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Comparison of CO2 emissions and potential efficiency between biodiesel and renewable diesel fuels

Comparación de las emisiones de CO2 y la eficiencia potencial entre el biodiesel y el diésel renovable

Comparação das emissões de CO2 e eficiência potencial entre biodiesel e diesel renovável

Jeronimo Alonso-Jaramillo[1], Leonardo Alexis Alonso-Gomez[2*]

***Autor de correspondencia:** lalonso@unillanos.edu.co

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Abstract

Renewable biofuels have several advantages, including increasing energy efficiency, diversifying the energy matrix of countries, and reducing greenhouse gases. Moreover, fossil fuels are gradually depleting. Biofuels such as biodiesel and renewable diesel, also known as green diesel or hydrotreated vegetable oil, are becoming essential fields of study as they can mitigate environmental damage without affecting transportation quality. Both biodiesel and renewable diesel are produced from the same biomass, which can come from vegetable oil, animal fats, microalgal oil, or waste cooking oil. Each fuel is created through a different process, transesterification for biodiesel and hydrotreatment for renewable diesel. As a result, each has distinct chemical and physical properties that determine their performance, including efficiency and CO2 emissions. This review examines the biomass feedstock used, compares the transformation processes, efficiency, and potential CO2 emissions, and identifies the advantages and disadvantages of using biodiesel and renewable diesel.

Keywords: Biomass; Fuel; Vegetable oil.

1 SENA Agroindustrial – Avenida Centenario carrera 6 # 44N-15 Armenia, Quindío, Colombia.
2 Universidad de los Llanos, Grupo de investigación Ciencia, Tecnología e Innovación Agroindustrial (CITIA). Km 12 Vía Puerto López. Villavicencio, Meta, Colombia. ORCID: https://orcid.org/0000-0001-9745-2529

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Resumen

El uso de biocombustibles renovables tiene importantes ventajas, como el aumento de la eficiencia energética, la diversificación de la matriz energética de los países y la reducción de los gases de efecto invernadero, entre otras. Los combustibles fósiles, además, están comenzando un paulatino agotamiento. Los biocombustibles, como el biodiésel y el diésel renovable (también llamado diésel verde o aceite vegetal hidro tratado), se han convertido en importantes campos de investigación, ya que pueden mitigar los perjuicios medioambientales sin afectar a la calidad del transporte. Tanto el biodiésel como el diésel renovable proceden de la misma biomasa, que puede variar entre aceite vegetal, grasas animales, aceite de microalgas y aceite de cocina usado. Cada combustible se produce mediante un proceso diferente (transesterificación en el caso del biodiésel e hidrotratamiento en el del diésel renovable). Por esta razón, cada uno de ellos tiene propiedades químicas y físicas diferentes que determinan su rendimiento, incluyendo su eficiencia y las emisiones de CO2. Esta revisión analiza las materias primas de biomasa utilizadas y realiza una comparación entre los procesos de transformación, la eficiencia y las emisiones potenciales de CO2. Por último, establece las ventajas e inconvenientes del uso de biodiésel y diésel renovable.

Palabras claves: Aceite vegetal; Biomasa; Combustible.

Resumo

O uso de biocombustíveis renováveis tem vantagens importantes, como o aumento da eficiência energética, a diversificação da matriz energética dos países e a redução dos gases de efeito estufa, entre outras. Além disso, os combustíveis fósseis estão a começar a esgotar-se gradualmente. Os biocombustíveis, como o biodiesel e o diesel renovável (também chamado de diesel verde ou óleo vegetal hidro tratado), tornaram-se importantes campos de investigação, pois podem mitigar os danos ambientais sem afetar a qualidade do transporte. Tanto o biodiesel como o gasóleo renovável provêm da mesma biomassa, que pode variar entre óleo vegetal, gorduras animais, óleo de microalgas e óleos alimentares usados. Cada combustível é produzido através de um processo diferente (transesterificação no caso do biodiesel e hidrotratamento no caso do gasóleo renovável). Por esta razão, cada um deles tem propriedades químicas e físicas diferentes que determinam o seu desempenho, incluindo a sua eficiência e emissões de CO2. Esta revisão analisa as matérias-primas de biomassa utilizadas e faz uma comparação entre os processos de transformação, a eficiência e as potenciais emissões de CO2. Por fim, estabelece as vantagens e desvantagens da utilização do biodiesel e do gasóleo renovável.

