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Bibliometric Analysis of Sustainable Aviation Fuels Using Biblioshiny

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Abstract

With the liberalization of the air transport sector and the positive impact of globalization, aviation activities are experiencing rapid growth. The growth in the aviation sector is not limited to passenger transportation, but also extends to air cargo transportation. While the sector offers numerous opportunities for economic development, it also brings various negative impacts, including high levels of carbon emissions and noise pollution. To reduce carbon emissions, businesses and authorized institutions have developed various projects, and the use of sustainable aviation fuels (SAF) is crucial in these initiatives. Although numerous studies are available in the literature, it is evident that insufficient studies are compiling the current status and future potential of sustainable aviation fuels. In this study, 480 scientific studies from the Web of Science database were examined, and 403 relevant scientific publications were systematically analyzed using a bibliometric analysis method in the Biblioshiny program. The analysis, data collection, and analysis processes, along with the findings obtained, are presented through visualizations. The fact that the words “emission” and “energy” are used 46 times each, and the word “airplane” is used 40 times, in the studies demonstrates the multidimensionality of the subject. According to the analysis, it is believed that SAF production has not yet reached the desired level, but is expected to become more effective in the future.

1. Introduction

With the end of the Cold War period and the more effective use of military technologies in the field of civil aviation, the aviation sector has gained significant momentum (Töret & Söğüt, 2022). With the impact of the moderate environment created by globalization worldwide, the development in the aviation field has continued at an accelerated pace. In 2019, airline passenger traffic worldwide increased by 4.1% (Dube et al., 2021). However, with the COVID-19 pandemic in 2020, these increases started to decline dramatically. In the second quarter of 2020, international passenger traffic dropped by approximately 95% (Sun et al., 2020). In the post-pandemic period, signs of slow recovery were seen. In 2021, air traffic worldwide increased by 13% compared to the previous year (Dube et al., 2021). Following this period of fluctuation and recovery, the aviation sector has undergone significant transformation. Especially with the investments made by developing countries in airport infrastructure, the demand for air transportation in these countries, along with the development of technological opportunities, is driving significant progress in the aviation sector (Erdem, 2023). The progress in the aviation sector not only creates employment but also has positive effects on other sectors that contribute to the country's economy. Airport investments have significantly expanded the country's trade and tourism potential by increasing air traffic (Aksoy & Dursun, 2018). While the aviation sector makes a significant contribution to global economic growth, it also generates high carbon emissions. Air transportation is a fossil fuel-intensive sector. Commercial aviation relies on liquid fuels derived from crude oil. The perfect combustion of 1 kg of kerosene produces 3.16 kg of CO2 (ICAO, 2017). According to the International Energy Agency, the aviation sector is responsible for about 2.5% of global carbon dioxide (CO2) emissions (Hannes Gauch, 2025). Today, this rate is constantly on an upward trend, driven by increasing air traffic and expanding air transportation. Sustainable aviation fuels play a crucial role in achieving net-zero emissions targets, with a 65% share (IATA, 2021). Sustainable aviation fuels are expected to produce fewer emissions than conventional fuels, improve air quality, be stable, be produced from a variety of sources, and improve flight operations (Heyne et al., 2021).

The technological processes and methods used in the production of sustainable aviation fuels are continually being developed and diversified, supported by various teams, companies, and even countries (Nigam & Singh, 2011). Since the conditions under which aviation activities take place are challenging and variable, several factors are considered when selecting a sustainable aviation fuel, including sensitivity to temperature changes, combustion rate, adaptability to the existing system, the amount of energy released, and the compounds formed as a result of combustion. Before an aviation fuel is put into commercial use, it must pass many tests and receive approval from authorized organizations. The approval of these tests is carried out by the American Society for Testing and Materials (ASTM) (Yaşar & Onat, 2025). Sustainable aviation fuels, which are approved and blended into fuels at specific ratios, are used in commercial flights (Yılmaz & Atmanlı, 2016). Hydrogenated esters and fatty acids (HEFA technology) are the most widely accepted products in this field. In the HEFA production technique, molecules containing long carbon chains, such as vegetable oils, used cooking oils, and animal fats, are processed using hydrogen to produce products with jet fuel properties (Ng et al., 2021). The most significant disadvantage of this method is the high energy requirement. The amount of energy required increases the cost significantly. The increasing use of renewable energy sources has the potential to reduce these costs (Zubaidi, 2024). The cost of SAF is projected to drop to around USD 1,000 per ton in the 2030s (Nyoh, 2021). As an alternative to this approach, Power to Liquid (PtL) technology comes to the fore. This technology represents an innovative approach that produces synthetic fuel from atmospheric carbon dioxide and water, utilizing renewable energy sources (Ridjan et al., 2016). It is promising for zero-emission fuel production, especially in environments with high potential for solar and wind energy. Due to the high economic investment requirements, PtL technology has not been as well accepted in the sector as HEFA (Schmidt et al., 2018).

