Supplementary Material

Sustainability assessment of the valorization scheme of used cooking oils (UCOs): the case study of Bogotá, Colombia

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Table S1. ICoS goals and principles [45, 51]

1st Goal: Securing human existence		**2nd Goal:** Maintaining society's productive potential		**3rd Goal:** Keeping options for development and action open	
Label	**Principle**	**Label**	**Principle**	**Label**	**Principle**
1.1	Protection of human health	2.1	Sustainable use of renewable resources	3.1	Equal opportunities
1.2	Ensuring basic needs	2.2	Sustainable use of non-renewable resources	3.2	Participation in societal decision-making processes
1.3	Securing an autonomous existence	2.3	Sustainable use of the environment as a sink for waste and emissions	3.3	Conservation of cultural heritage and diversity
1.4	Fair sharing in the use of natural resources	2.4	Avoiding unacceptable technical risks	3.4	Conservation of the cultural function of nature
1.5	Balancing inequalities in income and wealth	2.5	Sustainable development of human-made, human and knowledge capital	3.5	Conservation of social resources

Table S2. Selected assessment criteria and indicators, and alignment with the ICoS goals and rules for interpretation

ICoS Sustainability Goal	ICoS Sustainability Rules	Understanding for this work	Assessment criterion	Indicator	Unit	Assessment tool
Securing human existence	Protection of human health	The magnitude of direct and indirect impacts on human health generated by all of the activities related to the production of UCO-based biodiesel must be minimized.	Human health	Fine particulate matter formation	kg PM2.5-eq	LCA
				Photochemical oxidant	kg NOx-eq	LCA
	Securing an autonomous existence	Like any other productive project, valorization of UCO should create a job market where labor conditions are fair and safe, contributing thereby to society's welfare	Labor conditions	Level of labor formality	Qualitative assessment	Literature review
			Work safety	Risk of labor incidents	Qualitative assessment	Literature review
Maintaining society's productive potential	Sustainable use of renewable resources	Required use of renewable resources for UCO valorization should not endanger long-term availability of these resources	Water use	Water stress index (WSI)	m^3 water	LCA
	Sustainable use of non-renewable resources	Use of non-renewable resources for UCO valorization should be minimized	Demand for fossil resources	Fossil resource use	kg oil-eq	LCA
	Sustainable use of the environment as a sink for waste and emissions	Waste and emissions produced by the UCO valorization system should be minimized so pollution levels do not surpass the earth's absorption capacity	Climate change	GHG emissions	kg CO_2-eq	LCA
			Water quality	Freshwater eutrophication	kg P-eq to freshwater	LCA
			Soil quality	Terrestrial acidification	kg SO_2-eq	LCA
			Waste management	Avoided GHG emissions	kg CO_2-eq	LCA
	Sustainable development of man-made, human, and knowledge capital	In order to effectively reduce waste generation and maintain the UCO valorization system for the long run, total costs should be less than the benefits.	Economic performance	Operating production costs for the first two life cycle stages[1]	COP (Colombian pesos) or US$	OpEx estimation
Keeping options for development and action open	Participation in societal decision-making processes	Involvement of society contributes to better sustainability of productive projects, such as UCO valorization	Social acceptance	Degree of public support	Qualitative assessment	Literature review
			Governmental framework	Robustness of related policy and regulations	Qualitative assessment	Literature review
	Conservation of the cultural function of nature	The UCO valorization system should contribute to the preservation of the social and cultural value of nature	Land-use change	Cultural effects of direct land-use change	Qualitative assessment	Literature review

[1] Only the first two life cycle stages of the study and reference systems are chosen, considering that the stages of distribution and biodiesel production are very similar in terms of mass and energy inputs. Furthermore, and considering the multiple variables that play a relevant role in an economic assessment, only the operational expenditure (OpEx) was approached in this work.

