Gazi Üniversitesi
Fen Bilimleri Dergisi
PART C: TASARIM VE TEKNOLOJİ

Gazi University
Journal of Science
PART C: DESIGN AND TECHNOLOGY

GU J Sci, Part C, 13(X): XX-XX (2025)

Reducing Carbon Footprint in Ankara: The Use of Biodiesel Produced from Waste Oils in Public Transportation

Osman Furkan KAPIKIRAN[1*], Halil İbrahim VARİYENLİ[1*], Mert ÖKTEN[3*], Semih Sadi KILIÇ[4*]

[1]*Gazi University, Faculty of Technology, Department of Energy Systems Engineering, Ankara, Turkey*

[2]*Manisa Celal Bayar University, Faculty of Hasan Ferdi Turgutlu Technology, Department of Energy Systems Engineering, Manisa, Turkey*

[3]*Gazi University, Graduate School of Natural and Applied Science, Department of Energy Systems Engineering, Ankara, Turkey*

[3]*Ministry of Energy and Natural Resources of Türkiye, General Directorate of Nuclear Energy and International Projects, Ankara, Turkey*

Article Info

Research article
Received: 07/11/2024
Revision: 20/12/2024
Accepted: 25/12/2024

Keywords

Biomass Energy
Biodiesel
Carbon Emission
Environmental Sustainability
Waste Oil Recycling

Makale Bilgisi

Araştırma makalesi
Başvuru: 07/11/2024
Düzeltme: 20/12/2024
Kabul: 25/12/2024

Anahtar Kelimeler

Biyokütle Enerjisi
Biyodizel
Karbon Emisyonu
Çevresel Sürdürülebilirlik
Atık Yağ Geri Dönüşümü

Graphical/Tabular Abstract (Grafik Özet)

This study evaluates the use of biodiesel produced from waste oils in Ankara's public transportation and its environmental and economic impacts. Biodiesel production was carried out through the transesterification process, and Figure A illustrates the flowchart of this process. The results show that biodiesel reduces carbon emissions by 76% while offering a sustainable fuel alternative. / Bu çalışma, atık yağlardan üretilen biyodizelin Ankara'da toplu taşımada kullanımını ve bunun çevresel ve ekonomik etkilerini değerlendirmektedir. Biyodizel üretimi transesterifikasyon süreci ile gerçekleştirilmiş olup Şekil A'da bu sürecin akış şeması gösterilmektedir. Sonuçlar, biyodizelin karbon emisyonlarını %76 oranında azalttığını ve sürdürülebilir bir yakıt alternatifi sunduğunu göstermektedir.

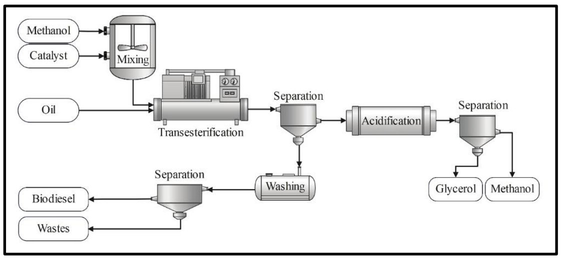

***Figure A**: Biodiesel production flow chart /**Şekil A:** Biyodizel üretim akış şeması*

Highlights (Önemli noktalar)

- *Biodiesel reduces emissions. / Biyodizel emisyonları azaltır.*
- *Waste oils recycled. / Atık yağlar geri dönüştürülür.*
- *Sustainable fuel alternative. / Sürdürülebilir yakıt alternatifi.*

***Aim (Amaç):** This study investigates the use of biodiesel produced from waste oils in public transportation in Ankara to assess its environmental and economic impacts, particularly its potential to reduce the carbon footprint. / Bu çalışma, atık yağlardan üretilen biyodizelin çevresel ve ekonomik etkilerini, özellikle de karbon ayak izini azaltma potansiyelini değerlendirmek amacıyla Ankara'da toplu taşımada kullanımını araştırmaktadır.*

***Originality (Özgünlük):** Data on waste oil collection and conversion efficiencies were analyzed to evaluate the impact on carbon emissions and fuel consumption. / Karbon emisyonları ve yakıt tüketimi üzerindeki etkiyi değerlendirmek için atık yağ toplama ve dönüştürme verimliliklerine ilişkin veriler analiz edilmiştir.*

***Results (Bulgular):** Biodiesel from 870,522 liters of waste oil collected monthly in Ankara reduces carbon emissions by 76%, producing 739,943 liters of fuel. Using biodiesel also reduces fossil fuel imports by approximately 9.77 million $ annually. / Ankara'da aylık olarak toplanan 870.522 litre atık yağdan elde edilen biyodizel, karbon emisyonlarını %76 oranında azaltarak 739.943 litre yakıt üretmektedir. Biyodizel kullanımı ayrıca fosil yakıt ithalatını yılda yaklaşık 9,77 milyon $ azaltmaktadır.*

***Conclusion (Sonuç):** The integration of biodiesel into Ankara's public transportation system significantly reduces carbon emissions and supports sustainable urban development. Expanding waste oil collection and biodiesel production can enhance environmental and economic benefits. / Biyodizelin Ankara'nın toplu taşıma sistemine entegre edilmesi karbon emisyonlarını önemli ölçüde azaltmakta ve sürdürülebilir kentsel kalkınmayı desteklemektedir. Atık yağ toplama ve biyodizel üretiminin yaygınlaştırılması çevresel ve ekonomik faydaları artırabilir.*

*Corresponding author, e-mail: mert.okten@cbu.edu.tr
DOI: 10.29109/gujsc.1581273

GU J Sci, Part C, 13(X): XX-XX (2025)

Gazi Üniversitesi
Fen Bilimleri Dergisi
PART C: TASARIM VE TEKNOLOJİ

Gazi University
Journal of Science
PART C: DESIGN AND TECHNOLOGY

http://dergipark.gov.tr/gujsc

Reducing Carbon Footprint in Ankara: The Use of Biodiesel Produced from Waste Oils in Public Transportation

Osman Furkan KAPIKIRAN[1*], Halil İbrahim VARİYENLİ[1*], Mert ÖKTEN[2*], Semih Sadi KILIÇ[3*]

[1]*Gazi University, Faculty of Technology, Department of Energy Systems Engineering, Ankara, Turkey*

[2]*Manisa Celal Bayar University, Faculty of Hasan Ferdi Turgutlu Technology, Department of Energy Systems Engineering, Manisa, Turkey*

[3]*Gazi University, Graduate School of Natural and Applied Science, Department of Energy Systems Engineering, Ankara, Turkey*

[3]*Ministry of Energy and Natural Resources of Türkiye, General Directorate of Nuclear Energy and International Projects, Ankara, Turkey*

Article Info

Research article
Received: 07/11/2024
Revision: 20/12/2024
Accepted: 25/12/2024

Keywords

Biomass Energy
Biodiesel
Carbon Emission
Environmental Sustainability
Waste Oil Recycling

