Biodiesel from Waste Cooking Oils in Portugal: alternative collection systems

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Abstract (150 to 250 words)

Waste Cooking Oils (WCO) have been gaining prominence as an alternative feedstock for biodiesel production due to is potential to improve the environmental performance of biodiesel produced with biomass. However, there are various types of WCO collection with different collection efficiency and environmental impacts. The aim of this paper is to present an environmental assessment of biodiesel from WCO addressing different collection schemes in Portugal. The implications of alternative allocation approaches (no allocation, mass allocation, energy allocation and economic allocation) in the final results are also assessed. Life Cycle Impact Assessment was calculated with the ReCiPe for: Climate Change (CC); Terrestrial Acidification (TA); Marine Eutrophication (ME) and Freshwater Eutrophication (FE). WCO collection contribution for the overall impacts ranged significantly for the various collection system and impact categories. The difference in the results by applying different allocation methods ranged between 1 to 11 % (absolute value). A comparison between the GHG emissions calculated for biodiesel from WCO collected in Portugal and the typical and default values presented in the Renewable Energy Directive (RED) was performed. The GHG emission saving for biodiesel from WCO collected in Portugal ranged from 81 to 89 %.

Keywords: waste collection; Life Cycle Assessment (LCA); Waste Cooking Oil (WCO); allocation

1. INTRODUCTION

The use of biofuels in transportation in Europe has been promoted by the implementation of policies such as the Directive 2009/28/EC, on the promotion of the use of energy from renewable sources, commonly known as Renewable Energy Directive (RED) [1]. However, questions raised concerning the sustainability of biofuels lead the European Union to propose an amend to the RED with the goal to reduce the conventional fuels required for transportation energy mix by 2020 and promote the use of waste-based biofuels [2]. In this context, Waste Cooking Oil (WCO) has been gaining prominence as an alternative feedstock for biodiesel production. However, there are various types of WCO collection with different collection efficiency and environmental impacts.

Most of the Life Cycle Assessment (LCA) studies of biodiesel from WCO have showed that the WCO collection had a small contribution to the overall impacts. For example, Chua *et al.* [3] showed that the WCO collection from restaurants in Singapure represented 1% of the overall biodiesel impacts; Dufour & Iribarren [4] and Peiró *et al.* [5], analyzing the WCO collection from restaurants, hotels and agro-food industry in Catalonia in Spain, and Thamsiriroj *et al.* [6] the WCO collected from restaurants in Ireland calculated both a contribution of about 4%.

However, McManus [7] calculated significant GHG emissions for WCO collected from pubs, restaurants and schools in the south west of England. Preliminary work of the same authors of this article, for WCO collected in Portugal focused on the GHG emissions of biodiesel from WCO, also showed that the collection stage can have significant GHG emissions [8]. Although these studies have showed that the collection stage may have significant impacts, they were focused only on GHG emissions. Other impact categories need to be addresses in order to assess the contribution of the collection stage in a more comprehensive way.

The results of LCA of WCO-based biodiesel can be also influenced by the allocation approach applied (based on mass, energy, exergy, market price,…) to partition the impacts between biodiesel and glycerine (a co-product for the biodiesel production). ISO 14044 [9] states that "Whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the departure from the selected approach". However, the RED has adopted an allocation approach based on the energy content, which has been an important issue of controversy among LCA researchers [10][11].

Most published LCA of WCO biodiesel have adopted mass allocation [3][4][12][13][14][15] The economic allocation approach was adopted by some authors that performed a sensitivity analyses for various allocation approaches, namely Lin *et al.* [16], who applied economic and energy allocation as well as system expansion and found that both allocation approaches lead to less than 10% of impacts compared system expansion. Thamsiriroj *et al.* [6] investigated three scenarios: no allocation, allocation by energy content and the substitution approach and the results for energy demand and GHG emissions, obtained by the allocation based on the energy content approach, were 10 % lower in comparison with the other two scenarios.

The main aim of this paper is to present a LCA of biodiesel produced from WCO collected in Portugal using alternative WCO collection systems. A comprehensive inventory for alternative WCO collection systems was implemented for households and the HoReCa (Hotels, Restaurants and Catering) sector. For the households, data from three collection systems using "street containers" and one collection system using "door to door" system was collected. For the HoReCa sector, WCO collection from restaurants in a Portuguese midsize municipality was selected as case study. The implications of alternative allocation approaches in the Life Cycle Impact Assessment (LCIA) was also assessed. The following scenarios were investigated: no allocation, mass allocation, energy allocation and economic allocation. Life Cycle Impact Assessment results were calculated using the ReCiPe method for Climate Change (CC), Terrestrial Acidification (TA), Marine Eutrophication (ME) and Freshwater Eutrophication (FE). A comparison between the GHG emissions of biodiesel from WCO collected in Portugal and the RED typical values was performed.