Table S3. Inventory data for the UCO collection stage [7, 46]

Inputs		
Flow	**Value**	**Ecoinvent provider dataset**
Available UCO	1 t	-
Transport, freight, light commercial vehicle	50 km·t	Transport, freight, light commercial vehicle (Rest of the world)
Outputs		
Flow	**Value**	**Ecoinvent provider dataset**
Collected UCO	1 t	-

Table S4. Inventory data for the UCO pretreatment stage [46]

Inputs		
Flow	**Value**	**Ecoinvent provider dataset**
Collected UCO	1.03 t *	UCO Collection stage
Electricity, medium voltage	8 kWh	Market for electricity, medium voltage (Colombia)
Heat, central or small scale	800 MJ	Heat production, light fuel oil, at boiler 100 kW condensing, non-modulating (Rest of the world)
Outputs		
Flow	**Value**	**Ecoinvent provider dataset**
Pretreated UCO	1 t	
Water vapor	0.0214 t	Emission to air/high population density
Biowaste	0.0086 t	Treatment of biowaste, industrial composting

* Collected UCO contains around 3% wt. of water and suspended solids that are removed with pretreatment

Table S5. Inventory data for the UCO distribution stage

Inputs		
Flow	**Value**	**Ecoinvent provider dataset**
Pretreated UCO	1 t	UCO Pretreatment stage
Transport, freight, lorry 16-32 metric ton, EURO4	1.000 t*km	Transport, freight, lorry 16-32 metric ton, EURO4 (Rest of the world)
Transport, freight, lorry 16-32 metric ton, EURO6	324 t*km	Transport, freight, lorry 16-32 metric ton, EURO6 (Rest of the world)
Transport, freight, sea, transoceanic ship	7.440 t*km	Transport, freight, sea, transoceanic ship (Global)
Outputs		
Flow	**Value**	**Ecoinvent provider dataset**
Distributed UCO	1 t	-

* Distances were measured by using Google maps

Table S6. Inventory data for the biodiesel production stage

Flow	Value	Ecoinvent provider dataset
Inputs		
Flow	**Value**	**Ecoinvent provider dataset**
Distributed UCO	0.930 t	UCO Distribution stage
Electricity	38.25 kWh	Market for electricity, medium voltage (Spain)
Heat, district or industrial, natural gas	835.44 MJ	Market for heat, district or industrial, natural gas (Europe without Switzerland)
Tap water	15.12 kg	Market for tap water (Europe without Switzerland)
Water, deionized, from tap water, at user	0.000532 kg	Market for water, deionized, from tap water, at user (Europe without Switzerland)
Methanol	102.74 kg	Market for methanol (Global)
Phosphoric acid, industrial grade, without water, in 85% solution	4.16 kg	Market for phosphoric acid, industrial grade, without water, in 85% solution state (Global)
Potassium hydroxide	10.27 kg	Market for potassium hydroxide (Global)
Sodium hydroxide, without water, in 50% solution state	0.000496 kg	Market for sodium hydroxide, without water, in 50% solution state (Global)
Sodium methoxide	0.057 kg	Market for sodium methoxide (Global)
Sulfuric acid	0.0047 kg	Market for sulfuric acid (Europe)
Outputs		
Flow	**Value**	**Ecoinvent provider dataset**
UCO-based biodiesel	1 ton	-
Municipal solid waste	0.0013 kg	Market for municipal solid waste (Spain)
Wastewater, average	0.0566 m^3	Market for wastewater, average (Europe without Switzerland)

* Data corresponds to the Ecoinvent dataset “Treatment of waste cooking oil, purified, esterification, vegetable oil methyl ester (Rest of the world)”

Table S7. Used datasets for the palm-based biodiesel reference system

Stage	Dataset	Remarks
Oil palm cultivation	Palm fruit bunch production (Colombia)	-
Palm oil extraction	Palm oil mill operation, crude palm oil (Rest of the world)	Providers of the dataset were modified to fit the geographical location (Colombia)
Biodiesel production	Esterification of palm oil, vegetable oil methyl ester (Rest of the world)	Providers of the dataset were modified to fit the geographical location (Spain)

Table S8. Selected impact categories for each assessment criterion

Assessment criterion	Impact category	Unit
Human health	Fine particulate matter formation	kg PM2.5-eq
	Photochemical oxidant formation	kg NOx-eq
Demand for fossil resources	Fossil resource use	kg oil-eq
Climate change	Climate change	kg CO_2-eq
Water quality	Freshwater eutrophication	kg P-eq
Soil quality	Terrestrial acidification	kg SO_2-eq

Table S9. Categorization for qualitatively assessed criteria

Overall performance	Negative impact	Assigned number
Excellent	None	0
Very good	Very low	1
Good	Low	2
Acceptable	Acceptable	3
Insufficient	High	4
Deficient	Very high	5

