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Recycling of used cooking oil and biofuel production possibility in KRG

Bachelor thesis

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Recycling of used cooking oil and biofuel production possibility in KRG

Anotace:
Tento projekt se zaměřuje na využití odpadního rostlinného oleje (WCO) jako potenciální suroviny pro výrobu biodieselu. Dále hodnotí ekonomické a environmentální výhody použití WCO jako zdroje materiálu pro biodiesel. Studie zjistila, že WCO má vysoký potenciál jako surovina pro biodiesel díky jeho dostupnosti, nižším nákladům, obnovitelnosti a netoxické povaze. Nicméně, předzpracování WCO je nezbytné k odstranění nečistot a snížení obsahu volných mastných kyselin a vody. Studie dále navrhuje zavedení mechanismu pro sběr WCO z různých zdrojů, včetně potravinářských průmyslů, restaurací a domácností. Studie dále doporučuje výstavbu závodů na výrobu biodieselu z WCO, což by mohlo mít ekonomické výhody a možnost exportovat WCO do Evropy pro výrobu biodieselu. Celkově tato studie poskytuje náhledy na proveditelnost a potenciál využití WCO pro výrobu biodieselu v regionu Kurdistan.

Klíčová slova: Kurdistán, Odpadní olej na vaření, WCO, bionafta, fosilní paliva

Počet stran: 48
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Anotation:

The production of biodiesel from waste cooking oil offers several important benefits, including environmental sustainability by reducing pollution, energy independence by reducing dependence on imported oil, cost savings due to low production costs and the abundance of waste cooking oil. The main aim of this project is to investigate the possibility of using waste cooking oil (WCO) as a raw material for producing biodiesel, and to evaluate the economic and environmental benefits of this approach. The study shows that WCO has great potential as a biodiesel feedstock due to its renewable, non-toxic, and cost-efficient properties, as well as its wide availability. However, before use, WCO needs to be pre-treated to eliminate impurities and reduce free fatty acid and water content. To obtain WCO from various sources, including food processing plants, restaurants, and households, a collection mechanism should be established. Additionally, it is recommended to build biodiesel production plants that can provide financial returns, as well as to export the WCO to Europe for biodiesel production. This study provides valuable insights into the feasibility and prospects of using WCO for biodiesel production in the Kurdistan Region.

Keywords: Kurdistan, Waste Cooking oil, WCO, Biodiesel, fossil fuels

Number of pages: 48

Number of annexes:

Declaration

I declare that I have prepared the bachelor's thesis myself and that I have stated all the used information resources in the thesis.

In Olomouc, May 08, 2023 ....

Darvan Ali Mohammed

Acknowledgment

I would like to express my gratitude to Palacky University for their support and for providing me with the necessary resources to write my project. I am particularly grateful to the Department of Geology and the Petroleum Engineering program for their dedication to my education and for their hard work. I also want to extend my appreciation to my supervisor, Dr. Pavel Spirov, and my adviser, Mr. Rebar Mahmmud, for their guidance and assistance throughout the project.

Lastly, I am grateful to my family and all those who assisted me in completing my work.

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List of abbreviations

BP	British petrol
CO	Carbon Monoxide
CO_2	Carbon dioxide
SO_2	Sulfur Dioxide
WCO	Waste cooking oil
UCO	Used cooking oil
CI	Compression ignition
PFCE	Photon to fuel conversion efficiency
EASAC	European Academies Science Advisory Council
MMT	million metric tons
FFA	Free fatty acids
KRG	Kurdistan Regional Government

1. Introduction

As the world's population grows, there is a corresponding increase in the consumption of limited fossil resources. In response to this issue, new renewable fuels, including biofuels, have been developed (Yaakob et al., 2013). Furthermore, the use of diesel engines which have superior performance compared to gasoline engines, as well as the increase in petroleum prices, environmental concerns regarding car emissions, local changes in the atmosphere, and the growing interest in biofuels as a substitute for fuel, are all factors that contribute to this trend (Hosseini et al., 2012).

According to a report by BP (2020), there is a growing trend towards the use of fossil fuels and petroleum-based products, as evidenced by the increase in global diesel consumption from 3.5 million tons in 2010 to 3.9 million tons in 2019. The Asia-Pacific region, including countries like China, Japan, and Malaysia, also saw an increase in diesel consumption from 1.1 million tons in 2010 to 1.4 million tons in 2019. These figures emphasize the need for alternative diesel fuels to meet the rising demand worldwide (BP, 2020).

Biofuel is a promising solution to address the issue of dependence on fossil fuels, as it is obtained from renewable sources. Researchers have conducted various studies on biofuel as an alternative energy source to petroleum diesel and found that it possesses several advantages. It has high biodegradability and low toxicity, emits fewer combustion emissions compared to petroleum diesel, and contributes less to global warming as it follows a closed carbon cycle. Biofuel also has the advantage of being usable in existing diesel engines with only minor modifications and without significant loss of performance (Ahmad et al., 2011). Research has shown that the presence of enough oxygen in biofuel leads to a substantial decrease in exhaust emissions, such as CO, CO_2, SO_2, hydrocarbons, particulate matter, and smoke, in comparison to diesel fuel. This is because the existence of sufficient oxygen in biofuel causes complete combustion and reduces emissions (Fazal et al., 2011).

Although biofuels are considered a cleaner alternative to fossil fuels, but there are several problems associated with their production and use. One of the major problems is that the production and use of biofuels can still result in emissions of greenhouse gases, particularly carbon dioxide (CO_2), which contribute to climate change.

The production of biofuels requires land use for growing crops, which can lead to deforestation and the release of carbon stored in the trees and soil. In addition, the process of converting crops into biofuels can also produce emissions, such as from the use of fossil fuels in the farming and transportation of the crops, as well as in the processing and refining of the biofuels. Moreover, the energy balance of biofuels is not always favorable, as the amount of energy required to produce biofuels can sometimes exceed the amount of energy they produce. This means that the production and use of biofuels may not actually result in a net reduction in greenhouse gas emissions. Another problem is the competition for resources, such as land and water, between the production of biofuels and food production. The use of crops for biofuels can increase food prices and exacerbate food insecurity, particularly in developing countries (Jeswani et al., 2020). Overall, while biofuels have the potential to reduce greenhouse gas emissions in the transportation sector, there are significant challenges associated with their production and use, including emissions from the production process, competition for resources, and the energy balance of biofuels. These challenges must be addressed in order to maximize the potential benefits of biofuels as a climate solution.

The process of producing biofuel involves a reaction between alcohol and triglyceride, a raw material that can be found in both plants and animals. Plant sources for biofuel production can be categorized into two groups: edible oils, such as soybean, peanut, palm, rapeseed, and coconut oil, and non-edible oils, such as algae, Karanja, sea-mangoes, jatropha, and halophytes. However, there are several challenges associated with their use, such as the food versus fuel crises, significant environmental issues like deforestation and soil depletion, and the need for a large amount of arable land. Furthermore, some sources may not be capable of meeting global energy demand adequately and may not perform well in cold weather conditions. Animal-derived triglycerides come mainly from tallow, yellow grease, chicken fat, and fish oil by-products, but their usage is challenging because many animal fats contain high levels of saturated fatty acids (Mustafa, B., 2010).

To address some of the issues related to the production of biofuel, a study was conducted to develop new raw materials for use in biofuel production. The study found that waste cooking oil (WCO) could be used as an alternative to palm oil, which is expensive and has environmental concerns associated with its production. WCO is similar to palm oil in terms of biofuel production and is less expensive.

Waste cooking oil is a byproduct of cooking and can be obtained from households or businesses. By recycling waste cooking oil, it can be used as a renewable feedstock to produce biofuels and biobased products while also decreasing greenhouse gas emissions and preventing environmental harm caused by improper disposal. Moreover, using waste cooking oil for non-food purposes such as generating electricity can help to prevent it from entering the food chain (Tsai, 2019). To promote the recycling of unused waste cooking oil, it is necessary to reduce food waste, which is essential for sustainable development. Although it has traditionally been used for biofuel production, waste cooking oils have great potential for producing oleochemicals. UCOs can be used to make plasticizers, binders, epoxides, surfactants, lubricants, polymers, biomaterials, and other building blocks, providing long-term supply chain stability, and reducing reliance on commodity products (Orjuela and Clark, 2020).

The common method used to produce biofuel from waste cooking oil (WCO) is transesterification, and several factors must be taken into account during the process, such as temperature, reaction time, alcohol to oil molar ratio, and catalyst. Optimal conditions for producing biofuel from WCO have been investigated in studies by Meng, X. and Chen, G. in 2008 and Topare et al. in 2008. The study by Meng, X. and Chen, G. found that a methanol to oil molar ratio of 9:1, 1.0wt% sodium hydroxide, a temperature of 50°C, and a reaction time of 90min produced a yield of 89.8%. The study by Topare et al. used a methanol to oil molar ratio of 6:1, 1.5wt% CaO, a temperature of 60°C, and a time of 60min, resulting in a yield of 93% biofuel.

1.1.Problem Statement

Although some countries utilize waste cooking oil (WCO) to produce soap and other valuable products, a significant amount of WCO generated globally is still being released into the environment. Kurdistan, like many other countries, faces waste management issues due to poor public participation and compliance in waste management practices such as waste collection and recycling. Unlike other countries such as Japan, the United States, Taiwan, China, and Singapore, Kurdistan does not have a specific policy regulating WCO management. Consequently, WCO is improperly disposed of, leading to various negative consequences such as water pollution, destruction of aquatic life, clogging of drains and sewer overflow, unpleasant odor and vermin in the surroundings, and the creation of breeding grounds for bacteria and viruses. Therefore, the WCO collection and recycling program requires careful evaluation and the use of appropriate methods to gather data on consumers.

1.2. Aim of study

The aim of this project is to produce the biofuel from the waste cocking oil, which can be summarized as follows:

1. Calculate the daily amount of the waste cooking oil of all restaurants in the Kurdistan Region of Iraq.
2. Calculate and evaluate the total amount of the waste cooking oil that can be converted to the biofuels.
3. Show the methods and mechanisms of collecting the waste cooking oil from the restaurants to the processing plant.
4. Show the methods and techniques used for processing the waste cooking oil to the biofuels.

2. Literature review

2.1. Biofuel

Biofuel is a term used to describe any fuel that is made from organic matter such as crops, wood, and waste. The chemical reactions involved in the process of converting biomass into biofuel may differ depending on the specific type of biofuel being produced. Ethanol and biodiesel are the most common types of biofuels (Jeswani et al., 2020).

Ethanol, which is a form of alcohol, is produced from crops like corn, sugarcane, and wheat. During the production of ethanol, enzymes and yeast break down the starch or sugar in the crops through a process called fermentation, resulting in the creation of ethanol and carbon dioxide as byproducts. Ethanol can be used as an additive to gasoline, and newer vehicles are designed to operate on a blend of gasoline and ethanol, such as E10 (10% ethanol and 90% gasoline) or E15 (15% ethanol and 85% gasoline).

In contrast to ethanol, biodiesel is a renewable diesel fuel produced from sources like vegetable oils, animal fats, or recycled cooking oil. To create biodiesel, the oil or fat is mixed with an alcohol like methanol through a process called transesterification, resulting in the production of biodiesel and glycerin byproducts. Unlike ethanol, biodiesel can be used directly in diesel engines without any modifications, or it can be blended with regular diesel fuel in different proportions (Hannah, 2022).

Second-generation biofuels, however, are derived from non-food sources like algae, switchgrass, and wood chips, and require more advanced technology such as thermochemical conversion. This involves heating the biomass in the absence of oxygen to produce a gas or liquid fuel. Third-generation biofuels are made from algae, while fourth-generation biofuels are still in the experimental stage and are being developed from advanced conversion technologies such as genetically engineered crops and synthetic biology. These biofuels have the potential to be more sustainable and efficient than earlier generations of biofuels (Figure 1).