2. LIFE-CYCLE MODEL

Figure 1 shows the main stages of the LC model implemented for biodiesel from WCO in Portugal. The LC follows a "well-to-gate" approach and includes the following stages: WCO collection, pre-treatment and biodiesel production (transesterification). The functional unit selected is 1 MJ of biodiesel.

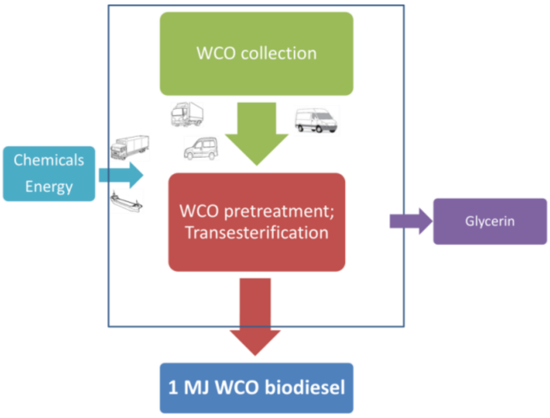


Figure 1. System Boundary: biodiesel from WCO

Inventories for five actual WCO collection systems were implemented: four for *households* ("Street containers" and "door-to-door" collection) and one for the *HoReCa sector*. Data for "Street containers" collection is from the following three areas:

- a municipality in the center of Portugal – Coimbra;
- an inter municipality area located in the south of Portugal covering the following municipalities Grândola, Alcácer do Sal, Ferreira do Alentejo and Aljustrel, Odemira, Santiago do Cacém and Sines;
- an inter municipality area located in the north of Portugal covering the following municipalities Espinho, Gondomar, Maia, Matosinhos, Porto, Póvoa de Varzim, Valongo and Vila do Conde

Within these systems the WCO collection containers are displaced in specific points in the street and the collection route and collection frequency are established by each collector.

The "door to door" collection system is located in the island of Angra do Heroísmo (AH) in the Azores. In this system the collection is performed once a month.

The inventory for the *HoReCa sector* was based on WCO collection from restaurants in the municipality of Coimbra (a Portuguese midsize city). The collection frequency is defined according the WCO supplier needs.

Table 1 shows the average quantity of WCO collected per km driven (a performance indicator for the WCO collection) for the various systems. The quantity of WCO and distance driven in each route (the exact collection points could change) was obtained from the actual companies collecting WCO. Table 1 shows that the collection system that presents the higher performance indicator is the system *Household - Street Containers* implemented in Coimbra (9.1 L WCO/km) and the lower, the system *Household - Door-to-Door* implemented in Angra do Heroismo (1,5 L WCO/km). The later presents values very close to the HoReCa system (1.6 L WCO/km). The type of fuel and the average fuel consumption was also provided by the actual companies collecting WCO and are presented in table 1. With exception for the inter-municipal system north, that used biodiesel in the collection vehicles, all the systems used diesel. The higher fuel consumption was registered for the Inter-municipal systems south (0.14 L/km).

Table 1. Vehicle fuel consumption and average WCO collected

Collection System			**Average Fuel consumption (L/km)**	**Average Performance Indicator (L WCO/km)**
Households	Street Containers	Coimbra	0.09	9.1
		Inter-municipal system north	0.11*	2.1
		Inter-municipal system south	0.14	3.1
	Door-to-Door	Angra do Heroísmo	0.09	1.5
HoReCa			0.09	1.6

*Biodiesel

Following collection, WCO was pretreated to remove impurities, such as free fatty acids (FFA) and water. Pretreatment involved oil filtering, water and impurities removal as well as acid esterification to reduce the quantity of FFA to a maximum of 0.5%[17]. Once the impurities were removed from the WCO, the following step was the transesterification: the reaction between the tri-glycerides (main component of vegetable oils) and an alcohol (Methanol) in the presence of a catalyst (NaOH). Products of the reaction are the glycerin and the biodiesel. Data used for the transesterification process was collected from Portuguese companies for the production of biodiesel [18].

In order to deal with the portioning of emissions between biodiesel and glycerine, four multifunctionality scenarios where investigated: no allocation (NA), mass allocation (MA), energetic allocation (EnA) and economic allocation (EcA).