Abstract

Biodiesel is derived from biomass and used as a motor fuel. Due to its renewable feature and lower carbon emission, biodiesel attracts attention as an environmentally friendly fuel alternative. This study examines the utilization of biodiesel derived from waste oils in public transport vehicles within the province of Ankara, and the impact of this utilization on the carbon footprint. Furthermore, the effects on the local economy are examined in the context of environmental sustainability. The conversion of waste oils into biodiesel represents a promising fuel alternative that simultaneously advances environmental sustainability and fosters energy diversity. The limited number of detailed analyses on biodiesel use in public transportation in Turkey positions this study as a novel contribution. The study presents a numerical analysis of the impact of biodiesel usage on fossil fuel consumption and carbon emissions in the public transport fleet, specifically in buses. Furthermore, the impact of this practice on the local economy and its long-term implications for sustainable urban transportation are also assessed. In Ankara, 870522 liters of waste oil are collected on a monthly basis, resulting in a reduction of 76% in carbon emissions due to the production of 739943 liters of biodiesel derived from these oils. As a result, energy consumption, efficiency and carbon emission analyses show that biodiesel is an economically and environmentally sustainable alternative. It is expected that the recycling of waste oils will improve waste management and reduce the negative impacts on the environment.

Ankara'da Karbon Ayak İzini Azaltmak: Toplu Taşımada Atık Yağlardan Üretilen Biyodizel Kullanımı

Makale Bilgisi

Araştırma makalesi
Başvuru: 07/11/2024
Düzeltme: 20/12/2024
Kabul: 25/12/2024

Anahtar Kelimeler

Biyokütle Enerjisi
Biyodizel
Karbon Emisyonu
Çevresel Sürdürülebilirlik
Atık Yağ Geri Dönüşümü

Öz

Biyodizel, biyokütleden elde edilir ve motor yakıtı olarak kullanılır. Yenilenebilir özelliği ve daha düşük karbon emisyonu nedeniyle biyodizel, çevre dostu bir yakıt alternatifi olarak dikkat çekmektedir. Bu çalışmada, Ankara ilinde toplu taşıma araçlarında atık yağlardan üretilen biyodizelin kullanımını ve bu kullanımın karbon ayak izi üzerindeki etkilerini incelemektedir. Ayrıca yerel ekonomi üzerindeki etkiler, çevresel sürdürülebilirlik bağlamında incelenmiştir. Atık yağların biyodizele dönüştürülmesi, hem çevresel sürdürülebilirliği destekleyen hem de enerji çeşitliliği sağlayan bir yakıt alternatifi olarak öne çıkmaktadır. Türkiye'de kamu ulaşımında biyodizel kullanımı üzerine yapılan detaylı analizlerin sınırlı olması, bu çalışmayı yenilikçi bir konuma taşımaktadır. Çalışmada, biyodizel kullanımının toplu taşıma filosundaki otobüslerde fosil yakıt tüketimini ne kadar azalttığı ve karbon emisyonlarına katkısı sayısal verilerle açıklanmaktadır. Ayrıca, bu uygulamanın yerel ekonomiye sağladığı katkılar ve uzun vadede sürdürülebilir kentsel ulaşım üzerindeki etkileri de değerlendirilmiştir. Ankara'da her ay 870522 l atık yağ toplanmakta ve bu yağlardan elde edilen aylık 739943 l biyodizel sayesinde karbon emisyonları %76 oranında azalmaktadır. Sonuç olarak, enerji tüketimi, verimlilik ve karbon emisyonu analizleri yapılan biyodizelin ekonomik ve çevresel açıdan sürdürülebilir bir alternatif olduğunu göstermektedir. Atık yağların geri dönüşümü sayesinde atık yönetiminin iyileşmesi ve çevreye olan olumsuz etkilerin azalması beklenmektedir.

ERKEN GÖRÜNÜM

*Corresponding author, e-mail: mert.okten@cbu.edu.tr
DOI: 10.29109/gujsc.1581273

1. INTRODUCTION (GİRİŞ)

The continuous increase in the world population leads to a rapid growth in energy demand. This situation has made the efficient use of energy and the dissemination of clean energy sources an important goal on a global scale. While the effects of the fluctuations in energy demand and prices experienced due to the Covid-19 pandemic in 2020 continue, Russia's war against Ukraine in early 2022 raised serious questions about how to ensure energy supply security for all countries. These events have necessitated a reconsideration of energy policies and emphasized the importance of sustainable energy sources. As a result, energy supply security and sustainability have focused on the need to replace traditional fossil fuels with clean and renewable energy sources. Increasing carbon emissions since the industrial revolution have led to an increase in climate change and natural disasters. For this reason, the UN encourages the whole world to reduce carbon emissions and turn to renewable energy sources with important steps such as the Paris Climate Agreement [1]. In this framework, transition from fossil fuels to clean energy is a critical step in terms of both environmental sustainability and energy security.

In recent years, the utilization of alternative fuels has been prioritized in an effort to achieve the environmental sustainability targets of public transport systems in urban areas. Biofuels, particularly biodiesel, which can supplant fossil fuels in the battle against global warming and climate change, have emerged as a pivotal solution. Biodiesel is a renewable energy source derived from organic wastes and has the potential to both curtail fossil fuel consumption and reduce carbon emissions [2]. Biodiesel is a biomass energy that has no toxin effect and can easily degrade in nature and can replace diesel fuel in the future. Biodiesel can be produced from animal and vegetable oils, wax oil and domestic waste oils. The process of converting these oils into biodiesel is called transesterification [3]. In this method, triglycerides react with alcohol to form esters and glycerol (Fig. 1). The most widely used biodiesel production method is base catalyzed transesterification. This method requires low temperature and pressure, and high yields can be obtained. Biodiesel is important in terms of environmental pollution and does not cause a net increase of carbon dioxide in the atmosphere. Also, biodiesel waste is less risky than waste from fossil fuels and has a higher flash point, which reduces the risk of explosion.

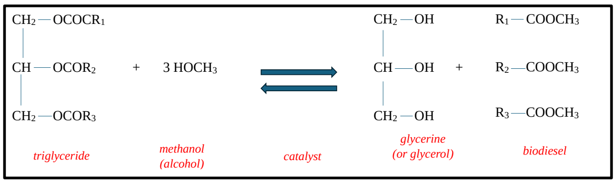

Figure 1. Transesterification reaction (Transesterfikasyon reaksiyonu)

Laboratory studies on biodiesel production are ongoing [4-11]. Initially based on 1st generation feedstocks, mainly edible oils, biodiesel production has shifted towards 2nd and 3rd generation sources such as non-edible vegetable oils, waste oils and algal biomass to overcome the food and fuel dilemma and increase sustainability [12]. In the literature, biodiesel is produced from sunflower oil [13-16], banana peel [17], hazelnut [18], palm [19, 20], rubber [21], soya [22] and olive oil [23], animal fats [24-28], waste frying oil [29, 30], seafood such as cowpea [31], scallop [32], algae [33].