Palavras-chave: Biomassa; Combustível; Óleo vegetal.

Introduction

In recent years, many countries around the world have made commitments to decrease air pollution and combat climate change. Two major international agreements that address this issue are the Kyoto Protocol and the Paris Agreement. The Paris Agreement, adopted in 2015, is a legally binding international treaty on climate change. It aims to keep global warming below 2°C above pre-industrial levels (United-Nations, 2022).

Petroleum diesel has been widely used in the transport sector since the creation of compression ignition engines (or diesel engines). From the energy conservation and global warming viewpoint, petroleum diesel is recommended rather than gasoline (Uchino, 2022)which requires (a because it has a better thermodynamic yield in the engine and produces lower emissions of CO2 for each kilometer driven. However, the combustion of petroleum diesel still produces an extensive emission of CO2 compared to biofuels. Fuels most used in the 20th century like coal, gas, and oil have lost a huge part of people's approbation due to the consequences they produce on the environment. Besides, the reserves of these fuels are suffering a gradual depletion making new energy sources an alternative to ensure a better future.

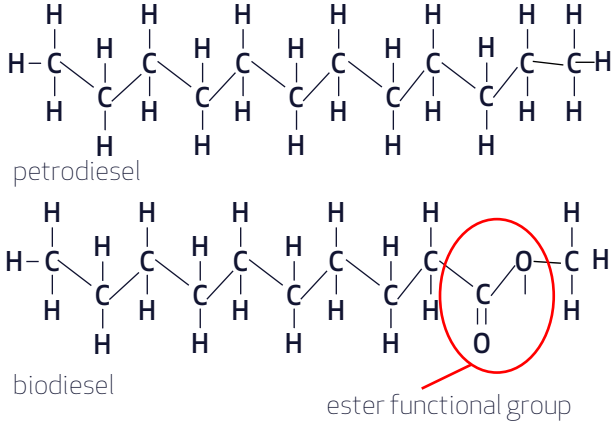
These days, many investigations are looking forward to discovering more and more about new energy sources. That is why renewable biofuels such as bio-hydrogen, biogas, bio-methane, bioethanol, green gasoline, biodiesel, and renewable diesel are becoming classic features. Biofuels come from renewable sources; thus, they can mitigate the emissions of CO2 in the environment. This lower CO2 emission is given because there is less of it as a sub-product in the combustion of biofuels than in the combustion of fossil fuels (Energy, 2019). Besides, the CO2 liberated in the combustion of biofuels is part of the natural cycle because it comes from biomass, and therefore is assimilable by the plant through photosynthesis, unlike the combustion of fossil fuels, which produces CO2 from a subterranean source adding to the current natural carbon cycle (Alonso-Gomez and Bello-Pérez, 2018).

Oil is the feedstock from which fuels like biodiesel and renewable diesel are produced, it is made up of molecules called triglycerides which are transformed into biodiesel through transesterification and into renewable diesel through a Hydro treatment. Both processes have as their principal aim to reduce the oil viscosity because it can cause damage to the engine. Triglycerides can be found in feedstocks such as vegetable oils, animal fats, micro-algal oils, and used cooking oils.

To understand the difference between petroleum diesel and biodiesel, let's look at Figure 1, petroleum diesel is a hydrocarbon-based substance that contains 8 to 21 carbon atoms per molecule (Douvartzides et al., 2019). It is obtained as a sub-product of fractional distillation of petroleum. In contrast, Costa et al. (2021), mention that vegetable oil contains 10 to 12 percent by weight oxygen (Figure 1), whereas fossil fuels usually contain insignificant amounts of it.

In figure 1, where petroleum diesel molecule is compared with a biodiesel molecule. It can be evidenced that the difference in the chemical aspect is that petroleum diesel is a hydrocarbon and biodiesel is an ester.

