

Determination of Carbon Footprint using LCA Method for Straight Used Cooking Oil as a Fuel in HGVs

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ABSTRACT

In order to improve energy supply diversity and reduce carbon dioxide emissions, sustainable bio-fuels are strongly supported by EU and other governments in the world. While the feedstock of biofuels has caused a debate on the issue of sustainability, the used cooking oil (UCO) has become a preferred feedstock for biodiesel manufacturers. However, intensive energy consumption in the trans-esterification process during the UCO biodiesel production has significantly compromised the carbon reduction potentials and increased the cost of the UCO biodiesel. Moreover, the yield of biodiesel is only ~90% and the remaining ~10% feedstock is wasted as by-product glycerol. Direct use of UCO in diesel engines is a way to maximize its carbon saving potentials. This paper, as part of the EPID (Environmental and Performance Impact of Direct use of used cooking oil in 44 tonne trucks under real world driving conditions) project, presents the life cycle analysis of Straight UCO (SUCO) in terms of CO₂ and energy consumption, compared with the UCO biodiesel and petroleum diesel. The UK carbon calculator developed by UK Department for Transport was used for the calculations. The results show that SUCO renewable fuel can reduce the WTW carbon footprint by 98% compared to diesel and by 52% compared to the UCO biodiesel.

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INTRODUCTION

The ever increasing consumption of conventional fossil fuels has caused serious concerns on climate change and energy supply security issues. Transport sector is one of the major CO₂ producers, accounted for about a quarter of total CO₂ emissions globally. Among the transport CO₂ emissions, road transport dominated the total transport CO₂ emissions. The UK Vehicle Certification Agency (VCA) reported that 90% of all transport GHG emissions from road transport [1]. Biofuels as a means to reduce road transport carbon footprint have attracted great attentions during the last decade.

Biodiesel is one of the major biofuels in Europe. The application of biodiesels in diesel engines is a relatively mature technology in terms of production and combustion in diesel engines. In general, biodiesel can burn well in diesel engines and produces lower CO, hydrocarbon and particulate matter (PM) emissions compared to petroleum diesel [2,3,4,5,6,7,8]. However, has the biodiesel delivered its main objective-carbon

reduction and by how much compared to petroleum diesel?

The answer will vary. The potential of carbon reduction by biodiesels will depend on feedstock and production processes but the feedstock is a key parameter [9]. Currently biodiesels produced in the EU are mainly using edible vegetable oils as feedstock such as rape seed oil [10, 11]. These biodiesels (first generation) are often the topics of public debates due to their effects on rising food price and ethical issues such as starvation in developing countries and the competition between land use for cultivation of oilseeds as feedstocks for bio-diesel manufacture, and land use for cultivation of food crops. The second generation of biodiesels uses non-edible biomass such as lignocellulose as the feedstock but the cost of the production process is high and not economically viable at present. Thus the attention has been diverted to using the Used/Waste Cooking Oil (UCO or WCO) as a feedstock to produce biodiesels [9, 12], which is much easier to be accepted by public with regard to moral aspects and more economically viable. In the UK, UCO's contributions to the total biodiesel productions reached 66% in 2011-12 [13].

However, converting UCO into biodiesel involves transesterification process, in which the carbon footprint of methanol is brought into the fuel chain. This factor along with the demand for extra energy for the process and a typical yield of 90% reduces the carbon reduction potential of UCO biodiesel. Esteban et al [14] assessed the advantages of use SVO (Straight Vegetable Oil) directly as biofuel versus biodiesel and showed a clear preference for SVO compared to biodiesel. Peiró et al [15] conducted a LCA (Life Cycle Analysis) assessment for a used cooking oil based biodiesel and found that the transesterification stage accounted for 68% of the total environmental impact.

To maximize the carbon reduction potential of UCO, the EPID project is set up to examine and investigate the environmental and performance impact of direct use of Straight UCO (SUCO) in diesel engine powered 44 ton trucks. Ten trucks have been converted to be able to burn the SUCO fuel with an on-board blending system-Bioltec system. A dual fuel tank containing SUCO and petroleum diesel has been fitted to each truck. The Bioltec blending system is a microcomputer controlled automatic fuel selection and blending system, which can select fuel supply (diesel or SUCO) and adjust blending ratio based on certain measured engine operational parameters such as fuel temperature and load [16]. Fuel consumption, engine deposits, exhaust emissions, lube oil aging and operational performance have been monitored. This paper, as part of the project, assessed the WTW (Well To Wheel) CO₂ emission for SUCO using the LCA method.

One of the major benefits for the SUCO fuel is the increased carbon reduction potential compared to the UCO biodiesel. This will not only be beneficial globally but also can improve companies' images and reputations on carbon footprint. This is particularly suitable for the catering and food sector as they may utilize their own waste cooking oils to produce energy/fuels for processes and/or drive their own vehicles. Other benefits of SUCO renewable fuels include its transportability (easy and safer to transport, compared with diesel), biodegradability, local accessibility, recyclability, no or trivial aromatic and sulphur contents, and eco-friendliness [17].

METHODOLOGY

Define the Goal and Scope

The goal of this work was to determine WTW energy consumption and carbon footprint (CO₂e) of SUCO renewable fuel in the UK using the Life Cycle Analysis (LCA) method. As the TTW (Tank To Wheel) carbon footprint of SUCO is zero, i.e. zero CO₂ emissions from tailpipe by SUCO are deemed because emitted CO₂ from tail pipe will be absorbed by plants during their growth. Therefore the WTW carbon footprint analysis of SUCO is equivalent to its WTT carbon footprint results. The scope of the system used in this paper included the raw UCO transportation after collection, factory processing stages and transportation and dispensing of the finished products. The energy consumption and carbon footprint for

each stage was calculated based on the production of one ton of the finished SUCO renewable fuel. The total carbon emission was calculated and compared with UCO biodiesel and diesel.

