste that becomes a raw material and its environmental impact has a lower ecological burden compared to first and third generation biodiesel (Foteinis *et al.*, 2020), as it does not require a stage of cultivation or extraction. Accordingly, it is reported that emissions avoided in these stages are 88% (Flach *et al.*, 2019). From the above, the use of used oils reduces the deforestation that arises from continuous and extensive cultivation, as well as the loss of biodiversity (Ayoola *et al.*, 2015; Viornery *et al.*, 2020)

The consumption of sunflower oil in UFC has an environmental impact benchmark that has been studied from the cultivation of seed to the production of biodiesel, the latter considering WCO as waste biomass producing energy from a renewable source, through the reuse and recycling of waste. At the cultivation stage, the most affected impact category is that of land use on agricultural land due to the use of fertilizers, as well as electricity consumption during drying and extraction; the greatest amount of CO_2 emissions from the waste generated are presented during refining (Sanz R. *et al.*, 2011), the above has been compared with seeds such as rapeseed and soybean. It should be noted that, in this research, they mention that there is a positive contribution to the climate change category, given that there is a net balance between CO_2 uptake by plants of sunflower seeds and emissions of greenhouse gases and compounds in the production process. This represents an area of opportunity, as several oils (soy, sunflower, and canola) studied by Belkhanchi *et al.*, (2021) the one employed in the present study (sunflower), is reported as the best yield for conversion to biodiesel by 99.3%, by homogeneous catalysis (NaOH and KOH). For the heterogeneous process with a bifunctional catalyst, WCO from UFC had a conversion to FAME of 91% triglycerides (Enguilo *et al.*, 2021).

The bifunctional catalyst (Fe_2O_3/CaO) used in the heterogeneous reaction replaces H_2SO_4 and NaOH in the homogeneous reaction, performing in a single step the esterification and transesterification reactions, although for simulation purposes it was assigned separately in the SimaPro. Calcium oxide is a potential catalyst for biodiesel production through transesterification that can be derived from biomass and waste resources due to its availability, low cost, and non-corrosive nature, as well as a low environmental impact thanks to its very low solubility in methanol (De Mora *et al.*, 2015) and (Marinković *et al.*, 2016).

In the reaction stage for the heterogeneous process, the impacts that had the greatest contribution of damage due to the high electrical and thermal consumption are summarized in Table 3.3 and were ADP (fossil fuels) (105.56 MJ), GWP (8.91 kg $CO_{2\,eq}$) and MAE (2568.40 kg 1.4-DB eq). These damages are attributed to fossil fuel consumption in the following equipment used during the reaction and separation stage of the biofuel: rotary evaporator, stirring system, recirculation system, vacuum pump and centrifuge. Studies conducted by Chung and collaborators (2019) indicate that the transesterification process is the stage that has the most impact categories due to its high electricity consumption, compared to the other stages of the process. The carbon footprint of the entire process has an emission of 9.61 kg CO_{2eq} per liter of biodiesel produced weekly, the reaction stage represents 93%.

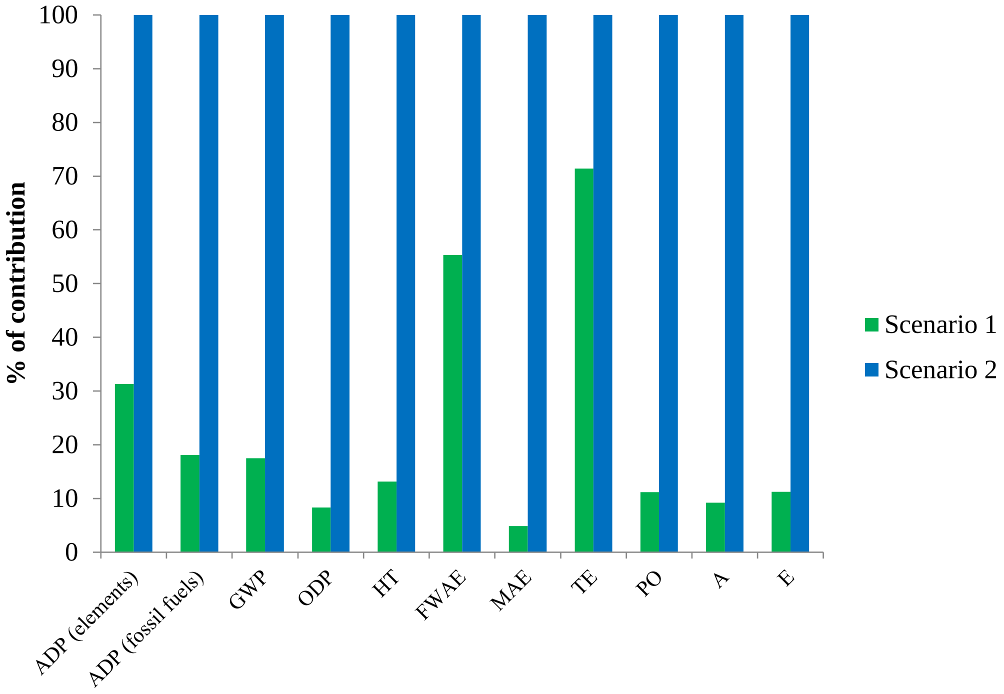
Table 3.3 Environmental impacts in the collection, pretreatment and heterogeneous reaction stages using the CML-IA baseline method V3.06/EU25 for 1 L biodiesel

