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Research Article

An Empirical Analysis on The Use of Sustainable Fuels in the Aviation Industry

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Abstract

This study aims to analyze and evaluate different types of alternative fuels for aviation from a life cycle and cost perspective. It aims to analyze different alternative fuels and their use in aircraft for this purpose in the aviation sector in relation to their potential to be a suitable transition solution towards sustainable transformation. Using the GREET (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) aviation module developed by the US National Research Laboratory (Argonne), the life cycles of petroleum and six different sustainable aviation fuel production methods were calculated, and the environmental impact of kerosene and sustainable aviation fuels in terms of cost and carbon dioxide emissions on long, medium and short-haul flights were analyzed. The life cycle values of carbon dioxide formed as a result of the production of corn, soybean and canola products, which are the most preferred to produce biofuel in the aviation industry, with hydro-processed esters and fatty acids (HEFA), alcohol-to-jet (ATJ), ethanol-to-jet (ETJ) methods, were calculated. As a result of the study, it was determined that the cost of the sustainable aviation fuels examined was higher than fossil fuel. The key to greater acceptance and deployment of sustainable aviation fuel is cost reduction. In the long term, this will require investment in advanced technologies to process feedstocks more efficiently on a larger scale and in the development of sustainable and scalable feedstock options. However, in the short term, temporary support from governments and other stakeholders through policy incentives is needed.

Keywords

Sustainable aviation fuels
Life cycle assessment
Life cycle cost
Carbon emissions
Environmental impact

Time Scale of Article

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1. Introduction

Demand for passenger and cargo flights has increased significantly over the past few years. Global air travel is expected to increase further, due to continued globalization and almost unlimited travel possibilities. According to studies by leading aircraft manufacturers Airbus and Boeing before COVID-19, it is estimated that flight demand will increase by up to 4.5% per year, resulting in air traffic doubling every 16 years. Although the COVID-19 pandemic has led to a 75% decrease in air travel according to 2020 data and slowed down this growth in the short term, the demand for flights is entering a recovery process and a strong positive trend is expected in the long term. However, while this development is seen as a positive development in economic terms, it is predicted that the effects of increasing global warming on the climate, especially the emission of greenhouse gases and carbon dioxide (CO2), will cause an increase in factors that negatively affect the environment. According to the 2019 EASA report, the aviation sector's global carbon dioxide emissions are 2.6%. It has been seen as responsible for the greenhouse

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gas emissions and 5.9% of the global greenhouse gas. Although approximately 25% fuel efficiency has been achieved thanks to new generation aircraft, the rate of emissions at high altitudes is expected to be 3 times more effective than those at ground level by 2050, due to the anticipated growth in flights.

This study aims to analyze and evaluate different alternative fuel types for aviation in terms of life cycle and cost. Life cycle and price analyzes of kerosene and six bio-fuels were made; The environmental effects in terms of cost and carbon dioxide emissions in long, medium and short-haul flights were examined. Since sustainable aviation fuel data produced by the different production techniques used in the research can only be provided by the US Federal Aviation Administration, calculations regarding sustainable aviation fuels were made based on these data. It is evaluated that the study can be a practice guide for the managers of our country and global airline companies, those working in the sector and the relevant academic environment.

In the next or second part of the study, regulations to reduce the greenhouse gas effect, and in the third part promising aviation fuels are defined, fossil fuels and sustainable aviation fuels are compared and the environmental and cost analysis results are presented. The conclusion section provides a summary of the benefits of the study and the prospects for future research.

The transition from fossil fuels to sustainable aviation fuels has become the focus of aircraft manufacturers, energy companies, researchers and governments in combating climate change. It is evaluated that the study will contribute to policy makers, airline companies and researchers by making carbon dioxide emissions and cost comparisons of fossil fuels and sustainable fuels. Introduction section should consist of information that presents the purpose of the research and the studies on the subject, prepares the article for reading and facilitates the understanding of the general article. In this section, citations to the current and important literature related to the subject covered are made. Literature review should be included in this section. You may use a second level heading for literature review or any focused section.

2. Literature Review

Climate change is generally defined as statistical changes in the average state or variability of the climate that last for many years (Türkeş, 2008). Changes in climate are seen as changes in temperatures and changes in precipitation in some parts of the world. Over the years, changes have occurred in the climate system on Earth. Changes in sea level and glacier movements have caused major changes in the ecological system (Türkeş, 2000).