The production of biodiesel from waste oils exhibits a number of innovative and advantageous features when compared to other methods of biodiesel production. The reuse of existing waste materials has the dual benefit of reducing raw material costs and contributing to the management of waste materials in an environmentally responsible manner. Furthermore, the utilization of this method results in a reduction in the consumption of natural resources, thereby contributing to the protection of agricultural areas. Furthermore, the production of biodiesel results in lower carbon emissions. The process in question has the effect of minimizing environmental impacts by reducing greenhouse gas emissions. Mitigates environmental contamination by addressing waste management concerns. Furthermore, the utilization of this method serves to reduce the costs associated with the production of biodiesel. This is a significant benefit, particularly when utilizing costly agricultural inputs. The collection and processing of materials at the local level can provide support to the local economy. The process can be made more efficient through the use of various catalysts and techniques. The recovery of additional by-products (e.g. glycerol) enhances the overall efficiency of the production process.

The production of biodiesel from waste oils represents an innovative approach from both an environmental and an economic perspective. This process presents a significant opportunity to enhance the availability of sustainable energy sources, optimize waste management practices and conserve natural resources. In comparison to alternative methods of biodiesel production, the

ERKEN GÖRÜNÜM

utilization of waste oils can result in reduced costs and a lesser environmental impact.

The amount of energy consumed in the collection of waste oils is dependent on a number of variables, and therefore it is challenging to provide an exact figure. Nevertheless, the principal factors influencing energy consumption can be broadly classified as follows:

- The collection method is a significant factor influencing the energy consumption associated with the collection of waste oils. The manual collection of waste oils may be less energy efficient. Nevertheless, the collection processes may prove to be more time-consuming and labor-intensive. The utilization of mechanical means for the collection of waste oils, such as tankers or specialized collectors, facilitates a more expeditious and less labor-intensive process. However, this approach may potentially lead to an increase in fuel consumption and energy costs.

- The distance between the areas where waste oils are collected, and the collection centre is a significant factor influencing energy consumption. The collection of waste oils from nearby locations has the potential to reduce energy consumption. The collection of waste oils from more distant areas may necessitate the use of greater quantities of fuel, which in turn may result in increased energy consumption.

- The frequency of collection is also a significant factor. The frequency of collection has an impact on the costs associated with energy consumption. A greater frequency of collection may result in increased fuel consumption, whereas a less frequent collection may increase the risk of oil spoilage during storage.

- The efficiency of the vehicles used for transportation is also a factor to be considered. The energy efficiency of the vehicles employed is a determining factor in the amount of energy consumed during the collection process. The utilization of vehicles with reduced emissions and enhanced fuel efficiency can contribute to a reduction in overall energy consumption.

The average volume of diesel fuel required to collect one liter of waste oil is 0.1–0.5 liters. This equates to an energy consumption of approximately 1.5–7.5 MJ [30].

In studies examining the use of biodiesel in public transport buses in Belgrade, it was concluded that emissions were reduced by an average of 60% and particulate matter emissions were one-third compared to conventional diesel-powered buses [34, 35]. It has been demonstrated that the utilization of biodiesel does not result in any alteration that will diminish the engine compression ratio, reduce engine power and torque. Furthermore, it has been shown to lead to a notable reduction in emission values [36]. In a separate investigation conducted in Portugal, it was observed that the fuel consumption of buses operating on B100 was 20% higher, while those utilizing B20 demonstrated a 4-6% reduction in fuel consumption [37]. In a study in which 27 technical literature sources on biodiesel engines were analyzed, it was reported that the emission of carbon monoxide was 80% lower, the emission of particulate matter was 65% lower and the emission of nitrogen oxides was 120% lower than that of normal diesel engines [38].

As one of the most populous cities in Turkey and a major hub for public transportation, Ankara province serves as a pivotal location for this transformation. The waste oils collected in Ankara are converted into biodiesel, which is then used in public transport vehicles. This process has the additional benefit of reducing the environmental impact of urban transport. The objective of this study is to examine the environmental and economic impacts of the utilization of biodiesel produced from waste oils in public transport in Ankara, and to evaluate the extent to which this practice reduces the carbon footprint, with reference to numerical data. In particular, the potential of biodiesel to reduce carbon emissions is closely related to the collection and conversion processes of waste oil in Ankara. The primary focus of this study is the reduction of carbon emissions through the use of waste oils in biodiesel production. Specifically, the case of Ankara province is used to highlight contributions to sustainable energy use. In this context, the objective is to ascertain the quantity of waste oil that can be converted into biodiesel within the city, the number of public transport vehicles utilizing this fuel, and the extent of carbon emissions that can be prevented as a result.

2. MATERIALS AND METHODS (MATERYAL VE METOD)

The Biodiesel is obtained by the transesterification process. The reaction rate depends on temperature, catalyst concentration, alcohol content and stirring speed. Usually, the reaction is carried out at a temperature of 60-65 °C, which is close to the

ERKEN GÖRÜNÜM

boiling point of methanol. The reaction rate constant k can be calculated using the Arrhenius equation (Eq. 1) [39]:

$$k = Ae^{-\frac{Ea}{RT}} \qquad (1)$$

k; reaction rate constant, A; frequency factor, Ea; activation energy (kJ.mol^{-1}), R; gas constant (8.314 J. mol^{-1}.K^{-1}), and T; temperature (K).

In the transesterification process, the alcohol/catalyst mixture is filled into a closed reactor with agitator mixer and vegetable oil is added. The system is then completely closed to the atmosphere to prevent alcohol loss. The reaction is carried out at 55-60°C. The recommended reaction time is between 1 and 2 hours. According to the stoichiometric value of the reaction, 3 mol alcohol is required for 1 mol oil. However, in order to increase the efficiency of the reaction, 1 mol oil is reacted with 6 mol alcohol. After the reaction is completed, two main products glycerin and biodiesel are formed. Since the density of the glycerin phase is higher than that of the biodiesel phase and biodiesel and glycerin do not dissolve in each other, these two phases separate from each other over time. Glycerin and biodiesel are completely separated when waiting for about 10 hours. After the glycerin and biodiesel phases are separated, the excess alcohol in each phase is removed by a flash evaporation or distillation process. In both processes, the alcohol vapor is cooled and condensed, recovered and reused. Figure 2 shows the biodiesel production flow chart [40].

