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# Life Cycle Analysis and Feasibility of the Use of Waste Cooking Oil as Feedstock for Biodiesel

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### *Abstract*

*Petroleum based fossil fuels used to power most processes today are non-renewable fuels. This means that once used, they cannot be reproduced for a very long time. The maximum combustion of fossil fuels occurs in automobiles i.e. the vehicles we drive every day. Thus, there is a requirement to shift from these non-renenewable sources of energy to sources that are renewable and environment friendly. This is causing the need to shift towards more environmentally-sustainable transport fuels, preferably derived from biomass, such as biodiesel blends. These blends can be made from oils that are available in abundance or as waste e.g. waste cooking oil, animal fat, oil from seeds, oil from algae etc. Waste Cooking Oil(WCO) is a waste product and so, converting it into a transportation fuel is considered highly environmentally sustainable. Keeping this in mind, a life cycle assessment (LCA) was performed to evaluate the environmental implications of replacing diesel fuel with WCO biodiesel blends in a regular Diesel engine. This study uses Life Cycle Assessment (LCA) to determine the environmental outcomes of biodiesel from WCO in terms of global warming potential, life cycle energy efficiency (LCEE) and fossil energy ratio (FER) using the life cycle inventory and the openLCA software, version 1.3.4: 2007 - 2013 GreenDelta. This study resulted in the conclusion that the biodiesel production process from WCO in particular is more environmentally sustainable as compared to the preparation of diesel from raw oil, also taking into account the combustion products that are released into the atmosphere as exhaust emissions.*

***Keywords****: Biodiesel, Renewable Energy, Biofuel, Feedstock, Sustainable Energy, Alternative Sources of Energy, Waste Cooking Oil, WCO Biodiesel, Life Cycle Analysis, LCA Energy Efficiency, Fossil Energy Ratio, Exhaust Emissions*

## NOMENCLATURE

**°C –** Degree celcius
**FFA –** Free fatty acid
**h –** Hour
**min –** minutes

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**g –** gram
**kg –** kilogram
**MJ –** Mega Joule
**L –** Litre
**ml –** millilitre
**eq –** Equivalent
**ppm –** parts per million
**KOH –** Potassium Hydroxide
**WCO –** Waste Cooking Oil
**FAME –** Fatty acid methyl ester
**NOx –** Nitrogen Oxide
**CO2 –** Carbon Dioxide
**HC –** Hydrocarbon
**CFC –** ChloroFluoroCarbon
**HCFC –** HydroChloroFluoroCarbon
**CO –** Carbon Monoxide
**PM –** Particulate Matter
**LCA –** Life Cycle Analysis
**GWP –** Global Warming Potential
**LCEE –** Life Cycle Energy Efficiency
**FER –** Fossil Energy Ratio
**SPI –** Sustainable Process Index
**FEI –** Fossil Energy Input
**RFO –** Renewable Fuel Output
**H2SO4 –** Sulphuric Acid
**ISO –** International Standards Organisation

## 1. INTRODUCTION

Oil, natural gas, and coal, which are the most common fuels in the world, are known as non-renewable due to the millions of years it takes for their formation and the inability of mankind to produce similar fuels independently. These are called **Fossil Fuels** because of their origin as decaying organic matter. These organic fuels account for about 85% of the world's energy supply, a share that has changed a little over recent decades due to the advent of Nuclear power which now accounts for 6.35%.[1]

Oil accounts for a whopping 38% of the world's energy sources, while gas and coal are 23% and 26% respectively. Nuclear energy has grown to provide 6% of the world's energy as does hydroelectric power, while geothermal, solar, wind energy and wood collectively provide a mere 1%. [1]

The increase in emission of CO2 from fossil-fuel combustion and other small industrial sources, which are the main cause of human-induced global warming, slowed down in 2012, but the average annual growth rate of atmospheric CO2 reached a rather high 2.4 ppm in concentration. There was a 1.4% increase in actual emissions over 2011, accumulating to a total of 34.5 billion tonnes in 2012. In 2012, this increase in actual emissions was reduced to only 1.1%, the average annual increase since 2000 having been 2.9%.[2] The CO2 emission trend mainly reflects energy-dependent human activities which, over the past decade, were determined mainly by economic growth, particularly in developing countries. In 2012, the relation between increase in CO2 emissions and global economic growth (in GDP)was observed to have weakened, pointing towards less fossil-fuel intensive activities, more use of renewable energy and increased energy saving. Amongst all major countries of the world, both developing and developed, China seemed to have rather increased it's CO2 emissions from fossil-fuel use and cement manufacturing to 10,000 Million Tonnes, whereas the United States, the United Kingdom and the rest of the European Union considerably reduced their CO2 emissions from the same sources.[3] The use of renewable resources has been catching up in the world energy scenario; the growth of use of alternative sources of energy from 1971 to 2012, though not as considerable as desired, can be observed in Table 2.