Climate change causes many negative consequences. When we look at the variability in climate, it is revealed by the standard deviations of the climate average and the changes in other statistics. Climatic variability can occur due to natural processes or external effects caused by forcing. Climate change can occur through natural processes or external factors, as well as human-induced factors in land use. For example; agricultural activities, use of fossil fuels that cause greenhouse gases, increase in waste, industrialization, etc. factors can be counted. Human-induced factors pose a great threat to the world. Climate and weather are different matters. Weather is a short-term factor, for a day or two or a week. Climate, on the other hand, is a cumulative situation. It covers all very long-term meteorological conditions of a region (Gerste, 2017).

When we look at the causes of climate change, it is seen that natural factors emerge and cause this change. The main reason for climate change is the change in the radiation balance in the world. Detection of this change is understood with long-term data. Under normal conditions, solar energy and radiation entering the atmospheric system must be balanced. Some gases found in the atmospheric system are known as "greenhouse gases". These gases are; They are “CO_2, CH_4, N_2O and O_3” gases. The short wave coming from the sun is permeable, while the long wave is less permeable. For this reason, greenhouse gases trap the heat energy reflected from the sun, causing the world to warm up more. This situation is explained as the "greenhouse effect" (Gündoğan et al., 2015).

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In the IPCC sixth assessment report (AR 6) published in August 2021, it was emphasized that the climate is changing as a result of human activities and that these activities have increased global warming to a level not seen in at least the last two thousand years. Due to climate change that has occurred since 1880, global temperature has increased by 1°C. The amount of snow and ice has decreased and sea levels have risen. 19 of the 20 hottest years on record have occurred since 2001. The level of CO2 in the air has reached its highest level in 650 thousand years. The cost of 2020, which was a year of disasters, reached billions of dollars. For example; The cost of the locust invasion in East Africa was 8.5 billion dollars, the cost of the hurricane in the USA was 41 billion dollars, and the cost of the forest fire in Australia was 5 billion dollars. In Turkey, 1.1 billion lira damage was detected in agriculture due to extreme weather events such as storms, floods and tornadoes.

According to OurWorld 2021a, the transportation industry generated almost 21% of all greenhouse gas emissions in 2018, while the aviation industry contributed 11.6% (OurWorld 2021a). Similar to the United States, regional aviation was the second largest source of transportation-related greenhouse gas emissions in 2017 in the European Union, accounting for 13.9% of emissions from the transportation sector (EC, 2021). Regulations for the transportation industry were created in Europe (under the Emissions Trading System, or ETS) to reduce emissions, and the aviation industry has been using them since 2012. Regarding CO2 emissions from airlines, there are international rules in addition to these European ones. One of them is the International Civil Aviation Organization's (ICAO) Carbon Offsetting and Reduction Plan for International Aviation (CORSIA). In order to attain emissions above 2020 levels for international flights beginning in 2016, 191 nations were required by the ICAO to create plans in October 2016 (Gill, 2017). Although the CORSIA program is voluntary for least developed nations, small island developing countries, and landlocked developing countries, it is not required for them. The CORSIA program will be implemented in four phases: the basic phase, which runs from 2019 to 2020; the pilot phase, which is voluntary; phase 1, which is voluntary; and phase two, which runs from 2027 to 2035. The International Air Transport Association (IATA) wants to cut carbon emissions by 50% by 2050 compared to current levels (IATA 2017).

Studies on the effectiveness of aircraft carbon emission reduction have started to appear in the literature as a result of these rules (Wang et al., 2020; Liu et al., 2017).

There are three distinct types of travel distances in the aviation industry: medium, long, and short. As the aviation sector grows, so does the amount of energy used and the negative effects it has on the environment. In order to stop rising energy consumption, the issue of airplane energy efficiency is becoming increasingly important for all modes of transportation. Albeit extremely long travel is more costly and utilizes more fuel, it is in any case liked over different types of movement. Because of the significant expense of fuel, mileage basically eco-friendliness implies in the flying industry. About 3% of all fossil fuel consumption worldwide is for aviation fuel. Consequently, aviation accounts for 3% of all CO2 emissions (Khandelwal et al., 2013).

Based on a policy assessment, he created the Aviation Integrated Model, which provides a comprehensive analysis of the local and global interactions between aviation and the environment (Jimenez et al., 2012).