The physical and chemical properties (density, viscosity, acid value, water content and free fatty acid (FFA) content of the collected domestic waste oils are determined, and their suitability is evaluated. Water content in domestic waste oils may adversely affect the transesterification reaction. Water can react with the catalyst and cause saponification. Therefore, the water content of oils should be minimized before transesterification. Water content is determined by Karl Fischer titration (Eq. 2) [39].

$$Water\ content\ = \frac{Titreated\ KF\ (ml)}{Oil\ (g)}\ x\ 100 \qquad (2)$$

Domestic waste oils generally have high FFA content. High FFA content may cause saponification side reactions in the transesterification reaction, which may reduce the biodiesel yield. The FFA content is found by Equation 3 [39].

$$FFA\ = \frac{Titrated\ KOH\ (mg)}{Oil\ (g)}\ x\ 100 \qquad (3)$$

For every mole of triglycerides (CH_2COOR_1-$CHCOOR_2$-CH_2COOR_3) of the oil, 3 moles of methanol ($HOCH_3$) must be used (Eq. 4). Energy is required for heating the reactor, operating the mixers and purification processes (Eq. 5). Conversion efficiency is found according to the theoretical and produced amount of biodiesel (Eq. 6). The amount of biodiesel required is calculated by Equation 7 [39].

$$n_{HOCH_3} = M \times n_{CH_2COOR_1-CHCOOR_2-CH_2COOR_3} \qquad (4)$$

$$Energy\ consumption\ (kWh) = Equipment\ power\ (kW) \times Operating\ time\ (h) \qquad (5)$$

$$\eta = \frac{Produced\ Biodiesel\ (g)}{Theoretical\ Biodiesel\ \ (g)}\ x\ 100 \qquad (6)$$

$$Amount\ of\ biodiesel\ required = \frac{Diesel\ energy\ content\ (MJ/l))}{Biodiesel\ energy\ content\ (MJ/l)} \qquad (7)$$

M; mole fraction, n; number of moles, and η; conversion efficiency.

The flash point of biodiesel is higher than diesel (>130°C). This feature makes biodiesel a safer fuel for use, transport and storage. A comparison of the fuel properties of diesel and biodiesel is given in Table 1 [39].

ERKEN GÖRÜNÜM

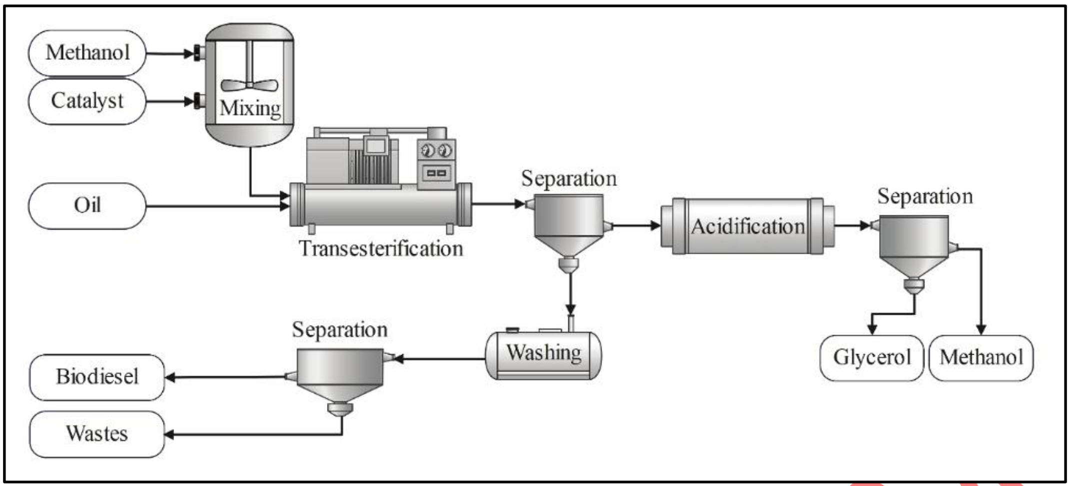

Figure 2. Biodiesel production flow chart (Biyodizel üretim akış şeması)

Table 1. Diesel and Biodiesel fuel properties (Dizel ve Biyodizel yakıt özellikleri)

Fuel specifications	Unit	Limit value	Biodiesel	Diesel
Closed formula	g/mol		$C_{19}H_{34}O_2$	$C_{12}H_{26}$
Molecular weight			296	120-320
Lower heating value:				
Mass	MJ/kg		37.1	42.7
Volumetric	MJ/l		32.6	35.5
Specific gravity (15 °C)	kg/l	0.875-0.90	0.86-0.90	0.82-0.86
Kinematic viscosity (40 °C)	mm²/s	2-4.5	3.5- 5.0	2.5-3.5
Flash point temperature	°C	> 55	> 100	> 55
Sulphur content	%Mass	< 0.05	< 0.01	< 0.05
Cetane number		> 49	> 55	49-55
Ash	%Mass	< 0.01	< 0.01	< 0.01
Water quantity	mg/kg	< 200	< 500	< 200

The combustion reactions of diesel and biodiesel fuels are chemically analogous; however, disparities in combustion products and efficiencies emerge due to discrepancies in their molecular structures. The combustion reactions of these two fuels are presented in Equations 8 and 9 [39]. The combustion products of biodiesel contain carbon dioxide and water in a similar manner to those of diesel, but with a reduced level of sulphur and toxic substances released.

$$C_{12}H_{26} + 18.5O_2 \rightarrow 12CO_2 + 13H_2O \tag{8}$$

$$C_{19}H_{34}O_2 + 27O_2 \rightarrow 19CO_2 + 17H_2O \tag{9}$$

Greenhouse gas emissions from the use of biodiesel are generally lower compared to fossil fuels. Carbon emissions were calculated based on fuel consumption data multiplied by CO_2 emission factors associated with biodiesel use (Eq. 10). This analysis follows internationally recognized emission calculation methodologies [41].

$$CO_2\ emission\ (kg) = Fuel\ consumption(l) \times Fuel\ emission\ factor\ (kgCO_2/l) \tag{10}$$

CO_2, which has a large share in greenhouse gases, causes global warming, the world's most important environmental problem, and is an emission resulting from combustion. CO_2, SO_x, NO_x emissions, which are also released as a result of combustion and are among greenhouse gases, are also harmful to human health. It has also been proven that CO, SO_x emissions, particulate matter and unburned hydrocarbons are released less. As a result of the tests, it has been revealed that NO_x emissions when using biodiesel are 13% higher than the amount generated when using diesel fuel [30]. However, biodiesel does not contain sulphur. Therefore, NO_x control technologies can be applied to systems using biodiesel fuel. Conventional diesel fuel is not suitable for NO_x control technologies because it contains sulphur. The negative effects on the ozone layer are 50% less when using biodiesel than diesel fuel. Sulfur components that cause acid rain are almost non-existent in biodiesel fuels. Table 2 shows the comparison of B20 and B100 life cycle

ERKEN GÖRÜNÜM

emissions with diesel emissions. With the use of biodiesel and diesel-biodiesel blends, CO, PM, HF, SO_x, and CH_4 emissions decrease, while NO_x, HCl, and HC emissions increase [42-46].

Biodiesel converts CO_2 with the help of photosynthesis in the carbon cycle. It accelerates the carbon cycle as it does not have a feature that increases the greenhouse effect. Since it is sulphur-free, it does not cause acid rain. The total pollution potential of biodiesel fuels is 50% less than diesel fuels [47].