Figure 1 *Comparison between petrodiesel and biodiesel molecules*



Source: Dynamicscience, 2020

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In this paper, the difference in CO2 emission and efficiency between biodiesel and renewable diesel will be highlighted based on literature data.

The first instance presents the biomass feedstock from where the triglycerides are obtained, and the different processes to transform them into the two mentioned biofuels. Followed by the comparison between the results of different studies about the performance of biodiesel and renewable diesel. Finally, conclude which is the biofuel that has a lower CO2 emission potential between biodiesel and renewable diesel according to previous investigations.

Background

The transport sector initially relied on biomass feedstock as the primary source of fuel. One of the famous examples is the use of corn ethanol to power the first Otto engine vehicles manufactured by Henry Ford. Similarly, biological sources have been used to run diesel engine vehicles since the inception of the Diesel engine by Rudolph Diesel in 1897. In the 1940s, the use of fossil fuels increased because they were cheaper than biofuels. Biodiesel remerged with the search for renewable and less polluting fuels. Nowadays biodiesel is approved in blends with petrodiesel in The United States, Brazil, France, China, Germany, United Kingdom, Italy, Spain, Poland, Thailand, Indonesia, and Colombia. Pure biodiesel was used first, but it showed incompatibility in the engine (IATA, 2019) again, there might be other countries which have mandates and are not on display. The circle's diameter represents the value of the mandate taking the highest mandate as the reference. In Fig.1 the country with the most ambitious bio-ethanol mandate is Brazil (27%. For this reason, in The European Union, 7% is the maximum amount of biodiesel allowed for blends to avoid engine damage (Douvartzides et al., 2019)from the classification and chemistry of the available biomass feedstocks to the possible production technologies and up to the final fuel properties and their effect in modern compression ignition internal combustion engines. Various biomass feedstocks are reviewed paying attention to their specific impact on the production of green diesel. Then, the most prominent production technologies are presented such as the hydro-processing of triglycerides, the upgrading of sugars and starches into C 15 –C 18 saturated hydrocarbons, the upgrading of bio-oil derived by the pyrolysis of lignocellulosic materials and the "Biomass-to-Liquid" (BTL.

Renewable Diesel was first produced in Europe by the renewable fuel company Neste in 2007. Nowadays, renewable diesel is the third most common biofuel worldwide, after bioethanol and biodiesel (ETIP Bioenergy - European Technology and Innovation Platform, 2020). It is commonly used in many countries; it can be used pure or in blends with petrodiesel due to its similarity with it.

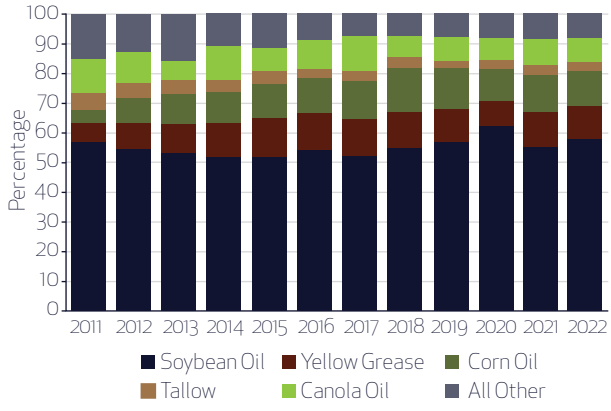
The base investigation that motivates this review is that made by Douvartzides et al. (2019)from the classification and chemistry of the available biomass feedstocks to the possible production technologies and up to the final fuel properties and their effect in modern compression ignition internal combustion engines. Various biomass feedstocks are reviewed paying attention to their specific impact on the production of green diesel. Then, the most prominent production technologies are presented such as the hydro-processing of triglycerides, the upgrading of sugars and starches into C 15 –C 18 saturated hydrocarbons, the upgrading of bio-oil derived by the pyrolysis of lignocellulosic materials and the "Biomass-to-Liquid" (BTL who provide an overview of the current technology related to renewable diesel, from the classification and chemistry of the available biomass feedstocks to the possible production technologies and up to the final fuel properties and their effect in modern diesel engines. They conclude that renewable diesel is an excellent fuel for combustion engines with remarkable properties and significantly lower emissions. But, although they do a very in-depth literature review, they do not make a comparison with other similar products, which are their direct competition in the fuel market. Therefore, this review seeks to compare

different literature sources so that it can be understood from a relative basis if renewable Diesel is indeed an excellent fuel as concluded by Douvartzides et al.