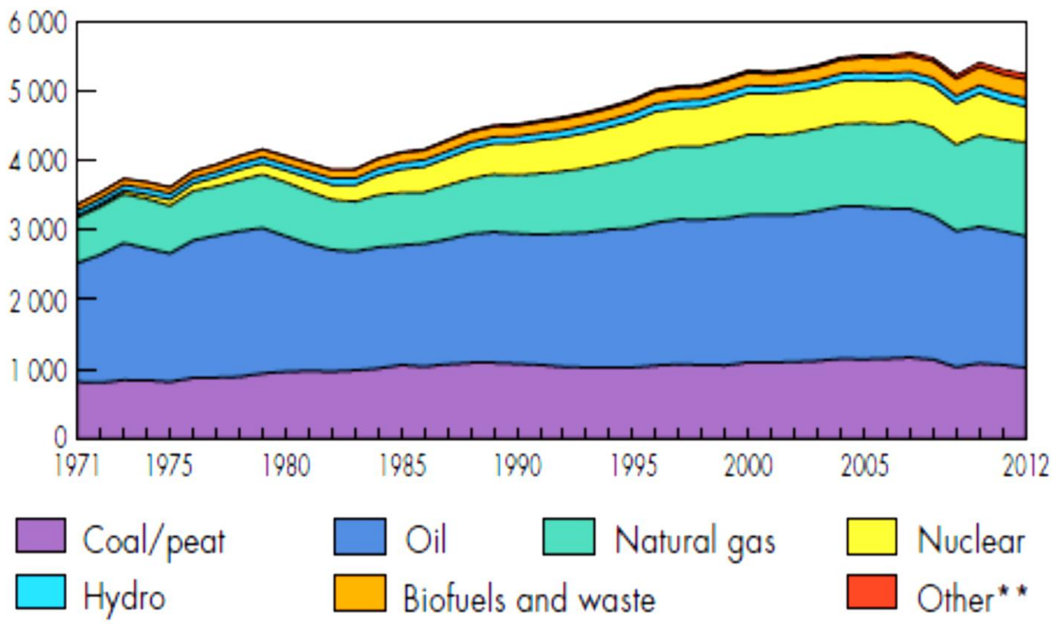


**Fig. 1. OECD total primary energy supply* from 1971 to 2012 by fuel (Mtoe)[4]**

Better as they may seem, even these figures cannot be considered environmentally sustainable and the doom of all mankind seems inevitable, as far as energy resources are concerned. To prevent exhaustion of fossil fuel reserves, research is going on to find viable **Renewable** alternatives fuels. Even electric cars and hydrogen fuel cells are being considered as feasible alternatives to oil as fuel.[5, 6] However, clean as this type of fuel may seem, it has various problems associated with it such as storage of Hydrogen, controlling of explosions(safety issues) and the lack of power and required frequency of charging in electric vehicles[5, 6, 7, 8]. To overcome these challenges, Biofuel is being considered a potential alternative. This fuel is made from biological ingredients instead of fossil fuels. The starting ingredients(feedstock) can range from corn to soybeans to vegetable oil to animal fat, depending on the type of fuel being made and the production method.

"Biodiesel is a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100, and meeting the requirements of ASTM(American Society for Testing and Materials) D 6751"- NBB. In the last few years, biodiesel has become a topic of great importance, which is impressively demonstrated by the large number of energy analyses and Life Cycle Assessments published to deal with this issue[9]. The advantages of Biodiesel are many and are further amplified by selection of a suitable feedstock.[10] As the calorific value of vegetable oils is comparable to that of diesel, they could be used as fuels in compression ignition engines.[11] Fatty acid methyl esters (FAME) show great potential as diesel substitutes, and they are known to be sources of biodiesel.[12] Waste Cooking Oil i.e. oil that has been used in kitchens for frying and other cooking purposes and is normally discarded post use, happens to be another contender for the position of the most ecologically suitable Biodiesel feedstock. The ease of availability, no requirement of using agricultural land for growth of feedstock plants along with the added advantage of reusing the otherwise wasted oil make it a potentially highly sustainable feedstock. The ecological footprint(SPI) for biodiesel from waste cooking oil(WCO) is of the order of -1,2 $m^2a$/MJ combustion energy (the negative value signifies the large positive impact of the replacement of fossil glycerol by the by-product of this production), thus giving us much reason to further study the use of this as a potential feedstock.[13] The Properties of Waste Cooking Oil[14] are given below and in Table 2.