Impact category	Unit	Collect	Pretreatment	Heterogeneous reaction	Total
ADP (elements)	kg Sb $_{eq}$	5.34E-06	1.72E-06	2.94E-05	3.64E-05
ADP (fossil fuels)	MJ	3.39	5.98	105.56	114.93
GWP	kg $CO_{2\,eq}$	0.24	0.46	8.91	9.61
ODP	kg CFC-11 $_{eq}$	3.87E-08	3.46E-08	6.10E-07	6.83E-07
HT	kg 1,4-DB $_{eq}$	0.06	6.99E-02	1.23	1.36
FWAE	kg 1,4-DB $_{eq}$	2.12E-03	8.18E-03	0.14	0.15
MAE	kg 1,4-DB $_{eq}$	44.50	136.01	2387.89	2568.40
TE	kg 1,4-DB $_{eq}$	4.11E-04	2.47E-03	0.04	0.05
PO	kg $C_2H_{4\,eq}$	9.02E-05	7.91E-05	1.55E-03	1.72E-03
A	kg $SO_{2\,eq}$	1.07E-03	1.96E-03	0.03	3.76E-02
E	kg $PO_{4\,eq}$	1.67E-04	1.96E-04	3.45E-03	3.81E-03

Source: Author´s Own Creation

To interpret the above results, the mid-point environmental impacts were compared with the CML-IA baseline method V3.06/EU25 for alternative scenarios of heterogeneous catalysis esterification and transesterification (scenario 1) and homogeneous catalysis (scenario 2), see Graph 3.2, which reports the largest contribution in all environmental impacts due to its high energy consumption. Talens Peiró and collaborators, (2010), mention that approximately 68% of the electricity production in the homogeneous process is due to the burning of coal, causing the release of toxic materials that affect different species in an ecosystem. Therefore, environmental impacts can be reduced through using alternative energy sources such as solar. The impact category TE of scenario 1 has a contribution of 71.43% with respect to scenario 2, which is interpreted by the final management of waste as methanol, catalyst and glycerol.

Graph 3.2 Percentage contribution of the mid-point impact categories for the heterogeneous process (scenario 1) and the homogeneous process (scenario 2) using the CML-IA baseline method V3.06/EU25