Biofuels are considered a viable alternative to petroleum-based fuels because they are renewable, emit fewer greenhouse gases, and can reduce dependence on foreign oil. However, the production of biofuels can also have environmental and social impacts, such as increased land use, competition with food crops, and water usage (Bergtold et al., 2017).

Therefore, the development of sustainable biofuel production practices is critical to maximizing the benefits and minimizing the negative impacts of biofuels.

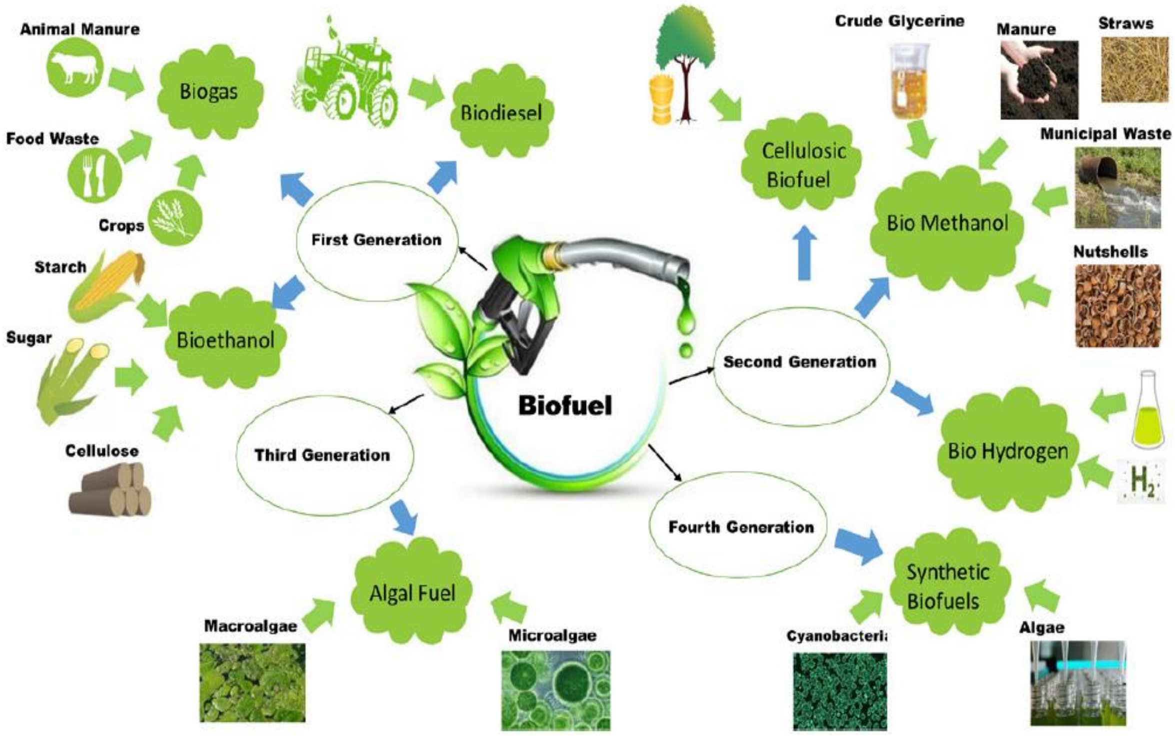

Figure 1 A diagram show the various kinds and production methods of biofuels (Javed et al., 2019).

2.2.Biodiesel

Biodiesel is a type of fuel made from monoalkyl esters of long-chain fatty acids. It can be derived from a variety of sources, including edible, non-edible, and waste oil feedstocks (Singh et al., 2020). Biodiesel has properties that are similar to conventional diesel fuel, which makes it a viable alternative for use in CI engines. The fuel is considered to be environmentally friendly because it does not contain sulfur, has a high cetane number, a high flash point, and is non-toxic, sustainable, and renewable (Marwaha et al., 2018). Additionally, the absence of sulfur in the fuel helps increase the lifespan of the engine (Aghbashlo et al., 2016). Biodiesel can be stored safely due to its higher flash point compared to regular diesel fuel (Farooq et al., 2013). Overall, biodiesel is a promising green fuel with unique characteristics that make it an attractive option in the energy sector.

2.3. Generations of biodiesel

Based on the type of feedstock utilized, the European Academies Science Advisory Council (EASAC) has divided biodiesel into four generations. Edible oil, non-edible oil, and waste-derived feedstocks are used, respectively, in the first three generations of biodiesel. The fourth generation of biodiesel feedstocks, known as solar biodiesel, makes use of synthetic biological technologies. Solar biodiesel is superior to previous generations of biodiesel in terms of quality and photon to fuel conversion efficiency (PFCE), however research on this form of feedstock is still in its infancy and the cost of manufacturing is very high (Singh et al., 2019). The most promising sources for the manufacture of biodiesel are therefore third-generation biodiesel feedstocks. Table 1 lists different third-generation biodiesel feedstocks together with information on their main producers and oil yields percentage.

Table 1 A summary of different types of feedstocks suitable for third-generation biodiesel, including their main sources, oil yield percentage, and producer countries (Singh et al., 2021).

Feedstocks	Primary Sources	Oil Yield (%)	Major Producer Countries
Microalgae	Marine and freshwater environments	25-80	USA, China, India, Japan
Macroalgae	Marine environments	10-30	Japan, Korea, China
Yeast	Agricultural and forest residues	2-20	USA, Canada, China, EU
Fungi	Agricultural and forest residues	2-15	EU, USA, China
Bacteria	Waste and industrial effluents	2-20	EU, USA, China, Brazil
Waste cooking oil (WCO)	Restaurants, food processing industries	75-85	China, USA, EU
Animal fats	Meat processing and rendering	50-70	EU, USA
Jatropha curcas	Marginal lands	30-40	India, Philippines, Africa
Pongamia pinnata	Marginal lands	20-25	India, Australia, Africa
Camelina sativa	Arid lands	35-45	USA, Canada, Europe

2.4. Waste cooking oil as a source of fuel

To ensure the economic feasibility of biodiesel production, manufacturers prioritize the use of low-cost feedstocks such as waste oils (Singh et al., 2020). If waste oils are not properly disposed of, they can contribute to water contamination, according to research by

Gui et al. (2008). Waste oils can be obtained from various sources such as the food and non-food sectors, restaurants, and households. Biodiesel production can also use non-food sector feedstocks such as waste tyre oil and waste plastic oils, which are typically converted using pyrolysis. Waste Cooking Oil (WCO) from different edible oils can also be used for biodiesel production (Figure 2). The global consumption of edible oils was estimated to be 191.71 million metric tons (MMT) in 2019-20, with palm, soybean, rapeseed, sunflower, peanut, cottonseed, coconut, and olive oil being the main sources. It is difficult to accurately estimate WCO production from edible oils due to a lack of reporting (Loizides et al., 2019). Jiang and Zhang in 2016 presented WCO generation data using Eq. (1).

$$\text{WCO generation} = \frac{(\text{Population} \times \text{Per capita edible oil consumprtion})\,\text{x}\,30}{100} \qquad \text{Eq. (1)}$$

Figure 2 Show an example of biodiesel which produce from waste cooking oil (Chhetri et al., 2008).

According to Equation 1, the world produced around 57.51 million metric tons (MMT) of waste cooking oil (WCO) in the 2019-20 periods. Using WCO for biodiesel production can be a solution to the expensive cost of feedstock. Nevertheless, the water content in WCO is higher than in fresh oils due to cooking and frying, which can cause an increase in free fatty acid (FFA) content and saponification during production, resulting in lower output and higher catalyst requirements. As a result, it is necessary to pre-treat the oil. Effective transesterification processes can be employed after pre-treatment to produce biodiesel at a reasonable cost. (Buffi et al., 2017).

2.5. Sources of WCO

Edible oils are extensively used by the food processing industries and fast-food chains for frying food items (Jamil et al., 2018). The process of frying involves submerging the food in oil, along with moisture, antioxidants, and prooxidants, at temperatures ranging from 150 to 200 C (Safari et al., 2018). This leads to various chemical reactions in the oil, such as hydrolysis, oxidation, polymerization, breakdown, and isomerization (Cao et al., 2017). These oils, once used for frying, are generally considered waste, but they can be utilized for producing biodiesel (Figure 3). Several types of edible oils, such as palm, canola, corn, rapeseed, mustard, and cottonseed, are used for biodiesel production after being utilized for frying or cooking. The significant producers of waste cooking oil include China, the European Union, Malaysia, Japan, and the United States (Figure 4).

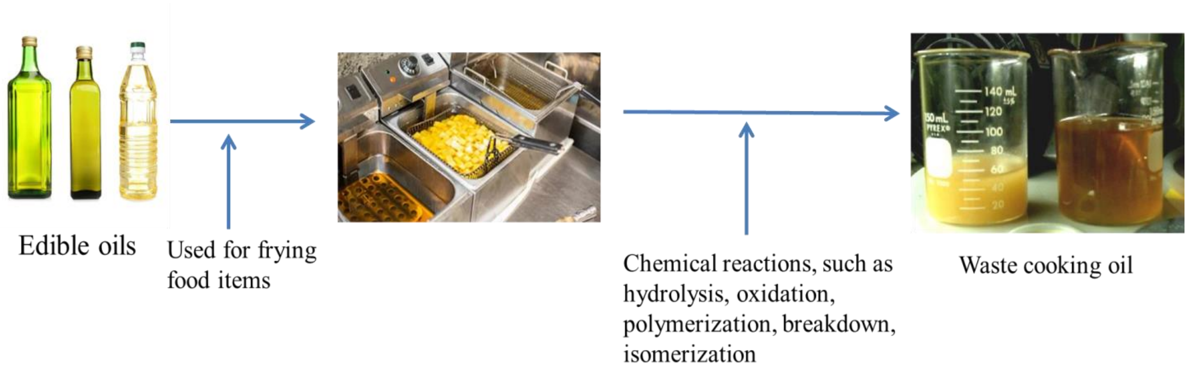

Figure 3 Show how waste cooking oil produced.

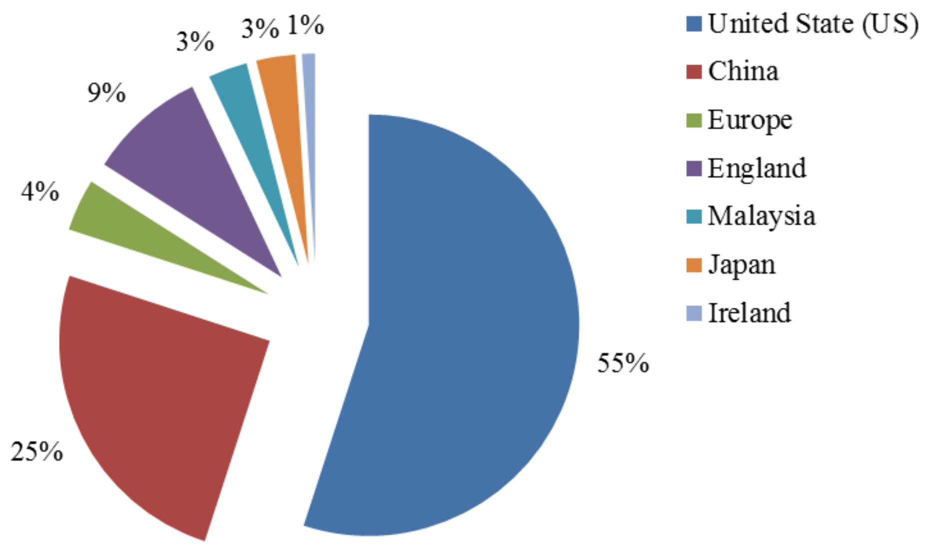

Figure 4 Show the important waste cooking oil producers' countries (Wan et al., 2016).