**Table 1. Properties of Environmental Importance of WCO**

| PROPERTY | VALUE |
|---|---|
| %Volatile Matter and Moisture | 0.078(MPOB p2.1)[V] |
| %Ash Content | 0.003(MPOB p3.5)[V] |
| %Fixed Carbon | 99.919 |
| Calorific Value | 38.314 MJ/Kg |

**Table 2. Properties of WCO(Source: [15])**

| Properties | Experimental value |
|---|---|
| Physical state | Liquid |
| Color | Deep oily |
| Specific gravity at 25°C | 0.902 |
| Kinematic viscosity, $mm^2/s$ at 40°C | 54.53 |
| FFA content (wt% of oil) | 1.9 |
| Average molecular weight of FFA (gm/mol) | 275.5 |
| Molecular weight of oil (gm/mol) | 864.5 |
| Saponification value (mg of KOH/gm of oil) | 238 |
| Cloud point (°C) | 12 |
| Pour point (°C) | 6 |

One of the biggest concerns regarding biodiesel production is that cultivation/production of biodiesel feedstock may compete with food supply in the long-term scenario. Non-edible plant oil has been found to be a promising raw material for the production of biodiesel. Non-edible oil is significantly used in developing countries for biodiesel production compared with edible oil because of the tremendous demand of edible oils as food; they are far too expensive to be used as fuel in these countries at least at present [16, 17]

More than 95% of the world's Biodiesel is currently sourced from edible oil which is easily available on a large scale from the agricultural industry i.e. it is produced from plants cultivated on a large scale as crops. However, continuous and large-scale production of biodiesel from edible crop oil has recently been rousing great concern in the renewable energy community of the world because they compete with the cultivation of crop used as food material(the food v/s fuel dispute). [16]

In India, the cultivation of a potential oil source has been investigated and it is found that the production potential is not too high. [18] Due to a very large population density, the edible oil sources i.e. crops cultivated in place of food crops, cannot be employed for the production of biodiesel. Moreover, the same factor causes us to have an extreme limitation of land. This makes acquiring and reserving additional land for the cultivation of these oil seeds also impossible. The oil seed sources that can be seen as potential sources for biodiesel production in India are WCO, soyabean oil, coconut oil, peanut oil, linseed oil, castor oil, jatropha oil etc.[18]

There are different methods for biodiesel preparation like base or acid catalyzed transesterification [19, 20], two step method[21] and three-step method[22]. Treatments that are used to overcome the significant problems associated with the high viscosity of vegetable oils when used as engine fuel are its dilution, micro-emulsification, pyrolysis and transesterification with methanol. The latter approach is used most commonly and is a basic method of preparation of Biodiesel. An oil/fat is reacted with alcohol(methanol), using a strong alkaline catalyst(sodium hydroxide NaOH or potassium hydroxide KOH). This yields mono-alkyl methyl esters (biodiesel) and glycerin.

**EXAMPLE**:

| | | | | | | |
|---|---|---|---|---|---|---|
| 100 pounds | + | 10 pounds | → | 10 pounds | + | 100 pounds |
| Triglyceride | | Alcohol | | Glycerin | | Mono-AlkylMethyl Esters(Biodiesel) |

The glycerin formed during Transesterification is also important because of its numerous applications in the food, cosmetic, and pharmaceutical sectors. FAME is not only currently useful as a diesel fuel additive, but it is also marketed as green industrial degreasing solvents; as diluents for pigments, paints, and coatings, and for military engine fuel applications. [23]

One of the main reasons of biodiesel not having caught up as a regular fuel yet is the cost factor; it turns out to be more expensive than regular diesel. The higher cost of biodiesel is mainly due to the cost of virgin edible plant oil. Therefore, it is not surprising that the biodiesel produced from vegetable oil (for example, pure soybean oil) costs much more than petroleum based diesel. This makes it necessary to explore ways to reduce the production cost of biodiesel. In this scenario, methods of production that permit minimization of the costs of the raw material are of considerable interest. The use of waste frying oil i.e. WCO, instead of virgin edible plant oil, to produce biodiesel is an effective way to reduce the raw material cost because waste frying oil is estimated to be about half the price of virgin oil [24]

Biodiesel was synthesized from WCO by M. Rakib Uddin et al[15] using the Three-Step-Method. It was found that Transesterification method gives lower yield than the three-step method. In the three-step method, the first step is Saponification of the oil, followed by Acidification to produce FFA, and finally Esterification of FFA to produce biodiesel. In the Saponification reaction, various reaction parameters such as oil to sodium hydroxide molar ratio and reaction time have to be optimized, In the Esterification reaction, the reaction parameters such as methanol to FFA molar ratio, catalyst concentration and reaction temperature must be optimized. Silica gel was used by them during Esterification reaction to adsorb the water produced in the reaction. Hence, the reaction rate was increased.