The mass allocation factors for biodiesel (89%) and glycerine (11%) were based on the actual mass flows (0.11 kg of glycerine per kg of biodiesel produced). Energy allocation factors were calculated based on the lower heating value content of biodiesel and glycerin. The glycerin produced contains a significant percentage of water and methanol that may influence its lower heating value. This value may range between 14 to 20.4 MJ/kg [6][19] and consequently, the allocation factor may range from 85% to 89% for biodiesel. An average value was used to allocate the impacts: 87% for biodiesel and 13% for glycerine. Economic allocation based on actual market prices were calculated: 97% for biodiesel and 3% for glycerine. Table 2 summarizes the allocation factors for the various scenarios investigated.

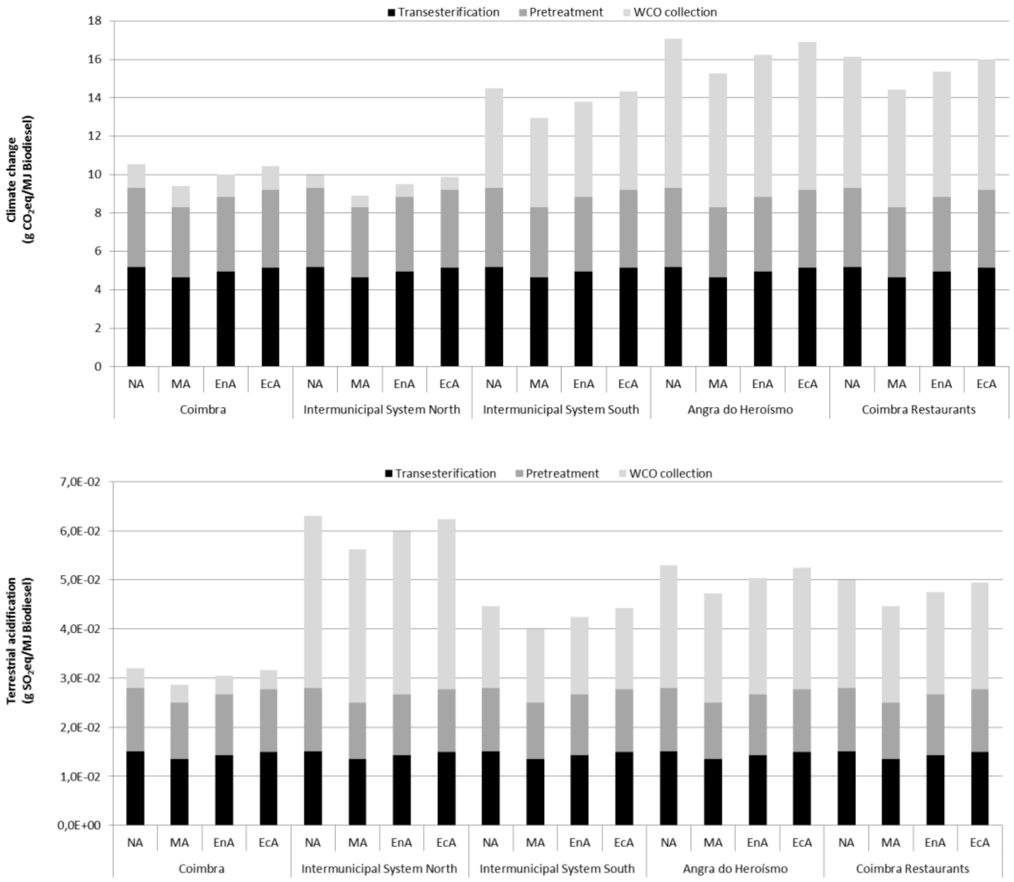
Table 2. Allocation factors applied in biodiesel from WCO production

Method	Allocation factors	
	Biodiesel	Glycerin
No allocation (NA)	1	0
Mass allocation (MA)	0.89	0.11
Energy allocation (EnA)	0.95	0.05
Economic allocation (EcA)	0.99	0.01

3. RESULTS AND DISCUSSION

3.1. Life-Cycle Impact Assessment

Figure 2 shows the environmental impacts of WCO-based biodiesel per life cycle stage (collection, pretreatment and transesterification), for the various collection systems and different allocation approaches.



