Dedication

My family, Thank you for your unconditional support with my studies. I am honored to have such a family. Thank you for believing in me, for always being there for me, for giving me a chance to prove and improve myself. I love you.

My friends and partners, thank you for every moment we have lived together, for all the struggles we have passed, all the laughers and tears which always made us stronger. Hoping that this project proven to you that there is no mountain higher as long as God is in our side.

My Lecturers, thanks for all the knowledge and patience you have given to us for all of these years. One day we'll make you proud.

Acknowledgments

First of all, we thank Allah for helping us to complete this project.

Special thanks to Dr. Husni Odeh –the department head of Chemical Engineering and the Energy engineering and environment- who has supplied us with every detail to complete this project.

We'd like to thank our project's supervisor Dr. Mohammed El-Sayed:

For his efforts and his great support which helped us to improve our performance and knowledge, since the very beginning he helped and gave us unconditional advices.

Finally, Thanks to everyone who supported us with their unconditional support in all phases of our life, specially our educational journey. We're so pleasured to have such great family, friends and lecturers.

Abstract

Biodiesel has attracted considerable attention as a renewable, biodegradable, and nontoxic fuel and can contribute to solving the energy problems, significantly reducing the emission of gases which cause global warming.

In this project the process of producing biodiesel was analyzed in addition to the use process. The raw material used was waste cooking oil in order to produce 1 kg of the biodiesel by transesterification, including a life cycle analysis for this type of biodiesel followed by an impact assessment analysis using Openlca program with ecoinvent database. The results show the main effect of producing 1 kg of biodiesel and it was the methanol with 0.149 kg of CO_2 eq. in contrary with vegetable oil which had a good impact on environment and absorbed approximately 2.66kg of CO_2 eq. in the plant's lifetime not differing much in using electricity generated from natural gas power plant , in addition to that comparing these results with the production phase of petro-diesel at refinery as it produced 0.5 kg of CO_2eq. , another environmental indicator was affected was the depletion of resources as it was found approximately 11 MJ for biodiesel and 51 MJ for petro-diesel. In the use phase it was clearly the biodiesel is more friendly on the environment from emissions aspect as the it has lower kg of CO_2 andSO_2 eq. per year of using the fuel for 5 hours a day .

These results demonstrate how biodiesel is superior and friendlier to environment comparing it with petro-diesel. As it's recommended to have more accurate and strict results to include the disposal phase of biodiesel in order to get new data inventory to analyze how it does affect the environment, along with an economic analysis for both fuels.

1. Introduction

1.1 Biodiesel Descriptions
1.1.1 Definition

Biodiesel is a relatively new synthetic fuel made chemical treatment of vegetable oils or animal fats. It is produced commercially and can be bought from some petrol stations. However, there are 'recipes' available on the Internet for domestic production of biodiesel. These usually involve mixing methanol with sodium hydroxide (also known as caustic soda or lye), then pouring the resulting mixture into vegetable oil.[1]

1.1.2 Advantage and Disadvantage

As known for every product there are pros and cons and for biodiesel the advantages can be mentioned for its low toxicity along with the derivation from a renewable and domestic feedstock, another advantage is the superior flash point and biodegradability, in addition to its negligible sulfur content and the lower overall exhaust emissions.

In the other hand biodiesel can be found asa high feedstock cost, along with the inferior storage and oxidative stability, also in consider to the superior flash point and biodegradability, some other disadvantages are the lower volumetric energy content and inferior low-temperature operability versus petro-diesel, and not to forget in some cases, the higher NOx exhaust emissions, along with the inferior low-temperature operability.[2]

Some few disadvantages took place in the ingredients of the biodiesel in the production process as Sodiumhydroxide, it's known for its extremely corrosive feature and it can cause burning to unprotected skin alongside with the chance to damage the eyes. Stirring the liquid can often produce a fine mist of liquid droplets. If this mist is inhaled, severe irritation of the respiratory tract and breathlessness can occur. Accidental swallowing can cause major damage to the throat lining and digestive system.

Another component is Methanol it's known as a toxic chemical. It can enter the body through breathing in the vapor, direct skin contact or by accidental swallowing. It can cause nausea, dizziness and visual disturbances that can result in blindness. Swallowing small quantities could pose a significant health threat to the central nervous system and could also affect other vital organs. It is a cumulative poison and repeated exposure to relatively low concentration could cause harm in the longer term.[1]

1.1.3 Production (Alkali catalyst)

Biodiesel derived from biological resources is a renewable fuel, which has drawn more and more attention recently. A fatty acid methyl ester is the chemical composition of biodiesel. Transesterification is widely used for the transformation of triglyceride into fatty acid methyl ester. The manufacturing process is based on the transesterification of triglycerides by alcohols to fatty acid methyl esters, with glycerol as a byproduct. The base catalyzed production of biodiesel generally has the following processes.

1.1.3.1. Mixing of Alcohol and Catalyst:

This typical process is mainly done by mixing alkali hydroxide (commonly potassium hydroxide and sodium hydroxide) with common alcohols (methanol and ethanol) in the mixer with standard agitator to facilitate the mixing. Alkali hydroxide is dissolved in the alcohol to produce alkoxide solution.

1.1.3.2. Chemical Reaction:

The alcohol and catalyst mixture is then charged into a closed reaction vessel and the oil is added. The reaction system is totally closed to the atmosphere to prevent the loss of alcohol, since it easily vaporizable. The reaction mixture is kept just near the boiling point of the alcohol to speed up the reaction. Excess alcohol is normally used to ensure total conversion of the oil to its esters as there is no problem of recovering of the alcohol for later use after recycling.

1.1.3.3. Separation:

After the reaction is completed, there exists glycerol and biodiesel formation. Both have a significant amount of the excess alcohol that was used in the reaction which is in need of being recovered. The reacted mixture is sometimes neutralized at this step if the basic media that is caused by alkali hydroxide is occurred. The glycerol phase is much denser than biodiesel phase, making biodiesel to be floated. The two products can be separated by gravity using settling vessel. The glycerol is drawn off at the bottom of the settling vessel and biodiesel is drawn off at the top. In some cases, a centrifuge is used to separate the two materials faster by screening both phases.

1.1.3.4. Alcohol Removal:

After the glycerol and biodiesel phases have been separated, the excess alcohol in each phase is removed with a flash evaporation process or by distillation commonly. But currently extractive distillation can instead be used to fasten the process and to be more economical. On the other hand, the alcohol is removed and the mixture neutralized before the glycerol and esters have been separated to prevent the effect of basic media inside the reactor. After the alcohol is being recovered it is used as main raw material.

1.1.3.5.Biodiesel Washing:

After transesterification the upper ester layer may contain traces of NaOH, methanol and glycerol. Since the remaining unreacted methanol in the biodiesel has safety risks and can corrode engine components, the residual catalyst (NaOH) can damage engine components, and glycerol in the biodiesel can reduce fuel lubricity and cause injector coking and other deposits. These being water soluble is removed by washing (4 -6 times) the biodiesel with water maintained at 40-50ºC. Washing is carried out by spraying hot water over the biodiesel; precautions were taken to avoid soap formation. The washed biodiesel needs drying in order to remove trace impurities. In some processes washing step is not necessary depending on the quality of biodiesel produced. (After the completion of washing process the biodiesel may contain some traces of water. Biodiesel is heated to 110 ºC to remove the trapped traces of water (for drying).[3]
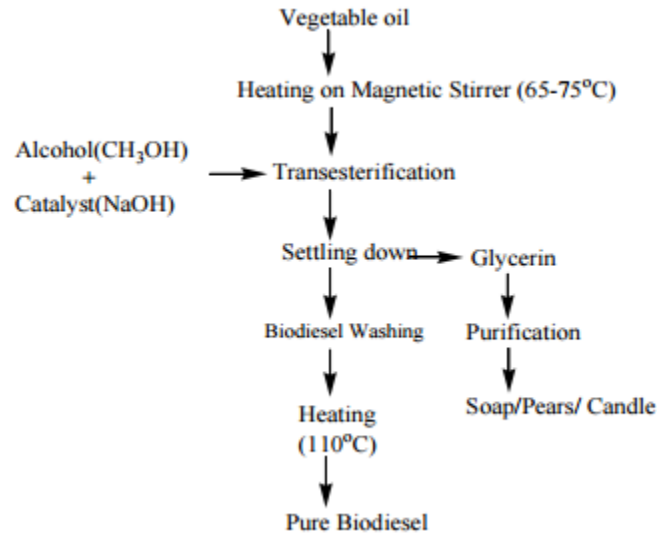
Figure 1 Flow chart of Biodiesel production process.

1.2 Diesel cycle

Petro-diesel fuel is a mixture of hydrocarbons obtained by distillation of crude oil. While diesel cycle is a gas power cycle invented by Rudolph Diesel in the year 1897. It is widely used in CI engines (also known as *diesel engines*),

The air is compressed to a temperature that is above the autoignition temperatureof the fuel, and combustion starts on contact as the fuel is injected into this hot air. Therefore, the spark plug and carburetor in gasoline engines are replaced by a fuel injector in petro-diesel engines. As only air is compressed during the compression stroke, eliminating the possibility of autoignition.Therefore, petro-diesel engines can be designed to operate at much higher compression ratios, typically between 12 and 24.[5]

Diesel cycle is similar to Otto cycle except in the fact that it has one constant pressure process instead of a constant volume process (in Otto cycle).

The two diagrams below p-V and T-s diagrams will explain the diesel cycle furthermore.[5]
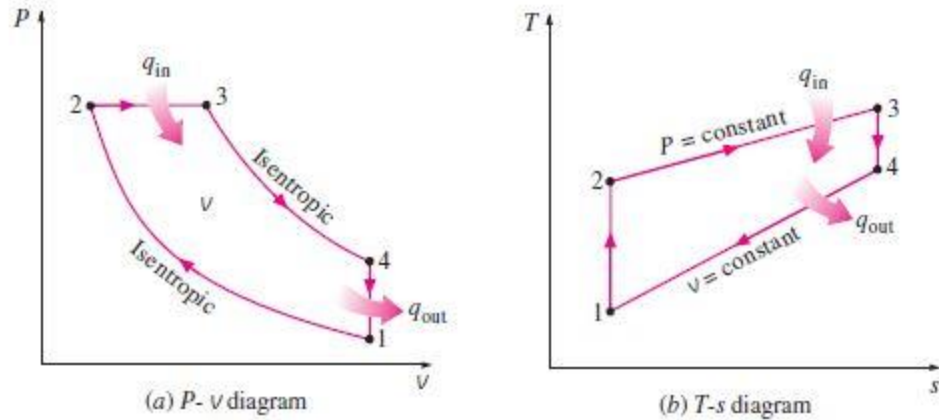
Figure 2 P-v & T-s diagrams of Diesel cycle

Diesel cycle has four processes. They are:

a) Process 1-2: Isentropic (Reversible adiabatic) Compression

In this process, the piston moves from Bottom Dead Centre (BDC) to Top Dead Centre (TDC) position. Air is compressed isentropically inside the cylinder. Pressure of air increases from p_1 to p_2, temperature increases from T_1 to T_2, and volume decreases from V_1 to V_2. Entropy remains constant (i.e., $s_1 = s_2$). Work is done on the system in this process (denoted by W_{in} in the diagrams above).

b) Process 2-3: Constant Pressure (Isobaric) Heat Addition

In this process, heat is added at constant pressure from an external heat source. Volume increases from V_2 to V_3, temperature increases from T_2 to T_3 and entropy increases from s_2 to s_3

c) Process 3-4: Isentropic Expansion

Here the compressed and heated air is expanded isentropically inside the cylinder. The piston is forced from TDC to BDC in the cylinder. Pressure of air decreases from p_3 to p_4, temperature decreases from T_3 to T_4, and volume increases from V_3 to V_4. Entropy remains constant (i.e., $s_3 = s_4$). Work is done by the system in this process (denoted by W_{out} in the p-V and T-s diagrams above).

d) <u>Process 4-1:</u> Constant Volume (Isochoric) Heat Rejection

In this process, heat is rejected at constant volume ($V_4 = V_1$). Pressure decreases from P_4 to P_1, temperature decreases from T_4 to T_1 and entropy decreases from s_4 to s_1.