3. RESULTS (BULGULAR)

The population of Ankara province is 5803482 people by the end of 2023 [48]. Assuming that 4 people live in each house, it is assumed that there are 1450870 houses in Ankara province. A daily oil consumption of 100 ml, a waste rate of 0.2 [49] and a conversion efficiency of 0.85 [50, 51] allow the production of 739943 liters of biodiesel from 870522 liters of waste oil collected monthly.

The lower heating value of diesel fuel is approximately 35.8 MJ/l. The lower heating value of B100 biodiesel is approximately 32.8 MJ/l [49-51]. This is approximately 91.6% of the energy content of diesel fuel. Since B20 biodiesel is a mixture of 20% biodiesel and 80% diesel, its energy content (35.2 MJ/l) is approximately 98.3% of the energy content of diesel fuel. In order to provide the same amount of energy as diesel, it is necessary to use 9.1% more than B100 biodiesel and 1.7% more than B20 biodiesel. If B100 biodiesel is used as fuel from the 870522 l waste oil amount that can be collected, 739943 l biodiesel can be used instead of 678225 l diesel; if B20 biodiesel is used as fuel, 2897928 l diesel and 739943 l biodiesel can be used instead of 3637871 l diesel.

Table 2. Comparison of B20 and B100 Biodiesel and Diesel emissions (B20 ve B100 Biyodizel ve Dizel emisyonlarının karşılaştırılması)

Emissions	B20 (20% Biodiesel)	B100 (100% Biodiesel)
CO: Carbon monoxide	-6.90%	-34.50%
PM: Particulate Matter	-6.48	-32.41
HF: Hydrofluoric Acid	-3.10%	-15.51%
SO_x: Sulphur Oxides	-1.61%	-8.03%
CH_4: Methane	-0.51%	-2.57%
NO_x: Nitrogen Oxides	2.67%	13.35%
HCl: Hydrochloric Acid	2.71%	13.54%
C_xH_y: Hydrocarbons	7.19%	35.96%

On average, the combustion of 1 liter of diesel fuel results in approximately 2.68 kg of CO_2 emissions [39]. CO_2 emissions of B20 are generally 15-20% lower than diesel fuel [50]. Using a reduction rate of 78% for B100 biodiesel and 17.5% for B20 biodiesel [51], the amount of CO_2 emission was calculated as 0.59 kg CO_2/l and 2.21 kg CO_2/l, respectively. When B100 biodiesel is used, 436.6 tonnes of CO_2 are emitted instead of 1817.6 tonnes of CO_2, and when B20 biodiesel is used, 8203 tonnes of CO_2 are emitted instead of 9749.5 tonnes of CO_2. In this case, with the use of B100 biodiesel produced only in Ankara province and only from waste oils collected from households, instead of diesel as fuel, there will be a 76% reduction in CO_2 emissions with 1381.2 tonnes/month and a 16% reduction in CO_2 emissions with 1546.5 tonnes/month with the use of B20 biodiesel.

The municipal fleet in Ankara comprises approximately 1900 buses, 1000 of which are diesel-fueled. Additionally, there are approximately 2000 diesel-fueled private and public buses in the city [52]. Table 3 presents a summary of the economic and environmental assessment for 3000 public transport vehicles in Ankara, which run on diesel fuel and travel an average of 50000 km per year (Fig. 3).

The analysis indicates that diesel fuel remains the most cost-effective option. Nevertheless, with the ongoing rise in costs, an annual expense of 2.7 billion ₺ has been projected. The utilization of B20 biodiesel results in an approximate additional cost of 100 million ₺. This increase in cost makes biodiesel a less economically viable option, despite its lower carbon emission advantage. The most expensive option is B100 biodiesel, with an estimated annual cost of 3.17 billion ₺. The cost of fully renewable biodiesel fuel is estimated to be approximately 468 million ₺ higher than that of diesel fuel. Although biodiesel use appears to be

ERKEN GÖRÜNÜM

more costly economically, long-term environmental benefits tied to carbon reduction could offset costs through reduced healthcare and air quality expenses.

It has been calculated that Ankara can prevent the import of 678225 l of diesel fuel per month by producing biodiesel from 870522 l of waste oil. This equates to the prevention of the import of approximately 8138700 l of fossil fuel on an annual basis. Assuming an average oil price of 1.20 $/l, it is estimated that approximately 9.77 million $ can be saved annually. The collection and conversion of waste oil into biodiesel has the additional benefit of eliminating the clean-up costs incurred as a result of waste oil spillage into sewers or nature. Assuming a cost saving of 0.5 ₺ per liter in waste management, an annual waste management cost saving of approximately 435261 ₺ can be achieved from 870522 l of waste oil. The biodiesel production process will create local employment opportunities, both directly and indirectly, in the collection, transportation, production and distribution of waste oil. For instance, it is estimated that a new labor force of 10-15 people will be required for the biodiesel production facility. When the long-term economic benefits of biodiesel are analyzed, the following can be concluded:

- An annual reduction of $ 9.77 million in fuel imports,
- A reduction of 435261 ₺ in waste management costs,
- A contribution to the local economy through the provision of new employment opportunities.

ERKEN GÖRÜNÜM

Table 3. Summary of the economic and environmental assessment (Ekonomik ve çevresel değerlendirmenin özeti)

Parameters	Diesel	B20 Biodiesel	B100 Biodiesel
Energy content (MJ/l)	35.8	35.08	33
Fuel cost (₺/l)	45	45.6	48
Fuel consumption (l/100 km)	40	40.8	44
Carbon emission (kg CO_2/l)	2.68	2.62	2.45
Annual fuel consumption (l)	20000	20400	22000
Annual fuel cost (₺)	900000	930240	1056000
Annual carbon emission (kg CO_2)	53600	53448	53900
Annual total fuel consumption (l)	60000000	61200000	66000000
Annual total fuel cost (₺)	2700000000	2790720000	3168000000
Annual total carbon emission (kg CO_2)	160800000	160344000	161700000

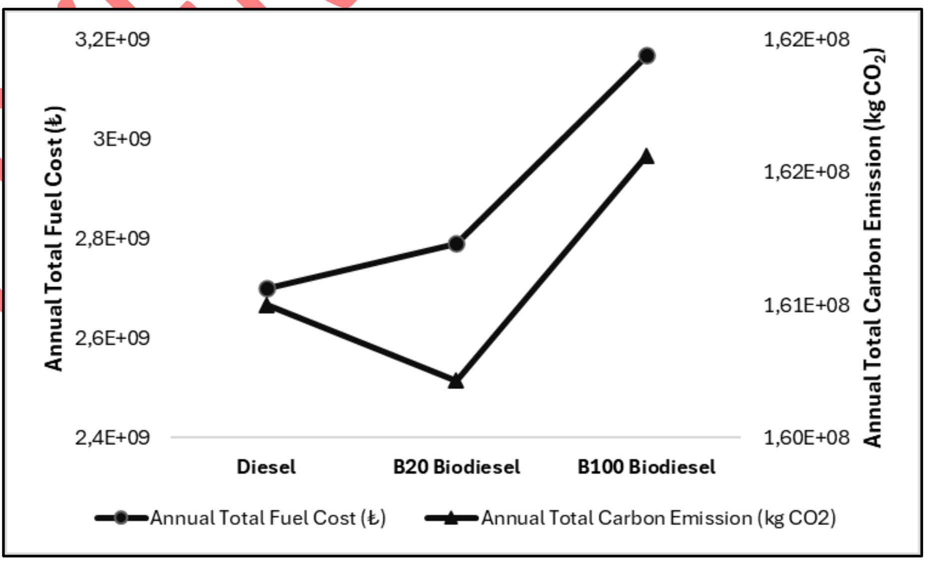

Figure 3. Cost and carbon emission variation by fuel type (Yakıt türüne göre maliyet ve karbon emisyonu değişimi)