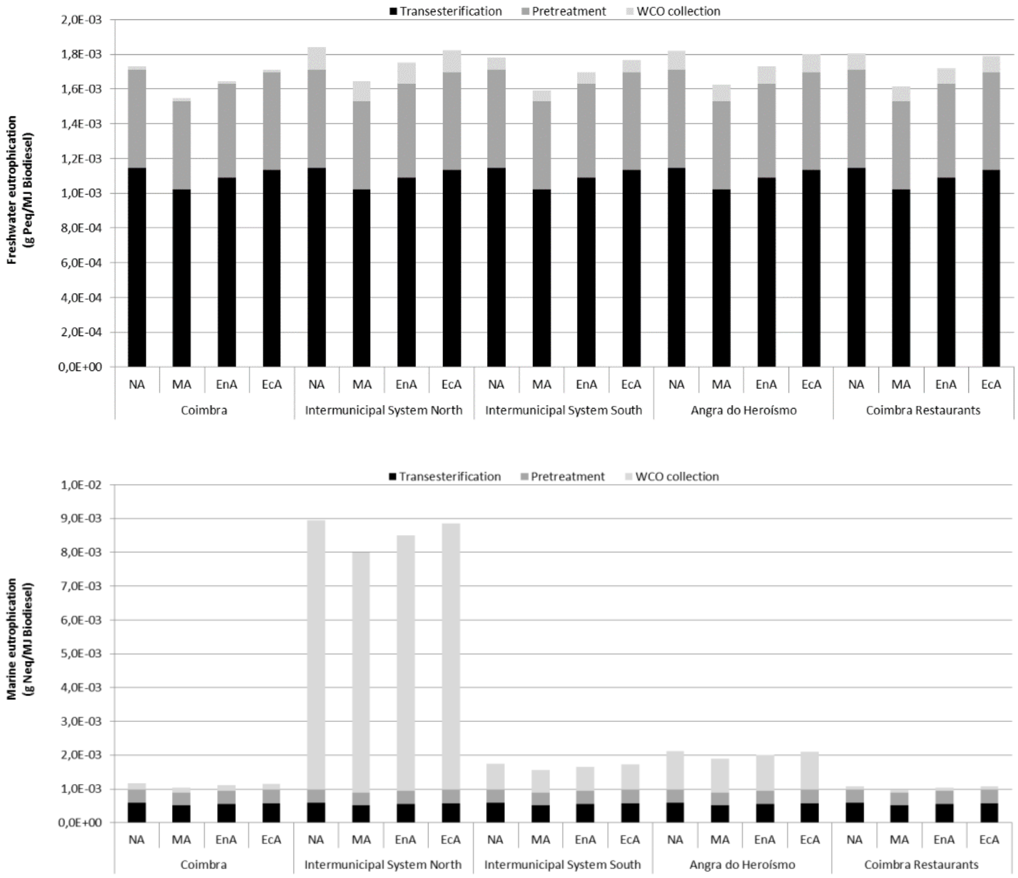


Figure 2. Environmental impacts (CC, TA, FE and ME) for WCO biodiesel, for the collection systems and allocation methods investigated.

A significant variation is observed in the results (for the same allocation approach), which is due to the collection stage since the biodiesel production (pretreatment and transesterification) data was assumed the same for all systems. The contribution of the WCO collection stage to the overall impacts range widely for the various categories. For CC, the contribution is less than 5% for Coimbra and the inter-municipal system north, but represents about 50% for the “door-to-door” system. For TA and MA, the collection stage contributes about 90% of the overall impacts in the inter-municipal system north. For FE, the collection stage has no significant contribution in all collection systems.

An inverse correlation is observed between CC impacts and the performance indicator show in table 1: lower performance indicators correspond to higher CC emissions. For these reason the “door-to-door” system presented the higher impacts for CC. The exception is for the inter-municipal system north, due to the fact that the fuel used in the collection vehicles is biodiesel. Although it reduces the impacts for CC, the use of biodiesel to perform the collection increases the impacts for TA and ME, due to SO_2 and nitrates emissions from the biodiesel production.

The difference in the results by applying different allocation methods ranges between 1 to 11 % (absolute value). Table 3 presents the variation (%) in the results by applying different allocation methods. For example, in relation to NA, MA presents results with a difference of - 11% , EnA of - 5% and EcA only of - 1%.

Table 3. Variation (%) in the results by applying different allocation methods. No allocation (NA), mass allocation (MA), energetic allocation (EnA) and economic allocation (EcA).

Allocation Method	NA	MA	EnA	EcA
NA	-	11%	5%	1%
MA	-11%	-	-6%	-11%
EnA	-5%	6%	-	-4%
EcA	-1%	11%	4%	-

3.2. GHG savings of biodiesel from WCO displacing fossil diesel

Figure 3 shows the comparison of GHG emissions of biodiesel from WCO collected in Portugal and RED default and typical values (10 and 14 g CO_2 eq/MJ of WCO biodiesel, respectively) [1].