1.3 Diesel Engines

Diesel engines have an excellent reputation for their low fuel consumption, reliability, and durability characteristics. They are also known for their extremely low hydrocarbon and carbon monoxide emissions. However, they have also been rejected by many for their odorous and sooty exhaust that is also characterized with high nitric oxide and particulate matter emissions. Since performance, fuel consumption, and emitted pollutants result from the combustion process, it is necessary first to understand the mechanisms of combustion in diesel engines if we are to improve it.

Diesel engine is internal combustion engine, meaning it burns the fuel-air mixture within the cylinder. and it's considered as a reciprocating engine, being driven by piston moving laterally in two direction.

If it's compared to a gasoline engine of equal horsepower, is heavier due to stronger, heavier materials used to withstand the greater dynamic forces from the higher combustion pressures present in the diesel engine.

The greater combustion pressure is the result of the higher compression ratio used by diesel engines. The compression ratio is a measure of how much the engine compresses the gasses in the engine's cylinder. In a diesel engine, compression ratios ranging from 14:1 to as high as 24:1 are commonly used. The higher compression ratios are possible because only air is compressed, and then the fuel is injected. This is one of the factors that allows the diesel engine to be so efficient.

Diesel engines are not self-speed-limiting because the air (oxygen) entering the engine is always the maximum amount. Therefore, the engine speed is limited solely by the amount of fuel injected into the engine cylinders. Therefore, the engine always has sufficient oxygen to burn and the engine will attempt to accelerate to meet the new fuel injection rate. Because of this, a manual fuel control is not possible because these engines, in an unloaded condition, can accelerate at a rate of more than 2000 revolutions per second. Diesel engines require a speed limiter, commonly called the governor, to control the amount of fuel being injected into the engine. Diesel engine does not require an ignition system because in a diesel engine the fuel is injected into the cylinder as the piston comes to the top of its compression stroke. When fuel is injected, it vaporizes and ignites due to the heat created by the compression of the air in the cylinder.

1.3.1 Working of Four Stroke Diesel Engine

The power generation process in four stroke diesel engine is also divided into four parts. Each part is known as piston stroke. In IC engine, stroke is referred to the maximum distance travel by the piston in a single direction. The piston is free to move only in upward and downward direction. In four stroke engine the piston move two time up and down and the crankshaft move two complete revolution to complete four piston cycle. These are suction stroke, compression stroke, expansion stroke and exhaust stroke.

Suction stroke:

In the suction stroke or intake stroke of diesel engine the piston start moves from top end of the cylinder to bottom end of the cylinder and simultaneously inlet valve opens. At this time air at atmospheric pressure drawn inside the cylinder through the inlet valve by a pump. The inlet valve remains open until the piston reaches the lower end of cylinder. After it inlet valve close and seal the upper end of the cylinder.
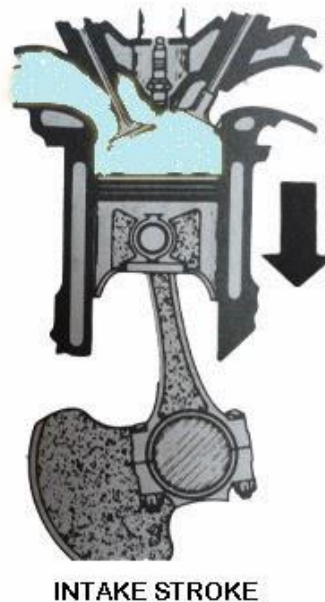

INTAKE STROKE

Figure 3 Intake stroke

Compression stroke:

After the piston passes bottom end of the cylinder, it starts moving up. Both valves are closed and the cylinder is sealed at that time. The piston moves upward. This movement of piston compresses the air into a small space between the top of the piston and cylinder head. The air is compressed into 1/22 or less of its original volume. Due to this compression a high pressure and temperature generate inside the cylinder. Both the inlet and exhaust valves do not open during any part of this stroke. At the end of compression stroke the piston is at top end of the cylinder.

COMPRESSION STROKE

Figure 4 Compression stroke

Power stroke:

At the end of the compression stroke when the piston is at top end of the cylinder a metered quantity of diesel is injected into the cylinder by the injector. The heat of compressed air ignites the diesel fuel and generates high pressure which pushes down the piston. The connection rod carries this force to the crankshaft which turns to move the vehicle. At the end of power stroke the piston reach the bottom end of cylinder.
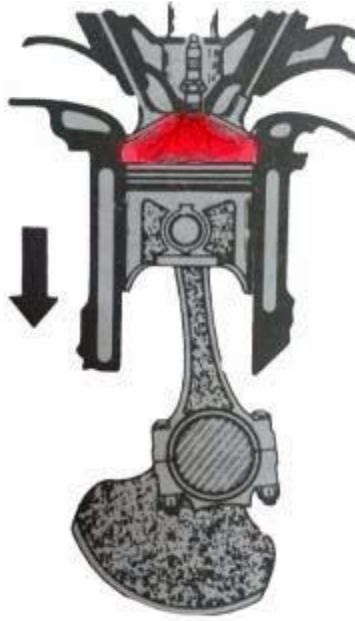
POWER STORKE

Figure 5 Power stroke

Exhaust stroke:

When the piston reaches the bottom end of cylinder after the power stroke, the exhaust valve opens. At this time the burn gases inside the cylinder so the cylinder pressure is slightly high from atmospheric pressure. This pressure difference allows burn gases to escape through the exhaust port and the piston move through the top end of the cylinder. At the end of exhaust all burn gases escape and exhaust valve closed. Now again intake valve open and this process running until your vehicle starts.[13]

Figure 6 Exhaust Stroke

1.4 The Combustion Process

Combustion is a chemical reaction of rapid oxidation started by the correct mixture of fuel, oxygen and an ignition source.
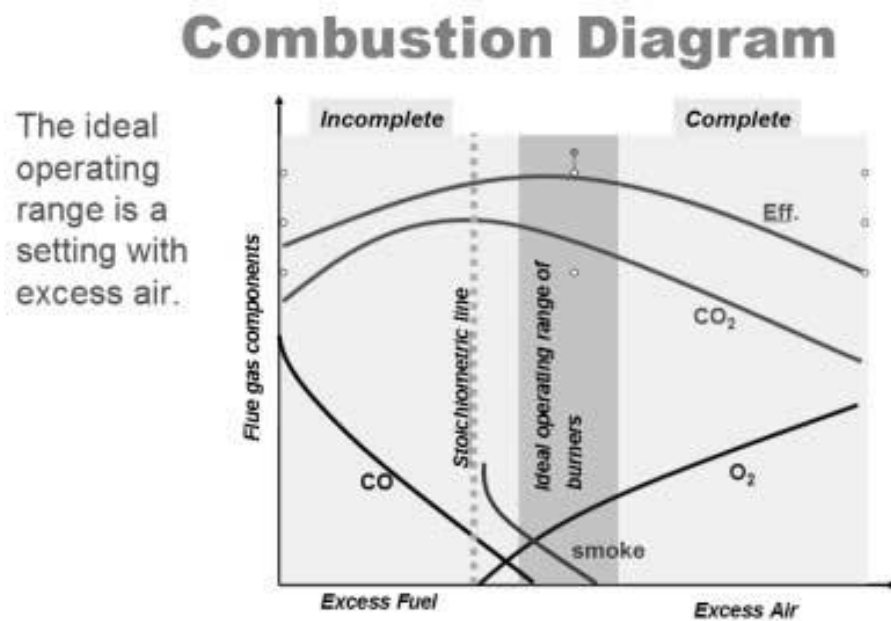

Figure 7 Combustion Diagram

The maximum amount of heat that can be derived from a fuel is based on using pure oxygen as the oxidizer in the chemical reaction and maximizing the fuel gas mixture. Infield practice, the oxygen is derived from the air which is 20.9% oxygen, 78% nitrogen and 1% other gasses.

Because the oxygen is not separated from the air prior to combustion, there is a negative effect on the chemical reaction. Air is primarily nitrogen. While nitrogen is inert, and plays no role in the combustion process, it cools the chemical reaction (burning temperature) and lowers the maximum heat content deliverable by the fuel. Therefore, it is impossible to achieve combustion efficienciesabove 95% for most fuels, including natural gas, when air is used as the oxidizer in the combustion process.

During combustion, new chemical substances are created from the fuel and theoxidizer. These substances are called exhaust gasses. Most of the exhaust gas comes from chemical combinations of the fuel and oxygen. When a hydrocarbon-based fuel (Natural Gas) burns, the exhaust gasses include water (hydrogen + oxygen)and carbon dioxide (carbon + oxygen). The temperature of the exhaust will be high because of the heat that is transferred to the exhaust during combustion. Because of its high temperature, exhaust usually occurs as a gas, but there can be liquid or solid exhaust products as well.

During the combustion process, as the fuel and oxidizer are turned into exhaustproducts, heat is generated. Interestingly, some source of heatis also necessary to start combustion. Gasoline and air are both present in your automobile fuel tank; butcombustion does not occur because there is no source of heat. Since heat is bothrequired to start combustion, and is itself a product of combustion, we can see whycombustion takes place very rapidly. Also, once combustion gets started, we don't have to continue to provide the heat source, because the heat produced by the combustion process will keep things going. We don't have to keep lighting a campfire, it just keeps burning.[14]

1.5 Waste oil

Waste/Used Cooking Oil the feedstock coming from waste vegetable oils or commonly known as waste cooking oils is one of the alternative sources among other higher grade or refine oils. Waste cooking oil is easy to collect from other industries such as domestic usage and restaurant and also cheaper than other oils (refine oils). And by using these oils as the raw material, the advantages of using waste cooking oils to produce biodiesel are the low cost and prevention of environment pollution. These oils need to be treating before dispose to the environment to prevent pollution. Due to the high cost of disposal, many individuals dispose waste cooking oils directly to the environment especially in

rural area. So that, the use of waste cooking oils is an effective way to reduce the cost of biodiesel production.