The total annual carbon emissions resulting from the utilization of diesel fuel are estimated to be 160800 tonnes of CO_2 equivalents. The application of B20 biodiesel results in a marginal reduction in emissions, with the annual emission total reduced to 160344 tonnes of CO_2 equivalent. Although the environmental benefit is limited, it can be considered as an alternative option for municipalities seeking to reduce their carbon footprint to a slight extent. B100 biodiesel maintains carbon emissions at 161700 tonnes of CO_2; furthermore, it offers a more sustainable alternative, given the near-zero net carbon emissions of biofuel. While the cost of using B20 biodiesel increases by 3%, its significant reduction in carbon emissions makes it an attractive option for environmental sustainability.

The Selective Catalytic Reduction (SCR) system is a technology that has been demonstrated to reduce NO_x emissions by up to 90%. In these systems, NO_x emissions are converted into harmless nitrogen gas using a urea solution, known as AdBlue. The integration of SCR systems in public transportation vehicles in Ankara has been shown to significantly offset the increase in NO_x emissions caused by biodiesel. The Exhaust Gas Recirculation (EGR) system has been found to increase the amount of exhaust gas returning to the engine, thereby lowering the combustion temperature and reducing NO_x emissions. In engines using biodiesel, a 30-40% reduction in NO_x emissions can be achieved with EGR technology [30]. The combustion process is optimized by making biodiesel-specific engine calibration, thus minimizing the NO_x increase caused by biodiesel The increase in NO_x emissions has been identified as one of the most significant environmental drawbacks associated with biodiesel utilization. The proposed technological solutions, namely the use of SCR to achieve a -90% reduction in NO_x emissions and EGR to achieve a 30-40% reduction in NO_x emissions, hold great promise in addressing this issue. The implementation of these solutions has the potential to significantly enhance the environmental sustainability of biodiesel use in Ankara's public transportation sector.

Furthermore, it is evident that the annual production of 887932.4 liters of B100 biodiesel derived from waste oil gathered in Ankara province is sufficient to fulfil the requirements of the entire diesel-powered public transport vehicle fleet. This will result in a 100% reduction in the amount of carbon emissions from diesel-powered public transport vehicles.

4. CONCLUSIONS (SONUÇLAR)

In this study, examined the environmental and economic consequences of utilizing biodiesel derived from waste oils in the public transportation system of Ankara province. The findings demonstrate that the utilization of biodiesel markedly diminishes carbon emissions in comparison to fossil fuels, thereby promoting energy sustainability.

This study represents one of the first detailed analyses of the impacts of using biodiesel produced from waste oils in the public transport system in Ankara on both the local environment and energy sustainability. While the literature contains numerous studies on the industrial and individual uses of biodiesel, comprehensive research on the use of biodiesel in public transport in Turkey, particularly at the metropolitan level, remains limited. This research project focuses on the conversion of waste oil collected in Ankara into biodiesel and its direct use in urban transport. It demonstrates the impact of this process in reducing carbon emissions and its potential to reduce energy dependency, presenting quantitative data to support these claims.

A further innovative aspect of the study is that the process of collecting waste oil, converting it into biodiesel and integrating it into the transport sector is considered at the city scale. Furthermore, the integration of this practice into public transport fleets and its contribution to the local economy are also examined. In this context, the study offers a tangible model for the implementation of sustainable transport solutions in large cities such as Ankara, as well as crucial data on the environmental and economic impacts of integrating biodiesel into urban transport systems.

The results of the study can be summarized as follows:

- 739943 l of biodiesel can be obtained from 870522 l of waste oil that can be collected on a provincial basis.
- If B100 biodiesel is used as fuel from the 870522 l waste oil amount that can be collected, 739943 l biodiesel can be used instead of 678225 l diesel; if B20 biodiesel is used as fuel, 2897928 l diesel and 739943 l biodiesel can be used instead of 3637871 l diesel.
- When B100 biodiesel is used, 436.6 tonnes of CO_2 emissions are emitted instead of 1817.6 tonnes of CO_2, and when B20 biodiesel is used, 8203 tonnes of CO_2 emissions are emitted instead of 9749.5 tonnes of CO_2.
- When diesel fuel is replaced with B100 biodiesel produced from waste oils, 1381.2 tonnes (76%) of CO_2 emissions per month and

ERKEN GÖRÜNÜM

1546.5 tonnes (16%) of CO_2 emissions per month are reduced with the use of B20 biodiesel. The findings align with studies conducted on the bus fleet in Belgrade, where biodiesel usage was also shown to reduce emissions by 60%

- Biodiesel produced from waste oil is capable of meeting the total energy requirements of diesel-powered public transport vehicles. Consequently, the carbon emissions from diesel-powered public transport vehicles have been reduced by 100%.

- While diesel fuel remains the most cost-effective option, the use of biodiesel, particularly B20, is preferable when considering the reduction of carbon emissions and the promotion of environmental sustainability.

- In consideration of the environmental benefits, B20 biodiesel emerges as a viable option for the reduction of carbon emissions. However, B100 biodiesel is relatively costly and may be viewed as a potential investment for achieving carbon neutrality targets.

These results show that waste oil has a significant potential for biodiesel production in Ankara province and the environmental benefits are considerable. The utilization of waste oil in accordance with the sustainable transport objectives of local governments and municipalities is regarded as a strategic measure with regard to both the environment and energy security. The findings of the study demonstrated that the integration of biodiesel into the public transport fleet in Ankara plays a significant role in reducing the carbon footprint, and that this practice can provide greater benefits if it is expanded. Furthermore, the production of biodiesel has had a positive impact on the local economy, creating new employment opportunities in waste management and energy production.