A study performed in Singapore by Celia Bee Hong Chua et al[25] on the Life Cycle Analysis of WCO used as a feedstock for biodiesel modelled the life cycle processes of manufacturing biodiesel from collection of WCO from food establishments to usage in transport, comparing the quantified impact against the use of conventional ultra-low sulphur diesel. The emission results and life cycle energy efficiencies indicated that it is more environmentally beneficial to collect, process and use WCO as biodiesel, replacing low sulphur diesel as a transportation fuel.[25]

An energy and cost analysis of production of biodiesel from waste cooking oil was performed by Ahmad Mohammadshirazi et al [26] using the conventional Transesterification method. "The benefit to cost ratio was found to be 2.081 according to the result of economical analysis of biodiesel production. The mean net return and productivity from biodiesel production were found to be 1.298 $\$ L^{-1}$ and 0.946 kg $\$^{-1}$, respectively. The results showed that by applying ultrasonic and microwave instead of transesterfication and great managing, more benefit can be resulted."[26]

A study was performed by Claudia Sheinbaum-Pardo et al [27] to find the potential use of biodiesel produced from waste cooking oil in Mexico. According to their figures, potential of Biodiesel from WCO is between 1.5% and 3.3% of transportation diesel use and $CO_2$ emission reduction represents 1.0%–2.7% of transport petro-diesel emissions. Also, it was discovered that Biodiesel costs are similar to petro-diesel costs if WCO is free.[27]

"The great promise of biofuels is their potential to be ‘carbon-neutral’ life cycle basis; all the carbon dioxide emitted during processing and use of the fuel being balanced by the absorption from the atmosphere during the fuel crop’s growth."[28] Considering the life cycle emissions of carbon dioxide and nitrous oxide (associated with crop growth), studies show that life cycle greenhouse gas emissions (per km) can be reduced by between 40%-57% (Concawe 2004; DfT 2004a). Proportionately, this means that a 5% blend would result in a carbon reduction of around 2.5%. Although independent test data is not readily available for WCOs, it is likely that, even after processing has been taken into account, carbon reductions of over 50% can easily be achieved.[28]

## 2. WORKING PRINCIPLE

**Life cycle assessment** (also known as **life cycle analysis**) is an internationally accepted method of evaluating the environmental impacts of processes, products and activities. It is a technique used to assess the environmental impact associated with all the stages of a product's life i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. The Life Cycle of a product is demonstrated in Fig. 2.

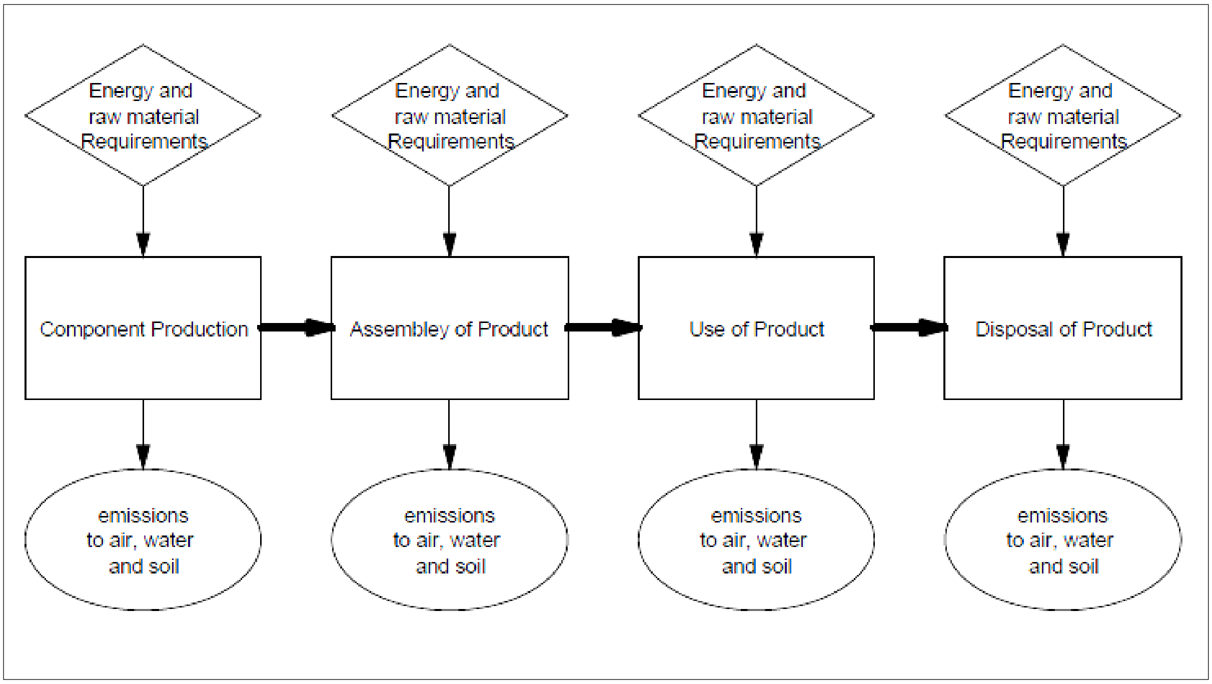


**Fig. 2. Life Cycle of a Product (Source: [37])**

LCA originated from energy analysis. SETAC(*Society of Environmental Toxicology and Chemistry*) set the first standards of Assessment in 1990. ISO produced a series of standards in 1997/98 which were recently revised in 2006.These are:

– ISO 14040:2006 outlining LCA principles and framework

– ISO 14044:2006 for requirements and guidelines

LCA is carried out to conserve non-renewable resources and ecological systems, develop and utilize cleaner technologies, and minimize the magnitude of pollution and maximize recycling of materials and waste by applying the most appropriate pollution prevention and/or abatement techniques. The most important goal of LCA, according to a survey of organizations actively involved in LCA, is to minimize the magnitude of pollution[29]

2.1 The LCA Approach:

Life Cycle Assessment is an extensive process with a number of steps to be followed in strict sequence. First of all, the system boundary conditions are set. This identifies the activity one is to study and observe e.g. in this case, it would be biodiesel production from WCO. The entire life cycle of the WCO biodiesel must be chalked out and understood to enable an effective and comprehensive LCA. Once the activity of choice has been focussed on, it is important to set a time basis for which the LCA must be carried out. This varies ccording to the industry and according to the time that the individual performing the LCA has at his disposal. After that, the areas of interest must be chosen. These are of major interest to decision-makers and are namely cost, air pollution, Green house gas emissions, wastes, resource depletion etc. These are the facets of the activity that have an impact on the environment that the decision-maker wants to focus on and later help reduce and combat its effects Once these areas have been identified, the lifecycle must be divided into parts along with the assigning of the impacts associated with the entire Life Cycle with these parts to enable more efficient analysis. Once the life cycle has been fragmented as such, overall tradeoffs of the process must be weighed, along with all uncertainties so as to enable the decision-

maker to make effective and safe assumptions and not let the final observations be affected by minor activities. Finally, once all this has been completed, all major sources of adverse impact along the entire life cycle of the subject must be identified, be it energy usage, waste production, emissions etc. Once identified, they must be assessed for possible improvements.
There are three main stages of a life cycle assessment:

2.1.1 Inventory

The Inventory includes determining the emissions that occur and the raw materials and energy that are used during the life of a product. It is simply the identification of all the information provided at the beginning of the LCA setup. It is also known as the data collecting stage. Data is collected from the source, literature or software(most commonly all three) and is gathered and analysed in a large spreadsheet or an LCA specific software. It is a largely time consuming process.

2.1.2 Impact Assessment

The Impact Assessment is done to assess what the impacts of these emissions and raw material depletions(that have been identified in the inventory stage) are. This stage helps quantify the contribution of a long list of different kinds of materials/emissions present in the inventory i.e. it measures their impact on the environment quantitatively. There are further three stages to a Life Cycle Impact Assessment: Classification, Characterisation, Valuation.

**Classification** groups the emissions and materials that have been gathered into different categories of environmental impact for easy analysis. For example, all ozone depleting gases (**CFC's, HCFC's**) can be grouped together.

**Characterisation** assigns magnitude to the environmental impacts identified. All the emissions contributing to one environmental impact may not have the same value of contribution. For example, **Product contribution to ozone depleting gases = total amount of CFC–11 generated over product lifecycle** x **ozone depleting potential of CFC-11(1) + total amount of HCFC-123 generated over the products lifecycle** x **ozone depleting potential of HCFC-123(0.02)**

**Normalisation** is the standardization of all values.(Equation (1), Source: [2])

$$\text{European emissions per capita} = \frac{\text{Total European output in each emission category}}{\text{Population of Europe}}$$

$$\therefore \text{People emission equivalents} = \frac{\text{Emissions from the process studied}}{\text{European emissions per capita}} \quad (1)$$

2.1.3 Improvement Analysis

Improvement Analysis is carried out to interpret the results of the impact assessment stage in order to suggest improvements to combat the environmental impacts found. When LCA is conducted to compare products, this step may consist of recommending the most environmentally desirable product of those in question. This stage identifies areas which have potential for improvement within a system. The Improvement Analysis is reliant on the practitioner noticing not only **areas which have significant environmental effects** but also **those with smaller effects** where **changes could be made easily**. A number of this type of change can result in a **large overall improvement**.

The various stages of an LCA are represented as a flow diagram in Fig. 3.