Many techniques have been developed to reduce the kinematic viscosity and specific gravity of vegetable oils, which include pyrolysis, emulsification, leaning and transesterification. Among these techniques, transesterification is the hot favorite. This is because of the fact that this method is relatively easy, carried out at normal conditions, and gives the best conversion efficiency and quality of the converted fuel.[3]

1.6 Glycerol

Glycerol is produced during transesterification of vegetable oils and animal fats. Prior to the increase in biodiesel production that occurred over the past decade as a result of the continued interest in renewable fuels, the market demand for glycerol was relatively balanced with supply. However, the emergence of the biodiesel industry has generated a surplus of glycerol, which has spawned numerous efforts to find new applications, products, and markets using this versatile chemical. In general, glycerol may be used as a chemical feedstock in the production of polyurethanes, polyesters, polyether, and other materials. Glycerol may also be found in lubricants, wrapping and packaging materials, foods, drugs, cosmetics, and tobacco products. Applications and products that displace existing petroleum-derived materials or feedstocks are of particular interest. A recent significant advance is the development of a synthetic route to propylene glycol from glycerol, which represents a viable alternative to the classic petrochemical route from propylene. Propylene glycol represents a replacement for the common toxic antifreeze component ethylene.[2]

1.7 Life cycle impact assessment

1.7.1 Global warming

Climate change can result in adverse effects upon ecosystem health, human health and material welfare. Climate change is related to emissions of greenhouse gases to air. The characterization model as developed by the Intergovernmental Panel on Climate Change (IPCC) is selected for development of characterization factors. Factors are expressed as Global Warming Potential for time horizon 100 years (GWP100), in kg carbon dioxide/kg emission. The geographic scope of this indicator is at global scale.

```
┌─────────────────────┐
│      Output         │
│   Emission(CO2)     │
└─────────────────────┘
          │
          ▼
┌─────────────────────┐
│      Impact         │
│       GW            │
└─────────────────────┘
          │
          ▼
┌─────────────────────┐
│      Damage         │
└─────────────────────┘
     │      │      │
     ▼      ▼      ▼
┌──────────┐ ┌─────────┐ ┌───────────────┐
│ Melting  │ │ Famines │ │ Desertification│
│   ice    │ │         │ │               │
└──────────┘ └─────────┘ └───────────────┘
```
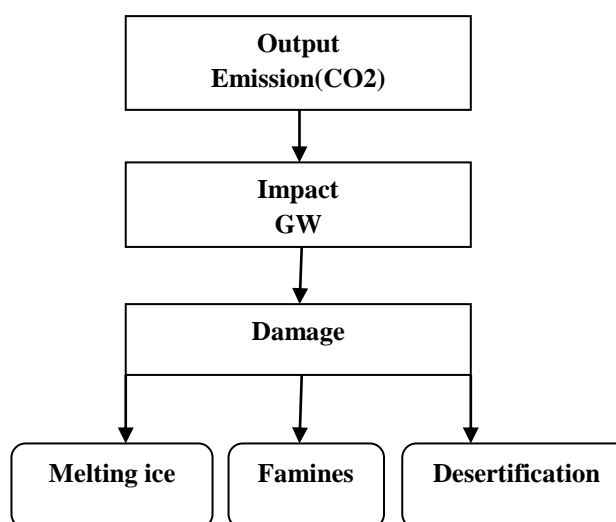
Figure 8 CO2 effect on global warming

1.7.2 Acidification

Acidifying substances cause a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems and materials (buildings). Acidification Potential (AP) for emissions to air is calculated with the adapted RAINS 10 model, describing the fate and deposition of acidifying substances. AP is expressed as kg SO_2 equivalents/ kg emission. The time span is eternity and the geographical scale varies between local scale and continental scale.

1.7.3 Ozone depletion

Because of stratospheric ozone depletion, a larger fraction of UV-B radiation reaches the earth surface. This can have harmful effects upon human health, animal health, terrestrial and aquatic ecosystems, biochemical cycles and on

materials. This category is output-related and at global scale. The characterization model is developed by the World 5 Meteorological Organization (WMO) and defines ozone depletion potential of different gasses (kg CFC-11 equivalent/ kg emission). The geographic scope of this indicator is at global scale. The time span is infinity.

1.7.4 Resource depletion

This impact category is concerned with protection of human welfare, human health and ecosystem health. This impact category indicator is related to extraction of minerals and fossil fuels due to inputs in the system. The Abiotic Depletion Factor (ADF) is determined for each extraction of minerals and fossil fuels (kg antimony equivalents/kg extraction) based on concentration reserves and rate of de-accumulation. The geographic scope of this indicator is at global scale.

2   Theoretical Background

2.1 Life cycle assessment

LCA is a technique to assess the potential environmental impacts associated with a product or service throughout its life cycle, by Goal and scope , Inventory analysis it's knows as compiling an inventory of relevant inputs and outputs of a product system. Impact assessment: Evaluating the potential environmental impacts associated with the selected inputs and outputs. Last but not least Interpretation is interpreting the results.

LCA considers the potential environmental impacts throughout a product's life cycle (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal. Examples of categories of environmental impacts included in commercial LCA software tools are resource use, human health and ecological consequences. The limitations of the LCA technique can be overcome by complementing with other tools and methods e.g. Environmental Risk Assessment.

The LCA study can assist in:

1- Identification of improvement opportunities for the studied product or service throughout its whole life.

2- Decision-making in industry, governmental and non-governmental organizations.

3- Selection of relevant environmental performance indicators and adequate measurement techniques.

4- Marketing opportunities for products, e.g. to use LCA data for eco-labeling, environmental product declaration (EPD), etc.

The International Standards ISO 14040-14043 provides principles, framework, and methodological requirements for conducting LCA studies. The framework of LCA includes definition of goal and scope, inventory analysis, impact assessment and interpretation of the results, as illustrated in the figure below
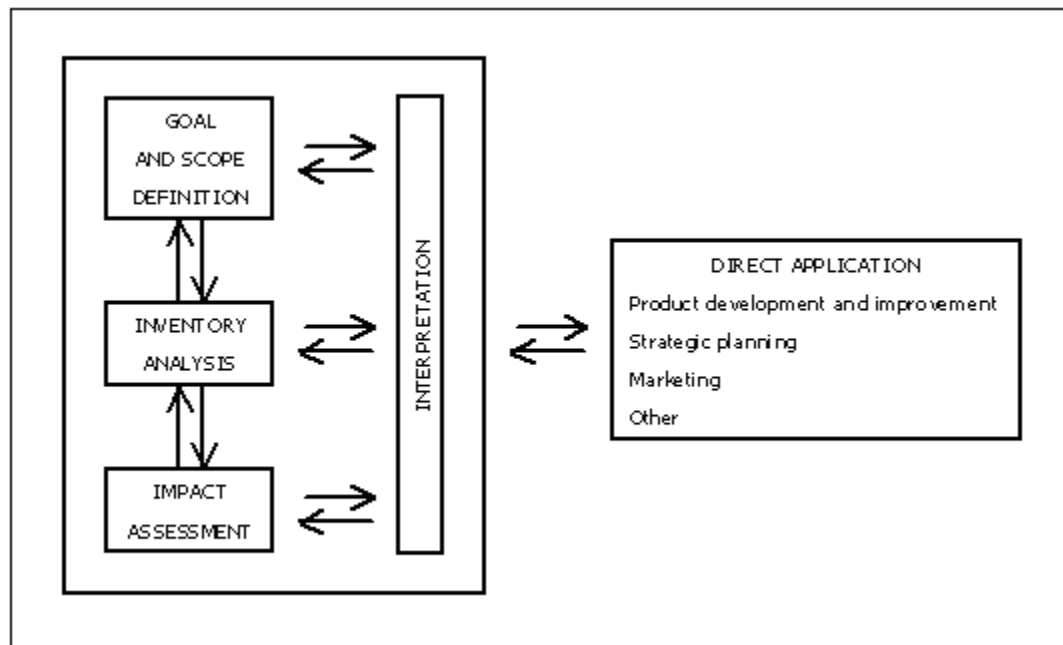
Figure 9 LCA Framework

Goal and scope definition

The first part of an LCA study consists of defining the goal of the study and its scope. The goal of the study should include a statement of the reason for carrying out the study as well as the intended application of the results and the intended audience. In the scope of an LCA the following items shall be considered and described:

1- The function of the product system.

2- The functional unit.

3- The system boundaries.

4- Allocation procedures.

5- Type of impact assessment methodology and interpretation to be performed.

6- Data requirements.

7- Assumptions and limitations.

8- Data quality requirements.

9- Type of critical review, if any.

10- Type and format of the report required for the study.

The scope should describe the depth of the study and show that the purpose can be fulfilled with the actual extent of the limitations.

Functional unit

The functional unit is a key element of LCA which has to be clearly defined. The functional unit is a measure of the function of the studied system and it provides a reference to which the inputs and outputs can be related. This enables comparison of two essential different systems. For example, the functional unit for a paint system may be defined as the unit surface protected for 10 years. A comparison of the environmental impact of two different paint systems with the same functional unit is therefore possible.

System boundaries

The system boundaries determine which unit processes to be included in the LCA study. Defining system boundaries is partly based on a subjective choice, made during the scope phase when the boundaries are initially set. The following boundaries can be considered:

1-Boundaries between the technological system and nature. A life cycle usually begins at the extraction point of raw materials and energy carriers from nature. Final stages normally include waste generation and/or heat production.

2-Geographical area. Geography plays a crucial role in most LCA studies, e.g. infrastructures, such as electricity production, waste management and transport systems, ivaries from one region to another. Moreover, ecosystems sensitivity to environmental impacts differs regionally too.

3-Time horizon. Boundaries must be set not only in space, but also in time. Basically LCAs are carried out to evaluate present impacts and predict future scenarios. Limitations to time boundaries are given by technologies involved, pollutants lifespan, etc.

4-Boundaries between the current life cycle and related life cycles of other technical systems. Most activities are interrelated, and therefore must be isolated from each other for further study. For example production of capital goods, economic feasibility of new and more environmentally friendly processes can be evaluated in comparison with currently used technology.

Data quality requirements

Reliability of the results from LCA studies strongly depends on the extent to which data quality requirements are met. The following parameters should be taken into account:

1- Time-related coverage.

2- Geographical coverage.

3- Technology coverage.

4- Precision, completeness and representativeness of the data.

5- Consistency and reproducibility of the methods used throughout the data collection.

6- Uncertainty of the information and data gaps.

Inventory analysis (LCI)

LCI comprises all stages dealing with data retrieval and management (see figure below). The data collection forms must be properly designed for optimal collection. Subsequently data are validated and related to the functional unit in order to allow the aggregation of results. A very sensitive step in this calculation process is the allocation of flows e.g. releases to air, water and land. Most of the existing technical systems yield more than one product. Therefore, materials and energy flows regarding the process as a whole, as well as environmental releases must often be allocated to the different products. This is recommended to be made according to a given procedure.

Wherever possible, allocation should be avoided.

Where allocation is not avoidable, inputs and outputs should be partitioned between its different functions or products in a way that reflects the underlying physical relationships between them.

If the latter is not possible, allocation should be carried out based on other existing relationships (e.g. in proportion to the economic value of products).