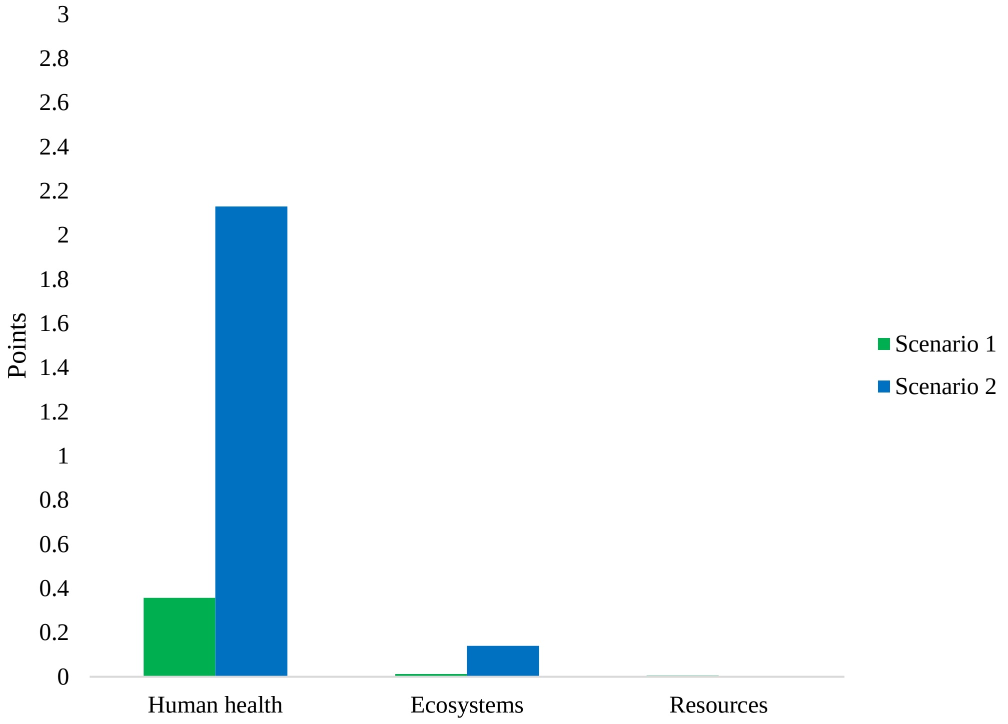


Source: Author´s Own Creation

The environmental endpoint indicators using the ReCiPe 2016 Endpoint (H) V1.04 method, to produce biodiesel in a heterogeneous process (scenario 1) with homogeneous process (scenario 2), are shown in Graph 3.3; the category of human health damage was the most affected in both processes, followed by the category concerning ecosystems and the category with the lowest natural resource score. Electrical energy consumption generates emissions such as sulphur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), particles below 10 micrometres (PM_{10}) and particles below 2.5 micrometres ($PM_{2.5}$) and volatile organic compounds (VOCs) affecting air quality by causing respiratory diseases.

Specifically, the category human health damage in scenario 1 is smaller with 1.77 points than that of scenario 2, because the heterogeneous process consumes less electricity and reuses the bifunctional catalyst (Fe_2O_3/CaO) at least three times triglycerides (Enguilo *et al.*, 2021). This is an important characteristic to consider for a LCA with circular economy approach (Al-Muhtaseb *et al.*, 2021), which secure sustainability in biodiesel production, compensating for the depletion of natural resources. It has been reported that homogeneous catalysts such as NaOH require the addition of chemicals, in addition to processes such as purification and neutralization, compared to the heterogeneous one, where there is only one purification process, avoiding the discharge of wastewater (Atadashi *et al.*, 2013).

Graph 3.3 Endpoint impacts for alternative scenarios using ReCiPe 2016.: heterogeneous process (scenario 1) and homogeneous process (scenario 2)



Source: Author´s Own

In the context of environmental sustainability, the production of biodiesel through a large scale heterogeneous process, has been reported technically efficient and economically viable in the industrial sector (Liu *et al*., 2021). For the development of public policies of the impact categories in a report of LCA, one of the most relevant and comparable impacts is 100-year global warming (GWP) or carbon footprint (Sala *et al*., 2021). In this case, the GWP or carbon footprint for the heterogeneous process is 82.52% lower than the homogeneous process (see Graph 3.2). This impact can still be further reduced with the use of renewable energies such as solar photovoltaic to power the reactor and separation equipment.

Acknowledgements

C. Alanis is grateful to the National Council of Science and Technology for the scholarship (CVU 360631) to obtain her doctorate degree. To Sustainable University Network for the Integral Management of Organic Waste of the Autonomous University of the State of Mexico with registration number 5083/REDP202 and to UAEMéx for financial support through project 6219/2020CIB. The technical support of Citlalit Martínez Soto is also acknowledged.

Conclusions

The type of oil consumed in the University food courts of the UAEMéx is mainly of sunflower and is converted into waste oil when subjected to cooking under high temperature; this was the raw material to produce biodiesel under a heterogeneous process. In this regard, the initial environmental load is zero because it is a residue, it should be noted that the impact was not quantified from the stage of cultivation or extraction of the oil, which makes the process studied sustainable.