Section S1. Sensitivity analysis

From preliminary analysis, the main factor affecting life cycle impacts of the study case was the commuting distances among the different collection routes in the city of Bogota. For the study system of this work, an average transportation distance of 50 km/ton UCO was calculated according to the findings of Rodríguez [7]. However, a high degree of dispersion was observed among the values for different collection routes reported in that study, ranging from 10 to even 1,200 km/ton UCO, and with a standard deviation of 220 km/ton UCO. It was identified that about 90% of the values are in the range of 10 to 250 km/ton UCO [7]. Therefore, it was decided to use these values for the sensitivity analysis, which correspond to one-fifth and five times the calculated average transportation distance. Three scenarios were then considered:

Table S10. Sensitivity analysis scenarios

Scenario	Transportation distance
Best case	10 km/ton UCO
Baseline	50 km/ton UCO
Worst case	250 km/ton UCO

A sensitivity ratio was calculated according to the following formula:

$$Sensitivity\ ratio = \frac{\frac{\Delta\ result}{Baseline\ result}}{\frac{\Delta\ result}{Baseline\ parameter}}$$

The calculated sensitivity ratios for the different impact categories ranged between 0.11 and 0.21. Hence, it is possible to state that the parameter has a significant influence in the overall results

[21]. it is important to acknowledge that such high values of the transportation distance reflect a low level of efficiency of the current UCO collection scheme. Figure S-1 presents the magnitude of the different impact categories relative to the baseline scenario, pointing out the potential increase of the impacts for the worst-case scenario It can be identified that the most sensitive impact categories are fresh water eutrophication, photochemical oxidant formation, fossil resource use and fine particulate matter formation. with changes >1.5 times those of the base case. On the other hand, climate change, water use, and terrestrial acidification exhibited maximum changes with respect to the base case of <1.4. These are still large, thus involving high uncertainty of the assessed impacts when using the reported average distance.