The data collection is the most resource consuming part of the LCA. Reuse of data from other studies can simplify the work but this must be made with great care so that the data is representative. The quality aspect is therefore also crucial.
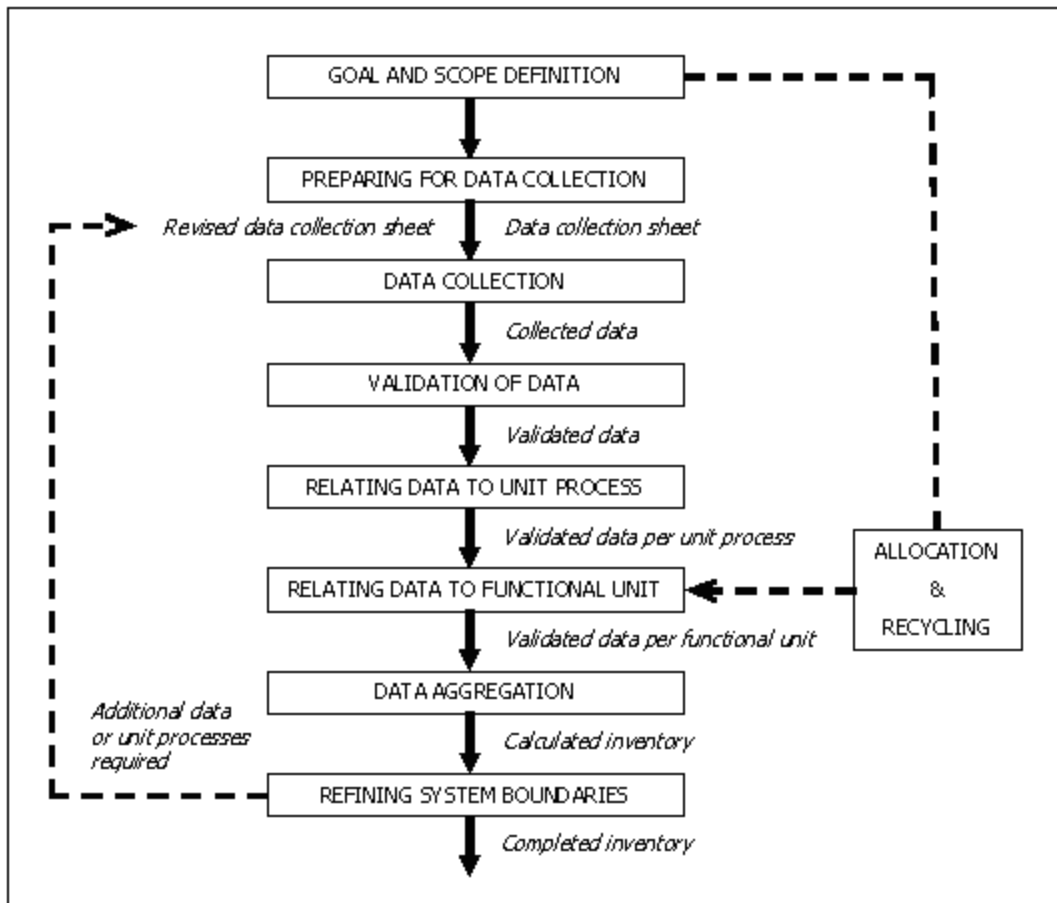
Figure 10 Data Management

Impact Assessment (LCIA)

LCIA aims to evaluate the significance of potential environmental impacts using the results coming out from the LCI phase. The ISO14040 suggests that this phase of an LCA is divided into the following steps:

Mandatory elements:

1-Selection of impact categories, category indicators and characterization models.

2-Classification, i.e. assignment of individual inventory parameters to impact categories, e.g. CO_2 is assigned to Global Warming. Common impact categories are Global Warming, Ozone Depletion, Photooxidant Formation, Acidification and Eutrophication.

3-Characterization, i.e. conversion of LCI results to common units within each impact category, so that results can be aggregated into category indicator results.

<u>Optional elements:</u>

1-Normalization. The magnitude of the category indicator results is calculated relatively to reference information, e.g. and old products constitutes baseline when assigning a new product.

2-Weighting. Indicator results coming from the different impact categories are converted to a common unit by using factors based on value-choices.

3- Grouping. The impact categories are assigned into one or more groups sorted after geographic relevance, company priorities etc.

The methods that are usually used for LCIA are e.g. EPS (Environmental Priority Strategies), ECO (Ecological scarcity) and ET (Environmental Theme).

Interpretation

The aim of the interpretation phase is to reach conclusions and recommendations in accordance with the defined goal and scope of the study. Results from the LCI and LCIA are combined together and reported in order to give a complete and unbiased account of the study. The interpretation is to be made iteratively with the other phases.

The life cycle interpretation of an LCA or an LCI comprises three main elements:

1- Identification of the significant issues based on the results of the LCI and LCIA phases of a LCA.

2-Evaluation of results, which considers completeness, sensitivity and consistency checks.

3-Conclusions and recommendations.

In ISO 14040 standard it is recommended that a critical review should be performed. In addition it is stated that a critical review must have been conducted in order to disclose the results in public.[8]

3   Literature review

In the last few years many studies have the biodiesel as a good material to do a life cycle assessment about as the bio diesel is one of the renewable sources which the world will use instead of fossil fuels .in our report we studied the life cycle assessment for the production of biodieselthat made from used cooking oil Such life cycle involves three stages: 1) collection, 2) pre-treatment and 3) transesterification of UCO. Generally, UCO is collected from restaurants, food industries and recycling centres. Then, UCO is pre-treated to remove solid particles and water to increase its quality. After that, it is then transesterified with methanol to biodiesel.

One of the studies in the same topic was done in Barcelona in 2010 about   The production of 1 ton of biodiesel then evaluated by a Life Cycle Assessment (LCA) to assess the environmental impact and by an Exergetic Life Cycle Assessment (ELCA) to account for the exergy input to the system. A detailed list of material and energy inputs is done using data from local companies and completed using Ecoinvent 1.2 database.
The results show that the transesterification stage causes 68% of the total environmental impact. The major exergy inputs are uranium and natural gas. If targets set by the Spanish Renewable Energy Plan are achieved, the exergy input for producing biodiesel would be reduced by 8% in the present system and consequently environmental impacts and exergy input reduced up to 36% in 2010.

Another study was made in Australia and this study uses the Life Cycle Assessment (LCA) to determine the environmental outcomes of biodiesel from UCO in terms of global warming potential, life cycle energy efficiency (LCEE) and fossil energy ratio (FER) using the life cycle inventory and the function unit used was also 1 ton of UCO. The finding of this study is the biodiesel production process is sustainable that compare to the fossil diesel process and exhaust tailpipe emission. If all UCO is collected and used to produce biodiesel, it will be 1.89% substitution of fossil petro-diesel consumption in Western Australia.

4 Methodology

4.1 Definition of the system

In this report life cycle assessment was done for the production of 1kg of biodiesel using cooked oil by following the four steps of any LCA which are goal and scope, inventory, impact assessment and finally interpretation the boundary was only the production phase and the results were given by using the open LCA program.

In order to follow ISO 14040 the four steps were defined as follow:

- **Goal :**
  This study is expected to be released to the public by student to produce the biodiesel.

- **Scope :**
  This projects aims to produce one type of biodiesel from waste cooking oil in order to operate the petro-diesel engine along with focusing on the environmental impacts of biodiesel production process as this depends on the used oil and the filtration process of it with catalyst to be used along the production process.

- **Function :**
  The biodiesel is alternative source, used in petro-diesel (cars & vehicles) because it reduces the emissions.

- **Functional Unit :**
  1 Kg of biodiesel

- Inventory :
  The inventory data was given from ecoinvent database to be analyzed in Openlca program as its shown in the figure below the inputs for the system were 1 kg of used cooked oil, 1 Kg of water, 0.200 Kg of methanol along with a catalyst used in the reaction which was Sodium Hydroxide (NaOH) 0.0075 beside a source of energy which was electricity to heat up the mixture.
  Electricity was generated from a Coal power plant (Orot Rabin) in Hadera, and in order to compromise between the data needed and the data given from the program France and Europe were chosen to make these analyses and simulate it.
  The amount of MJ of electricity needed in this process was calculated by

  $\mathbf{Q = mC_p\Delta T}$ the heat needed to be transferred and rise the temperature of biodiesel equals 25 °C as ($\Delta T = 50° - 25° = 25°C$) and C_p of biodiesel = 1.9135KJ/Kg.C.[9]

it was chosen to be the sunflower oil which is similar to the oil used in restaurants and domestic houses at 50 °C 1.9315 J/ g. °C

The specific heat in $\frac{KJ}{Kg}$. c= 1.9315 (J/g.C) x$\frac{1\,KJ}{1000\,J} \times \frac{1000g}{1\,Kg} = 1.9315 \frac{KJ}{Kg}$. c

Then Q = 1.275 Kg * 1.9315 $\frac{KJ}{Kg}$. c * (25 ° C) = 61.56 KJ just in order to produce 1 Kg of biodiesel.

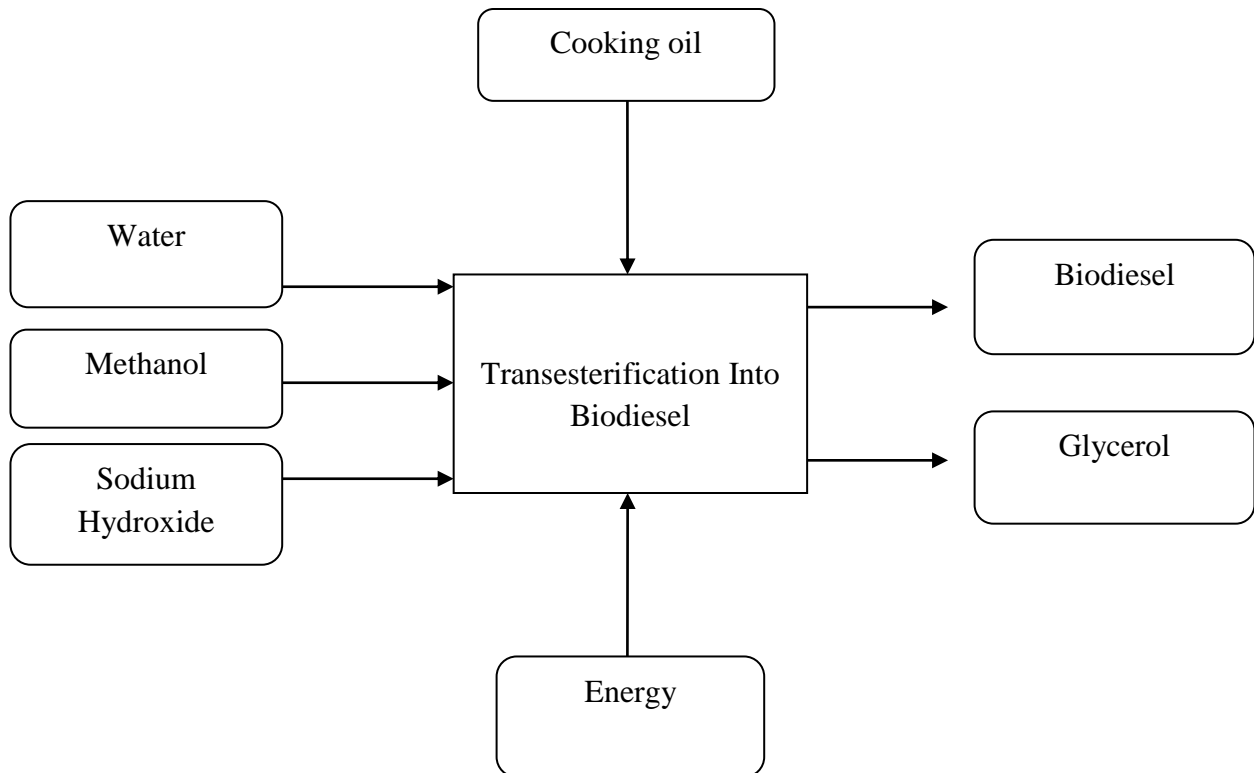The outputs of the system were 1Kg of biodiesel and glycerin

Figure 11 Unit Process of Biodiesel Production

- Impact assessment: it was chosen four indicators for the impact assessment which were: a) Global warming, b) Acidification, c) Depletion of ozone Layer d) and Depletion of resources. Alongside with the CML method used which is known by the CML-IA methodas in 2001, a group of scientists under the lead of CML (Center of Environmental Science of Leiden University) proposed a set of impact categories and characterization methods for the impact assessment step. The impact assessment method implemented as CML-IA methodology is defined for the midpoint approach. Normalization is provided but there is neither weighting nor addition.[10]

- Interpretation: in this section of project the results and discussion of it will be analyzed and explained as a final result of the program and the project this section will be discussed in the next chapter.