LCA Flow Chart, Functional Unit and System Boundary

Appendix A presents the production process of the SUCO renewable fuel and its system boundary. The functional unit is kgCO₂ equivalent emitted for the production of one ton of the SUCO renewable fuel and gCO₂ equivalent emissions for one MJ of energy from the SUCO fuel. As shown in [appendix A](#), there are four stages in the LCA, which are transportation and loading off, refining, delivering and fuel dispensing. The energy consumption of the refining stage is divided into three sections: pumps, heating and compressor for the transfer of UCO between vessels, internal flows within vessels, heating UCO and providing compressed air etc.

Inventory Analysis

The inventory analysis has focused on energy consumption (MJ/ton) and carbon emission (kgCO₂e/ton and gCO₂e/MJ). Electricity and diesel were the main energy sources consumed during the UCO refining.

Definition of the Reference Systems

The UCO derived biodiesel and petroleum diesel were taken as the reference systems during the whole LCA of the SUCO renewable fuel. The UCO biodiesel was used a reference system as it had the same feedstock as the SUCO but with different processing pathways. Petroleum diesel was the ultimate target for the determination of carbon reduction potentials of the SUCO. Typical values for the carbon footprint of petroleum diesel from literature were used.

The location for the LCA analysis was based in the UK. The time of the analysis was between 2012 and 2013, which meant that the electricity and diesel emission factors were taken from the UK during 2012 to 2013 as references. The emission factor was 0.128 kgCO₂e/MJ for electricity and 0.0876 kgCO₂e/MJ for diesel.

UK Carbon Calculator

The UK carbon calculator is a software package for carbon emission calculation for any fuels. Under the requirement of Renewable Transport Fuels Obligation (RTFO), Life Cycle Analysis (LCA) methodology is a normalized carbon calculator in the UK to quantify the carbon emission for bio-fuels production [18]. The software provides not only readily available standard fuel chains like biodiesel fuel chain containing standard production stages or modules using standard values but also has flexibilities for modifying individual stages or modules for particular cases such as adding extra stages or deleting some stages. The type of the feedstock can be selected. The production processes could be edited within the software to meet individual requirement and it could generate

reports by monthly or yearly and calculate the carbon emissions for each step or module of the whole fuel production chain. An example of the graphic representation of a fuel chain is shown in [figure 2](#) for the UCO biodiesel production.

Results and Discussions

Energy Consumption during SUCO Renewable Fuel Production

The transportation of the raw UCO and its loading off was the first stage within the LCA boundary. The raw UCO was collected from factories in Manchester and Rotherham and delivered to the biofuel refining factory. The distances from these two collection points were different and the amount of raw UCO was also different as shown in [Table 1](#). Based on the share of the amount of the raw UCO transported, an average distance of 70km was obtained. 10-ton diesel trucks were used as a means of transportation of the raw UCO.

Table 1. Distance for the transportation of raw UCO

Collection point	Distance	Percentage
Manchester	45 km	64%
Rotherham	114 km	36%
Average distance	70 km	

[Table 2](#) shows the energy consumption of each stage of the SUCO production which were derived from the measured data by manufacturer. It can be seen that the heating loads were the most energy intensive process consuming a large amount of electricity by a pump, a heater and an air compressor. The transportation of the finished SUCO fuel to the fleet was the second largest energy consuming module. Electricity was the dominant form of the energy required for the production of the SUCO fuel.

Table 2. Energy consumption (Unit: MJ/ton)

Process	Consumer	Energy type	Amount (MJ/ton)
Transportation and loading off	Road tanker and Tanker PTO	Diesel	84
Refining process	Heating loads	Electricity	202.2
	Pump loads	Electricity	31.86
	Compressor loads	Electricity	108
Transportation of finished SUCO	Road Tanker and Tanker PTO	Diesel	141.26
Fuel dispensing	Heater	Electricity	39
Total			606.32

Carbon Emissions for SUCO Renewable Fuel Production

The carbon emissions in the six stages/phases of the production of the SUCO renewable fuel were calculated by the UK carbon calculator and are presented in [Table 3](#) in terms of kgCO₂e per ton of SUCO fuel. The results are also converted to fractions of CO₂e emissions for each stage/phase as shown in [Figure 1](#).

From [Table 3](#) and [Figure 1](#), it is observed that the largest carbon emissions were from the heating loads of the refining process, accounted for more than a third of the total SUCO CO₂ emissions. The heating was provided by electric heaters. It is possible to reduce carbon emissions if the industrial compressed air was used and the heating sources from other industrial processes could be used, especially waste heat. It is also possible to reduce carbon emissions from the refining process using a combined heat and power (CHP) unit burning SUCO fuel so that the electricity can be used to drive compressor and transfer pumps and the heat from CHP can be used to heat the UCO. The process itself could also be further optimized such as more efficient heater and shorter heating time etc.

The second largest carbon emission source was from pumps for circulating and transferring the UCO with a share of 21%. The third largest carbon emission source was SUCO product transportation, accounted for 16%. The way to reduce carbon emissions for this stage was localization, i.e. set up the refinery factory close to end users.

Table 3. Carbon emissions for SUCO fuel production

Modules	Carbon emission (kgCO ₂ e/ton)
Transportation of raw UCO and loading off	7.41
Refining Process-heating	26.42
Refining Process-compressor	4.16
Refining Process-pump	14.11
Transportation of finished SUCO fuel	11.2
Fuel dispensing	5.42
Whole fuel chain	68.73
Whole fuel chain carbon intensity (gCO ₂ e/MJ)	1.76