Moreover, the implementation of a more extensive network of waste oil collection facilities in Ankara will facilitate an increase in biodiesel production, consequently leading to a further reduction in carbon emissions. It is crucial to enhance the awareness of the local population and expand waste oil collection initiatives in order to achieve this objective. An increase in the capacity of existing biodiesel production facilities will facilitate a more efficient conversion of waste oils into biodiesel. It is possible to reduce production costs by conducting research into innovative technologies and more efficient production processes. It would be prudent for the government to provide support and tax reductions in order to encourage the use of biodiesel. The collaboration of the public and private sectors in the production of biodiesel can facilitate a more efficient process of energy generation from waste oils. Such collaboration can simultaneously reduce the cost of production of biodiesel and promote the use of sustainable fuel. The acceleration of the transition to biodiesel in the transport and industrial sectors will result in increased environmental benefits. The integration of biodiesel, which is currently employed in a restricted number of buses, into the entirety of Ankara's public transportation fleet would result in significant energy savings and environmental benefits across the city. In order to achieve this, it is necessary to increase investment in infrastructure and encourage the implementation of policies that facilitate the use of biodiesel. It is recommended that the environmental impacts of biodiesel use be subjected to regular monitoring and reporting. In addition to the reduction of CO_2 emissions, the impact of biodiesel on other air pollutants should also be considered. An increase in the use of biodiesel will contribute to Ankara's achievement of national and international carbon reduction targets. It is therefore recommended that legal regulations and incentives for the use of environmentally friendly fuels such as biodiesel be increased.

DECLARATION OF ETHICAL STANDARDS
(ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

Bu makalenin yazarı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

***Osman Furkan KAPIKIRAN*:** He conducted the numerical analysis and performed the writing process.

Sayısal analizi yapmış ve maklenin yazım işlemini gerçekleştirmiştir.

***Halil İbrahim VARİYENLİ*:** He conducted the numerical analysis and performed the writing process.

ERKEN GÖRÜNÜM

Sayısal analizi yapmış ve maklenin yazım işlemini gerçekleştirmiştir.

***Mert ÖKTEN*:** He conducted the numerical analysis and performed the writing process.

Sayısal analizi yapmış ve maklenin yazım işlemini gerçekleştirmiştir.

***Semih Sadi KILIÇ*:** He conducted the numerical analysis and performed the writing process.

Sayısal analizi yapmış ve maklenin yazım işlemini gerçekleştirmiştir.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

REFERENCES (KAYNAKLAR)

[1] United Nations. Treaty of Paris. 2024. https://www.unep.org/environmental-moments-unep50-timeline.

[2] Ökten M. An investigation on provincial production & consumption of electric energy: A case analysis for Ankara. Kocaeli Journal of Science and Engineering (KOJoSE). 2021; 4(1): 59-68.

[3] Brown A, Smith B. Environmental impacts of biodiesel versus diesel fuel: A comparative study. Journal of Environmental Science. 2017; 15(2): 123-135.

[4] Aydın K, Keskin A. Dizel motorlarında motorin, bitkisel yağlar ve alkol karışımlarının performans ve emisyona etkilerinin araştırılması Yanma ve Hava Kirliliği Kontrolü V. Ulusal Sempozyumu. 2000.

[5] Yücesu HS, Altın R, Çetinkaya S. Dizel motorlarında alternatif olarak bitkisel yağ kullanımının deneysel incelenmesi. Türk Journal Engineering Environment Science. 2001; 25: 39-49.

[6] Taşyürek M, Acaroğlu M. Biyoyakıtlarda (Biyomotorinde) emisyon azatlımı ve küresel ısınmaya etkisi. Uluslararası Küresel İklim Değişikliği ve Çevresel Etkileri Konferansı. 2007.

[7] Çaylı G, Küsefoğlu S. Increased yields in biodiesel production from used cooking oils by a two-step process: Comparison with one step process by using TGA. Fuel Processing Technology. 2008; 89(2): 118-122.

[8] Özbay N, Oktar N, Tapan NA. Esterification of free fatty acids in waste cooking oils (WCO): Role of ion-exchange resins. Fuel. 2008; 87(10-11): 1789-1798.

[9] Gürü M, Koca A, Can A, Çınar C, Şahin F. Biodiesel production from waste chicken fat based sources and evaluation with Mg based additive in a diesel engine. Renewable Energy. 2010; 35: 637–643.

[10] Altinok F, Albayrak S, Arslan NP, Taskin M, Aygun E, Sisecioglu M, Adigüzel A. Application of Anoxybacillus gonensins UF7 lipase as a catalyst for biodiesel production from waste frying oil. Fuel. 2023; 334(1): 126672.

[11] El-Khair MAA, El Saied M, El Naga AOA, Morshedy AS. Rapid and low-temperature biodiesel production from waste cooking oil: Kinetic and thermodynamic insights using a KOH/ZnAl2O4 nanocatalyst derived from waste aluminum foil. Energy Conversion and Management. 2024; 318: 118898.

[12] Anil N, Rao PK, Sarkar A, Kubavat J, Vadivel S, Manwar NR, Paul B. Advancements in sustainable biodiesel production: A comprehensive review of bio-waste derived catalysts. Energy Conversion and Management. 2024; 318: 118884.

[13] Antolin G, Tinaut FV, Briceño Y, Castaño V, Pérez C, Ramírez AI. Optimisation of biodiesel production by sunflower oil transesterification. Bioresource Technology. 2002; 83(2): 111-114.

[14] Vicente G, Martínez M, Aracil J. Integrated biodiesel production: A comparison of different homogeneous catalysts systems. Bioresource Technology. 2004; 92(3): 297-305.

[15] Ayhan V, Tunca S, Özsert İ, Ergen G, Cesur İ. Ayçiçek yağı metil ester karışımlarının bir dizel motorunun performans ve emisyonlarına etkisi. APJES. 2019; 7(1): 67–73.

[16] Samuel OD, Okwu MO, Oyejide OJ, Taghinezhad E, Afzal A, Kaveh M. Optimizing biodiesel production from abundant waste oils through empirical method and grey wolf optimizer. Fuel. 2020; 281: 118701.

[17] Foroutan R, Peighambardoust SJ, Mohammadi R, Peighambardoust SH, Ramavandi B. The potential of biochar derived from banana peel/Fe3O4/ZIF-67@K2CO3 as magnetic nanocatalyst for biodiesel production from waste cooking oils. Results in Engineering. 2024; 22: 102005.

[18] Usta N, Conkur ES, Can AC, Topcu M, Öztürk E, Can O, Nas S, Çon AH. Combustion of biodiesel fuel produced from hazelnut soapstock/waste sunflower oil mixture in a diesel engine. Energy Conversion and Management. 2005; 46(5): 741-755.

[19] Kalam MA, Masjuki HH. Biodiesel from palmoil—an analysis of its properties and

ERKEN GÖRÜNÜM

potential. Biomass and Bioenergy. 2002; 23(6): 471-479.

[20] Torres EA, Cerqueira GS, Ferrer TM, Quintella CM, Raboni M, Torretta V, Urbini G. Recovery of different waste vegetable oils for biodiesel production: A pilot experience in Bahia State Brazil. Waste Management. 2013; 33(12): 2670-2674.

[21] Ramadhas AS, Jayaraj S, Muraleedharan C. Biodiesel production from figh FFA rubber seed oil. Fuel. 2005; 84: 335-340.

[22] Çanakçı M, Van Gerpen JH. Comparision of engine performance and emissions for petroleum diesel fuel, yellow-grease biodiesel and soybean-oil biodiesel. Trans ASAE. 2003; 46: 937-944.