The Warning Board for Flying Exploration in Europe (ACARE) was laid out to foster an essential examination program to accomplish the objectives of Vision 2020. The Gathering makes sense of its goals for 2020 as later:

The aviation activities are contributing significantly to the environmental pollution and the current situation of increasing climate change concerns has abundant support to the growing need for sustainable practices (Singh et al., 2023). The major environmental effects comes through the noise and carbon emissions and pollution through air logistics (Karaman et al., 2018). This discussion has highlighted the responsibility of industries to address carbon emissions and noise pollution. Organizations are facing the challenge of aligning their operations with environmental considerations, incorporating eco-friendly practices, and investing in alternative fuels and propulsion systems to enhance sustainability (Undavalli et al., 2023).

Besides the technological and environmental factors, the aviation industry is also vulnerable to unforeseen challenges and external disruptions. The ability, flexibility, or the capacity of the organizations operations to respond the disasters or any unforeseen events or challenges is termed the “agility” and is crucial for the organizations resilience (Ding et al., 2024). Research by Pettit and Beresford (2019) underscored the importance of agility in navigating uncertainties, such as economic fluctuations, geopolitical events, and global health crises (Lim et al., 2019). The recent pandemic of COVID-19 has urged the significance of organizational agility in adapting to rapidly changing circumstances (Wils et al., 2006).

One key aspect of sustainable performance in aviation is the industry's environmental impact, particularly its contribution to carbon emissions and climate change. Researchers have emphasized the need for the aviation sector to address its carbon footprint and adopt measures to mitigate environmental harm (Ding et al., 2024; Gudmundsson et al., 2021). This sustainability means the vibrant investments in fuel-efficient aircraft, introducing the alternative efficient fuel fuels, and to extend the efforts to increase operational efficiency and to reduce emissions (Undavalli et al., 2023).

Hollingsworth and others (2008), as well as Schäfer Furthermore, Tetzloff and Crossley (2014) created improvement programming that decides the ideal designation of current and future airplane numbers in a course organization.

Technology has continuously impacted the aviation business and is known one of the main pillars supporting the aviation industry's expansion. This journey took start from the Wright brothers' groundbreaking flight to the current era of sophisticated aircraft design and state-of-the-art avionics (Ding et al., 2024). It is essential that to for the improvement in the operational efficiency and safety the aviation industry shall have a strong technological adoption strategy (Williams, 2019). In this regard the adaptability, or capacity of aviation industry's to adhere and quickly accept and incorporate new technology has become a key concern for the aviation operations businesses and it is considered a crucial to stay ahead of the competition (Ding et al., 2024).

The term Triple-A consist of the Adoptability, Alignment and Agility, and is known as the Triple-A Framework. In the sustainability perspective the role of the triple-A is vital in terms of sustainability and it stands at the forefront of strategic considerations. This framework provides a guides for aviation organizations and it interlinks the paradigms of environmental and social responsibility with a harmonious balance. The adoptability in aviation industry is now beyond the concept of traditional aircraft design which shall include the fuel efficiency, now the pace of adoptability is extended to electric propulsion and autonomous aircrafts. This advancement has bring the concept of the autonomous aircrafts, advance materials, learning of the organization culture and to bring a continuous improvement into the overall system (Ding et al., 2024; Nazeer et al., 2020).

The alignment perspective in the aviation industry means the synchronization of various aviation operational strategies in its pursuit of sustainable practices e.g. environmental and social sustainable perspectives. In the current scenario the environmental considerations are at the top of the aviation industry alignment efforts and the significant efforts has been noticed to shift the aviation operations towards eco-friendly and less corban emission technology. Various studies has been carried on to scores the importance of the alignment of aviation operational with environmental regulations and fuel efficient operations (Seo et al., 2018).

The term Agility is coined as an ability of an aviation organization to respond the fluctuation and immediate challenges in the prompt and more effective way. The agility is crucial and plays a vital role in the aviation industry resilience and the organization capability to handle and implement the sustainability practices in efficient and effective way (Yılmaz, 2023). The sudden disruption due to the geopolitical issue, global health crises and weather factors are the common aspects of aviation industry. In such scenarios, organizational agility becomes imperative for the industry's survival and continued sustainable performance.

Owen and others (2010), as well as Terekhov et al. (2018) centers around the investigation of new flight innovations. Consider applying these examinations to cutting edge airplane, uncovering future carbon dioxide emanations. The primary finding of these studies is that new application technologies are only slowly making their way into the market. Other areas need to be cut back, like the use of environmentally friendly alternative fuels and operational measures. As per IATA's methodology, the improvement of avionics biofuels has the best potential to lessen flying CO_2 outflows (Hassan et al., 2017). As a result, the number of publications on biofuels has increased and biofuels have become a top priority for aircraft manufacturers, biofuel companies, researchers, and governments. in recent years significantly increased (Wang et al., 2019). The majority of these studies concentrate on various processing technologies, various raw materials, and production technology.