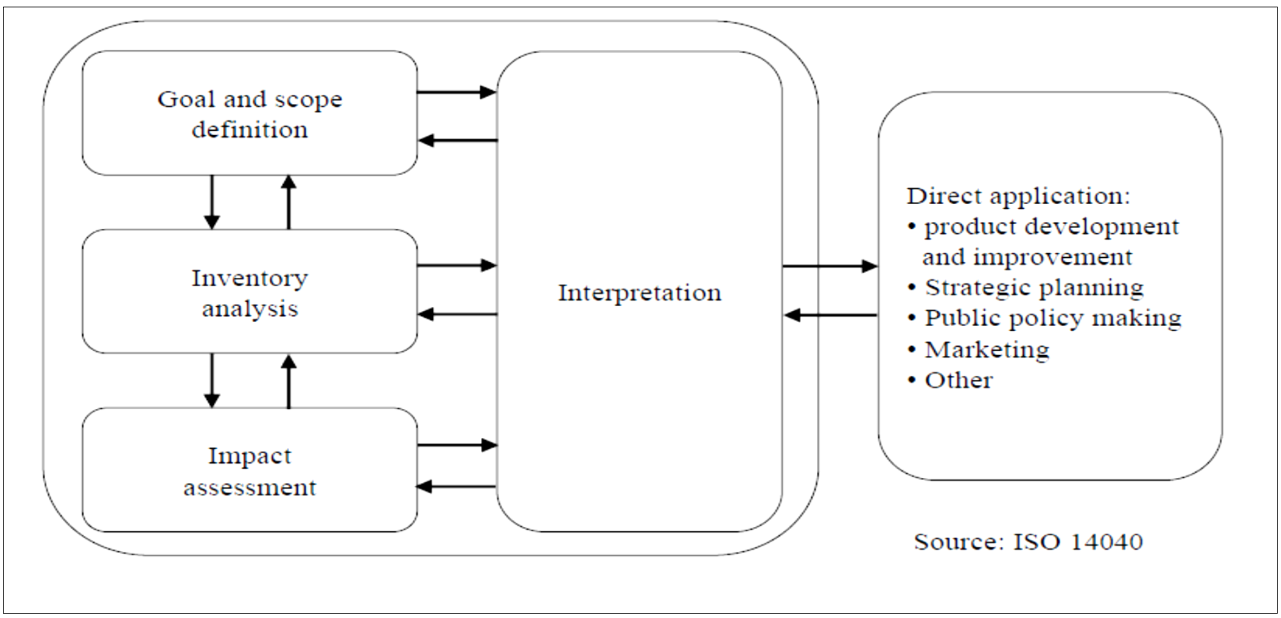


**Fig. 3. Various Stages of an LCA(Source: ISO 14040)**

## 3. DATA HANDLING AND SCOPE OF STUDY

The study data includes a description of functions, functional units and reference flows of system boundaries, data categories and data quality requirements.

**Function**: The function of the product is to serve as fuel for combustion in (unspecified) motor vehicles.

**Functional Unit**: The functional unit used to quantify this function is the combustion energy of biodiesel.

**Reference Flow**: The reference flow is 1 MJ of combustion energy.

**System Boundaries**: This LCA considers the production of biodiesel from Waste Cooking Oil(WCO) from raw material extraction to utilization of the finished product(fuel combustion). The production of energy, raw materials and auxiliary materials is taken into account, along with the disposal of waste generated and treatment of liquids and gases emitted throughout the length of the life cycle.

**Data and Collection**: Data has been organised as flows under economic and environmental types. Economic flows connect processes(energy, transport services, raw materials, chemicals, waste that go to a treatment facility). Environmental flows flow from the environment to a process(such as when dealing with resources) or from a process to the environment(emissions after combustion)(Heijungs 2003). The data taken for flow inventory are from an external source, the U.S. inventory Database.[30]

Data is also compared with the values found from the Sustainable Process Index LCA, given in the journal "Feedstocks for the Future".[31] The results from this assessment have been helpful in identifying optimisation potentials from the point of view of lower environmental impacts.

## 4. INVENTORY SCENARIO

The commencing point for the inventory scenario is the transesterification process followed by chemical and energy production process and fuel delivery and combustion (end use). This scenario addresses the production of biodiesel from WCO. The first step in the life cycle of producing biodiesel from WCO is the collection of raw material (waste cooking oil), causing the formation of a transport unit. The collected raw material is processed using transesterification which yields biodiesel. A further transport unit for fuel delivery is included before the biodiesel is combusted in an engine.

**Unit Processes and their Allocation**: Inputs, outputs and environmental impacts can be allocated to products according to the physical properties of the product flow i.e. mass or energy flow. If this is not justifiable, allocation can be done according to the cost of the products. In our study, both, mass and price allocation have been applied.

The Unit processes in this scenario include -

- Economic - Transport(diesel, to plant), fossil energy(electrical), manufacturing of additional chemicals(KOH, methanol), waste disposal, transportation(diesel, to combustion site), combustion.
- Environmental - Raw materials from environment to process, emissions to environment.
- Multi-output processes for biodiesel from WCO are the processes of transesterification and KOH-production.
- Transesterification - Outputs of the Biodiesel Transesterification process are Biodiesel, Glycerol, $K_2SO_4$. Glycerol is a marketable co-product of the process. Therefore, mass allocation can be justified. Due to similar prices for biodiesel and glycerol, economic allocation would only yield a slightly changed picture.
- KOH Production - Outputs of the KOH-production process are KOH, Chlorine gas, Hydrogen. Potassium hydroxide is a by-product of chlorine production in the chlor-alkali process. It's low relative market value (Chlorine 37,5 €/kg; $H_2$ 123,8 €/kg; KOH 0,65 €/kg)[1] makes economic allocation seem sensible.