2.6. Environmental impact of waste cooking oil

Improper disposal of waste cooking oil can have several negative environmental impacts, including water pollution, soil contamination, greenhouse gas emissions and resource depletion (Yuanhao et al., 2021).

When cooking oil is poured down the drain, it solidifies and sticks to the inside of pipes, which can eventually lead to a blockage. Over time, this can lead to serious problems, including backups and overflows, which lead to the release of untreated wastewater into rivers, lakes, and oceans. This can harm aquatic life and affect the quality of drinking water. In addition to causing blockages in the sewage system, waste cooking oil can also contribute to the formation of "fatbergs," which are large masses of solidified fat, oil, and grease that can accumulate in sewer pipes. These fatbergs can be difficult and costly to remove and can cause serious damage to the sewage system infrastructure (Tsoutsos et al., 2016).

Waste cooking oil can also have a negative impact on soil if it is not disposed of properly. If waste cooking oil is dumped directly onto soil, it can seep into the ground and contaminate the soil. The high levels of fat and oil in waste cooking oil can cause soil compaction, which can make it difficult for plants to grow and can lead to reduced soil fertility. Additionally, waste cooking oil can attract pests and rodents, which can further damage the soil and crops. The oil can also affect the microbial activity in the soil, which can have a negative impact on the health of the soil and the plants that grow in it. Waste cooking oil that is not properly disposed of can release methane, a potent greenhouse gas that contributes to climate change. Methane is produced when organic matter, such as waste cooking oil, decomposes in landfills or in the environment. Moreover, when waste cooking oil is not recycled, it is a wasted resource that could have been used to produce biodiesel, a renewable energy source that can reduce dependence on fossil fuels. Therefore, collecting waste cooking oil is a beneficial practice for several reasons (Dias et al., 2014). Proper collection and disposal of waste cooking oil can help protect the environment by reducing water pollution, soil contamination, and greenhouse gas emissions. Additionally, recycling waste cooking oil into biodiesel can reduce reliance on fossil fuels, promoting sustainable resource management. Collecting and recycling waste cooking oil can also save money for businesses and households by reducing the frequency of drain blockages and plumbing problems. Moreover, it can generate revenue for those who collect and sell it to biodiesel manufacturers, creating jobs and stimulating local economies. Furthermore, collecting waste cooking oil can be a way to engage with and educate the community about the importance of proper waste disposal and sustainability.

Blockages in pipes WCO contaminate soil WAC contaminate rivers, lakes, ..etc.

Figure 5 Show the effect of improper disposal of waste cooking oil on the environment (modify after HGIC, 2019).

2.7. Collection of waste cooking oil (WCO)

Waste oils generated by food processing industries are often sent directly to biodiesel production units, and some industries may utilize their waste oil for biodiesel production and use the resulting biodiesel to power their machinery.

The process of collecting waste cooking oil for the production of biodiesel involves the identify source of waste cooking oil, collecting the waste cooking oil and transporting the waste cooking oil (Figure 6). For identify a source of WCO, contact local restaurants, cafeterias, or other food service establishments to inquire about their waste cooking oil. Many of these establishments may already have arrangements in place for the collection and disposal of their used cooking oil. Once you have identified a source of waste cooking oil, collect it using appropriate containers, such as plastic drums or tanks that are suitable for the quantity of oil you plan to collect. Make sure that the containers are clearly labeled and properly sealed to prevent any spills or leaks. Then, transport the collected waste cooking oil to a biodiesel processing facility using a suitable vehicle. Make sure to comply with any regulations for the transportation of hazardous materials, such as the use of appropriate signage and equipment.

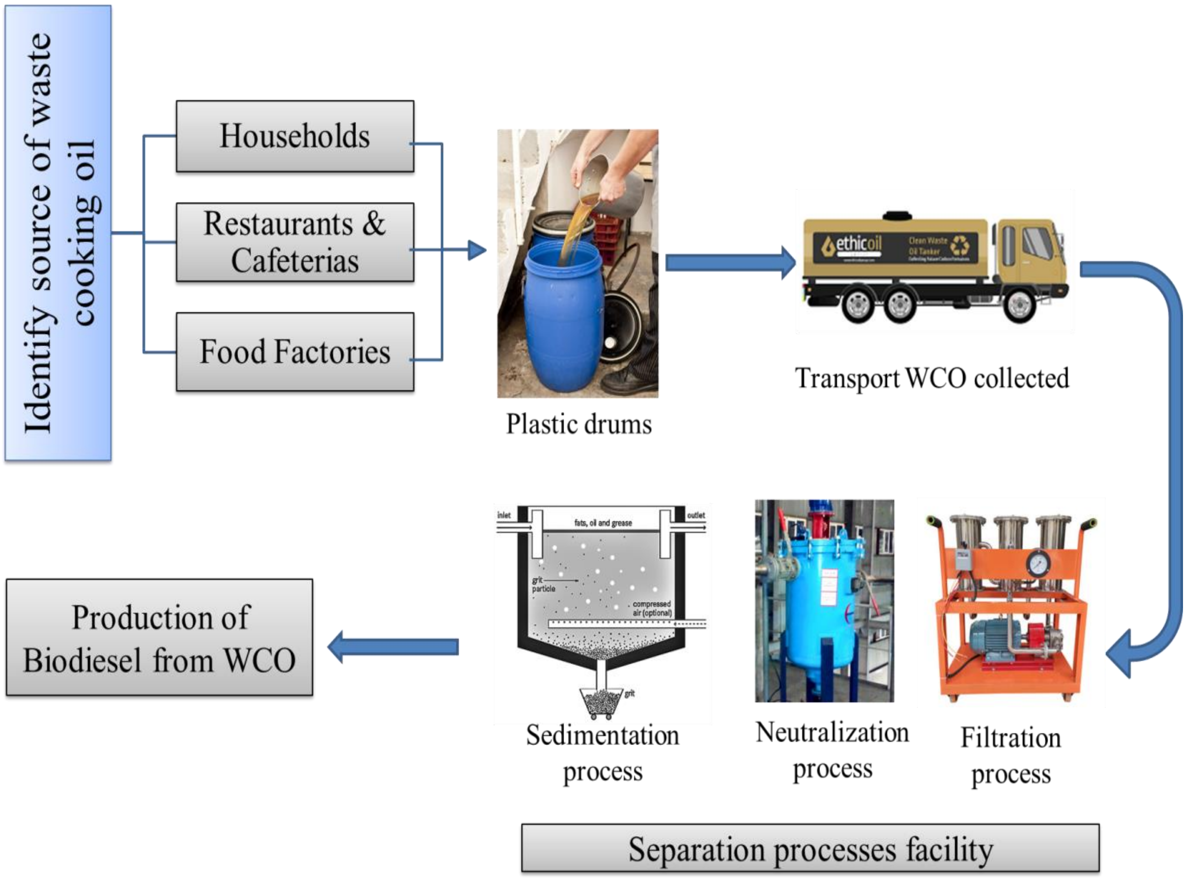

Figure 6 Collection process of waste cooking oil (Modify after Eliezer et al., 2016)

2.8. Pre-treatment of WCO

Reusing cooking oil for frying can lead to increased viscosity, acidity, specific heat, and an unpleasant odor. This makes it necessary to pre-treat waste cooking oil (WCO) to make it economically viable for further use. During frying, water from the food mixes with the oil and causes hydrolysis of triglycerides, resulting in the formation of more free fatty acids (FFAs), which increases the viscosity and acidity of the waste oil. The high water and FFA contents of WCO make it difficult to produce biodiesel, and these levels must be lowered before proceeding with further production steps (Cao et al., 2017).

There are several pre-treatment methods that can be used to reduce the levels of water, free fatty acids (FFA), and viscosity in used cooking oil (WCO). These processes include neutralization, vacuum filtration, ion exchange resin, film vacuum evaporation, steam and sedimentation, steam injection, neutralization, vacuum filtration, and reaction with glycerin and catalyst (Kulkarni and Dalai, 2006). Furthermore, pre-treatment helps remove solid contaminants that might have been added during the handling and cooking procedures

(Figure 7). High water content can be removed from the WCO by heating it to 100°C (Li et al., 2014), and acid ion exchange resins can be used to lower the FFA concentration. Moreover, the FFA content of glycerin can be reduced by using a catalyst of zinc chloride at 200 °C, resulting in the conversion of FFA into monoglycerides and diglycerides (Ozbay et al., 2008). Ultimately, the esterification procedure or transesterification reaction can be used to further process pre-treated WCO for the creation of biodiesel.

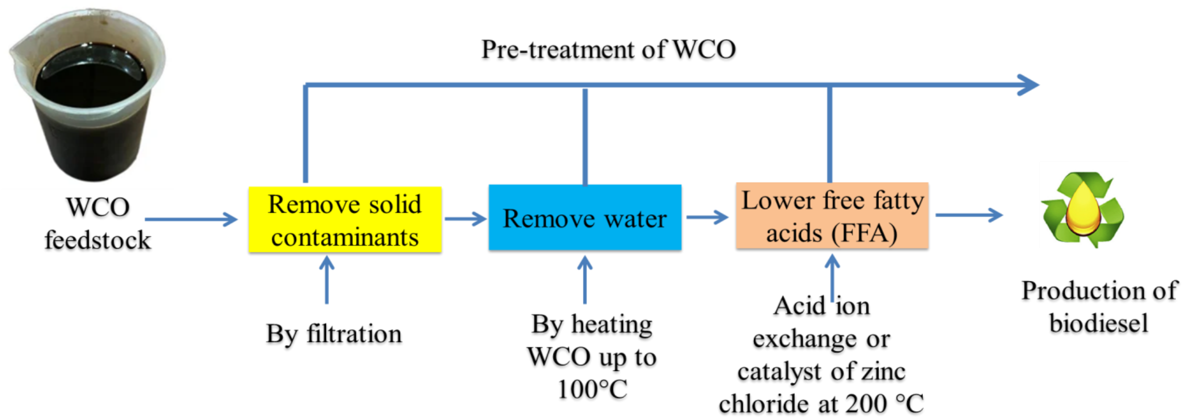

Figure 7 Show pre-treatment processes of waste cooking oil (Modify after Singh et al., 2020).

2.9. Production of biodiesel from WCO

To produce biodiesel from oil's fatty acids, it is necessary to reduce the length of their carbon chains. A study by Hajjari et al. (2017) outlines the steps involved in creating biodiesel from waste cooking oil (WCO), which includes the collection and pre-treatment of the oil, reducing its viscosity, and processing it after production. Verma and Sharma (2016) suggest several methods for making biodiesel, such as transesterification, thermal cracking (pyrolysis), micro-emulsification, and dilution/mixing. Figure 8 illustrates the complete process of converting WCO into biodiesel.