Thanks to the GREET application module, the environmental impact of raw materials required for sustainable aviation fuel production can be calculated. There is no open source module that can perform calculations in this way.

The output of Lissys' commercial Piano-X model has been used to calculate flight-specific emissions (ICAO, 2017) and global carbon accounting (Graver et al., 2019, Winther and Rypdal, 2019). Dray (2018) used Piano-X to explore interactions between passengers, airlines, airports, and other system actors in an integrated evaluation model.

The Atmosfair Airline Index has been calculated since 2011 by the independent German organization Atmosfair to measure carbon emissions (Atmosfair, 2021). In the calculation, each airline earns efficiency points between 0 and 100 in the index depending on flight duration. Piano-X and Atmosfair modules are developed only for corporate companies.

3. Method

Two different techniques were used to collect data in the research. In order to search the literature, the method of using secondary sources was preferred, current publications, academic studies and articles were examined. The Excel program-based GREET aviation (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) life cycle analysis (LCA) module developed by the US National Research Laboratory

(Argonne) was applied. LCA, generally allows a holistic comparison of environmental measurements of various systems and is used to evaluate the environmental impacts of various technologies. In the conclusion and evaluation section, life cycles of oil and six different sustainable aviation fuel production methods are calculated with the GREET aviation module. Price analysis evaluation was made using secondary sources.

Since sustainable aviation fuel data produced by the different production techniques used in the research can only be provided by the US Federal Aviation Administration, calculations regarding sustainable aviation fuels were made based on these data. Due to time constraints, the life cycle and price analysis of oil and six biofuels was conducted; The effects of kerosene and sustainable aviation fuels on the environment in terms of cost and carbon dioxide emissions in long, medium and short-haul flights were investigated. In order for the study to be generalized to all aviation fuel products, a larger population needs to be studied. While sustainable aviation fuel raw material products were preferred, products with available price data were preferred.

The life cycle values of carbon dioxide formed as a result of the production of the most preferred corn, soybean and canola products for the production of biofuels in aviation using hydroprocessed esters and fatty acids (HEFA), alcohol-to-jet (ATJ), ethanol-to-jet (ETJ) methods has been calculated. Examining the life cycle of oil and six biofuels constitutes the limitation of the study.

3.1. Greet aviation module

Developed by the United States Argonne National Laboratory, the GREET (Greenhouse gases, Regulated Emissions and Energy Utilization in Technologies) aviation LCA module aims to assess the environmental impact of various aviation fuel production routes, including both fossil and bioderived aviation fuels. Life cycle analysis is often performed to assess the environmental impacts of technologies, providing a holistic comparison of systems' environmental measures.

The GREET model is developed and updated annually with support from various programs at the U.S. Department of Energy. It is structured to systematically examine the energy and environmental impacts of a wide range of products, including petroleum-based and sustainable aviation fuels (SAF). By using the GREET module, life cycle analysis results can be created at the process level and the emissions of technologies throughout the supply chain can be determined.

In the GREET aviation module, users can change key parameters for LCA simulation. In the aviation module, users can add production routes of new sustainable aviation fuels and then generate the results. In addition to the US Department of Energy, the US Federal Aviation Administration (FAA) supported the development and implementation of the GREET aviation module.

Argonne National Laboratory has developed the “GREET for ICAO CORSIA” (ICAO, GREET) version that is built into GREET 2019 and includes parameters for ICAO-approved pathways used for CORSIA. It has joined the International Civil Aviation Organization's (ICAO's) Fuels Task Group (FTG) to contribute to the calculation of the life cycle and greenhouse gas emissions (carbon intensities) of sustainable aviation fuels production routes for carbon offsetting and reduction and is used by other participating bodies (ICAO 2019b) .

Historically, a GREET aviation module within the GREET model and ICAO-GREET have been used to assess the environmental impacts of aviation fuels and aircraft. With all the current life cycle inventory (LCI) offered by GREET and ICAO, the interest in a standalone and user-friendly version of the aviation module enables users to easily generate results for aviation fuels and aircraft operations. To this end, Argonne National Laboratory has developed an interactive, standalone aeronautical module to have an aeronautical LCA platform consistent with the most current datasets. For ease of use, the module uses Microsoft Excel to enable an interactive user interface. Comparable LCA results based on reliable and consistent datasets are produced using a user-friendly interface. Above all, it enables transparent comparison of inputs and outputs of various processes/pathways.