Within the system boundary, it was established that the collection of waste cooking oil had the least contribution in the impacts studied, then the pretreatment stage. In the reaction stage for the heterogeneous process, the energy consumption due to electrical and thermal demands resulted in the greatest environmental impacts in the following categories: abiotic depletion potential (fossil fuels) (105.56MJ), 100-year global warming (8.91 kg $CO_{2\ eq}$) and marine water ecotoxicity (2387.89 kg 1.4-DB eq).

In the heterogeneous reaction step, the bifunctional catalyst (Fe_2O_3/CaO) replaces H_2SO_4 and NaOH, performing in a single step the esterification and transesterification, consuming less electricity at the activation of the catalyst that is at least three times reused and does not require any further thermal treatment; methanol is recovered for recycling during the reaction; as for glycerol, it is purified, which gives the process a circular economy approach that ensures the sustainability of biodiesel production.

With respect to the end-point environmental impacts, the homogeneous process has greater to human health damage with 1.77 points more than the heterogeneous process. This process is mainly affected by emissions from waste disposal and electricity consumption.

The carbon footprint for the heterogeneous process is lower by 82.52% compared to the homogeneous process. This contributes to the mitigation of greenhouse gases and compounds, as it replaces fossil fuels, maintains carbon sinks and prevents deforestation.

The identified areas of opportunity were the reduction of electricity consumption using renewable energies such as solar photovoltaics; the environmental sustainability of the process from the energy generated by the production of biodiesel and the energy consumed; the economic and environmental valorization of glycerol. In the University food courts, it is suggested to conduct environmental education campaigns in the collection sites to efficiently perform this stage with a pretreatment (purification of impurities), as well as standardizing a process that allows sampling to verify the initial quality of waste cooking oil and a collection route that guarantees the recycling of waste cooking oil. Finally, it was also concluded that a program of management of waste cooking oil in the UAEMéx should be implemented in order to reduce the carbon footprint of the University food courts.

References

Al-Muhtaseb, A. H., Osman, A. I., Murphin Kumar, P. S., Jamil, F., Al-Haj, L., Al Nabhani, A., Kyaw, H. H., Myint, M. T. Z., Mehta, N., & Rooney, D. W. (2021). Circular economy approach of enhanced bifunctional catalytic system of CaO/CeO2 for biodiesel production from waste loquat seed oil with life cycle assessment study. *Energy Conversion and Management*, *236*, 114040. https://doi.org/10.1016/j.enconman.2021.114040

Amaya, J., Coello, S., Crespo, T., Hidalgo, J., Jervis, F., Moreira, C., & Soto, M. (2020). Waste to Energy Potential of Domestic Waste Cooking Oil in Guayaquil: A review. *18th LACCEI International Multi-Conference for Engineering, Education, and Technology:*, 1–7. https://doi.org/10.18687/laccei2020.1.1.485

Antoniadou, M., Tsarouhas, P., & Varzakas, T. (2020). *GSC Advanced Research and Reviews Life cycle assessment and circular economy in conjunction with treatment methodologies : Presentation and critical comparison between different food industry waste*. *03*(03).

Atadashi, I. M., Aroua, M. K., Abdul Aziz, A. R., & Sulaiman, N. M. N. (2013). The effects of catalysts in biodiesel production: A review. *Journal of Industrial and Engineering Chemistry*, *19*(1), 14–26. https://doi.org/10.1016/j.jiec.2012.07.009

Ayoola, B., Ayodele, A., Submitted, T., Engineering, C., & Engineering, C. (2015). *Production and Life Cycle Assessment of Biodiesel from Three Waste Oils By A Thesis Submitted in the Department of Chemical Engineering to the School of Post Graduate Studies (Ph . D .) in Chemical Engineering , College of Science and Technology , Covena*.

Belkhanchi, H., Rouan, M., Hammi, M., & Ziat, Y. (2021). *Synthesis of Biodiesel by Transesterification of Used Frying Oils (UFO) through Basic Homogeneous Catalysts (NaOH and KOH)*. *11*(5), 12858–12868.