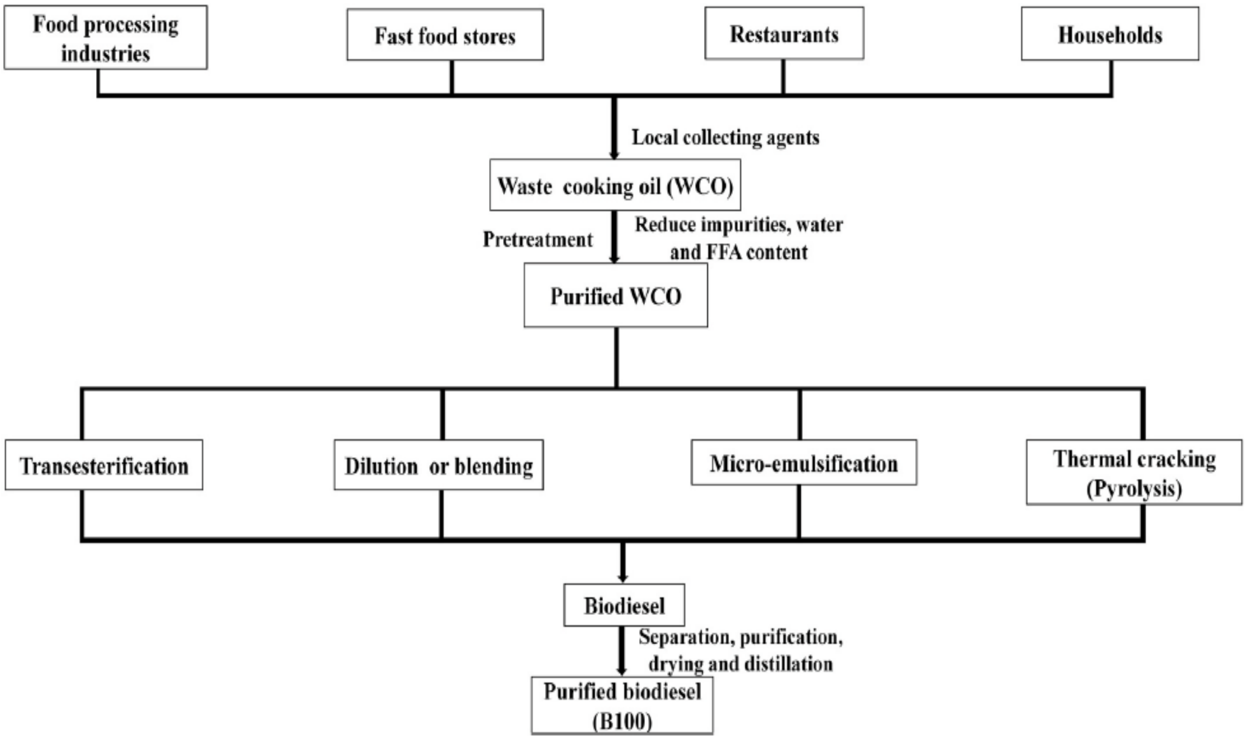

Figure 8 Illustrate processes for the production of biodiesel from WCO (Singh et al., 2020).

As soon as the pre-treatment procedure is finished, the production of biodiesel from waste cooking oil (WCO) is comparable to the manufacture of biodiesel from vegetable oils. Yet there are a number of things to take into account, including high viscosity, high free fatty acid (FFA) concentration, water content, density, and more, which make it inappropriate for direct use in compression ignition (CI) engines. Excessive water content can increase engine wear and cause corrosion, while high viscosity can cause gum to build in the combustion chamber and injection system. Lifespan of the engine is also decreased by the high acidity of the gasoline. Reducing each of these values to acceptable ranges is therefore essential. In order to lower these values and produce biodiesel from waste oils, several techniques are used, including transesterification, dilution (blending), micro-emulsification, and thermal cracking (pyrolysis).

2.9.1. Transesterification

Transesterification or alcoholysis is the process by which fats or vegetable oils are transformed into FAME and glycerol. This procedure uses a particular ratio of alcohol to catalyst and takes place at a predetermined temperature. When one mole of triglycerides combines with three moles of alcohol, three moles of esters and one mole of glycerol are produced. The reaction is depicted in Figure 9, and a higher amount of alcohol is preferred to maximize the yield of biodiesel. Choosing the appropriate catalyst is critical as an unsuitable one can led to increased soap formation. Acid, base, enzyme, and nano-catalysts are some of the available options, but alkali catalysts are preferred due to their high product yield. Methanol is the preferred alcohol for transesterification as it is less expensive (Zou et al., 2013). Figures 10 and 11 illustrate the process of transesterification for producing biodiesel from waste cooking oil (WCO).

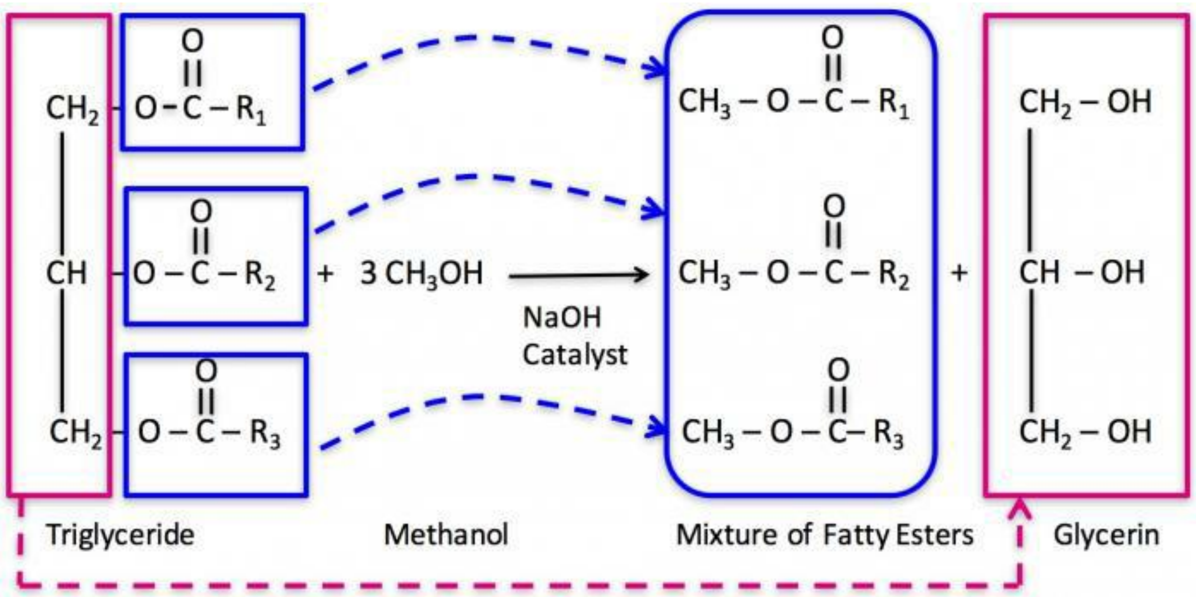

Figure 9 Demonstrate the transesterification reaction technique used to convert fats or waste oils into biodiesel (Singh et al., 2021).

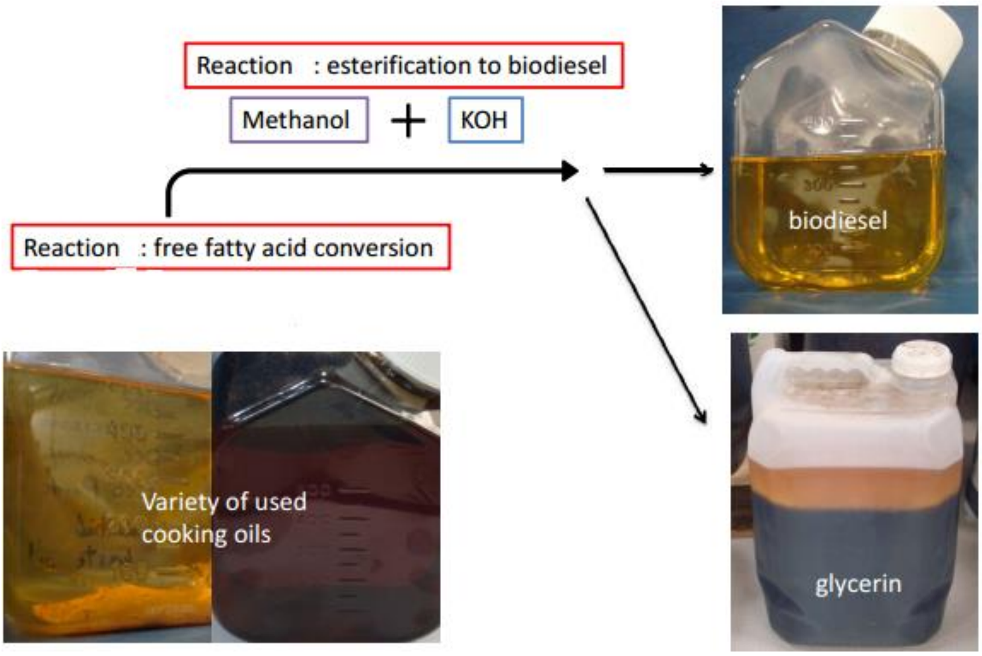

Figure 10 show the process of produce biodiesel from WCO by transesterification method (Gumahinet al., 2019)

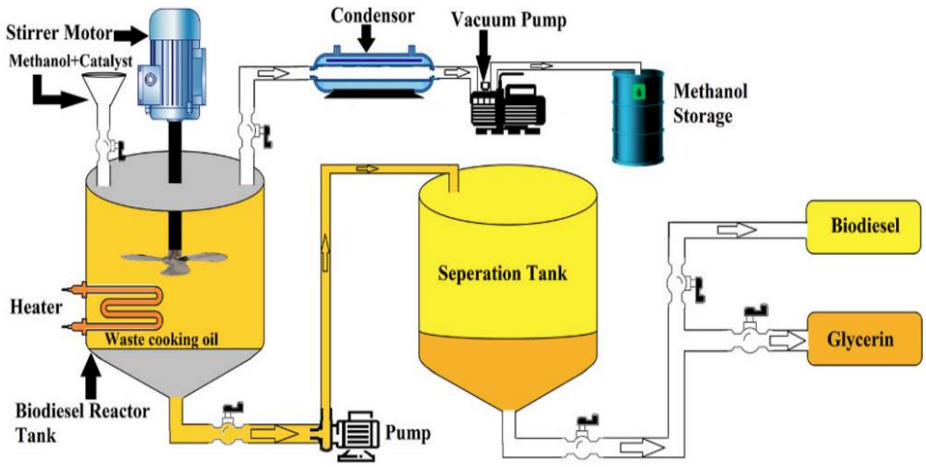

Figure 11 A diagram that illustrates the process of producing biodiesel using transesterification reaction (Singh et al., 2021).

2.9.2. Dilution or blending

Blending or dilution is the process of directly combining pre-treated waste cooking oil (WCO) with diesel fuel (Figure 12). However, this can cause problems in engines due to the high levels of water and free fatty acids (FFA) in WCO, which can lead to engine wear and reduced performance. The use of high viscosity WCO directly in compression ignition (CI) engines can also cause the formation of gum, blockage of injector nozzles, and the deposition of high levels of carbon on piston heads. To mitigate these issues, a small percentage (around 20%) of WCO is usually blended with traditional diesel fuel to reduce its viscosity (Singh and Singh, 2010).

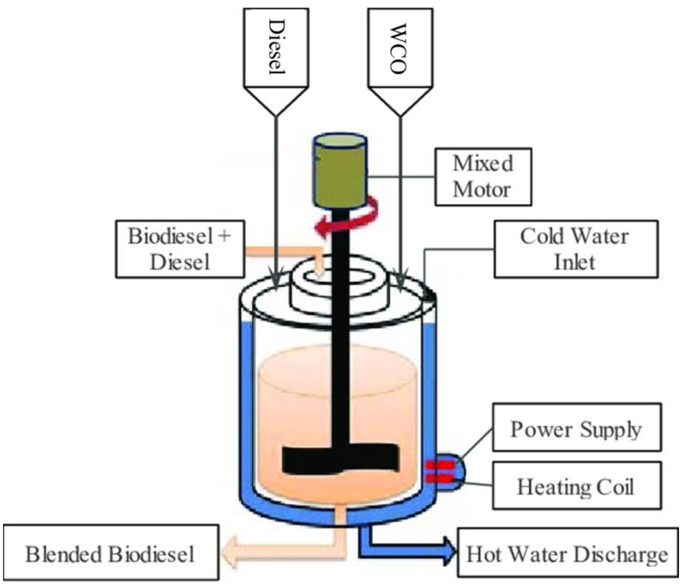

Figure 12 Show the production of biodiesel from WCO by blending process (Khalid et al., 2014).