An attempt has been made to create a data structure that can be used for all routes. Data sets can be easily imported from other sources, and data/results can be exported for other purposes. Additionally, the module has a dashboard where users can change parameters and interactively check relevant results (Wang et al., 2021).

4. Results and Discussion

The findings obtained when comparing aviation fuels in terms of carbon emissions and cost are given on the next page.

When Figure 1 is examined, it is observed that oil has a much higher value than corn obtained by using the ethanol-to-jet (ETJ) method, which has 81,67085 grams of carbon dioxide emissions per megajoule and the closest carbon dioxide emission value of 53,32535 g/MJ. It has been observed that corn obtained by using the hydroprocessed esters and fatty acids (HEFA) method has the most beneficial environmental impact in terms of carbon dioxide emissions with a value of 14,73431 g/MJ.

Table 1. Life/Energy Cycle and Cost Chart

Product Name	CO_2 Life Cycle (g/MJ)	Total Energy Life Cycle (MJ)	Current Price (kg/US Dolar)
Jet_A1	81,67085	1,08513	1,09
HEFA_Corn	14,73431	2,16851	27,3
HEFA_Soybean	25,79986	1,33447	55,91
HEFA_Canola	29,39803	1,40311	71,53
ATJ_Corn	42,24828	1,64473	27,3
ATJ_Soybean	25,79986	1,33447	55,91
ETJ_Corn	53,32535	1,84929	27,3

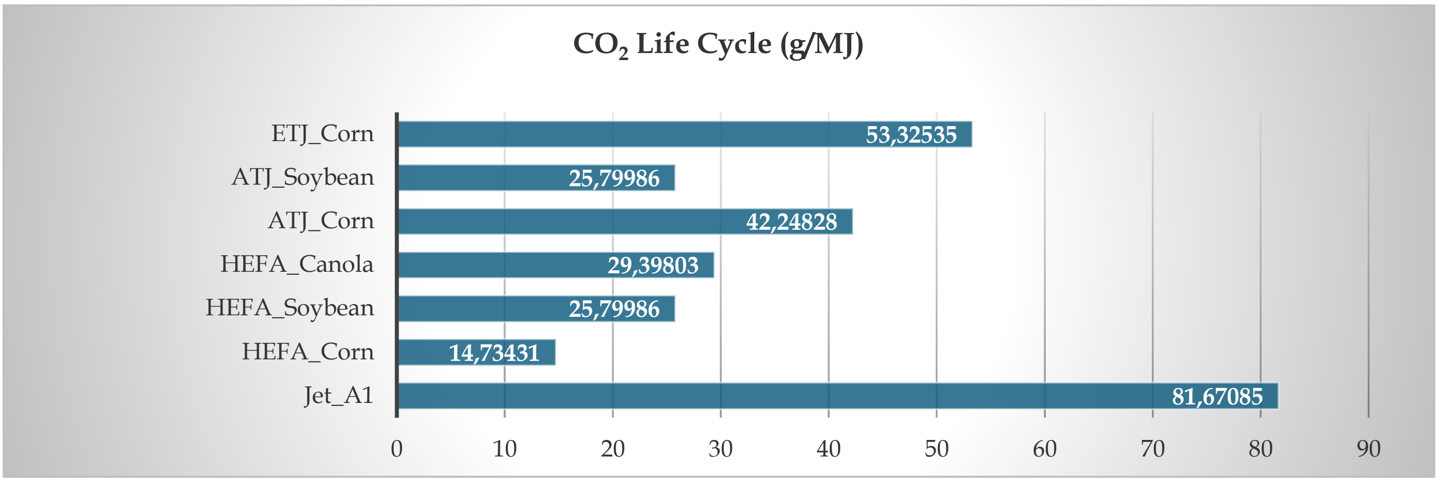

Fig. 1. Carbon Dioxide Life Cycle Graph.

