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Incorporating uncertainty in the life cycle assessment of biodiesel from waste cooking oil addressing different collection systems

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ABSTRACT

Waste Cooking Oil (WCO) is increasing prominence as a feedstock for biodiesel production due to its potential in reducing costs and environmental impacts of biodiesel when compared with virgin oils. However, several life-cycle studies have reported a wide range of WCO biodiesel impacts, mainly due to the WCO collection stage, which has not been discussed in the literature. The lack of a comprehensive assessment of the collection stage influence on biodiesel overall impacts motivates this article, in which a detailed Life-Cycle Assessment (LCA) of biodiesel produced from WCO addressing different collection systems is presented. An inventory for WCO collection was implemented for different systems in the domestic and the food service industry sectors in Portugal as well as for biodiesel companies. The characterization and incorporation of the variation associated with WCO collection systems, parameter uncertainty and variability, as well as modelling options was performed. A wide range of impacts was calculated. Two factors contribute the most to the variation observed: the WCO collection efficiency and the characteristics of the collection system (e.g. sector, type of collection and population density). Results show that WCO collection cannot be neglected or simplified when assessing the overall environmental performance of biodiesel produced from WCO.

1. Introduction

Waste Cooking Oil (WCO) are an attractive alternative feedstock for biodiesel production due to its potential in reducing costs and environmental impacts of biodiesel when compared with conventional feedstocks. Biodiesel production from WCO in Europe increased from 800 thousand tonnes (in 2011) to approximately 1800 (in 2014) (Grennea, 2014). In the US, it is expected to represent more than 60% biodiesel production by 2020, together with tallow and corn oil by-product of ethanol plants (OECD-FAO, 2011).

The Life-Cycle Assessment (LCA) methodology has been employed to analyse the environmental impacts of WCO based biodiesel showing that WCO can be environmentally beneficial compared with virgin oil feedstocks (de la Rúa et al., 2005; Upham et al., 2009; Liang et al., 2013; Varanda et al., 2011 Upham et al., 2009; Liang et al., 2013; Varanda et al., 2011) or with fossil fuels (Chua et al., 2010; Dufour and Iribarren, 2012; Pleanjai et al., 2009; Wang, 2013). However, the LCA studies show a wide range of impacts due to WCO collection causing a large variation in the overall WCO-biodiesel impacts, as discussed below.

The LCAs reported very different WCO collection situations: some presented a negligible contribution of the collection stage to the overall impacts (Peiró et al., 2008; Dufour and Iribarren 2012; Peiró et al., 2010; Souza et al., 2012), while others calculated a wide range of impacts due to collection. Chua et al. (2010) showed that the collection of WCO from restaurants in Singapore (an average of 8 kg of WCO per km) contributed about 1% to the overall biodiesel life-cycle GHG emissions (0.0028 in a total of 0.28 g CO_2 eq/L biodiesel). Thamsiriroj and Murphy (2011) assessed the collection of WCO from restaurants in Ireland using a van (average of 50 km) followed by transport by lorry (about 300 km) to a cleaning plant; WCO collection was responsible for 4% of the overall impacts (0.9 kg CO_2 eq/GJ in a total of 25 kg CO_2 eq/GJ biodiesel). McManus (2011) analysed two WCO biodiesel systems: a small scale biodiesel production (0.22 million litres per year) and a medium scale production (3 million litres a year). In the small scale system, WCO was collected from pubs, hotels, restaurants and schools in the local area (two collections per week in a maximum radius of 25 miles) using a "flat bed" truck running on their own biodiesel. For the large

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scale system, the WCO was obtained from national oil collectors and delivered in loads of 30 thousand litres to the company by oil tanker, which was also used to transport the biodiesel produced, avoiding empty tank journeys. McManus (2011) calculated significant GHG emissions for small scale (343 g CO_2 eq/L of biodiesel) and medium scale (228 g CO_2 eq/L) biodiesel production systems and concluded that the collection of the WCO contributes significantly to the overall emissions. Ortner et al. (2016) calculated about 10% contribution of the collection stage to the overall biodiesel production environmental burden. The Renewable Energy Directive (RED) (European Comission, 2009) assumes an emission of 1 g CO_2 eq/MJ from the overall transportation and distribution stage of biodiesel from WCO, without a specific reference to the WCO collection system. Caldeira et al. (2015) (a previous work of the authors of this article) showed that the collection of WCO in Portugal can have impacts ranging from 7% (0.7 in a total of 10 g CO_2 eq/MJ biodiesel) to about 50% (8 in a total GHG intensity of 17 g CO_2 eq/MJ biodiesel) and a wide variation between different types of collection systems.

The wide range of impacts of WCO collection and the lack of a comprehensive assessment of its influence on biodiesel production motivates this article, which aims at assessing the impacts of WCO collection as well as the sources of variation for different systems and situations. A comprehensive LCA of different types of WCO collection systems for biodiesel production in Portugal is presented. An inventory was implemented for three WCO collection systems from the domestic sector and the food service industry (restaurants). Data from four small biodiesel producers were collected. We characterize and incorporate the variation associated with collection (assessment of different types of systems), modelling options (analysis of different multifunctionality scenarios), as well as parameter uncertainty and variability (Monte Carlo simulation).