Biomass feedstock

Triglycerides are composed of three fatty acid esters combined with a glycerol molecule. Biofuels, such as biodiesel and renewable diesel, can be produced using any organic matter that contains a high concentration of triglycerides. This includes vegetable oils (e.g., rapeseed, soybean, cottonseed, palm, corn, sunflower, coconut, peanut, camelina, and jatropha oils), animal fats, micro-algal oils, and used cooking oils.(Anuar and Abdullah, 2016) Figure 2 shows that certain biomasses are more commonly used, depending on their availability in the country.

Figure 2 *Composition of feedstock usage in the USA, for annual production of biodiesel and renewable diesel 2011 – 2022*



Source: Gerveni et al., 2024.

The most used feedstock in the USA to produce biodiesel and renewable diesel is soybean, which has a high concentration of oil and therefore is better for its extraction compared to other feedstock.

Biofuels have been produced using different types of biomass over the years. These types of biomass are categorized into three generations. The first generation primarily focused on producing biofuels easily with conventional processes using feedstock that had the highest concentration of raw material (oil) and was more abundant. Edible feedstock such as soybean, sunflower, canola, and others were commonly used during the first generation of biofuel production.(Moodley, 2021). The second generation focused on food security, using non-edible oils like jatropha, camelina sativa, and cotton that do not compete with food production. (Banković-Ilić et al., 2012). This generation encouraged the use of waste oils with higher complexity processes.(Ahmad et al., 2023), and microalgae oils (Mofijur et al., 2019).

Transformation

Oil is the feedstock used for the production of many liquid biofuels; however, its high viscosity is a problem when it is used crudely as fuel. The processes used to transform biomass oil into biofuels have as their principal aim to reduce its viscosity since the high viscosity of vegetable oil can cause damage to the engine (Figure 3).

Figure 3 *Damages caused by using crude vegetable oil in diesel engines, This is a 4-cylinder engine with 200 hours of use with 100% sunflower oil*

Soruce: Maziero et al., 2007.

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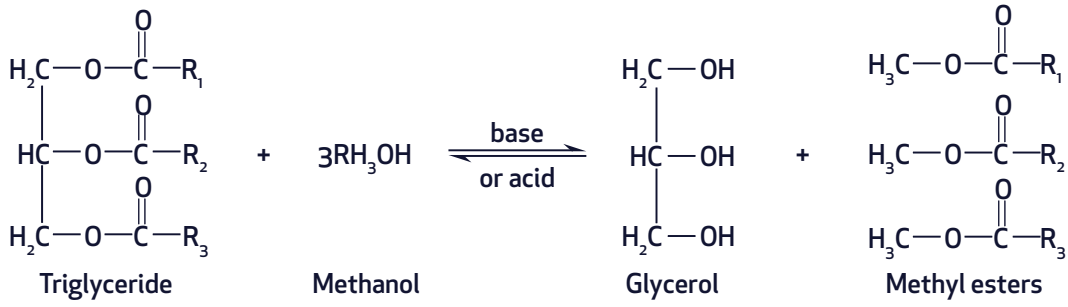
Several methods are used to achieve this objective (reduce viscosity), including mixing with hydrocarbons, micro emulsification, pyrolysis, transesterification, and hydro-deoxygenation (Garraín et al., 2010).

In the production of biodiesel, the triglycerides in the oil pass through a transesterification. Transesterification is the reaction in which triglycerides are transformed into Methyl or Ethyl Esters (biodiesel) and glycerol as a sub-product through the addition of methanol or ethanol to the vegetal oil in the presence of a catalyst (Figure 4).