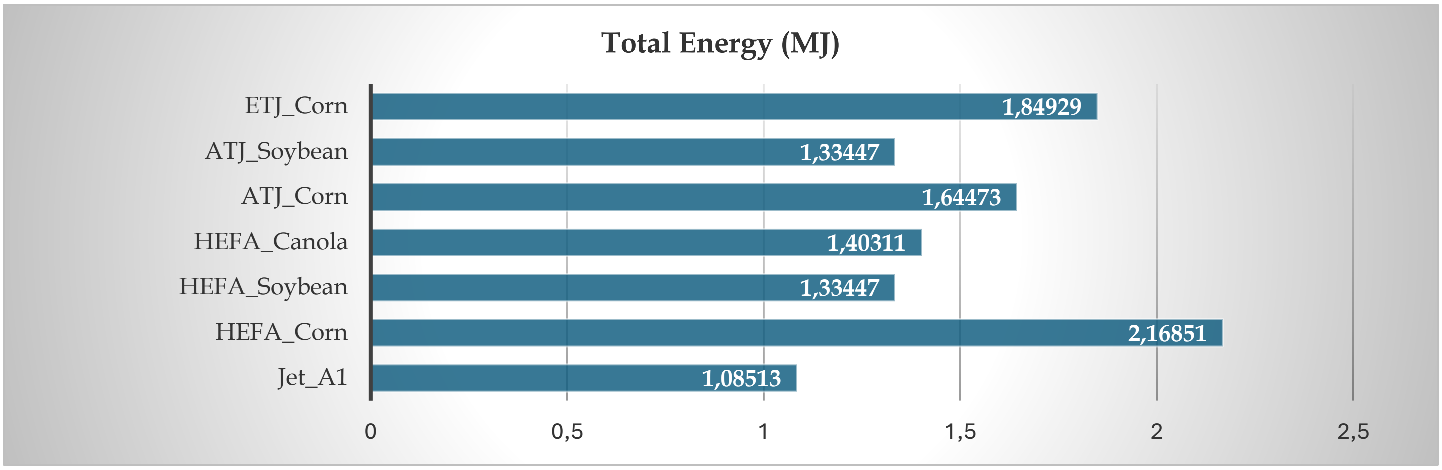

Fig. 2. Total Energy Graph.

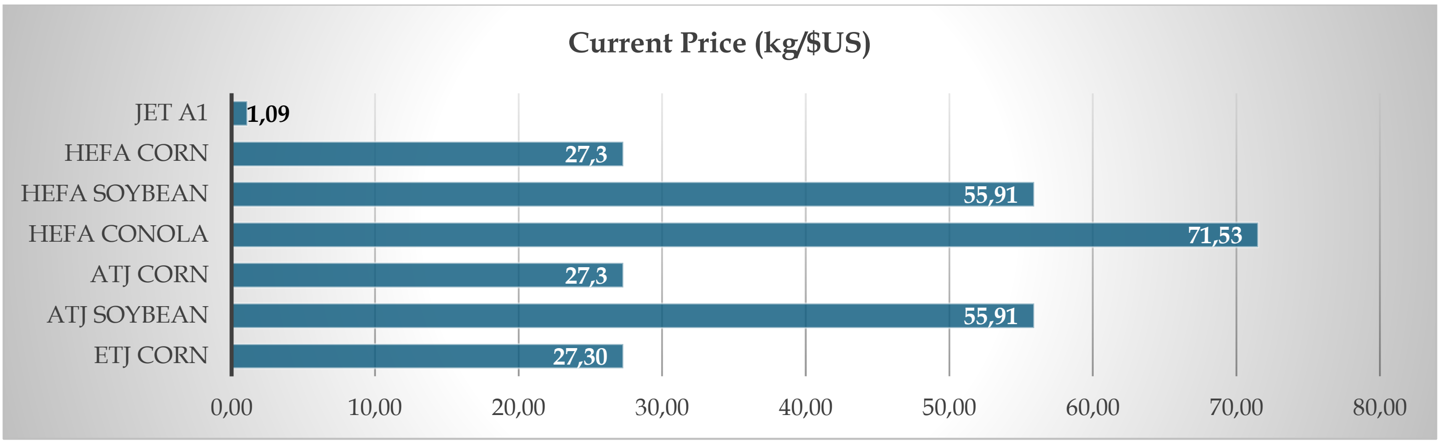

Fig 3. Cost Graph.

When Figure 2 is examined, it can be seen that the corn obtained using the Hydroprocessed esters and fatty acids (HEFA) method has the highest value with 2.16851 megajoules, while the total energy life cycle values of soybeans obtained using the alcohol to jet (ATJ) method are calculated as 1.33447 MJ. It was observed that it had the same results as the soybean value obtained using the hydroprocessed esters and fatty acids (HEFA) method, while the total energy life cycle of oil had the smallest value with a value of 1.08513.

When Figure 3 is examined, it is observed that the cost of oil, which is 1.09 US dollars, is 25 times lower than the cost of corn, which is 27.3 dollars, obtained using other methods, which is the closest cost to it. It was observed that the highest cost belonged to canola obtained by the Hydroprocessed esters and fatty acids (HEFA) method, which is 65.6 times more costly than oil, with 71.53 US dollars.