4.2 Openlca program

OpenLCA is the open source software for Life Cycle Assessment (LCA) and Sustainability Assessment, developed since 2006 by GreenDelta2. As open source software, it is freely available, e.g. from the project website (www.openlca.org), without license costs.
OpenLCA can be used in various application areas:
• Environmental Life Cycle Assessment (LCA)
• Economic Life Cycle Costing (LCC)
• Social Life Cycle Assessment (social LCA)
• Carbon and Water Footprint
• Design for Environment (DfE)
• Environmental Product Declaration (EPD)
• Product Environmental Footprint (PEF).[11]

4.2.1 Ecoinvent Database

Ecoinvent builds on more than 20 years of experience in LCA methodology development and LCI data compilation for different industrial sectors.as it lays the foundation for the LCA study. With over 12,800 LCI datasets in many areas such as energy supply, agriculture, transport, biofuels and biomaterials, bulk and specialty chemicals, construction materials, wood, and waste treatment.[12]

5 Results and Discussion

5.1 Production of biodiesel results (coal power plant generated electricity):

The inventory data was based on the ecoinvent database taking Europe in place and France as it has the similar conditions as Palestine Authority recording to their database locations provided.

The results shows for each category impact how each input or component in the biodiesel production phase can affect the environment in quantities.

5.1.1 Global warming:
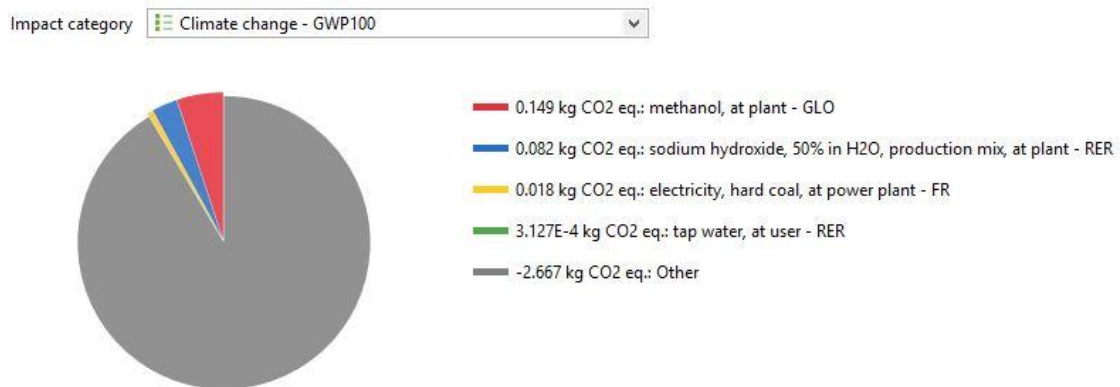
Figure 12 CO2 eq. of global warming using electricity from coal power plant

As it shown in the figure above the methanol is the most affecting component on the environment as it produce 0.149 kg of CO_2 eq. per 1 kg of biodiesel .

This condition is based on power plant located in France using hard coal similar to Orot Rabin power plant in Hadera which is the source of electricity is provided to Nablus city by Northern electricity Distribution Company (NEDCO).

In the other hand we can find that using vegetable oil and other contributors can help the environment by reducing the amount of CO_2 equivalent as it reduced by 2.667 Kg CO2 eq. per 1 Kg of biodiesel.

5.1.2 Acidification:

Impact category: Acidification potential - average Europe

- 4.525E-4 kg SO2 eq.: vegetable oil, from waste cooking oil, at plant - FR
- 3.948E-4 kg SO2 eq.: sodium hydroxide, 50% in H2O, production mix, at plant - RER
- 2.439E-4 kg SO2 eq.: methanol, at plant - GLO
- 1.394E-4 kg SO2 eq.: electricity, hard coal, at power plant - FR
- 1.391E-6 kg SO2 eq.: Other
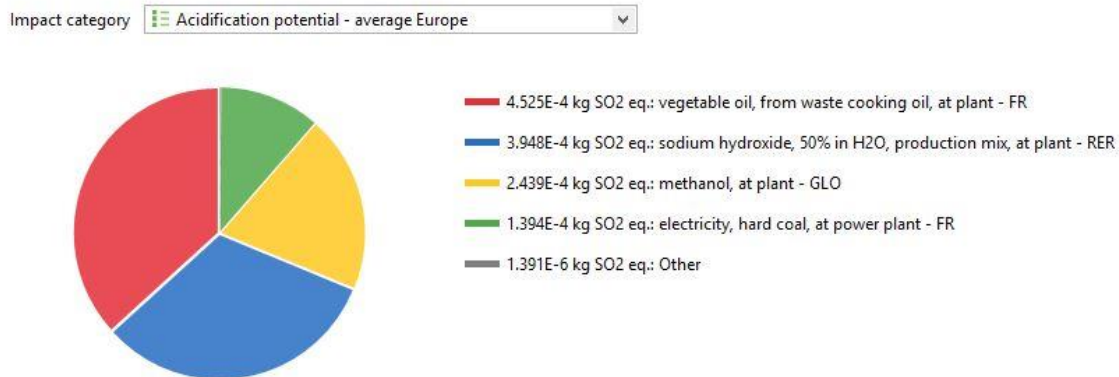
Figure 13 SO2 eq. of acidification using electricity from coal power plant

The numbers shows that the production phase of biodiesel doesn't severely affect the environment by acidification because of the small amounts of SO_2 equivalents for 1 kg of biodiesel and there's a noticeable variation in the results as the effect of Vegetable oil which is used cooked oil is the most contributor which releases 4.525E-4 kg of SO_2 equivalent and 3.948E-4 kg SO_2 eq. for Sodium hydroxide.

5.1.3 Depletion of Ozone Layer:

Impact category: Ozone layer depletion - ODP steady state

- 3.271E-8 kg CFC-11 eq.: methanol, at plant - GLO
- 2.459E-8 kg CFC-11 eq.: vegetable oil, from waste cooking oil, at plant - FR
- 5.020E-9 kg CFC-11 eq.: sodium hydroxide, 50% in H2O, production mix, at plant - RER
- 1.560E-10 kg CFC-11 eq.: electricity, hard coal, at power plant - FR
- 1.613E-11 kg CFC-11 eq.: Other
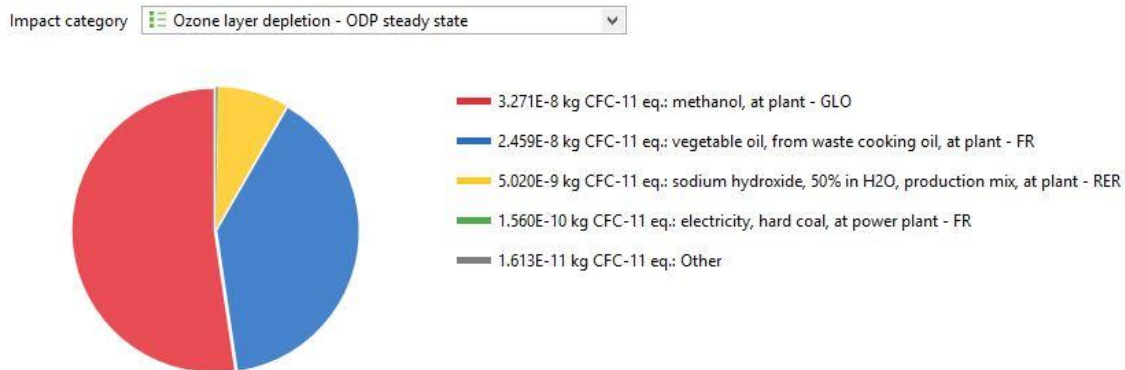
Figure 14 CFC-11 eq. of ozone layer depletion using electricity from coal power plant

In this figure a variety of the quantities that affect the ozone layer as methanol noticeably is getting a fine percent alongside with the waste cooked oil used but in general the small amount is a compelling factor.

5.1.4 Depletion of resources:

Impact category: Depletion of abiotic resources - fossil fuels

- 6.647 MJ: methanol, at plant - GLO
- 3.403 MJ: vegetable oil, from waste cooking oil, at plant - FR
- 0.932 MJ: sodium hydroxide, 50% in H2O, production mix, at plant - RER
- 0.197 MJ: electricity, hard coal, at power plant - FR
- 3.320E-3 MJ: Other
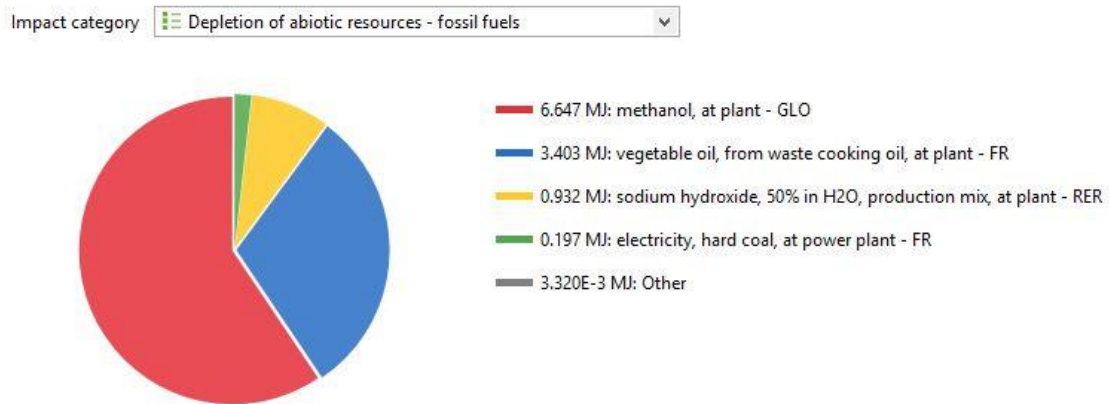
Figure 15   Amount of MJ of energy consumed for each ingredient

Apparently, again the Methanol is the most consuming input of resources next to it the vegetable oil.