### 4.1 Life Cycle Assessment Study

OpenLCA, a life cycle analysis modelling framework provided by GreenDelta along with the USLCI database was used to shed light over the environmental impacts of the Transesterification process of producing biodiesel. The data was sourced from other literary sources as referenced and more common data was taken from the U.S. Life Cycle Inventory Database[8]. This data was then arranged as flows and Unit Processes in OpenLCA and a general LCA of the WCO biodiesel was carried out, taking all system boundaries into account. The results were compared to the net environmental impacts of the conventional fossil fuel diesel lifecycle from data provided by the U.S. Life Cycle Inventory Database.[30] All data was standardized to the functional unit MJ for transportation fuel combusted in a passenger vehicle.

### 4.2 Global Warming Potential(GWP)

Global Warming Potential(GWP) is simply the extent to which a given amount of gas affects ozone depletion and/or rise in temperature and aids in Global Warming. The concept of a Global Warming Potential has been developed to allow the comparison of the ability of each greenhouse gas to trap heat in the atmosphere relative to carbon dioxide ($CO_2$) over a specified time horizon.
The main impact to climate change is due to process chemicals. Methanol from fossil resources used at this stage accounts for 40 % of the overall global warming potential caused by biodiesel, whereas the impact of other chemicals, like KOH or H2SO4, can be neglected.

### 4.3 FER and LCEE

Sheenhan et al. has performed extensive research on biodiesel and fossil diesel with relation to Life Cycle Assessment and concluded that there were two types of energy efficiencies: **fossil energy ratio (FER)** and **Life Cycle Energy Efficiency ratio (LCEE).** FER indicated the degree to which a fuel is or is not renewable. It is defined as the ratio of the final fuel product energy to the amount of fossil energy required to make the fuel. LCEE indicated the total amount of energy that goes into a fuel cycle compared to the energy contained in the fuel product. [32].
In the vegetable oil production process, the major energy-consuming step for petroleum diesel is refining, which takes up 60% of total energy used. The crude vegetable production consumes 14.9% of total energy.[33] It can be seen clearly that utilising waste cooking oil will save the virgin oil production step as well as crop cultivation. It also relieves the tense of small amount of available crop land, water and labour usage.
The formula used to estimate the fossil energy ratio (FER) is defined as follows[32]:

$$FER = \frac{FEI}{RFO} \tag{2}$$

FEI - Fossil Energy Input
RFO - Renewable Fuel Output

Biodiesel production from waste cooking oil requires high thermal energy from the transesterification stage, due to impurity removal and thermal reactor energy demand. However the overall yield of the biodiesel process from WCO is notably high, this has been confirmed with Picton plant production documents [34].

## 5. RESULT

The LCA was successfully theoretically reviewed using various references as have been and are to be listed, giving the forecasted results which displayed the environmental sustainability of WCO as a potential raw material for Biodiesel. The quantified values of different types of emission from the exhaust of an engine running on WCO biodiesel[25] are given below.

**Table 3. Quantitative Value of Emissions From WCO Biodiesel**

| Emission | Amount of Emission(B100 or WCO) |
|---|---|
| Carbon dioxide | 69.17 g CO2 |
| Carbon Monoxide | 0.190 g CO2 |
| Sulphur dioxide SO2 | 0.032 g SO2 |
| Methane | 0.001 g CH4 |
| Oxides of Nitrogen | 1.020 g NOx |
| Particulate matter (<10 μm) | 12.39 mg PM10 |

The GWP values (in kg CO2 eq yr-1 MJ-1) calculated from the SPI LCA values of WCO Biodiesel[1] are:

**Table 4. Global Warming Potential of Various Areas of Life Cycle of WCO Biodiesel**

| Process | GWP( kg $CO_2$ eq $yr^{-1}$ $MJ^{-1}$) |
|---|---|
| Combustion | 29.1 |
| Process energy | 20.7 |
| Process chemicals | 40.5 |
| Transport | 9.7 |

According to Ahmad Mohammadshirazi et al[26], the total energy input and energy output were calculated as **30.05** and **44.91 MJ $L^{-1}$**, respectively. The energy output/input ratio was **1.49** in biodiesel production. The shares of renewable and non-renewable energy were **77.31%** and **22.69%,** respectively from total energy input. Which further goes to show that the LCEE was **1.49** and FER **0.152,** calculated using the theory explained in 4.3.

The properties of Biodiesel differ from that of regular petroleum based diesel as is represented by the following table[15].