2.9.3. Micro-emulsification

Micro-emulsification refers to the process of creating a stable mixture of a homogeneous fluid, which is optically isotropic, at a colloidal level. This technique can be used to reduce the viscosity of waste cooking oil (WCO). By using solvents such as octanol, hexanol, butanol, ethanol, and methanol, the viscosity of the oil can be lowered to the desired level. This technique can also increase the fuel's spray characteristic by creating explosive vapors at a low boiling point (Koh and Ghazi, 2011). However, using micro-emulsified fuel in compression ignition (CI) engines for an extended period can lead to issues such as incomplete combustion, high carbon deposition, and injector nozzle sticking.

2.9.4. Thermal cracking or pyrolysis

Anaerobic decomposition, or thermal cracking, is the process of breaking down oil by heating it to a medium temperature range without exposing it to oxygen or air. With this technique, different sorts of oils, including vegetable oils, waste plastic, and used tire oils, can be transformed into biodiesel. Depending on the particular needs, the process can be run with or without a catalyst. The pyrolysis process's temperature is the most important variable for this approach. Nevertheless, because this method requires a lot of energy, the cost of the biodiesel produced using this method is expensive. The poor biodiesel yield and high costs make it a less than ideal technique for manufacturing biodiesel from waste cooking oil (WCO) (Jain and Sharma, 2010).

2.10. The downstream processing of biodiesel produced from waste cooking oil

Once the fundamental steps of biodiesel production are finished, additional downstream procedures are necessary to create biodiesel that meets standard requirements. These procedures involve separation, purification, drying, and distillation (Figure 13).

There is an excess of glycerol, catalyst, and methanol in the finished biodiesel after the production process is finished. Gravity-based separation can be used to separate the glycerol from the biodiesel because their specific gravities differ. Additional separation techniques include sedimentation, microwave irradiation, and the decantation technique to separate the glycerol from the biodiesel. The use of a separating funnel is the most economical method of all these to separate glycerol from biodiesel (Meng et al., 2008).

Several contaminants, such as alcohol, catalyst, soap, and other dissolved compounds, may be present in biodiesel after it separates from glycerol (Chozhavendhan et al., 2020). With the following techniques, these contaminants can be removed:

1. Alcohol can be removed by evaporation using a vacuum pump.
2. Mist, bubble and stir, wet and dry procedures can be used to wash biodiesel to remove unreacted oil, soap, and catalyst.
3. Alcohol, water, and sodium soap can all be separated using a membrane extraction process.
4. Calcium ions can be removed from crude biodiesel by applying the precipitation method, as proposed by.

In some cases, certain impurities that are dissolved can be challenging to separate because they can form an emulsion. To overcome this issue, centrifugal brakes and sodium chloride can be utilized to speed up the process of phase separation.

Biodiesel appears transparent instead of colorless in its pure form, and the presence of smoke or cloudiness indicates that it needs purification. Drying biodiesel can be accomplished through heating and the use of chemicals. The two most recommended techniques for drying biodiesel are heating and chemical processing. Biodiesel just needs to be heated to 55°C for 15-20 minutes to dry it, following which any water left over can be drained or evaporated. Additionally, heating can also eliminate residual concentrations of alcohol. The most widely utilized chemical for cleaning WCO biodiesel is anhydrous sodium sulfate; however other industrial substances, including anhydrous magnesium sulfate, have also been employed for drying (Felizardo et al., 2006). The last purification phase for producing biodiesel from WCO involves distillation, which is necessary to obtain a final product that meets standard specifications. According to Zullaikah et al. (2005), distillation is a widely used method to eliminate undesired impurities and odor from biodiesel. This process can be accomplished using a condenser and a vacuum gauge.

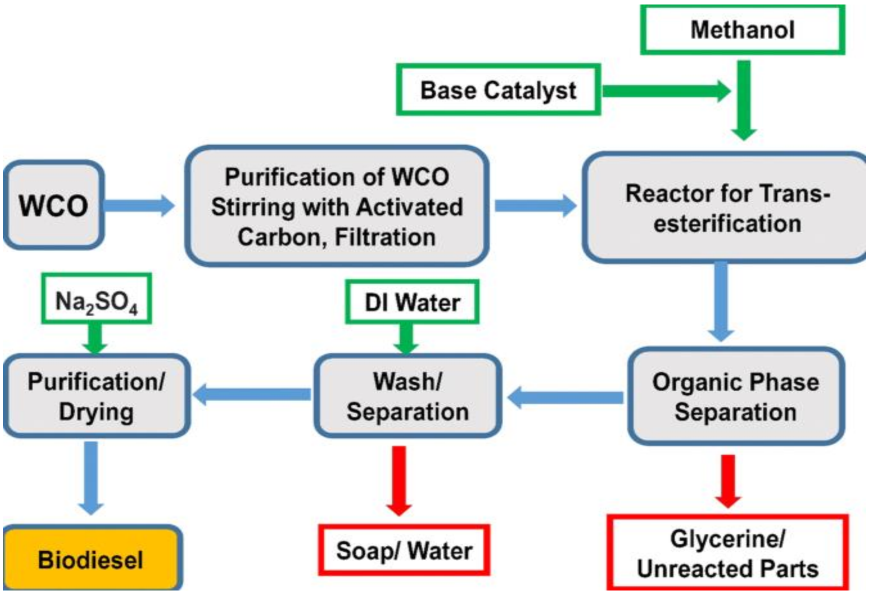

Figure 13 A diagram that illustrates a methodical process for creating biodiesel from waste cooking oil (Samanta and Sahoo, 2021).

2.11. Characteristics of waste cooking oil biodiesel

Vegetable oil undergoes physical and chemical changes when it is used for frying, which result in oligomeric compounds being formed, which decrease volatility and increase molecular weight. Oleic acid (45.15%) and linoleic acid (39.74%) are the two main acids found in waste cooking oil (WCO). Biodiesel's physicochemical characteristics might change depending on the amount of free fatty acids present (Felizardo et al., 2006). The number and length of carbon chains, as well as the presence or absence of double bonds, all affect the fatty acid profile. Stearic acid is a saturated fatty acid that contains no double bonds. On the other hand, unsaturated fatty acids like linoleic acid have double bonds, which limit carbon atoms from forming the strongest possible bonds with hydrogen atoms. The performance of biodiesel in compression ignition engines can be impacted by changes in the physicochemical properties (Chozhavendhan et al., 2020).

When compared to diesel fuel, biodiesel made from waste cooking oil (WCO) has different physical and chemical characteristics (Table 2). WCO biodiesel is physically superior to diesel fuel in terms of density, viscosity, and flash point. This indicates that WCO biodiesel has a higher tendency to ignite and is thicker and less energy-dense than diesel fuel. Moreover, WCO biodiesel has a higher pour point than diesel fuel, which implies it may solidify at lower temperatures.

In terms of chemical properties, when compared to diesel fuel, WCO biodiesel has a greater acid value and water content. The acid value of biodiesel measures the amount of acidic compounds in the fuel, which can contribute to engine corrosion and decrease the fuel's storage stability. The water content of biodiesel can cause fuel filter plugging and microbial growth, which can lead to engine damage. Moreover, compared to diesel fuel, WCO biodiesel has a lower sulfur concentration. This makes it a more environmentally friendly substitute for diesel fuel because it emits fewer hazardous emissions like sulfur dioxide and particulate matter when burned. WCO biodiesel also has a higher cetane number than diesel fuel, which measures the fuel's combustion quality. A higher cetane number indicates that the fuel burns more effectively and ignites more readily, improving engine performance.

Table 2 Comparing waste cooking oil (WCO) biodiesel's physical and chemical properties to those of diesel fuel (Singh et al., 2021).

Property	**Unit**	**Range of Values**	
		WCO biodiesel	**diesel fuel**
Density	kg/m^3	870 - 900	833 - 881
Viscosity	mm^2/s	3.5 - 6.0	1.9-4.1
Flash Point	°C	120 - 170	70°C
Cloud Point	°C	0-15°C	10°C
Pour Point	°C	-7°C	-6°C
Cetane Number	-	47.7-59.8	40-55
Acid Value	mg KOH/g	0.67-3.64	0.5
Sulfur Content	%	0.015	0.05
Water content	%	0.8-1.9	0.02

2.12. WCO as a source of biofuel in the European Union

The use of waste cooking oil (WCO) for producing biodiesel in the EU is expected to rise substantially, particularly due to the Renewable Energy Directive II. WCO can be utilized to decrease carbon dioxide emissions in road transportation and is frequently proposed as a potential source for sustainable fuels in shipping and air travel (ECA, 2016).

Only five Member States, namely Germany, France, Italy, Spain, and the Netherlands, dominate the production of biodiesel in the EU+UK, which amounted to 2.8 million tonnes in 2019. Approximately 18.5% of the biodiesel produced in the EU comes from waste cooking oil, which is comparable to the 19% share in consumption. Furthermore, almost all of the biodiesel produced in the EU is designated for the European market. The changes in the feedstock used for biodiesel production in the EU are demonstrated in Figure 14.

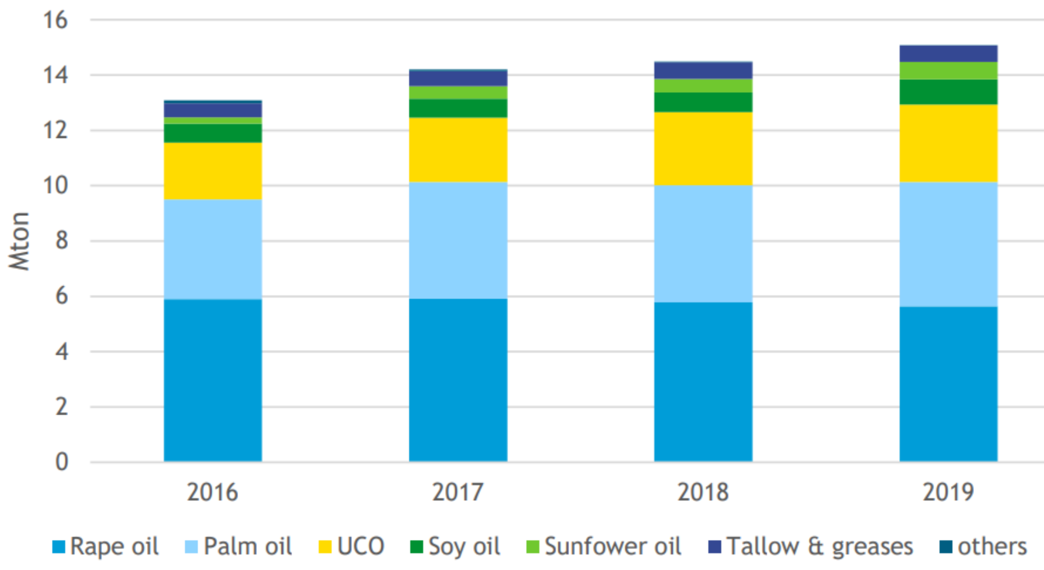

Figure 14 Show different feedstock used to produce biodiesel in EU (Eurostat, 2020).