5.2 Production of biodiesel (Natural Gas power plant generated electricity)

5.2.1 Global warming:

Impact category: Climate change - GWP100

- 0.149 kg CO2 eq.: methanol, at plant - GLO
- 0.082 kg CO2 eq.: sodium hydroxide, 50% in H2O, production mix, at plant - RER
- 8.339E-3 kg CO2 eq.: electricity, natural gas, at power plant - FR
- 3.127E-4 kg CO2 eq.: tap water, at user - RER
- -2.667 kg CO2 eq.: Other
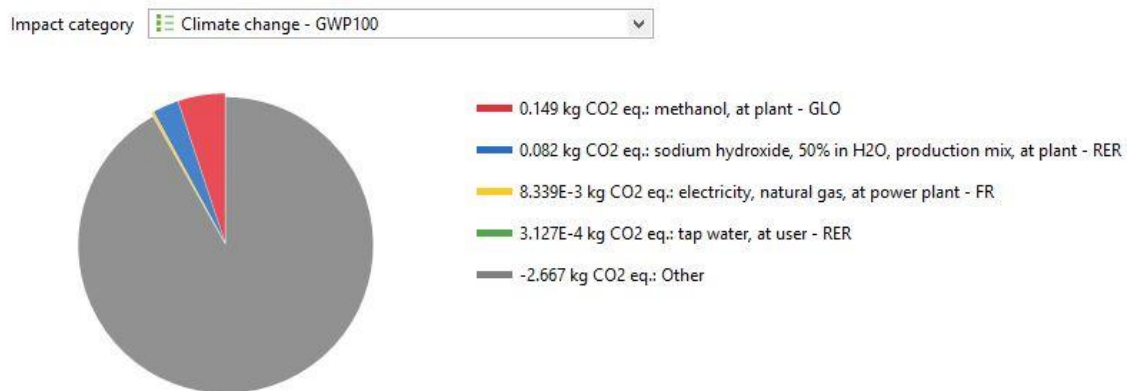
Figure 16 CO2 eq. for global warming using Electricity from NG power plant

In the figure above similar to biodiesel produced from coal power plant results as the Methanol the main contributor on global warming as it produce approximately 0.149 kg of CO_2 eq. and with -2.667 kg of CO_2 eq. from used cooked oil and other components as it's considered a positive indicator.

5.2.2 Acidification:
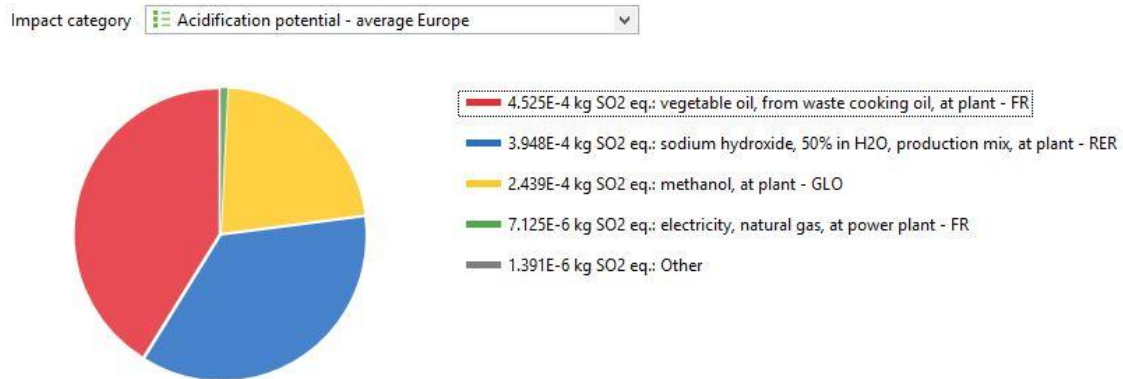
Figure 17 SO2 eq. of acidification using electricity from NG power plant

In these results we have a variation of each one's effect but the dominant factor isSodium hydroxide (NaOH) with total effect 3.948E-4 kg andit's very adjacent to Vegetable oil with total effect 4.525E-4kg of SO_2 eq.

5.2.3 Ozone Layer Depletion:
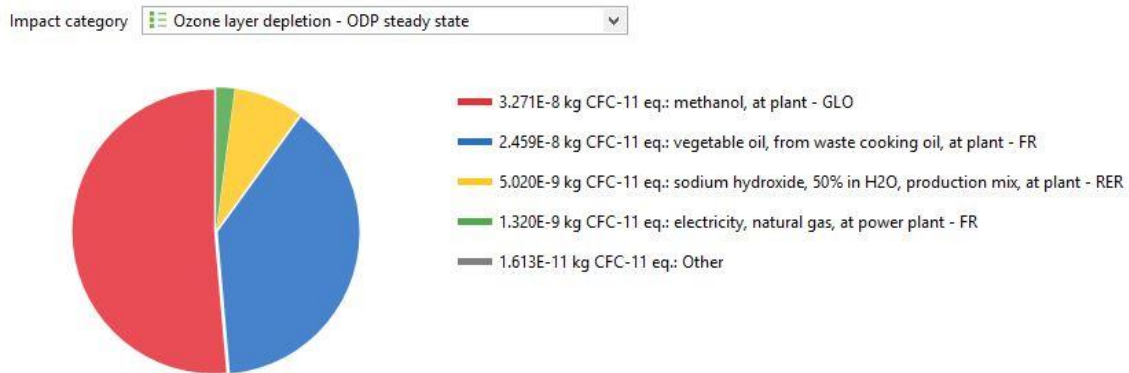
Figure 18 CFC-11 eq. of ozone layer depletion using electricity from NG power plant

For Ozone layer depletion once again we find the highest result goes for Methanol with 3.271E-8 Kg CFC-11 eq. and surprisingly the vegetable oil 2.459E-8 Kg CFC-11 eq.

5.2.4 Depletion of resources
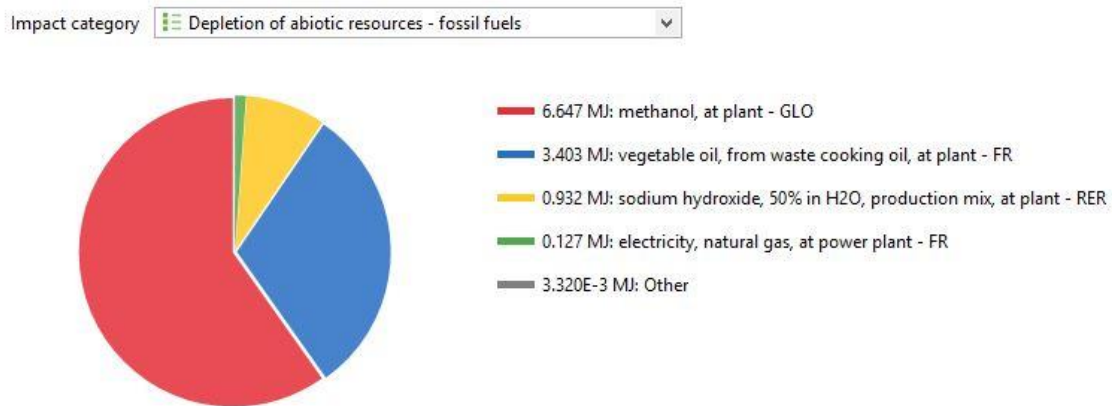
Figure 19 MJ of energy consumed for each ingredient

To produce 1 kg of biodiesel, 6.647 MJ is consumed only in methanol as it's the dominant consumer along with 3.403 MJ from vegetable oil.

5.3 Petro-Diesel Production:

5.3.1 Global warming:
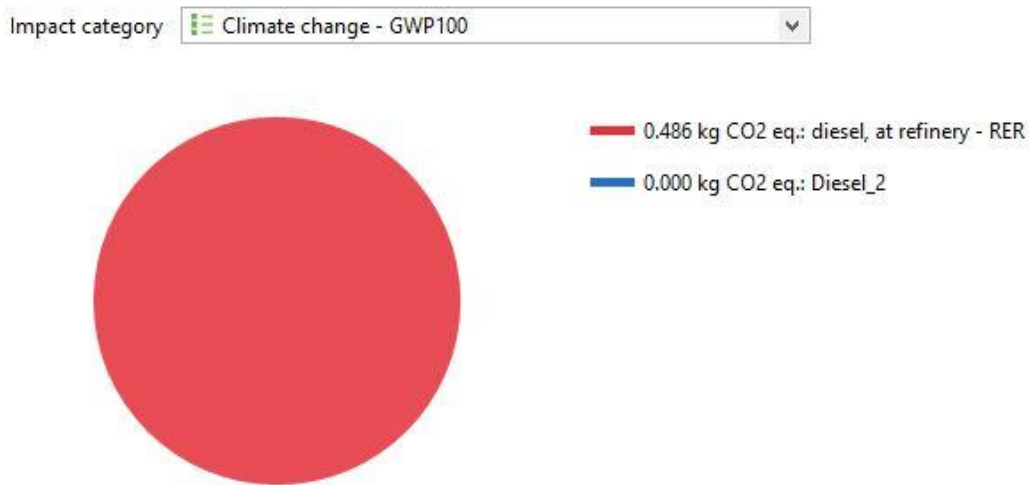
Figure 20 CO2 eq. of Global warming for producing petro-diesel

The figure above shows the CO_2 eq. of the production of petro-diesel at refinery which equals 0.486 Kg and in it's obviously much lower than biodiesel production.

5.3.1 Acidification:

Impact category | Acidification potential - average Europe

- 5.898E-3 kg SO2 eq.: diesel, at refinery - RER
- 0.000 kg SO2 eq.: Diesel_2
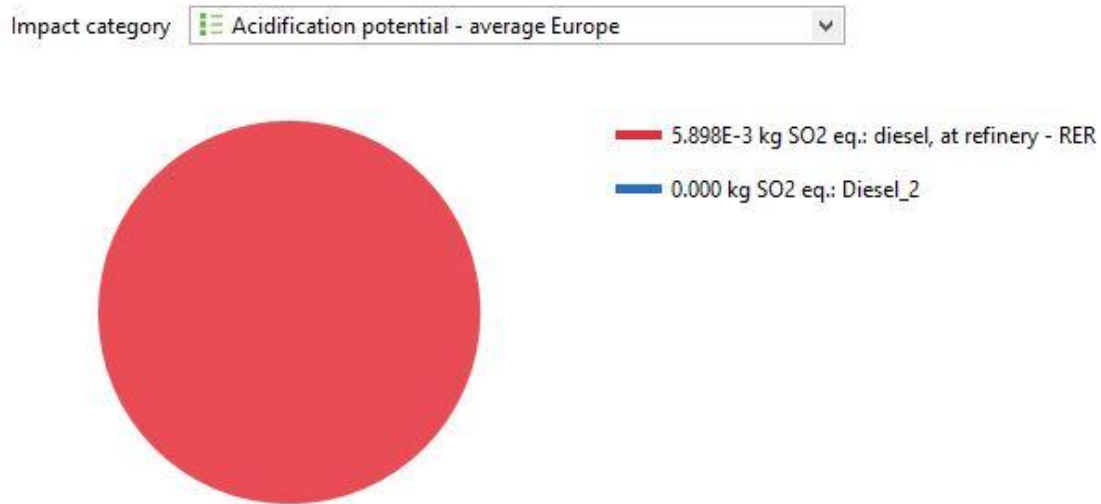
Figure 21 SO2 Eq. of Acidification for producing Petro-diesel

For acidification petro-diesel production phase can produce 5.898E-3 Kg SO_2 eq.