**Table 5. Properties of Biodiesel(produced) Compared to Diesel(Source: [15])**

| Properties | Produced biodiesel value | Biodiesel Standard [12,15] | Diesel standard [15] |
|---|---|---|---|
| Specific gravity, at 25°C | 0.792 | 0.88 (at 15.5°C) | 0.85(at 15.5°C) |
| Kinematic viscosity ($mm^2/s$), at 40°C | 3.29 | 1.9–6.0 | 1.3 – 4.1 |
| FFA content (wt%) | 0.94 | - | - |
| Moisture content (%) | 0.12 | 0.05% max. | 0.161 |
| Saponification value | 194 | - | - |
| Flash point (°C) | 150 | 100 to 170 | 60 to 80 |
| Iodine value | 88 | - | - |
| Cloud point (°C) | 0 | -3 to 12 | -15 to 5 |
| Pour point (°C) | -3 | -15 to 10 | -35 to -15 |
| Yield (%) | 79 | - | - |

## 6. CONCLUSION

This paper has analysed through modelling and theoretical review and understanding, the life cycle processes of producing biodiesel from Waste Cooking Oil(WCO) collected from food establishments and using it as a B100 biofuel in a diesel engine. Many studies have been carried out on the topic and on ones related to it; these have been of much assistance in the concluding of this study and have proved the environmental sustainability of processed WCO as a biodiesel. The environmental impact results of the life cycle process have shown that it is environmentally as well as economically beneficial to collect Waste Cooking Oil and process it in order to produce functional biodiesel. The exhaust emission results and Global Warming Potential of individual exhaust gases, as well as the Fossil Energy Ratio and Life Cycle Energy Efficiency(FER and LCEE) have indicated that the biodiesel derived from WCO as a full-scale transportation fuel is favourable(refer to section 5). There are substantial advantages especially in the context of energy security, waste recycling and greenhouse gas control. The most basic advantage of using WCO is the elimination of requirement of energy and other resource-intensive methods to produce and prepare feedstock as raw material for Biodiesel production. Also, the FER and LCEE prove it to be an economical process in terms of energy, giving a considerably greater output of renewable energy than the input of non-renewable energy required for the summation of the process.

Fig. 4 represents the total contribution of WCO Biodiesel to the Carbon Footprint.

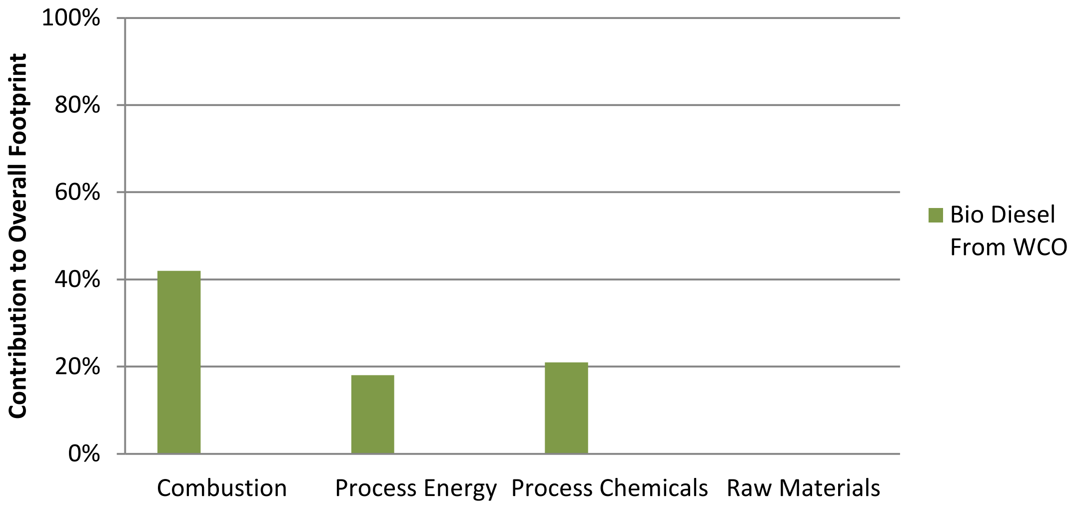


**Fig. 4. Overall Contribution of WCO Biodiesel to Carbon Footprint**

The basic advantages of WCO Biodiesel, a few of which are common with other forms of feedstock-intensive Biodiesel, can be listed simply as below:

1. Amount of fossil fuel used is reduced, thus, making countries and even individuals secure as far as energy is concerned.
2. Concentrations of unburned hydrocarbons(HC), carbon monoxide(CO), sulfates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons, and particulate matter (PM) in exhaust emissions are substantially reduced.
3. Fuel lubricity is improved and the cetane number of the fuel is raised, thus increasing the life of the engine. The cetane index of waste cooking oil from experiment was found to be 61[35]. Hilber et al. [36] reported the cetane number of methyl esters of rapeseed oil, soybean oil, palm oil, lard and beef tallow to be 58, 53, 65, 65 and 75 respectively
4. Cooking/frying oil that would otherwise have gone waste is recycled as a feedstock for producing the biodiesel.
5. The fuel can be implemented in pre-existing diesel engines with little or no required modification, blended with standard diesel.

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