Published as part of the European Commission's climate package, the ReFuelEU proposal obliges fuel suppliers to include sustainable aviation fuel (SAF) in aviation fuel supplied at European Union airports (Weforum, 2023).

The obligation is projected to start with 2-5% sustainable aviation fuel from 2025 and gradually increase to 63% by 2050. In our study, 5% sustainable aviation fuel was added to jet fuel and jet fuel. Hydroprocessed esters and fatty acids (HEFA), which are one of the lowest priced products and specified as the usage method in the 2021 sustainability report by Turkish Airlines, the flag carrier airline of our country. The price of corn obtained using the method is taken as basis (turkishairlines, 2021).

In the study, flights up to 800 km were considered short distance, flights between 800 and 3000 km were considered medium distance, and flights over 3000 km were considered long distance flights (lufthansagroup, 2021).

Table 2 presents the data calculated for the distance of approximately 500 kilometers from Istanbul Airport (LTFM) to Ankara Esenboğa Airport (LTAC). Flight duration was calculated as 50 minutes and fuel consumed was 1350 liters. According to Lufthansa Airlines 2021 data, the approximate fuel consumption value for such a short-haul flight is 6.67 liters per 100 passenger kilometers, and carbon dioxide emissions are 16.78 kg. While there was a price increase of 1782 dollars between jet fuel and fuel with 5% biofuel added, it was observed that there was a decrease of 4.19 kg in carbon dioxide emissions.

Table 3 presents the calculated data for the distance of approximately 2000 kilometers from Germany Munich Airport (EDDM) to Ankara Esenboğa Airport (LTAC). The flight time was calculated as 180 minutes and the fuel consumed as 3500 liters.

Table 2. İstanbul- Ankara Flight

İstanbul- Ankara			
	Jet A1 Oil	5% Bio Oil Contribution	Difference
Price (USD)	1471	3253	1782
CO_2 Emisssion (Kg)	83,9	79,7	4,19

Table 3. Munich-Ankara Flight

Munich- Ankara			
	Jet A1 Oil	5% Bio Oil Contribution	Difference
Price (USD)	3815	8400	4585
CO_2 Emisssion (Kg)	191,4	181,3	10,1

Table 4. New York- Ankara Flight

New York- Ankara			
	Jet A1 Oil	5% Bio Oil Contribution	Difference
Price (USD)	16132	35527	19395
CO_2 Emisssion (Kg)	1392,6	1323	69,5

Table 5. Cost-CO_2 Emission Comparing

	Costs ($)	CO_2 Emission (kg)
Jet A1 Fuel	100	100
Bio Oil	12000	94,74
Percentage(%)	120,00	-5,26

According to Lufthansa Airlines 2021 data, the approximate fuel consumption value for such a medium-distance flight is 3.80 liters per 100 passenger kilometers, and carbon dioxide emissions are 9.57 kg. While there was a price increase of 4585 dollars between jet fuel and fuel with 5% biofuel added, it was observed that there was a 10.1 kg decrease in carbon dioxide emissions.

Table 4 presents the calculated data for the distance of approximately 9100 kilometers from the United States New York Airport (KJFK) to Ankara Esenboğa Airport (LTAC). Flight duration was calculated as 600 minutes and fuel consumed was 14800 liters. According to Lufthansa Airlines 2021 data, the approximate fuel consumption value for such a long-distance flight is 3.75 liters per 100 passenger kilometers, and carbon dioxide emissions are 9.41 kg. While there was a price increase of 19395 dollars between jet fuel and fuel with 5% biofuel added, it was observed that there was a decrease of 69.5 kg in carbon dioxide emissions (lufthansagroup, 2021).

When the values for three different distances are examined, it is seen that as the distance increases, the fuel consumed by the aircraft is more; It is observed that while the price increase increases, the amount of carbon dioxide emissions decreases. Prices increased at the same percentage rate, and carbon emissions decreased at the same percentage rate. As shown in Table 5, it is seen that the use of aviation fuel with the addition of sustainable 5% biofuel reduces carbon dioxide emissions by 5.26%, but the cost increases by 120%.

The findings obtained in the study are reported in the literature by Undavalli et al., 2023 Gudmundsson et al., 2021; Ding et al., 2024; Owen et al., 2010; Therekhov et al., 2018; Wang et al., 2019; It partially overlaps with the studies carried out by. Because all of these studies focus on reducing carbon emissions caused by the airline industry. This study also emphasizes reducing carbon emissions but focuses on its costs and the feasibility of sustainable eco-friendly fuels in the future as well.