Carlos, S., & Díaz, M. D. L. V. (2018). Evaluación De Un Proceso Industrial De Producción De Biodiésel Mediante Análisis De Ciclo De Vida. *Revista Internacional de Contaminacion Ambiental*, *34*(3), 453–465. https://doi.org/10.20937/RICA.2018.34.03.08

Chung, Z. L., Tan, Y. H., Chan, Y. S., Kansedo, J., Mubarak, N. M., Ghasemi, M., & Abdullah, M. O. (2019). Life cycle assessment of waste cooking oil for biodiesel production using waste chicken eggshell derived CaO as catalyst via transesterification. *Biocatalysis and Agricultural Biotechnology*. https://doi.org/10.1016/j.bcab.2019.101317

Clabeaux, R., Carbajales-dale, M., Ladner, D., & Walker, T. (2020). Assessing the carbon footprint of a university campus using a life cycle assessment approach. *Journal of Cleaner Production*, 122600. https://doi.org/10.1016/j.jclepro.2020.122600

De Mora, E. F., Torres, C., & Valero, A. (2015). Thermoeconomic analysis of biodiesel production from used cooking oils. *Sustainability (Switzerland)*, *7*(5), 6321–6335. https://doi.org/10.3390/su7056321

Enguilo, V., Romero, R., Gómez-Espinosa, R. M., Romero, A., Martínez, S. L., & Natividad, R. (2021). Biodiesel Production from Waste Cooking Oil Catalyzed by a Bifunctional Catalyst. *ACS Omega*. 24092−24105. https://doi.org/10.1021/acsomega.1c03586

EPA. (2000). Recycled cooking oils: Assessment of risks for public health. *Working document for Scientific and Technological Options Assessment (STOA). European Union, September*, 373–385. http://dx.doi.org/10.1016/B978-1-893997-92-9.50027-X

Flach, B., Lieberz, S., & Bolla, S. (2019). GAIN Report - EU Biofuels Annual 2019. *Global Agricultural Information Network*, 52. https://apps.fas.usda.gov/newgainapi/api/report/downloadreportbyfilename?filename=Biofuels Annual_The Hague_EU-28_7-15-2019.pdf

Foteinis, S., Chatzisymeon, E., Litinas, A., & Tsoutsos, T. (2020). Used-cooking-oil biodiesel: Life cycle assessment and comparison with first- and third-generation biofuel. *Renewable Energy*, *153*, 588–600. https://doi.org/10.1016/j.renene.2020.02.022

Gaceta oficial de la Ciudad de México. (2018). NADF- 012-AMBT-2015. En *Diario Oficial de la Federación*. https://doi.org/10.1017/CBO9781107415324.004

Gaur, A., Mishra, S., Chowdhury, S., Baredar, P., & Verma, P. (2020). Materials Today : Proceedings A review on factor affecting biodiesel production from waste cooking oil : An Indian perspective. *Materials Today: Proceedings*, 7. https://doi.org/10.1016/j.matpr.2020.09.432

González, I., & González, J. (2015). Aceites usados de cocina. problemática ambiental, incidencias en redes de saneamiento y coste del tratamiento en depuradoras. *Consorcio de Aguas Bilbao Bizkaia*, 1–8. http://www.aguasresiduales.info/revista/articulos/problematica-ambiental-incidencias-en-redes-de-saneamiento-y-coste-del-tratamiento-en-depuradoras-de-los-aceites-usados-en-cocina

Gu, Y., Wang, H., Robinson, Z. P., Wang, X., Wu, J., Li, X., Xu, J., & Li, F. (2018). Environmental footprint assessment of green campus from a food-water-energy nexus perspective. *Energy Procedia*. https://doi.org/10.1016/j.egypro.2018.09.109

Güereca, L. P., Torres, N., & Noyola, A. (2013). Carbon Footprint as a basis for a cleaner research institute in Mexico. *Journal of Cleaner Production*, *47*, 396–403. https://doi.org/10.1016/j.jclepro.2013.01.030

Hartini, S., Puspitasari, D., Aisy, N. R., & Widharto, Y. (2020). Eco-efficiency Level of Production Process of Waste Cooking Oil to be Biodiesel with Life Cycle Assessment. *ICENIS*, *10004*, 1–9.