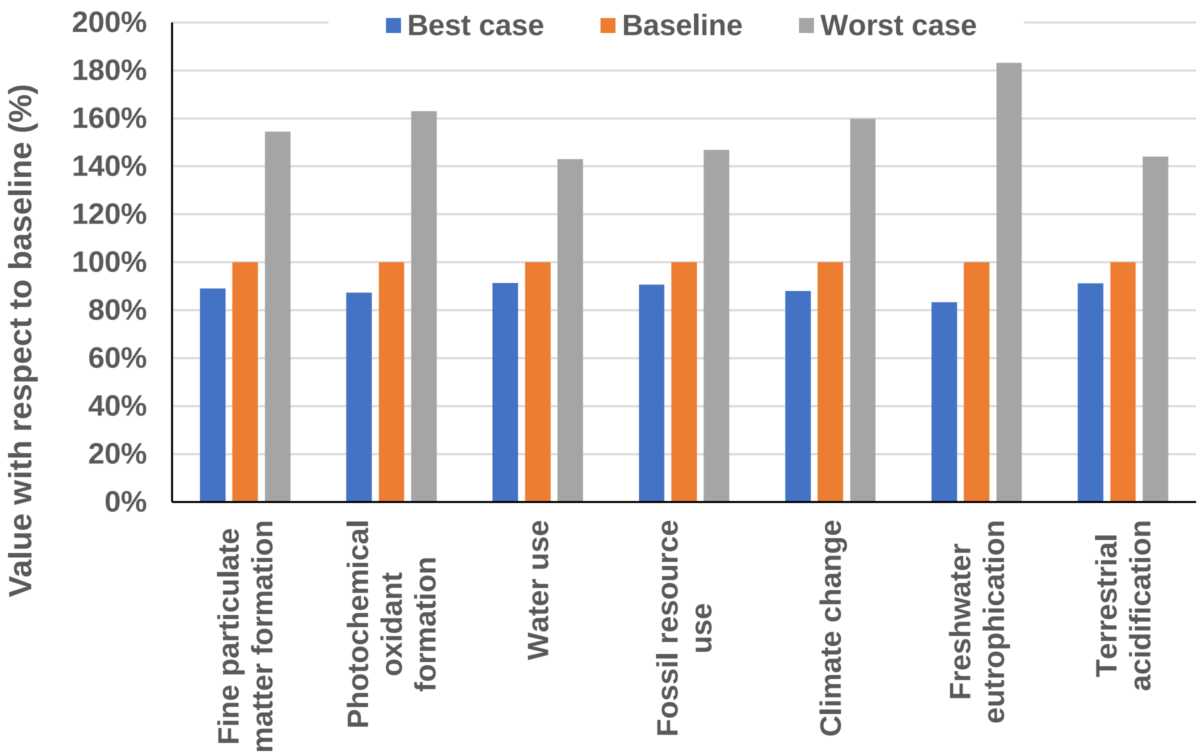

Figure S1: Impact results of the best- and worst-case scenarios relative to the baseline Variation parameter: Transportation distance per unit of collected UCO (See Table S10)

Figure S-2 shows the contribution share of the UCO collection stage. For the baseline scenario, these values range between 11% and 21%, which are low but non-negligible. For the best-case scenario, contribution shares can be considered small since the maximum value is 5%. As for the worst-case scenario, these values are at least 38% and even reach 57% for the impact category of freshwater eutrophication.

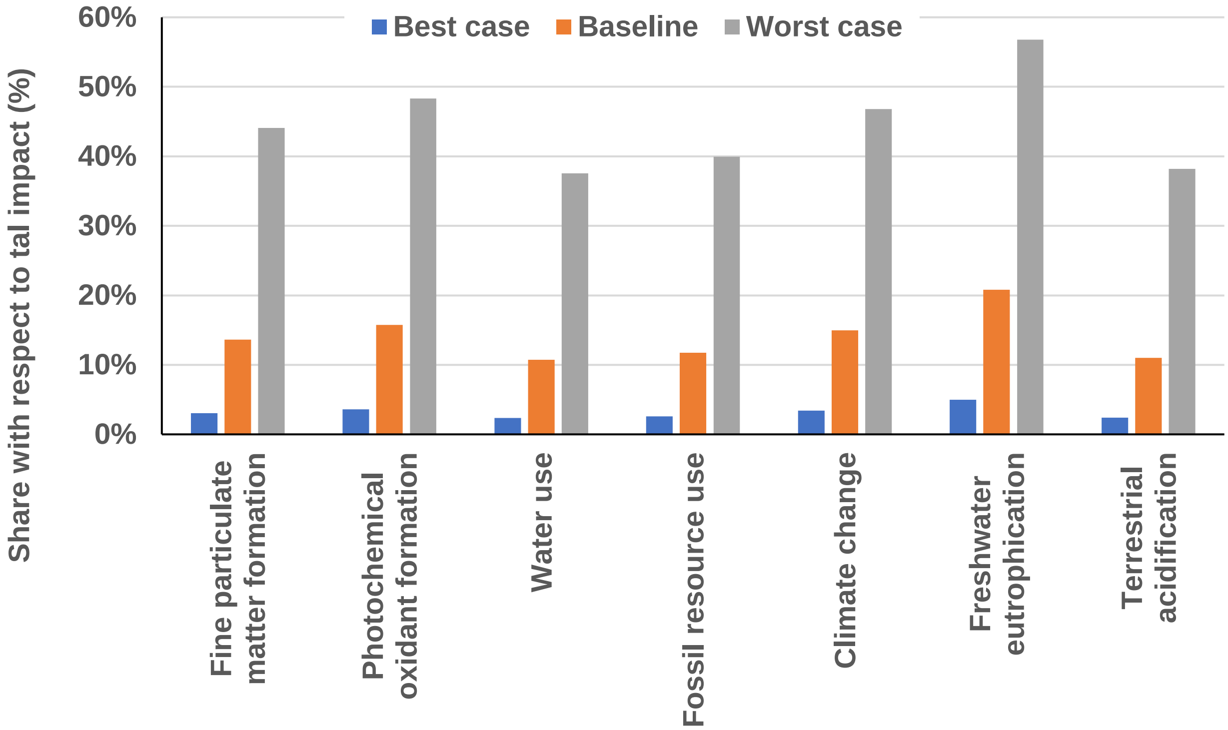

Figure S2: Contribution share of the UCO collection stage for each of the considered scenarios Variation parameter: Transportation distance per unit of collected UCO (See Table E-1)