Europe has several refineries that produce biodiesel from waste cooking oil, which is a sustainable way to reduce greenhouse gas emissions and promote circular economy. Some of the most prominent companies in this sector include Neste, Greenergy, VERBIO, and Bio-Oil. Neste, a Finnish company that produces renewable diesel and other renewable products. They have several refineries in Europe, including one in Rotterdam, the Netherlands, that produces renewable diesel from waste cooking oil. The refinery has a production capacity of 800,000 tons of renewable diesel per year, and it is one of the largest renewable diesel refineries in the world. Neste sources its waste cooking oil from various European countries, including the Netherlands, Belgium, and Germany. Greenergy is another UK-based company that produces biodiesel from waste cooking oil. They have a biodiesel refinery in Immingham, UK, which produces around 100 million liters of biodiesel per year. Greenergy sources its waste cooking oil from various sources, including restaurants, food manufacturers, and supermarkets. The company has a dedicated team that works with waste collectors and local authorities to ensure a reliable and sustainable supply of waste cooking oil (GREENEA, 2016 and 2018).

VERBIO is a German company that produces biodiesel from waste cooking oil, among other renewable fuels. They have several refineries in Germany, including one in Schwedt, which produces biodiesel from waste cooking oil. The refinery has a production capacity of

150,000 tons of biodiesel per year. VERBIO sources its waste cooking oil from various sources, including restaurants, canteens, and food manufacturers. Bio-Oil is a Belgian company that produces biodiesel from waste cooking oil (Eurostat, 2020). They have a refinery in Ghent, Belgium, that produces around 30,000 tons of biodiesel per year. Bio-Oil sources its waste cooking oil from various sources, including restaurants, food manufacturers, and households. In addition to these companies, there are many other refineries in Europe that produce biodiesel from waste cooking oil (NNFCC, 2019). These refineries are leading the way in sustainable fuel production and demonstrate the potential for waste cooking oil to be transformed into a valuable resource for renewable energy. By using waste cooking oil as a feedstock for biodiesel, these companies are contributing to the circular economy and reducing the environmental impact of the transportation sector.

2.13. Case studies

In 2013, the London Borough of Barking and Dagenham launched a project to collect waste cooking oil from households and convert it into biodiesel. The project was called "Green Redeem", and it was a partnership between the borough council and a waste management company called Living Fuels. Under the project, residents could deposit their used cooking oil at designated recycling bins, which were then collected and transported to a plant where the oil was converted into biodiesel. The biodiesel was used to power the borough's fleet of vehicles, including buses and waste collection trucks. The project was a success, and it helped the borough reduce its carbon emissions by 20% (London Borough of Barking and Dagenham, 2018).

Another real case study about the conversion of waste cooking oil into biodiesel is the project carried out by the city of Paris, France. In 2016, the city launched an initiative called "Huile Pro" (Pro Oil), which aimed to collect waste cooking oil from restaurants and households and convert it into biodiesel. Under the Huile Pro initiative, the city installed 146 collection points throughout Paris where people could drop off their used cooking oil. The collected oil was then transported to a biodiesel plant in Normandy, where it was converted into biodiesel. The plant had a production capacity of 20,000 tons of biodiesel per year. The biodiesel produced from waste cooking oil was used to fuel the city's fleet of diesel vehicles, including buses, garbage trucks, and street cleaning vehicles. By using biodiesel produced from waste cooking oil, the city was able to reduce its greenhouse gas emissions and improve air quality. The Huile Pro initiative was a success, and it inspired other cities in France and across Europe to launch similar projects. In 2020, the city of Paris announced that it had collected over 8,000 tons of waste cooking oil since the launch of the initiative in 2016, which had been converted into biodiesel and used to fuel its fleet of vehicles (Dft, 2020). Furthermore, in 2018, the city of Barcelona launched a project called "B-MOVING" to collect waste cooking oil from households and convert it into biodiesel. Under the project, residents could deposit their used cooking oil at designated recycling bins, which were then collected and transported to a plant where the oil was converted into biodiesel. The biodiesel was used to power the city's fleet of buses and garbage trucks. The project was a success, and it helped the city reduce its greenhouse gas emissions by 10% (Argus, 2020b).

These case studies demonstrate the potential for waste cooking oil to be transformed into a valuable resource for renewable energy. By collecting and converting waste cooking oil into biodiesel, cities and municipalities can reduce their dependence on fossil fuels, improve air quality, and contribute to the circular economy.

3. Methodology

3.1. Data collection

The project obtained Waste Cooking Oil (WCO) from different cities in the Kurdistan region, including Erbil, Sulaymaniyah, and Duhok (as shown in Figure 15). To gather as much data as possible for each restaurant, a questionnaire template was created (Table 3). This questionnaire included questions about the number of customers who visited the restaurant, the daily amount of oil used (measured in liters), how the restaurant disposed of the waste cooking oil, and the number of times the oil was reused. All this information was taken into consideration during the data collection process.

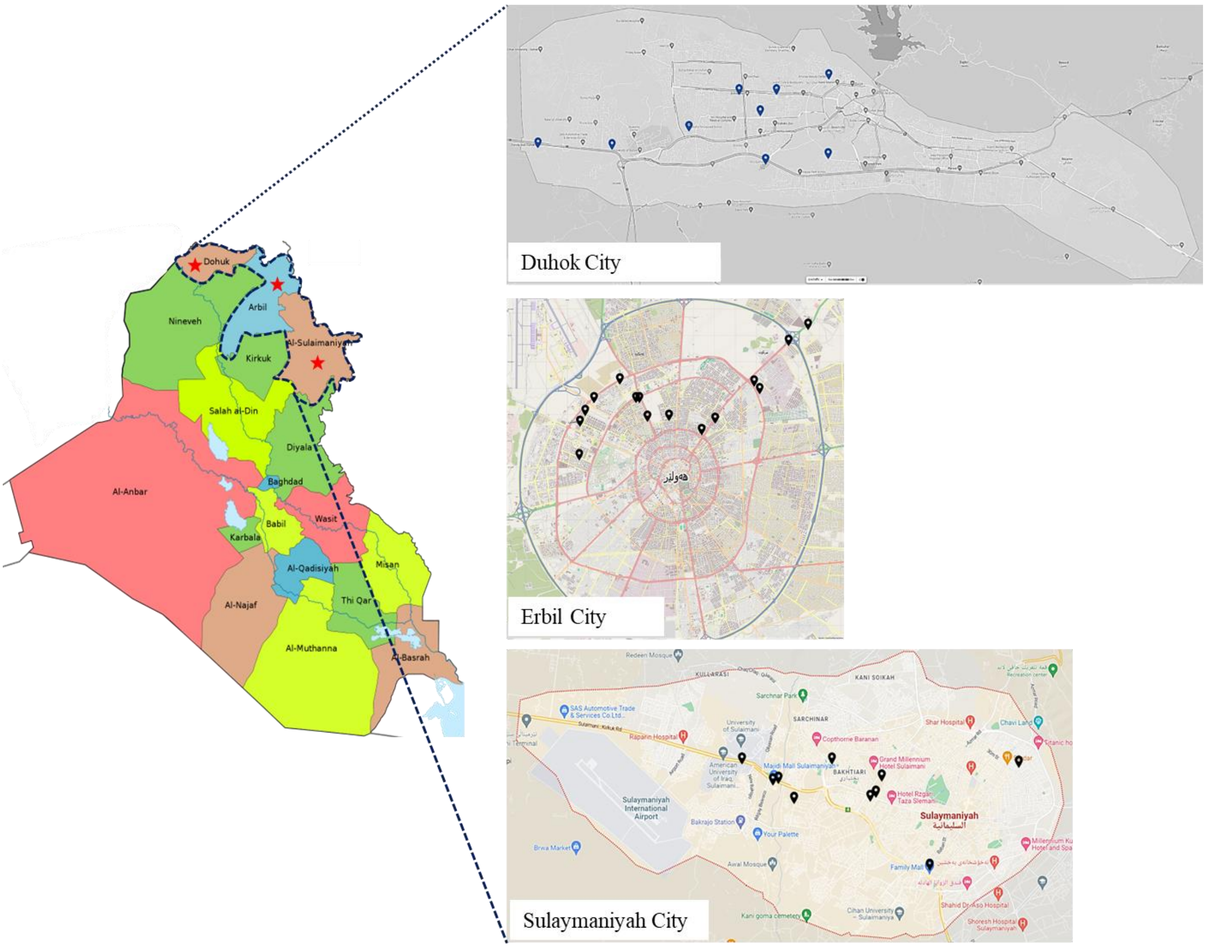

Figure 15 Sampling locations in the Kurdistan Region of Iraq.

Table 3 Questionnaire form for data collection in the restaurants

<table>
<tr><td colspan="6">Name of Restaurant:</td></tr>
<tr><td>Restaurant locations</td><td></td><td>Erbil</td><td></td><td>Sulaymaniyah</td><td></td><td>Duhok</td></tr>
<tr><td colspan="4">Longitude Latitude</td><td colspan="3"></td></tr>
<tr><td colspan="4">Question</td><td colspan="3">Answer</td></tr>
<tr><td colspan="4">Number of customers per day</td><td colspan="3"></td></tr>
<tr><td colspan="4">How many liters of waste oil per day?</td><td colspan="3"></td></tr>
<tr><td colspan="4">How long the oil will be used?</td><td colspan="3"></td></tr>
<tr><td colspan="4">How often the oil will be changed per day?</td><td colspan="3"></td></tr>
<tr><td colspan="4">What are you going to do with wasted oil?</td><td colspan="3"></td></tr>
<tr><td colspan="4">Type of used oil?</td><td colspan="3"></td></tr>
</table>

Erbil, Sulaymaniyah, and Duhok were selected as research sites due to their high number of restaurants, with an average of more than 100 restaurants per 1000 people. Furthermore, the study area has a population of over one million people, which provides a sufficiently large number of different eateries to be studied within a manageable geographic region. To ensure that the sample of restaurants selected for the study was representative of the overall population, the restaurants were categorized based on the variations in oil output across different locations.

It should be noted that the data was not obtained from any government ministries or organizations in the Kurdistan region. Instead, the data was gathered by visiting restaurants in the specified cities. In Erbil, data was collected from 20 restaurants (Table 4), and using this information, an estimate was made for the average amount of waste cooking oil generated per day for 1120 restaurants by applying equation 2. Similarly, in Sulaimaniyah and Duhok, data was collected from 10 restaurants in each city, and by applying equation 2, an estimate was made for the average amount of waste cooking oil generated per day for 761 and 485 restaurants, respectively (Table 5 and 6). In total, data was collected from 2366 restaurants across the aforementioned cities (Figure 16 and 17).

$$\text{Average generated WCO}\left(\frac{\text{L}}{\text{day}}\right)=\frac{\sum \text{WCO for each restaurant}}{\text{No. of restaurants}} \qquad \text{Eq. (2)}$$

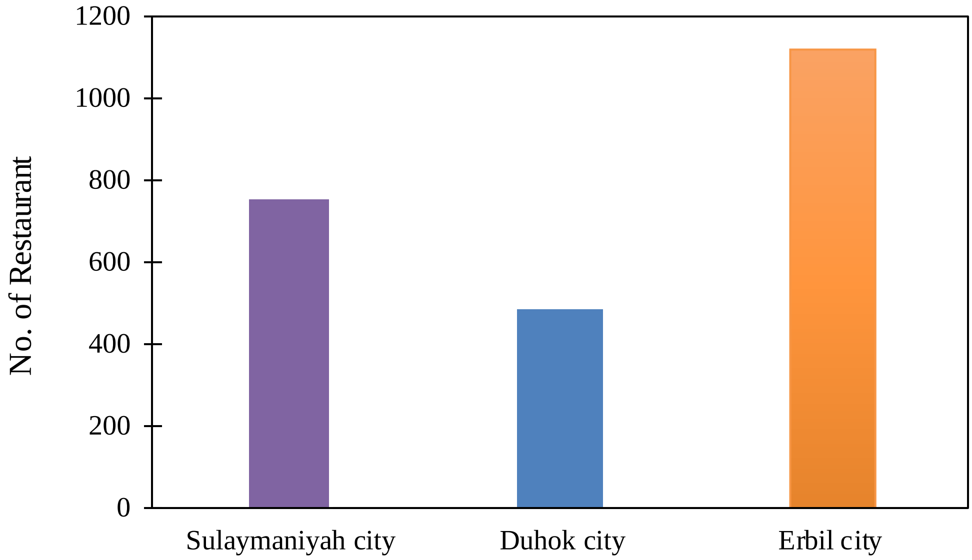

Figure 16 Show the collected data from various restaurants in different cities.