ISO 14044. (2006). Environmental management — Life cycle assessment — Requirements and guidelines. En *International Organization for Standardization*. http://www.springerlink.com/index/10.1007/s11367-011-0297-3

Liu, Y., Yang, X., & Zhu, Z. (2021). Economic evaluation and production process simulation of biodiesel production from waste cooking oil. *Current Research in Green and Sustainable Chemistry*, 100091. https://doi.org/10.1016/j.crgsc.2021.100091

Marinković, D. M., Stanković, M. V., Veličković, A. V., Avramović, J. M., Miladinović, M. R., Stamenković, O. O., Veljković, V. B., & Jovanović, D. M. (2016). Calcium oxide as a promising heterogeneous catalyst for biodiesel production: Current state and perspectives. *Renewable and Sustainable Energy Reviews*, *56*, 1387–1408. https://doi.org/10.1016/j.rser.2015.12.007

Mendoza, R., Quintero, R., & Ortiz, I. (2019). The carbon footprint of a public university campus in Mexico City. *Carbon Management*, *10*(5), 501–511. https://doi.org/10.1080/17583004.2019.1642042

Narasimhan, M., Chandrasekaran, M., Govindasamy, S., & Aravamudhan, A. (2021). Heterogeneous nanocatalysts for sustainable biodiesel production: A review. *Journal of Environmental Chemical Engineering*, *9*(1), 104876. https://doi.org/10.1016/j.jece.2020.104876

Orjuela, A., & Clark, J. (2020). Green Chemicals from Used Cooking Oils: Trends, Challenges and Opportunities. *Current Opinion in Green and Sustainable Chemistry*, 100369. https://doi.org/10.1016/j.cogsc.2020.100369

Rincón, J., & Silva, E. (2015). *Bioenergía: Fuentes, conversión y sustentabilidad* (CYTED). https://books.google.com/books?id=YpnxCAAAQBAJ&pgis=1

Rincón, L., Cadavid, J., & Orjuela, A. (2019). Used cooking oils as potential oleochemical feedstock for urban biorefineries – Study case in Bogota, Colombia. *Waste Management*, *88*, 200–210. https://doi.org/10.1016/j.wasman.2019.03.042

Sala, S., Martino, A., Antoine, A., & Fulvio, B. (2021). The evolution of life cycle assessment in European policies over three decades. *The International Journal of Life Cycle Assessment*, *0123456789*. https://doi.org/10.1007/s11367-021-01893-2

Sangwan, K. S., Bhakar, V., Arora, V., & Solanki, P. (2018). Measuring Carbon Footprint of an Indian University Using Life Cycle Assessment. *Procedia CIRP*, *69*(May), 475–480. https://doi.org/10.1016/j.procir.2017.11.111

Sanz R., J. F., Guimaraes, A. C., Quirós Alpera, S., Relea Gangas, E., Hernandez-Navarro, S., Navas Gracia, L. M., Martin-Gil, J., & Fresneda Cuesta, H. (2011). Life Cycle Assessment (LCA) of the biofuel production process from sunflower oil, rapeseed oil and soybean oil. *Fuel Processing Technology*, *92*(2), 190–199. https://doi.org/10.1016/j.fuproc.2010.03.004

SEMARNAT. (2019). *Visión Nacional hacia una gestión Sustentable: Cero Residuos*.

SEMARNAT. (2020). *Programa Sectorial de Medio Ambiente y Recursos Naturales 2020-2024.*

Sheinbaum, C., Caldero, A., & Ramı, M. (2013). Potential of biodiesel from waste cooking oil in Mexico. *Biomass and Bioenergy*, *6*(55). https://doi.org/10.1016/j.biombioe.2013.05.008

Talens, L., Lombardi, L., Villalba Méndez, G., & Gabarrell i Durany, X. (2010). Life cycle assessment (LCA) and exergetic life cycle assessment (ELCA) of the production of biodiesel from used cooking oil (UCO). *Energy*, *35*(2), 889–893. https://doi.org/10.1016/j.energy.2009.07.013

Tsai, W.-C., Chen, X., & Yang, C. (2020). Consumer Food Waste Behavior among Emerging Adults: Evidence from China. *Foods*, *9*(7), 961. https://doi.org/10.3390/foods9070961

UNEP/SETAC Life cycle Initiative. (2005). Life Cycle approaches : The road from analysis to practice. En *Assessment*.

Viornery, E. A., Bravo, B., & Mena, V. Y. (2020). Life cycle assessment and emission analysis of waste cooking oil biodiesel blend and fossil diesel used in a power generator. *Fuel*, *281*(March), 118739. https://doi.org/10.1016/j.fuel.2020.118739

Yañez, P., Sinha, A., & Vásquez, M. (2020). Carbon footprint estimation in a university campus: Evaluation and insights. *Sustainability (Switzerland)*, *12*(1), 1–15. https://doi.org/10.3390/SU12010181