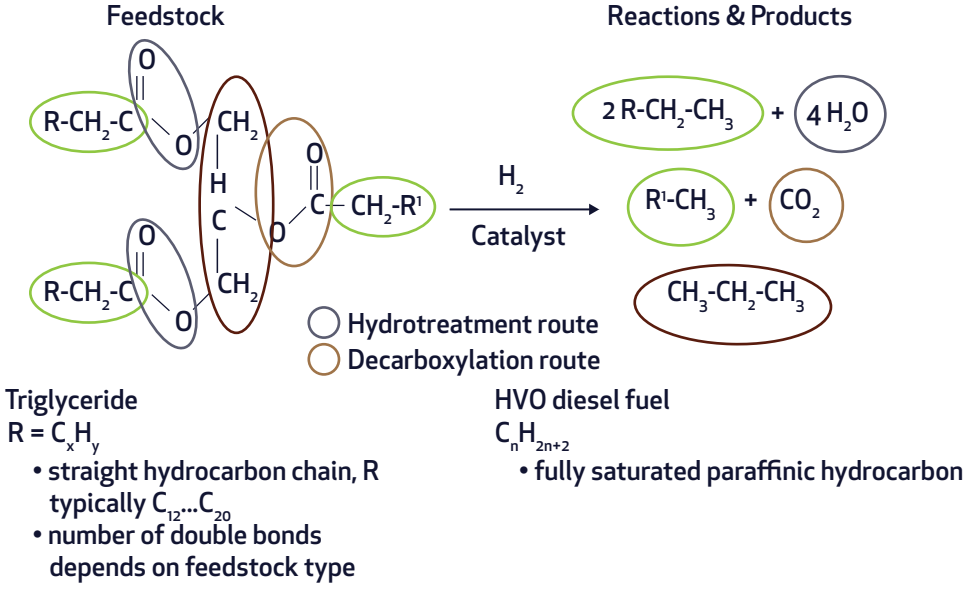
On the other hand, renewable diesel or hydrogenated vegetable oil (HVO) is produced through the hydro processing or hydrotreating of triglycerides producing saturated hydrocarbon chains with 15 to 18 atoms per molecule and propane as a sub-product (Figure 5).

Figure 4 *Chemical reaction of the production of biodiesel*



Source: Douvartzides et al., 2019

Figure 5 *Chemical formation and composition of the renewable diesel or HVO*



Source: Neste Corporation, 2020.

Renewable Diesel can be also produced from hydro processing, biological upgrading of sugars, starches, and alcohols, and thermochemical processes (Julio et al., 2022). It can be one of its most important advantages because it can be produced in countries where there is not enough lipid feedstock. Indeed, the different ways that can be used to produce renewable diesel are described in Figure 6.

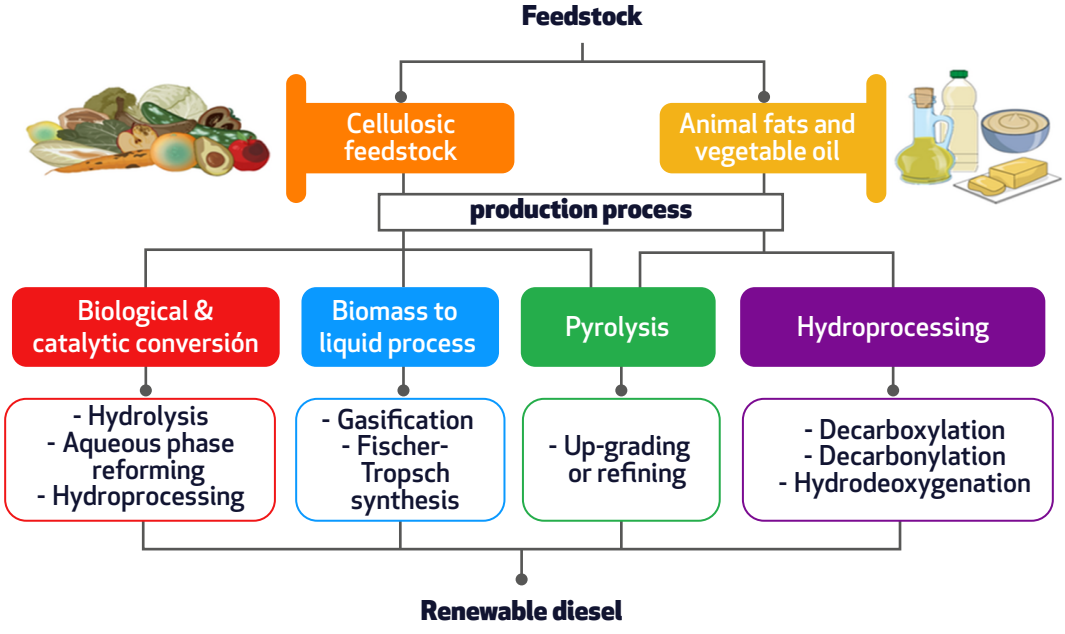
It is important to declare that the processes involved in the production of biodiesel and Renewable Diesel are different. Renewable Diesel production involves higher temperatures, pressure, and more processes than biodiesel production.