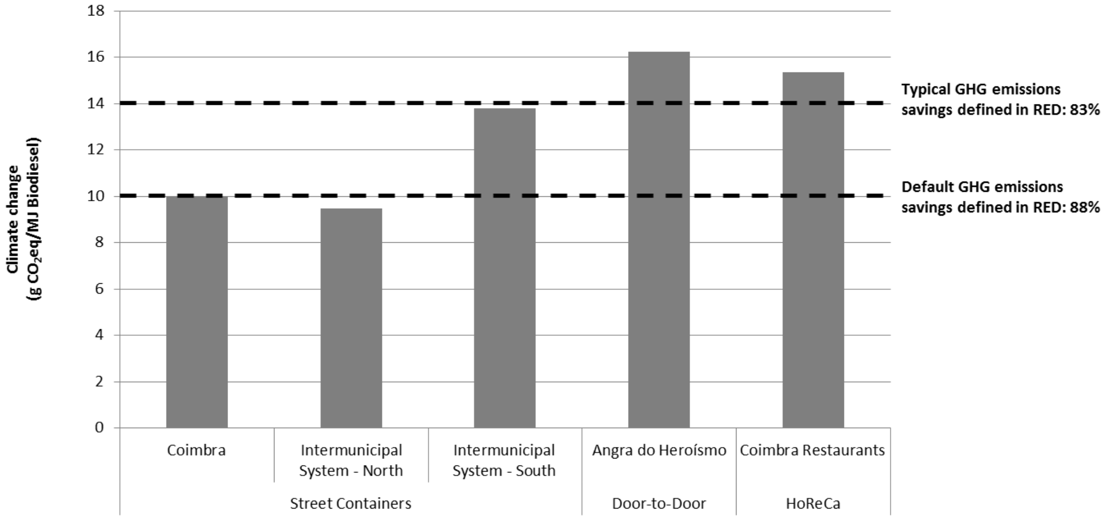


Figure 3. Comparison of GHG emissions of biodiesel from WCO collected in Portugal and RED typical and default values

It can be observed that the collection systems for Coimbra, Intermunicipal system north and south presented GHG emissions lower than the typical value and the “door to door” and HoReca systems are slightly above this value.

The RED establishes sustainability criteria for biofuels that include GHG saving targets to achieve. In particular, from 1 January 2018, the GHG emission saving from the use of biofuels shall be at least 60% for biofuels and bioliquids produced in installations in which production started on or after 1 January 2017 [1]. According to this document, the GHG saving from biofuels and bioliquids shall be calculated as:

$$GHG\ Saving = \frac{(E_F - E_B)}{E_F}$$

where,

E_B =total emissions from the biofuel or bioliquid;

E_F = total emissions from the fossil fuel comparator (83.8 gCO_2eq/MJ).

The GHG emission saving for biodiesel from WCO collected in Portugal ranged between 81% (Households - Door-to-Door) to 89% (Households - Street containers, Inter-municipal system north).The favourable GHG emission saving obtained for biodiesel from waste vegetable oils agrees with the results reported by Thamsiriroj *et al.* [6] and Durfour & Iribarren [4].

4. CONCLUSIONS

A LCA of biodiesel from WCO collected in Portugal using alternative WCO collection systems was presented. A comprehensive inventory for alternative WCO collection systems was implemented for households and the HoReCa (Hotels, Restaurants and Catering) sector. For the households, data from three collection systems using “street containers” and one collection system using “door to door” system was collected. For the HoReCa sector, WCO collection from restaurants in a Portuguese midsize municipality was selected as case study. The implications of alternative allocation approaches (no allocation, mass allocation, energy allocation and economic allocation) in the LCIA were also assessed. Life Cycle Impact Assessment results were calculated using the ReCiPe method for Climate Change (CC), Terrestrial Acidification (TA), Marine Eutrophication (ME) and Freshwater Eutrophication (FE). A comparison between the GHG emissions of biodiesel from WCO collected in Portugal and the RED typical values was performed.

The “door-to door” system presented the higher impacts for CC and the inter-municipal system north the higher impacts for TA and ME. The system implemented in Coimbra presented the lower impacts for CC, TA and ME. For FE, no significant difference is observed between the systems analyzed. Depending on the impact category and the collection system, the contribution of the collection stage to the overall impacts can range significantly. For CC the contribution can be less than 5% (Coimbra and inter municipal system north) or represent about 50% (“door-to-door” system). For MA, the collection stage can reach 90 % (inter-municipal system north) of contribution to the overall impacts. Only for FE, in all the collection systems, the collection stage as no significant contribution. The difference in the results by applying different allocation methods ranges from 1% to 11 % (absolute value). The GHG emission saving for biodiesel from WCO collected in Portugal ranged from 81% to 89%.

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