5. Conclusions

In aviation, carbon dioxide emissions are priced through the European Emissions Trading Scheme (EU-ETS). To reduce the price gap, one option could be to increase carbon dioxide emissions costs from the use of conventional fuels, while exempting users from any taxes, duties or emissions allowances on the portion of fuel consumption from sustainable aviation fuels.

As stated in the literature review, sustainability in the aviation sector in general has been examined and evaluated in terms of adaptation, agility and technology adoption criteria. When examined the mentioned articles in terms of our study, sustainable fuel use is related to all three determined factors. In this sense, sustainable fuel use in the aviation sector will be an important component of sustainability practices and policy in the aviation sector as a whole.

Another effective policy measure is the introduction of green certificates. Certificates are a means of proving that biofuels are used somewhere in the aviation system. The green certification system can be considered a hybrid solution between blending quota and surcharge. As an element of the mixing quota, the total amount of certificates determines the average share of biofuels in the system. As one element of the surcharge, money collected through green certificates can be redistributed to producers or users of biofuels. Also, regarding the number of regulated entities, an upstream approach would be preferred as there are only a very small number of fuel suppliers and a much larger number of aircraft operators. This can ultimately lead to a reduction in transaction costs. For example, the redistribution of money to biofuel users/producers appears preferential for a number of issues, such as overcoming the logistical problems of a uniform blending quota and the possibility given for a phased implementation.

The key to greater acceptance and deployment of sustainable aviation fuel is cost reduction. In the long term, this will require investment in advanced technologies to process raw materials more efficiently on a larger scale and in the development of sustainable and scalable raw material options. However, in the short term, temporary support from governments and other stakeholders through policy incentives is needed.

Broader strategic concepts are extremely important for developing the independence of the aviation sector and sustainable aviation. Although aviation technologies are assumed to be constantly improved, increasing existing technologies will not be sufficient to reduce harmful environmental impacts. For this purpose, it is considered that the aviation industry's focus on developing the use of alternative power transmission technologies such as fuel cell-based and battery-based concepts in aircraft fleets can be much more effective in protecting the environment.

The necessity of reducing costs in the intensely competitive environment in the aviation industry and the obligation to comply with global environmental regulations will enable airline companies to develop and implement the most appropriate strategies based on cost and regulation, minimizing carbon emissions that are both low-cost and environmentally friendly. In this sense, it is evaluated that this study can be a practice guide for the managers of our country and global airline companies, those working in the sector and the relevant academic environment.

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Since sustainable aviation fuel data produced by the different production techniques used in the research can be provided by the US Federal Aviation Administration, calculations regarding sustainable aviation fuels were made based on these data.

Due to time constraints, the life cycle and price analysis of petroleum and six biofuels was conducted; The environmental impact of kerosene and sustainable aviation fuels in terms of cost and carbon dioxide emissions in long, medium and short-haul flights was examined. In order for the study to be generalizable to all aviation fuel products, it is necessary to study a wider scope.

In the future, it is recommended that researchers analyze other sustainable fuel use and their costs in the airline industry and present their findings and inferences to industry managers.

Acknowledgement

The authors of the paper submitted declare/declares that nothing which is necessary for achieving the paper

requires ethical committee and/or legal-special permissions.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors of the paper declare that not use of generative AI and AI assisted technologies in the writing process.

Data will be made available on request.

CRediT Author Statement

Emre Oğuzhan Polat: Conceptualization, Methodology, Software, Visualization, Investigation, Validation, Writing- Reviewing and Editing. **Yaşar Köse**: Conceptualization, Data curation, Writing- Original draft preparation, Supervision, Software, Validation, Writing- Reviewing and Editing

Nomenclature

ATJ	: Alcohol-to-jet
CORSIA	: Carbon Offsetting and Reduction Scheme for International Aviation
EASA	: European Aviation Safety Agency
ETJ	: Ethanol-to-jet
EU-ETS	: European Emissions Trading Scheme
FAA	: US Federal Aviation Administration
GREET	: Greenhouse gases, Regulated Emissions, and Energy use in Technologies)
HEFA	: Hydro-processed esters and fatty acids
IATA	: The International Air Transport Association
IPCC	: Intergovernmental Panel on Climate Change
LCA	: Life cycle analysis
SAF	: Sustainable aviation fuels

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