5.3.4 Ozone Layer Depletion

Impact category | Ozone layer depletion - ODP steady state

- 4.601E-7 kg CFC-11 eq.: diesel, at refinery - RER
- 0.000 kg CFC-11 eq.: Diesel_2
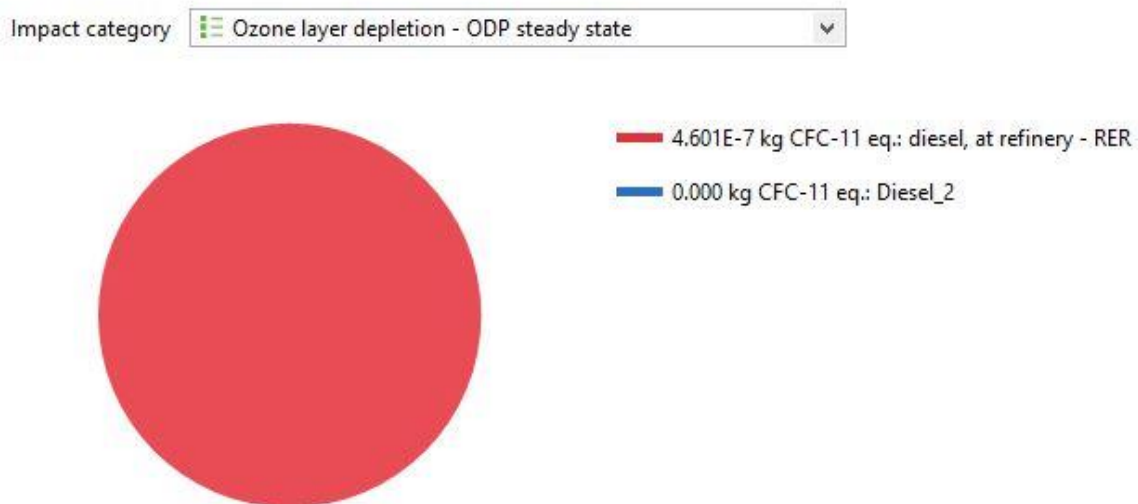
Figure 22 CFC-11 eq. of Ozone layer Depletion for producing Petro-diesel

The figure above shows a total of 4.601E-7 Kg of CFC-11 eq. which is slightly lower than biodiesel production phase.

5.3.4 Depletion of resources:
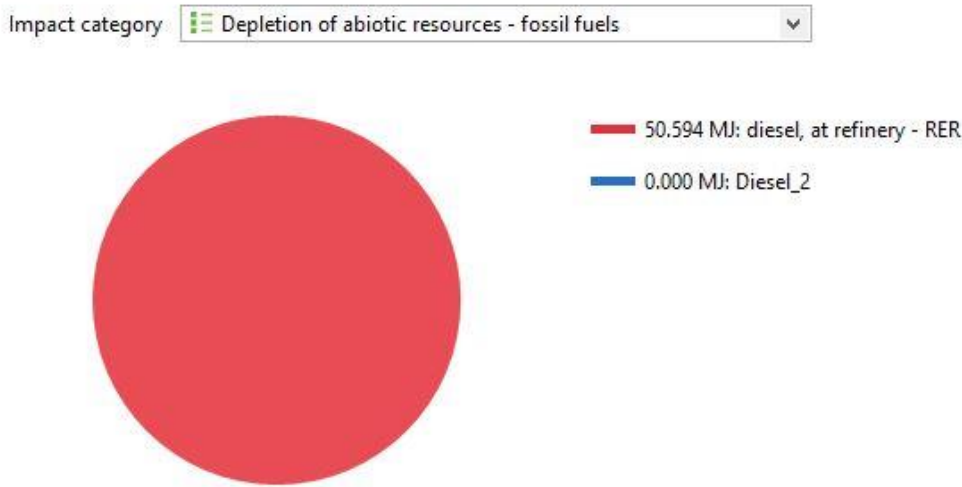
Figure 23 MJ consumed to produce petro-diesel

Only 51 MJ are consumed to produce Petro-diesel at refinery which is much higher than biodiesel 11 MJ approximately.

The three tables below illustrates the amount of equivalents of SO2, CO2, CFC-11 and MJ for the same results we got and comparing it with changing the type of the power plant to produce the electricity and the production phase of petro-diesel instead of biodiesel to demonstrate more their effect on the environment.

Table 1: Environmental impact of producing 1Kg of biodiesel from UCO (electricity generated from a coal power plant)

Impact category	Result	Reference unit
Climate change - GWP100	-2.4169	kg CO2 eq.
Acidification potential - average Europe	0.00123	kg SO2 eq.
Depletion of abiotic resources - fossil fuels	11.18229	MJ
Ozone layer depletion - ODP steady state	6.25E-08	kg CFC-11 eq.

Table 2: Environmental impact of producing 1Kg of biodiesel from UCO (electricity generated from a natural gas power plant)

Impact category	Result	Reference unit
Climate change - GWP100	-2.42688	kg CO2 eq.
Acidification potential - average Europe	0.0011	kg SO2 eq.
Depletion of abiotic resources - fossil fuels	11.11141	MJ
Ozone layer depletion - ODP steady state	6.37E-08	kg CFC-11 eq.

Table 3: Environmental impact of producing petro-diesel at refinery.

Impact category	Result	Reference unit
Climate change - GWP100	0.48638	kg CO2 eq.
Acidification potential - average Europe	0.0059	kg SO2 eq.
Depletion of abiotic resources - fossil fuels	50.59355	MJ
Ozone layer depletion - ODP steady state	4.60E-07	kg CFC-11 eq.

From table 1 and Table 2 we can recognize that thecoal power plant and Natural Gas power plant doesn't differ a lot as the first gives total emissions of CO_2 eq. -2.4169kg and the second is -2.42688 kg of $CO_2$and even for the total amount of energy used and consumed to produce 1 kg of biodiesel using natural gas or coal power plant as a source of electricity gives approximately 11 MJ demonstrates how the source of energy to produce electricity is important and how does it affect the environment.

In the other hand, comparing the production phase of petro-diesel at refinery and the actual process of producing biodiesel as the electricity is generated from coal power plant it reveals that the biodiesel is much way better than petro-diesel with a total emissions of CO_2 eq. 0.48 Kg .inaddition to 50.59 MJ are consumed from fossil fuel to produce it alongside with the higher emissions of the other indicators than biodiesel.

5.4 Use phase of Biodiesel and Petro-Diesel

The results were maintained by using previous researches on the same topic due to the lack of accuracy in the practical part as the results of combusting both fuels were not precise.

The table below shows the effect of Petro-Diesel and Biodiesel on the tailpipe emissions (g/bhp-h) as considering the biodiesel which is used 100% neat biodiesel.[15]

Table 4: Effect of Biodiesel on Tailpipe Emissions (g/bhp-h)

Emission	Diesel Fuel Baseline	20% Biodiesel Blend	100% Neat Biodiesel
Carbon Dioxide (fossil)	633.28	534.10	136.45
Carbon Dioxide (biomass)	0	108.7	543.34
Carbon Monoxide	1.2	1.089	0.6452
Hydrocarbons	0.1	0.09265	0.06327
Particulate Matter (PM10)	0.08	0.0691	0.02554
Sulfur Oxides (as SO_2)	0.17	0.14	0
Nitrogen Oxides (as NO_2)	4.8	4.885	5.227

In order to unify between the units and make them more simpler the (g/bhp-h) was converted to Kg of X/year as X can be CO_2 , NO_2 and SO_2 of using the vehicle for 5 hours a day for a whole year , as the brake hour power per hour (bhp-h) of the vehicle used .

5.4.1 Emissions from Biodiesel:

1. **NO_2 :**
   $= (98bhp * 5.227\ NO_2\ g/bhp.hr * 5hr/day\ 360day/yr)/1000kg/g$
   $= 922.0428\ kg\ NO_2/yr$

2. **CO_2 :**
   $= (98bhp * 136.45 CO_2\ g/bhp.hr * 5hr/day\ 360day/yr)/1000kg/g$
   $= 24069.78\ kg\ CO_2/yr$

3. **SO_2:**
   $= (98bhp * 0\ SO_2\ g/bhp.hr * 5hr/day\ 360day/yr)/1000kg/g$
   $= 0kg\ SO_2/yr$

- **Global warming from biodiesel :**
   $= (1 * 24069.78) + (270 * 922.0428)$
   $= 273021.39\ kg\ CO_2\ eqv/yr$
   $= 2.7 * 10^5\ kg\ CO_2\ eqv/yr$

- **Acidification from biodiesel :**
   $= (1 * 0) + (0.7 * 922.0428)$
   $= 645.43\ kg\ SO_2 eqv/yr$

5.4.2 Emissions from Petro-Diesel:

4. **NO_2 :**
   $= (98bhp * 5\ NO_2\ g/bhp.hr * 5hr/day\ 360day/yr)/1000kg/g$
   $= 882\ kg\ NO_2/yr$

5. **CO_2 :**
   $= (98bhp * 633.28\ CO_2\ g/bhp.hr * 5hr/day\ 360day/yr)/1000kg/g$
   $= 111710.59\ kg\ CO_2/yr$

6. **SO_2:**
   $= (98bhp * 0.17 SO_2\ g/bhp.hr * 5hr/day\ 360day/yr)/1000kg/g$
   $= 29.988\ kg\ SO_2/yr$

- **Global warming from diesel :**
   $= (1 * 111710.59) + (270 * 882)$
   $= 349850.59\ kg\ CO_2\ eqv/yr$
   $= 3.5 * 10^5\ kg\ CO_2\ eqv/yr$

- **Acidification from diesel :**
   $= (1 * 29.988) + (0.7 * 882)$
   $= 647.388\ kg\ SO_2 eqv/yr$
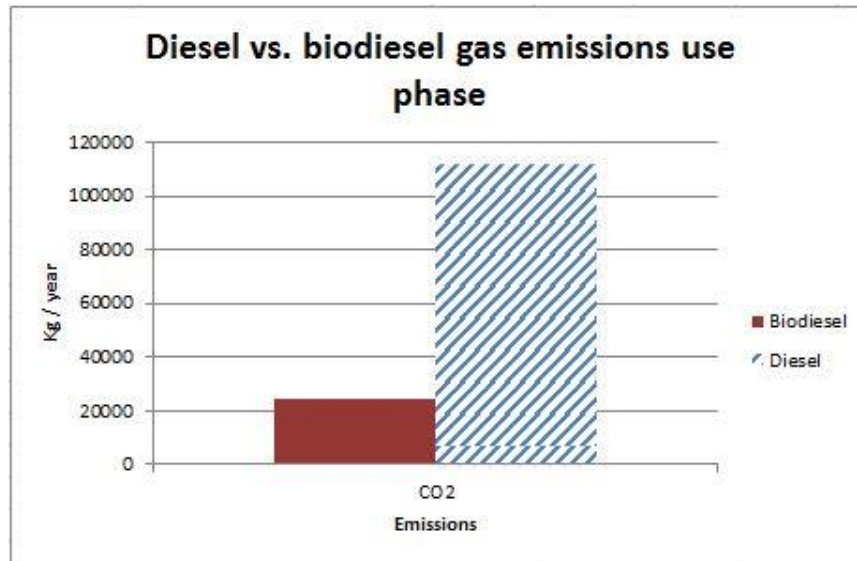
Figure 24 Biodiesel vs. Petro-Diesel CO2 emissions