Physical and chemical properties of biodiesel and renewable diesel

Renewable diesel and biodiesel are both renewable fuels as they both come from biomass. The difference between them is based on the process by which the biomass is transformed (transesterification in biodiesel and Hydrotreatment in renewable diesel), each of these processes makes two different biofuels with different compositions, properties, and performance when they are burned in the engine.

Biodiesel and renewable diesel have substantial differences in their composition, biodiesel is an ester and renewable diesel is a hydrocarbon. Biodiesel's chemical composition makes it more susceptible to microbial contamination during storage which may result in the corrosion of storage tanks and clogging of fuel lines (Komariah et al., 2022). The presence of oxygen in biodiesel may produce oxidation which can cause corrosion on the engine. Biodiesel can also have a higher viscosity than petrodiesel, and due to the presence of oxygen, it has poor cold-weather performance (Simbi et al., 2022)which faces challenges. With the high

Figure 6 *Thermochemical routes to upgrade biomass into Renewable Diesel*



Source: Quevedo-Amador et al., 2024.

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intake temperatures, low lubricity and need for a high compression ratio for this engine, the use of a petrol-biodiesel blend as a fuel addresses such issues. This study evaluates the characteristics of fuel quality and performance of blended fuels with biodiesel additives (5%, 15%, and 25%. Despite the disadvantages of Biodiesel, it has a lubricity that allows a better functioning of the engine.

Renewable diesel is a hydrocarbon, similar to Diesel, thus allowing its use in Diesel engines in pure form without any engine modification or mixes. As it does not have oxygen in its molecule it is less corrosive and has a superior cold-weather performance than biodiesel (Table 1). Renewable diesel has a cetane number between 60 and 65, it is very important to highlight this characteristic because the cetane number means the ignition capacity in a certain period and it is higher compared to fossil diesel and biodiesel.

CO2 emission

In general, it can be said that, given the great variety of feedstocks, and also because there are several ways of carrying out transesterification, there is a great variety of biodiesels. Likewise, as different feedstocks may contain different fatty acid profiles, this is reflected in a heterogeneity of methyl or ethyl esters. This results in a large number of possible combinations that generate a large number of biodiesel qualities and CO2 emissions.

The high hydrogen/carbon ratio (H/C) in renewable diesel is often attributed as the main cause of low CO2 emissions. Dimitriadis et al. (2018) found 4% less CO2 in the exhaust emissions when using renewable diesel. Hernández et al. (2020)namely HVO (Hydrotreated Vegetable Oil found 2.5 g km−1 less CO2 in emissions when 30% renewable diesel was mixed with diesel.

Table 1. *Physicochemical properties of Biodiesel and Renewable diesel.*

	Unit	Biodiesel	Renewable diesel	Min-max	Method
Cetane number		58,6	60-65	>51	ASTM D 445
Kinematic viscosity 40°C	mm^2/sec	4,71	3	(2,3 - 6)	ASTM D 614
Flash point	°C	160	>70	>55	ASTM D 93
Cloud point	°C	9	(-5 to -25)	<18	ASTM D 5949
Sulfur	mg/kg	3,85	<1	<50	ASTM D 4294
Water content	mg/kg	588,36	7	<500	ASTM D 6304

Adapted from (Firdaus et al., 2022), (Aatola et al., 2008), and (Neste Corporation, 2020).