Figure 17 WCO in one of the restaurants in Erbil

Table 4 Sample of data collection in Erbil City

No	Name of Restaurant	WCO (Liter)	Changing cooking oil	Visiting people daily	WCO (L/day)
1	Pizza Family Mall	20	3-4 times a week	100-150	11.43
2	Hardees Family Mall	60	Twice a week	150-200	17.14
3	Hardees Bakhtyari	85	Twice a week	200	24.29
4	KFC Masif Road	300	Once a week	200	42.86
5	KFC 100m Road	300	Once a week	200	42.86
6	KFC Royal Mall	150	Once a week	100	21.43
7	KFC Mega Mall	200	Once a week	130-150	28.57
8	KFC Family Mall	220	Once a week	150	31.43
9	2 in 1 100 m Road	20	Every day	50-60	20.00
10	2 in 1 Masif	12	Every day	20-30	12.00
11	2 in 1 English Village	23	Every day	70-80	23.00
12	Burger King Masif Road	26	Every day	200	26.00
13	Burger King Family Mall	20	Every day	100-150	20.00
14	Burger King	20	Every day	100-150	20.00
15	Iceland	12.5	Every day	100	12.50
16	The Grill Gulan Tower	22.5	Every day	100	22.50
17	Laventana Café & Restaurant	25	Every day	250-300	25.00
18	Pizzana Gulan St.	15	3 times a week	30-50	6.43
19	UK Pizza and More	25	Twice a week	100	7.14
20	99 Grill Dream City	19	Every day	50-80	19.00

Table 5 Sample of data collection in Sulaymaniyah City

No	Name of Restaurant	WCO (Liter)	Changing cooking oil	Visiting people daily	WCO (L/day)
1	Burger king (Family mall)	23	Every day	150-170	23.00
2	Burger king (Majidi mall)	21	Every day	140-165	21.00
3	Burger king (Bakhtiyari)	18	Every day	100-130	18.00
4	99 Grill	14	Every day	60-100	14.00
5	2 in 1	22	Every day	50-70	22.00
6	NRT pizza	35	Once a week	60-80	5.00
7	Bees	16	3 times a week	40-60	6.86
8	Defarmo	17.5	Twice a week	120-150	5.00
9	Gasy sazi	38	Once a week	100-150	5.43
10	The station	20	Twice a week	50-70	5.71

Table 6 Sample of data collection in Duhok City

No	Name of Restaurant	WCO (Liter)	Changing cooking oil	Visiting people daily	WCO (L/day)
1	Malta	100	Once a week	300	14.29
2	2 in 1	15	Every day	35-50	15.00
3	Media Saray	42.5	3 times a week	200	15.00
4	Kebab House	35	3 times a week	50-75	15.00
5	D-DK	70	Once a week	100	10.00
6	KFC Family Mall	200	Once a week	100-120	28.57
7	Shindoxa	42.5	Twice a week	125-150	12.14
8	Hardees Family Mall	50	Twice a week	80	14.29
9	Ofilia	50	Once a week	70	7.14
10	Zainal Asta	27.5	Once a week	80-100	3.93

3.2. *Data analysis*

Using data gathered from various restaurants, the estimated amount of cooking oil waste produced by 2366 restaurants will be computed. An economic assessment will then be conducted to determine the viability of the project in Kurdistan. Afterwards, a plan will be recommended for gathering the waste cooking oil and exporting it to a board.

4. Results and discussion

4.1. Produced waste cooking oil.

Economically, it is financially viable to produce biodiesel from waste cooking oil only if more than 15 tons of such oil is collected daily. Taking this into account, calculations were carried out to determine the overall amount of waste cooking oil generated in the study area. The results of these calculations are shown in Figure 18.

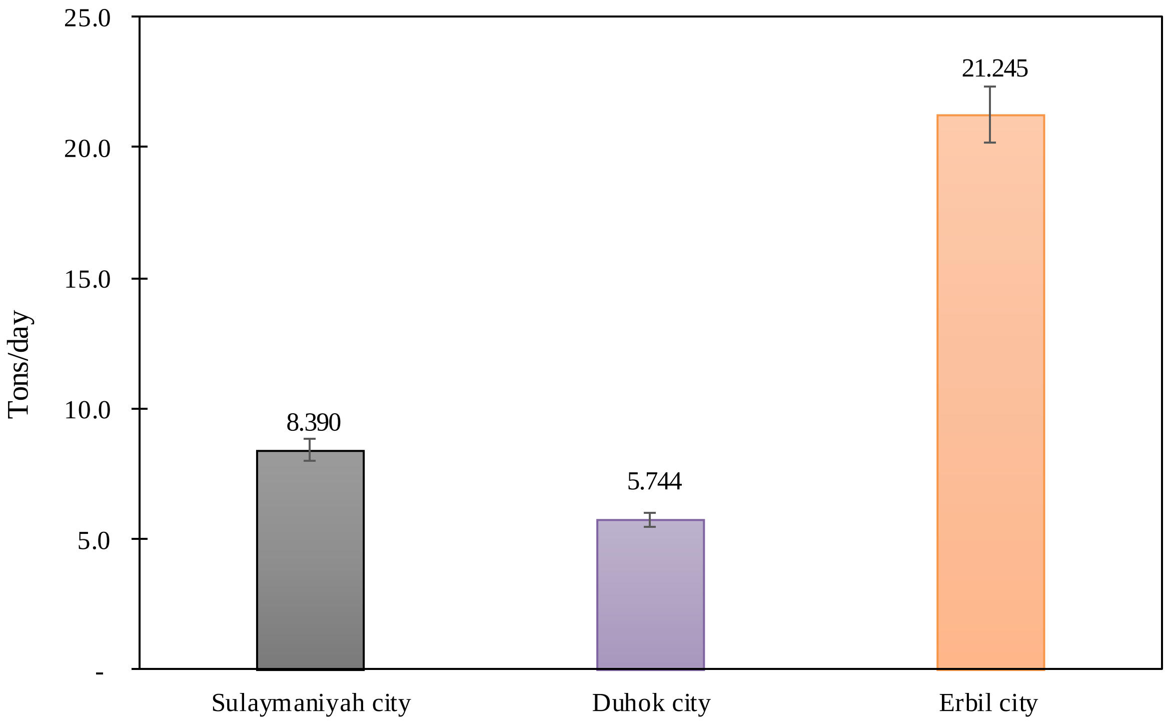

Figure 18 Total produced waste cooking oil for different cities

Figure 18 illustrates that in Erbil, the total anticipated amount of waste cooking oil generated from 1120 restaurants is 21.245 tons per day, with each restaurant averaging 21.68 liters per day. Sulaymaniyah, on the other hand, is the second-highest city in terms of waste cooking oil production. Approximately 8.39 tons of waste cooking oil are produced from 761 restaurants, averaging 12.6 liters per restaurant per day. Finally, Duhok produces 5.744 tons of waste cooking oil per day from 485 restaurants, with each restaurant contributing an average of 13.54 liters per day. The total amount of waste cooking oil from 2366 restaurants is 35.379 tons per day, which confirms that the production of biodiesel from waste cooking oil is economically feasible in Kurdistan.

4.2. Economic Analysis

To confirm the financial feasibility of producing biodiesel from waste cooking oil in Kurdistan, a simple calculation was conducted. The assumptions used for the production of one liter of biodiesel from waste cooking oil in the year 2023 are presented in Table 7.

Table 7 Assumptions for producing 1 L of biodiesel from WCO (Gharabawy, A., 2017)

Item (USD/ton)	Estimated price in 2023	Reference
Methanol cost ($/L biodiesel)	0.072	Gharabawy, A. (2017)
KOH cost ($/L biodiesel)	0.02	
Waste cooking oil cost ($/L biodiesel)	0.333	
Utilities cost ($/L biodiesel)	0.036	
Fixed cost (maintenance, salaries, etc.) ($/L biodiesel)	0.027	
Biodiesel production cost ($/L biodiesel)	0.515	
Average Current market price of biodiesel ($/L)	1.10	

For 35.379 ton of WCO in Kurdistan

Assume average WCO density is 887 kg/m^3 or 0.887 kg/L

1 ton=1000 kg= $\frac{1000}{0.85}$=1176 L

Amount of WCO in liter=35.379 $\frac{\text{ton}}{\text{day}}$ x 1176 $\frac{\text{L}}{\text{ton}}$ = 41606 L

Item (USD/ton)	Estimated Price in 2023	For 41606 L WCO in Kurdistan	Total Cost ($)	Profit ($)
Methanol cost ($/L biodiesel)	0.072	2995.632	**39026.428**	**6740.172**
KOH cost ($/L biodiesel)	0.02	832.12		
WCO cost ($/L biodiesel)	0.333	13854.798		
Utilities cost ($/L biodiesel)	0.036	1497.816		
Fixed cost (maintenance, salaries and insurance) ($/L biodiesel)	0.027	1123.362		
Biodiesel production cost ($/L biodiesel)	0.45	18722.7		
Average Current market price of biodiesel ($/gallon)	3.77	45766.6		

It can be stated that the production of biodiesel from waste cooking oil (WCO) has yielded a profit of $6,740.172. This indicates that the process of converting WCO into biodiesel has been successful in generating a substantial amount of profit. By converting WCO into biodiesel, not only is a valuable resource being utilized, but it also presents an opportunity for businesses to generate revenue while promoting sustainability.

4.3. WCO Collection mechanism and processes

Despite the various benefits of collecting waste cooking oil, there are several challenges associated with it. As a result, many countries have established their own regulations and incentive programs for collecting waste cooking oil.

Municipalities, non-profit organizations (NGOs), and private companies often collaborate to manage the collection system. In more than 85% of cases, a public organization or an NGO played a role in initiating the program, while private companies were responsible for collecting and transporting the waste.

Due to the absence of a dependable system for supply chain and enforcement in Kurdistan, the gathering of produced waste cooking oil has been unsuccessful. Consequently, it is crucial to create a unique circular economy model to collect waste cooking oil from different sources. Figure 19 depicts a suggested mechanism that can be put in place in Kurdistan to gather waste cooking oil from various locations.