As it shown in in the chart above the Petro-Diesel emissions is clearly more higher than the biodiesel one as for Petro-diesel equals 111710.59 kg CO_2/yr .
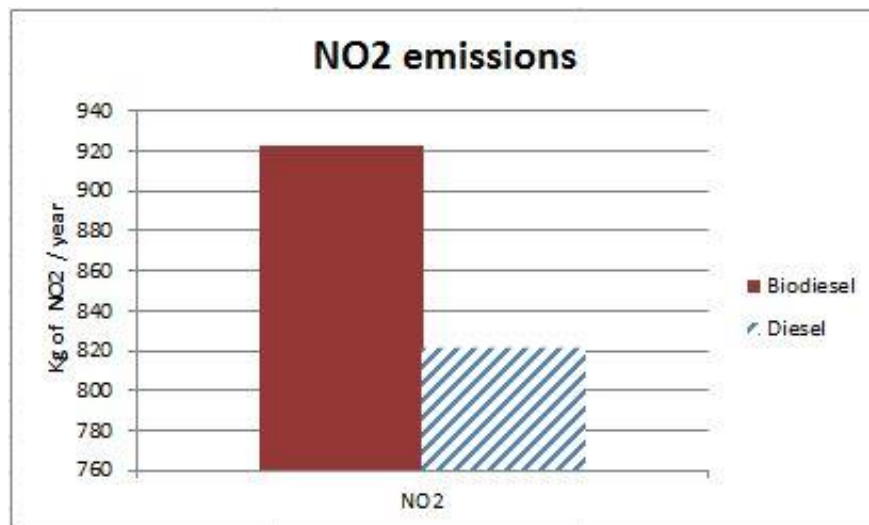
Figure 25 Biodiesel vs. Petro-Diesel NO2 emissions

Appearantl y the emissions of NO_2 for biodiesel is higher due to different determinants on of them The presence of oxygen in biodiesel fuel results in higher heat release during the premixed phase combustion which can be regarded as the main contributor to increased NOx emissions.[16]
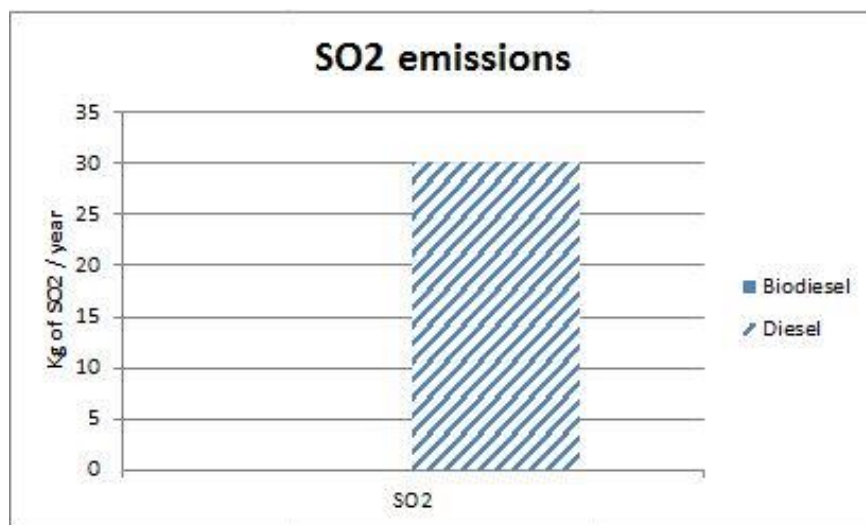
Figure 26 Biodiesel vs. Petro-diesel SO2 emissions

Positively, there is no SO_2 emissions for biodiesel as it clearly shown the chart above, because SOX is generated from the sulfur present in diesel fuel and most biodiesel fuels have naturally low sulfur content, equivalent to or lower than ultra-low sulfur diesel. The concentration of SO_2 in the exhaust gas depends on the sulfur content of the fuel the more sulfer content in the fuel the higher emissions of SO_2 .[17]
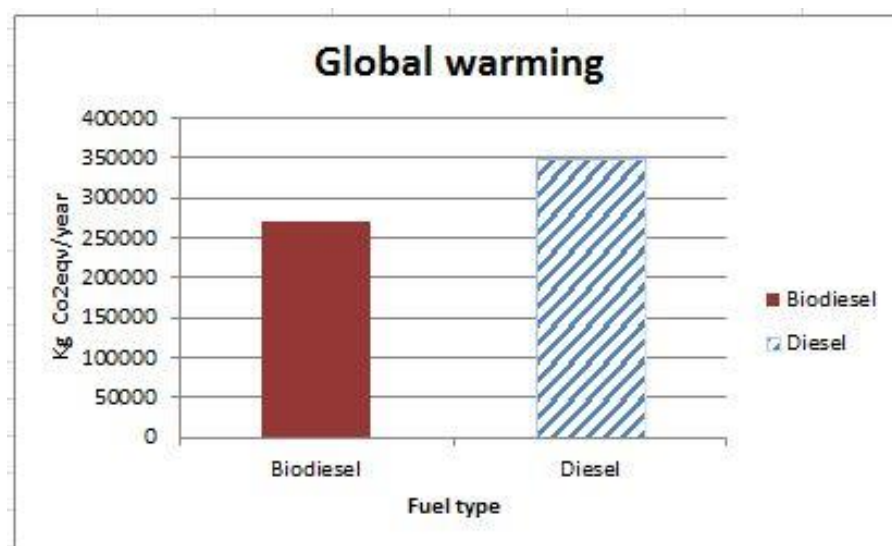
Figure 27 Global warming Kg CO2 eq. / year

As the chart above shows obviously, the Diesel contribute more in the global warming as it emit approximately $3.5 * 10^5$ Kg of CO_2 eq. per year.
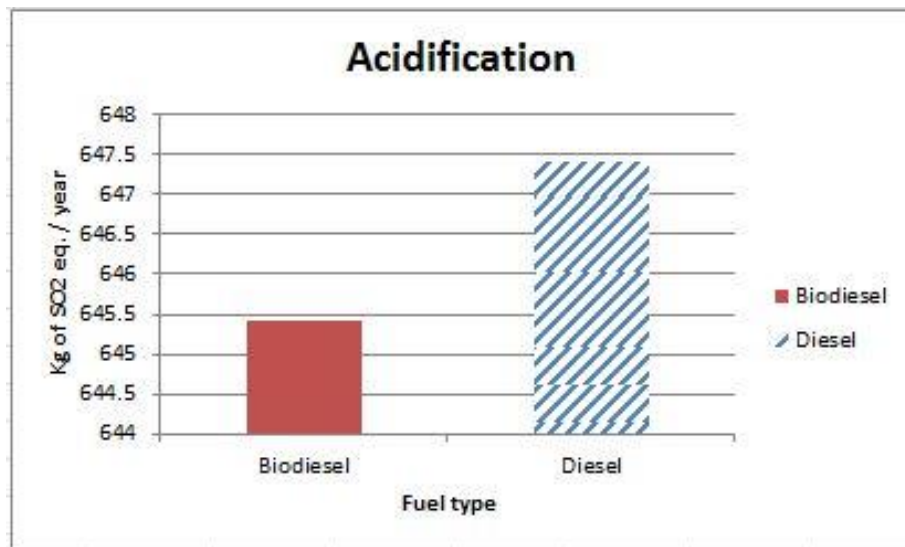
Figure 28 Acidification Kg of SO2 eq./ year

Following to Global warming, the Acidification chart clearly shows the higher value of Kg of SO_2 eq. per year due to the higher sulfur content in petro-diesel then the biodiesel.

6 Conclusion

In the end, biodiesel can be classified as a better alternative thanpetro-diesel with respect to its low emission's quantities in the production phase for 1 kg as it help environment in the oil's plant life for the absorption of CO_2 with a magnitude equals 2.4169 kgand consuming about 11 MJ of fossil fuel.In thecontrary,petro-diesel found to be more influential on the environment with 0.48 kg of CO_2 eq. and approximately 51 MJ consumed from fossil fuel.

In the use phase the biodiesel also has better results than the petro-diesel as the last one contributes in global warming approximately 350000 kg of CO_2 eq. per year and in acidification 647 kg of SO2 eq. per year as in the other hand we found that the biodiesel is much lower.

7   Recommendation and future work

It is recommended to do more LCA studies on this topic involving a largerboundary as including the waste process of both fuels to attain more accurate results and trying to find more data in our region and country if possible, furthermore we recommend to continue the work we have done as adding an economic analysis on this project comparing between the two fuels from price point of view and supporting the marketing process of the biodiesel.

8 References

1) Domestic production of biodiesel - health and safety warning website. http://www.hse.gov.uk/pubns/biodiesel.htm Last accessed on 12\11\2016.

2) Bryan R. Moser, Biodiesel production, properties, and feedstocks, In Vitro Cell.Dev.Biol.—Plant; March 2009,229-266.

3) Abile Teshita, Alemayehu Gashaw, Production of biodiesel from waste cooking oil and factors affecting its formation, International Journal of Renewable and Sustainable Energy;September 2014,95-97.

4) J.M. Marchetti_, V.U. Miguel, A.F. Errazu, Possible methods for biodiesel production, Renewable and Sustainable Energy Reviews; November , 2007,1300-1311.

5) Petro-diesel Cycle – Processes with p-V and T-s Diagrams website. http://mechteacher.com/diesel-cycle/ Last accessed on 12\11\2016.

6) Palligarnai, T.Vasudevan, Michael Briggs, Biodiesel production—current state of the art and challenges ,J Ind Microbiol Biotechnol; January 2008,421-430.

7) L. TalensPeiro, L. Lombardi , G. VillalbaMe´ndez, X. Gabarrell i Durany, Life cycle assessment (LCA) and exergetic life cycle assessment (ELCA) of the production of biodiesel from used cooking oil (UCO), Energy ,35; August 2010,889-893.

8) More about LCAwebsite. http://www.dantes.info/Tools&Methods/Environmentalassessment/enviro_asse_lca_detail.html Last accessed on 12\11\2016.

9) José Carlos Oliveira Santos, José PiresDantas, AntônioGouveia de Souza, Marta Maria da Conceição, SPECIFIC HEAT OF SOME VEGETABLE OILS BY DIFFERENTIAL SCANNING CALORIMETRY AND MICROWAVE OVEN;,610-614

10) Putting the metrics behind sustainability website. https://www.pre-sustainability.com/download/DatabaseManualMethods.pdf,%202016 Last accessed on 14\12\2016.

List of Figures