However, some authors dare to give answers based on research averages, as shown in Table 2. (Adetunji, 2017), (Your, 2023), (Morgenstern, 2022).

Comparing renewable diesel with fossil diesel, renewable diesel produces up to 56 % less CO2. Fossil diesel produces 3.6 tons of CO2 per 1,000 L, compared to just 195 kg per 1,000 L of renewable diesel. This translates to approximately 53.9 g CO2 eq/ km for renewable diesel, assuming similar energy content and efficiency as diesel (Morgenstern, 2022). Biodiesel, specifically B100 (100% biodiesel), offers a significant reduction in CO2 emissions compared to regular diesel. Compared to regular diesel, unblended biodiesel (B100) offers a 75% reduction in CO2. This translates to approximately 30g CO2eq/km (Tavel CO2, 2017).

Table 2. *CO_2 emission of biodiesel, diesel, and renewable diesel*

Fuel	CO2 emissions (CO_2 eq/km)	Reference
Biodiesel	30,0	Travel CO2, 2017
Renewable diesel	53,9	Morgestern, 2022
Diesel	120,0	Adetunji 2017

Source: Own elaboration

Efficiency

Fuel efficiency can be analyzed from different perspectives, for example, it can be made a comparison of the energy densities of biodiesel and renewable diesel, in energy units per unit of mass. Expressing the energy in every gallon of fuel. For instance, it can be converted to what kind of mileage would the Diesel motor get from each fuel, and this is very important, assuming the same car and the same driving conditions (the same average speed).

Several authors have tried to standardize the methodology of measurement of fuel efficiency to obtain equivalent and comparable results. One of these attempts at standardization is called the New European Driving Cycle (NEDC). The NEDC test is made up of four urban driving cycles (called UDC) and one extra-urban driving cycle (called EUDC) (Cárdenas et al., 2016). Both types of cycles are composed of increasing, constant, and decreasing vehicle speed sequences.

The easiest way to compare the potential efficiency of a biofuel is the cetane number. Which represents the quality or performance of the fuel. The higher the number is the faster and better it burns in the engine. It refers to how brief is the time between the injection of the fuel in the chamber and the beginning of the combustion of the fuel.

Renewable diesel has a cetane number of 60 to 65 and biodiesel of 58,6 (Neste Corporation, 2020) correspondence principle and inverse Laplace transforms. This means that the time between the injection of renewable diesel in the chamber and its combustion is shorter than the time between the injection of biodiesel in the chamber and its combustion. Therefore, it can be said that renewable diesel has a superior efficiency than biodiesel.

Conclusion

Values of CO2 emissions and efficiency can vary based on the specific conditions of use, such as the type of vehicle and driving conditions. Also, it is important to remember that while renewable diesel options can significantly reduce CO2 emissions, they are not completely carbon-neutral. The production and distribution processes also contribute to their overall carbon footprint.

Both biodiesel and renewable diesel have advantages in terms of efficiency and reduced environmental impact compared to fossil fuels. However, each biofuel has its specific characteristics and advantages.

Renewable diesel can be an excellent alternative where oil feedstocks do not meet the demand. This is because renewable diesel can also be obtained from other raw materials such as carbohydrates. It has a higher cetane number than biodiesel and petroleum diesel. And due to its similarity with petroleum diesel, it can be used pure or blended unlike biodiesel which should not be used pure Biodiesel has lower CO2 emissions; however, it requires careful management as it can suffer microbial contamination during storage. It can cause corrosion on the engine and it has a poor weather performance.

The fuel with the highest cetane number between biodiesel and renewable diesel is renewable diesel, with a cetane number between 60 and 65. This means that it ignites faster than biodiesel, which has a cetane number of 58,6 and therefore is more efficient. Nevertheless, biodiesel has a lower emission of CO2, it emits 30 CO_2 eq/km, unlike renewable diesel which produces 53,9 eq/km.

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