[23] Çaynak S, Gürü M, Biçer A, Keskin A, İçingür Y. Biodiesel production from pomace oil and improvement of its properties with synthetic manganese additive. Fuel. 2009; 88(3): 534-538.

[24] Tashtoush MG, Al Widyan MI, Al Jarrah MM. Experimental study on eveluation and optimization of conversion of waste animal fat into biodiesel. Energy Conversion and Management. 2004; 45: 2697-2711.

[25] Reyes JF, Sepulveda MA. PM-10 emissions and power of a Diesel engine fueled with crude and refined Biodiesel from salmon oil. Fuel. 2006; 1-6.

[26] Altıparmak D, Keskin A, Koca A, Guru M. Alternative fuel properties of tall oil fatty acid methyl ester-diesel fuel blends. Bioresource Technology. 2007; 98(2): 241-246.

[27] Moraes PS, Igansi AV, Cadaval Jr TRS, Pinto LAA. Biodiesel produced from crude, degummed, neutralized and bleached oils of Nile tilapia waste: Production efficiency, physical-chemical quality and economic viability. Renewable Energy. 2020; 161: 110-119.

[28] Sharma P, Usman M, Salama ES, Redina M, Thakur N, Li X. Evaluation of various waste cooking oils for biodiesel production: A comprehensive analysis of feedstock. Waste Management. 2021; 136: 219-229.

[29] Fawaz EG, Salam DA. Preliminary economic assessment of the use of waste frying oils for biodiesel production in Beirut Lebanon. Science of The Total Environment. 2018; 637-638: 1230-1240.

[30] Fonseca JM, Teleken JG, de Cinque Almeida V, da Silva C. Biodiesel from waste frying oils: Methods of production and purification. Energy Conversion and Management. 2019; 184: 205-218.

[31] AlYammahi J, Chelaifa H, Hasan A, Darwish AS, Lemaoui T, Hernandez HH, Galvan AR. Salicornia seed oil: A high-yielding and sustainable halophytic feedstock for biodiesel and energy in underutilized hypersaline coastal deserts. Energy Conversion and Management. 2024; 318: 11891.

[32] Nahas L, Dahdah E, Aouad S, El Khoury B, Gennequin C, Aad EA, Estephane J. Highly efficient scallop seashell-derived catalyst for biodiesel production from sunflower and waste cooking oils: Reaction kinetics and effect of calcination temperature studies. Renewable Energy. 2023; 202: 1086-1095.

[33] Adib AR, Rahman MM, Hassan T, Ahmed M, Al Rifat A, Novel biofuel blends for diesel engines: Optimizing engine performance and emissions with C. cohnii microalgae biodiesel and algae-derived renewable diesel blends. Energy Conversion and Management: X. 2024; 100688.

[34] Ivkovicˇ I, Kaplanovicˇ S, Zˇezˇelj S. Višekriterijumsko rangiranje konstrukcijsko-koncepcijskih rešenja autobusa u cilju stvaranja odrzˇivog JMTP-a u Beogradu. Journal of Applied Engineering Science. 2007; 5(15): 57–66.

[35] Petrovicˇ J, Ivkovicˇ I, Vujacˇicˇ I, Zˇezˇelj S. Possibilities of buses on alternative fuel in public urban transport in Belgrade. Technology Econimical Devolution Economy. 2009; 15(1): 78–89.

[36] Tica S, Filipovic´ S, ˇZivanovic´ P, & Milovanovic´ B. Test run of biodiesel in public transport system in Belgrade. Energy Policy. 2010; 38: 7014–7020.

[37] Serrano LMV, Camara RMO, Carreira VJR, da Silva MCG. Performance study about biodiesel impact on buses engines using dynamometer tests and fleet consumption data. Energy Conversion Management. 2012; 60: 2–9.

[38] Bunger J, Krahl J, Schroder O, Schmidt L, Westphal GA. Potential hazards associated with combustion of bio-derived versus petroleum-derived diesel fuel. Criteria Revolution Toxicology. 2012; 42(9): 732–750.

[39] Akgül G, Sözer S, Culfa M. Atık yağlardan biyodizel üretiminde yenilikçi biyokömür katalizörü TÜBAV Bilim Dergisi. 2017; 10(4): 29-39.

[40] Ahmadbeigi A, Mahmoudi M, Fereidooni L, Akbari M, Kasaeian A. Biodiesel production from waste cooking oil: A review on production methods, recycling models, materials and catalysts. Journal of Thermal Engineering. 2024; 10(5): 1362-1389.

ERKEN GÖRÜNÜM

[41] IPCC. Climate change 2014: Mitigation of climate change intergovernmental panel on climate change. 2024. https://www.ipcc.ch/report/ar5/syr/.

[42] Green C, Brown D, Black E. Effects of biodiesel on NOx emissions: A comparative analysis. Journal of Sustainable Energy. 2019; 25(4): 321-335.

[43] Johnson F, Brown A. Reduction of CO and SOx emissions with biodiesel: A case study. Environmental Engineering Review. 2018; 10(3): 210-225.

[44] Jones G. Sulfur compounds in biodiesel fuels. Biodiesel: Production, Properties, and Applications. 2019; 87-102, Springer.

[45] Smith B. Impacts of greenhouse gas emissions on global warming. Environmental Health Perspectives. 2020; 128(5): 450-465.

[46] Demirbas A. Progress and recent trends in biodiesel fuels. Energy Conversion Management. 2009; 50(1): 14–34.

[47] De Paulo AA, Da Costa RS, Rahde SB, Vecchia FD, Seferin M, Dos Santos CA. Performance and emission evaluations in a power generator fuelled with Brazilian diesel and additions of waste frying oil biodiesel. Applied Thermal Engineering. 2016; 98: 288–297.

[48] TÜİK. Adrese dayalı nüfus kayıt sistemi sonuçları. 2024. https://data.tuik.gov.tr/Bulten/Index?p=Adrese-Dayali-Nufus-Kayit-Sistemi-Sonuclari-2023-496884#:~:text=%C4%B0stanbul'un%20n%C3%BCfusu%2C%20bir%20%C3%B6nceki,249%20ki%C5%9Fi%20ile%20Antalya%20izledi.

[49] U.S. Department of Energy. Biodiesel benefits and considerations. alternative fuels data center. 2024. https://afdc.energy.gov/fuels/biodiesel_benefits.html

[50] National Renewable Energy Laboratory. Biodiesel handling and use guide (4th edition). 2009. https://www.nrel.gov/docs/fy09osti/43672.pdf

[51] Environmental Protection Agency. A comprehensive analysis of biodiesel impacts on exhaust emissions. 2002. https://nepis.epa.gov/Exe/ZyPDF.cgi/P1001YTB.PDF?Dockey=P1001YTB.PDF.

[52] Ankara EGO. 2024. https://m.ego.gov.tr/haber/6155/egonun-otobus-filosu-genisliyor-16-solo-tip-otobus-daha-alindi.

ERKEN GÖRÜNÜM