2. Material and methods

2.1. Life-cycle modelling and inventory

The WCO-biodiesel life-cycle can be divided in three main stages: WCO collection, WCO pre-treatment and biodiesel production (transesterification). A description of these stages and the inventory implemented follows. In Portugal, between 43–65 thousand tonnes of WCO are generated as residues per year from the domestic sector (62%), the food service industry sector (37%) and from industry (residual quantity) (APA, 2010). A comprehensive inventory for three alternative WCO collection systems was implemented, which included two types for the domestic sector and one for the food service industry. A description follows. The **domestic sector** included:

i) Street *Drop-off containers*: Plastic containers placed in specific points within the collection area where citizens can dispose the recipients with WCO. The collection (frequency and routes) is planned by each collector according to the specificity of each location. Six collection locations (A to F) were considered. The location and population density are presented in Table 1.
ii) *Door-to-door* (DtD)*:* The citizens store the WCO at home using 5 L plastic containers and, once a month, a special collection service collected the containers. This system has been implemented in locations where the placement of street containers is not practical (e.g. historical neighborhoods, areas of difficult access). Table 1 shows data for one collection system implemented in the Azores—Angra do Heroismo.

For the **food service industry** sector, WCO collection from restaurants in a Portuguese midsize municipality (Coimbra) was selected as case study (Table 1). The oil is stored in 30 or 50 L plastic containers and once a month the container is collected and replaced by an empty one. Fig. 1 shows the location and areas covered by each system analysed.

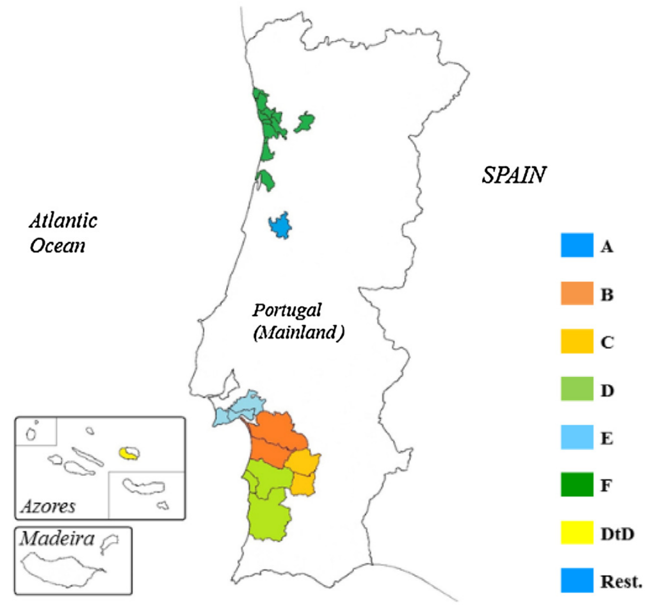

Fig. 1. Map of Portugal, showing the WCO collection areas covered by each collection system.

The distance travelled and quantity of WCO collected in each route were provided by the collection companies. The temporal horizon of the data is from 2008 to 2013, as detailed in Table 1. The quantity of WCO collected and the distance travelled in each route were different within each system (the collection routes do not cover always the same collection points).

A performance indicator (PI) for WCO collection—defined as the average volume of WCO collected per kilometre travelled— was calculated (Table 1). The highest PI (18.4 L WCO/km) was calculated for the system implemented in Coimbra to collect WCO from restaurants and the lowest (1.5 L WCO/km) for the system *Door-to-Door* implemented in Angra do Heroísmo. Within the same type of collection system (Drop-off containers, A–F), the PI ranged significantly: from 9.1 (A) to 2 (C) L WCO/km. Low values were calculated for low population density areas (B–E). Despite covering the highest population area analysed, system F did not have the highest PI (5.2 L WCO/km).

The type of fuel and average fuel consumption for WCO collection were provided by the WCO collectors and are presented in Table 1. Systems E and F collection used biodiesel from WCO as fuel in the collection fleet. All the other systems used diesel. The higher fuel consumption registered for systems B–D (0.14 L/km) is related to the size of the vehicle (3.5–7.7 tonnes capacity). In the other systems, although smaller vehicles were used (maximum capacity of 3.5 t), some differences in the consumption were observed. The higher consumption observed for the system E (0.10 L/km) and F (0.11 L/km) is due the use of biodiesel in the vehicle (increases the consumption comparatively to diesel) (Dermibas, 2003). Emission factors for diesel and biodiesel from Jungbluth et al. (2007) were considered.

For the household systems, a recovery ratio between the WCO actually collected and the WCO generated as waste was estimated between 4% and 6%. The WCO generated was calculated based on the virgin oil consumption in Portugal (22.1 kg per inhabitant per year), number of inhabitants and considering that 45% of the virgin oil become a residue (IPA, 2004). According to Math et al. (2010), if adequate collection incentives are applied, a recovery ratio of about