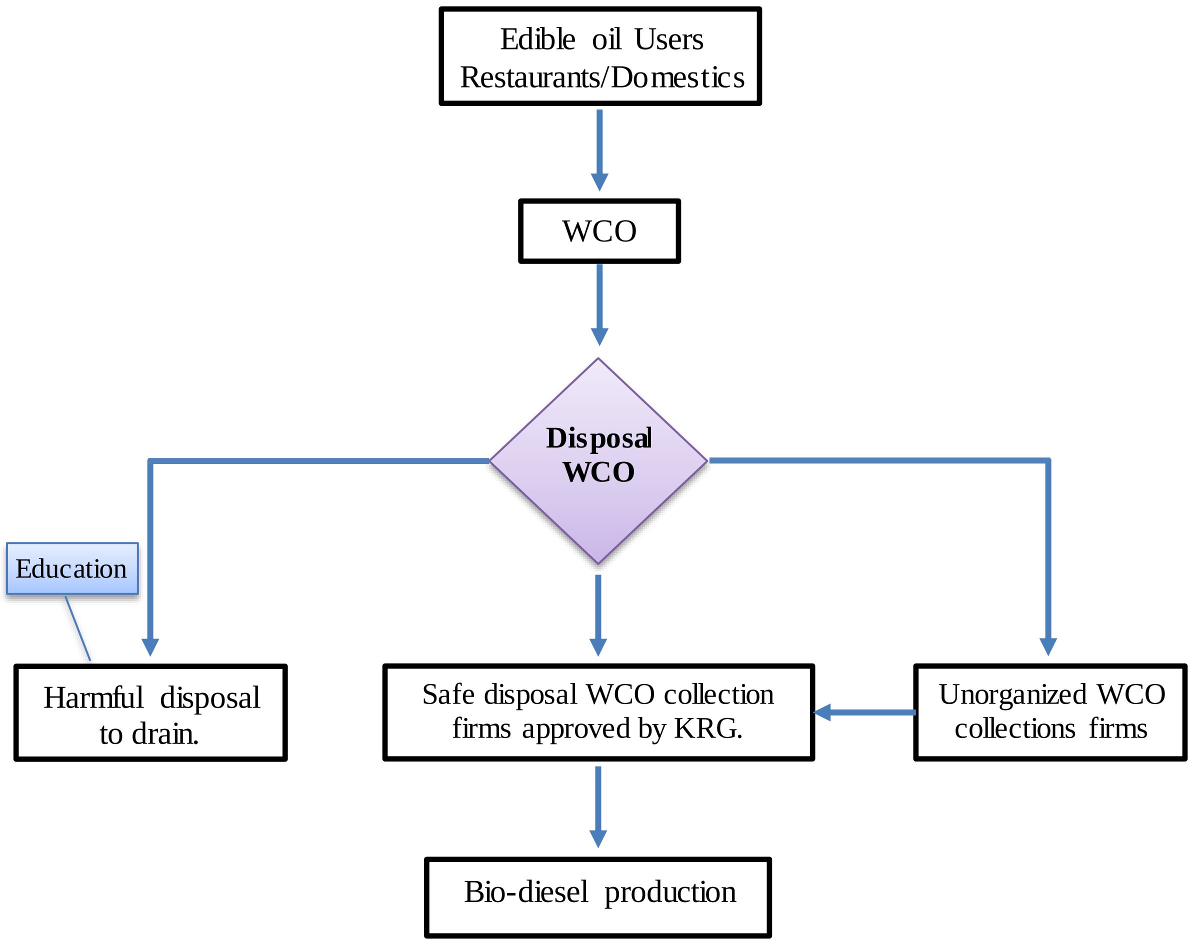

Figure 19 Proposed WCO collection mechanism in Kurdistan region.

Apart from collecting waste cooking oil, distribution centers and storage should also be established, considering factors such as facility capacity, transportation, and location. Figure 20 shows a proposed plan for the collection and storage of waste cooking oil in the Kurdistan region.

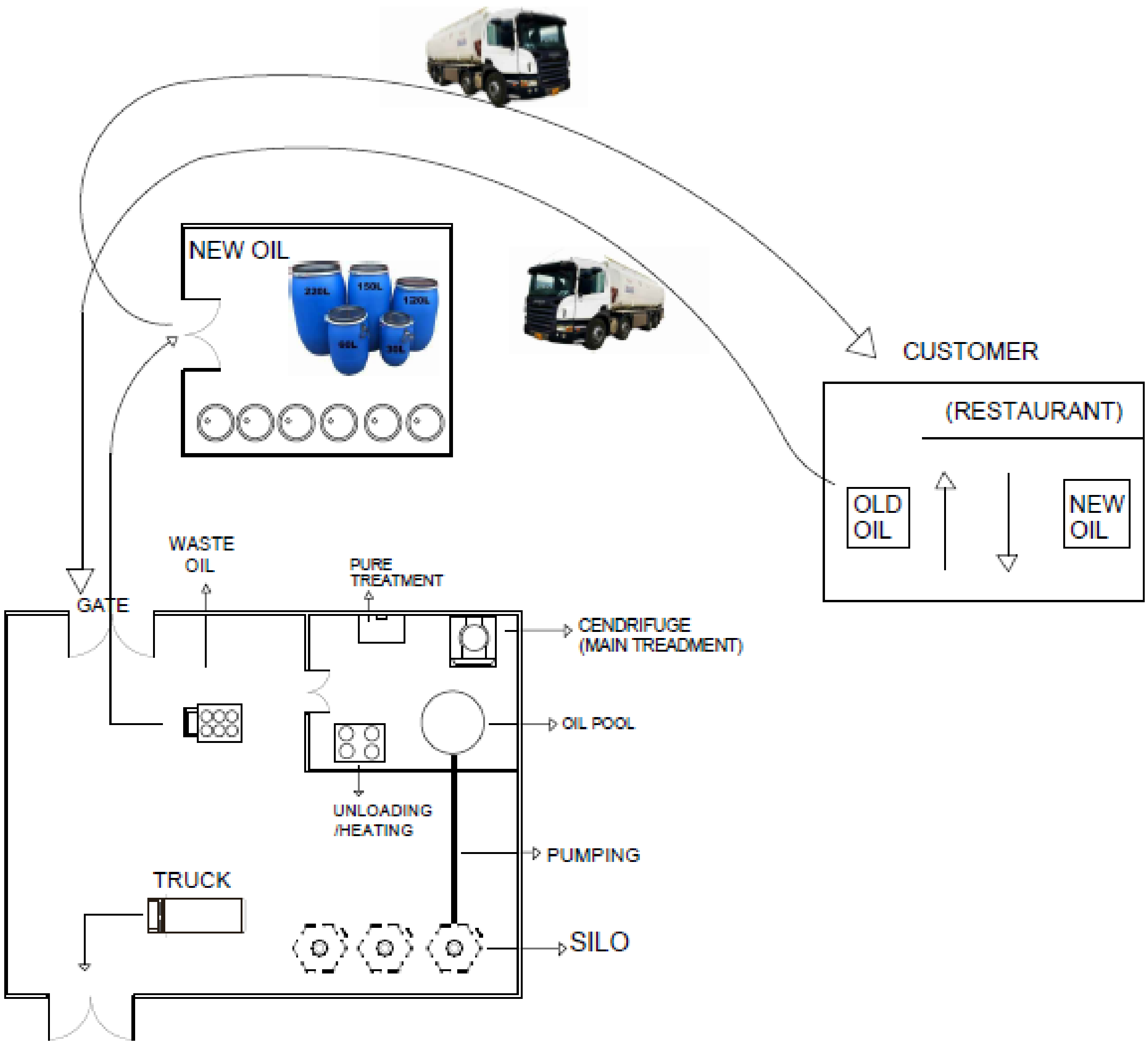

Figure 20 Show processed plant and storage of WCO.

4.4. Export WCO

In Kurdistan, besides the possibility of constructing manufacturing facilities to convert leftover cooking oil into biodiesel, there is also an alternative option to export the used cooking oil (UCO) to Europe where it can be utilized as a feedstock for the production of biodiesel made from waste cooking oil. However, this process is only feasible for larger collectors, while smaller collectors are likely to transfer the collected WCO to larger collectors. The bulk oil can then be loaded onto tank-trucks or modified vans with tanks and pumps and transported (Figure 21).

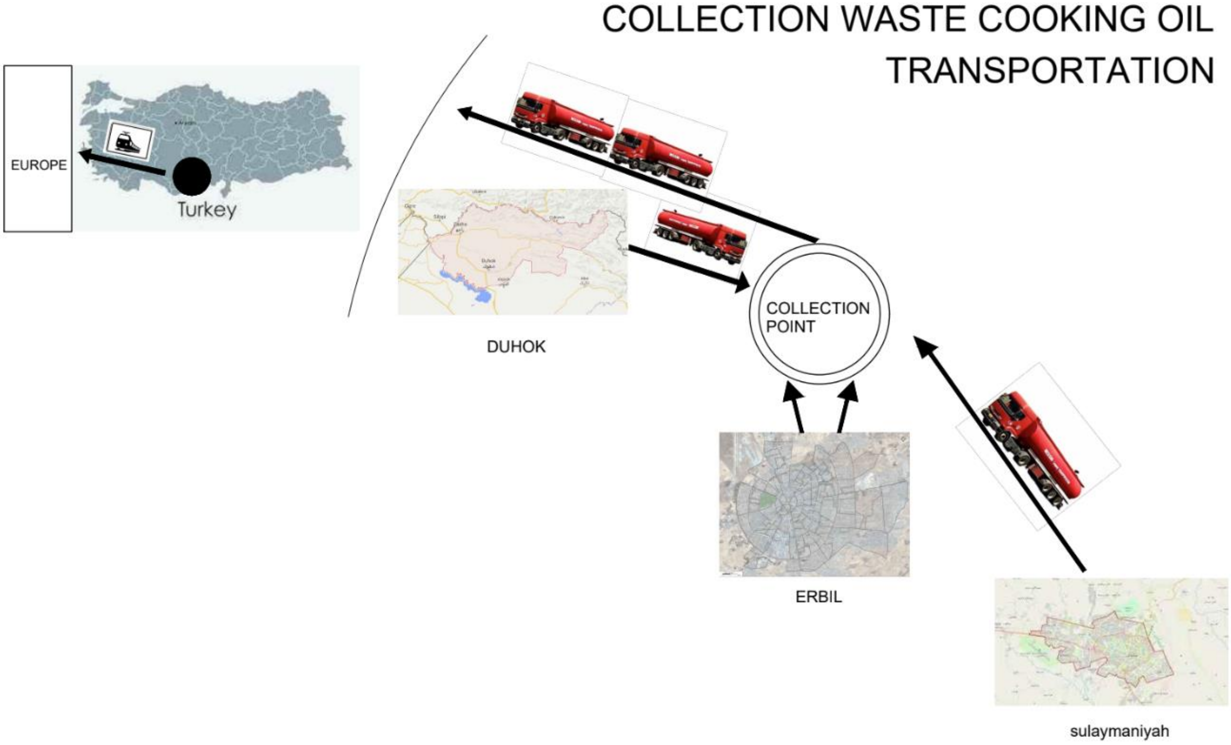

Figure 21 Show the export of WCO from Kurdistan to Europe

5. Conclusion

This project aims to collect the latest information on the production of biodiesel from waste cooking oil and its effective use in the Kurdistan Region. For that purpose, data collected from 40 restaurants in Erbil, Sulaymaniyah and Duhok and analyzed and based on the that, the wasted oil estimated due to the total number of the available restaurants in the Kurdistan Region.

The main outcomes of this study are explained as follows:

- Biodiesel has been shown to be a highly effective substitute for fossil fuels since it is renewable, biodegradable, and non-toxic, making it superior than fuels derived from petroleum.

- In the Kurdistan Region of Iraq, waste cooking oil (WCO) can be found in several places, including households, restaurants, and food processing facilities. Nonetheless, the collected WCO often has a lot of water and free fatty acids (FFA) content. To lower these values, pre-treatment of the oil is necessary prior to producing biodiesel.

- Establishing a biodiesel plant that uses WCO as feedstock would be economically advantageous, given that the 2366 restaurants in Kurdistan generate 35.379 tons of WCO per day.

- Developing a standard procedure for collecting waste cooking oil from various sources is essential. This may involve the collaboration of municipalities, non-profit organizations (NGOs), and private companies.

- From economic points of view, exporting WCO to Europe could be a crucial alternative. However, this approach requires careful examination and analysis.

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