The barriers to sustainable fuel production are not only production-related, but also include economic, environmental, and technological barriers. From an economic perspective, the cost of sustainable aviation fuel production is 2 to 4 times higher than that of conventional jet fuel. In 2022, the cost of SAFs ranged from $ 1,500 to $ 2,500 per ton (Souza et al., 2024). However, with technological advances, R&D studies, optimizations in production processes, and support, the production cost of pure fuels is expected to reach a level comparable to that of conventional jet fuels by 2035. To achieve this goal, several steps should be taken in conjunction, including increasing production capacity, diversifying raw material sources, strengthening the supply chain, and obtaining support from the authorities. High costs are incurred for the establishment and operation of the facilities necessary for producing Sustainable Aviation Fuels (SAFs). In this respect, especially the costs related to licensing, construction, and the labor force are significant (Bielski, 2015).

The aviation sector is taking important steps towards the use of sustainable aviation fuels. Large aviation companies enter into long-term supply agreements with sustainable fuel producers, supporting technology transfer, incentives, and R&D collaborations to increase the use of these fuels (Yaşar & Onat, 2025). However, the support of countries, along with businesses, is greatly needed. For the effective use of SAFs, international cooperation and the support of leaders who have a significant influence on country governance are crucial. It is assessed that many financial and political obstacles can be overcome through tax incentives, mandatory blending rates, and support for installation and deployment (Abbas et al., 2024).

Table 1. Companies producing pure fuels

Producer	Production location	Anticipated supply start	Technology
BP	Europe; China	since 2021	HEFA
Neste	Finland; Singapore	since 2021	HEFA
Phillips 66	Humber, UK	since 2022	HEFA
Repsol	Cartagena, Spain	since 2022	HEFA
Moeve (formerly Cepsa)	Huelva, Spain	since 2023	HEFA
EcoCeres	Shanghai; China	since 2024	HEFA
ST1	Gothernburg, Sweden	since 2024	HEFA
LanzaJet	Georgia, USA	2025	Alcohol-to-jet
Twelve	Washington, USA	2025	Power-to-Liquid

Source: International Airlines Group (*Sustainable Aviation Fuel*, 2024)

The environmental and socio-economic impacts of sustainable aviation fuels become more visible as their use increases. The use of these fuels can reduce carbon emissions by up to 80% and contribute positively to the circular economy and the environment through the utilization of agricultural and organic waste (Wang & Rijal, 2024). Diversification of raw materials to be used for the production of sustainable aviation fuels also supports agricultural producers and rural development (Bielski, 2015). Considering technological developments, environmental regulations, and sectoral targets, sustainable aviation fuels are expected to be one of the strategically important issues for the aviation sector in the coming period. As SAF production increases, the aviation sector is expected to make a significant contribution to achieving zero carbon emission targets and combating climate change.

2. Literature Review

Nygren et al. (2009) found that the aviation industry should focus on alternative fuel initiatives to prevent a shortage of jet fuel in the coming years, resulting from a 3% growth in air traffic and a 3% annual growth in fuel demand. It was also noted that new fuel sources should be both sustainable and cost-effective (Nygren et al., 2009).

In 2009, Barros and Peypoch used a two-stage Data Envelopment Analysis method to examine the operational performance of airlines that are members of the Association of European Airlines (AEA). It was demonstrated that there are significant differences in the efficiency of airlines in Europe, with most operating at high technical efficiency. In the second stage, regression analysis revealed that population size, low-cost airline status, and network alliance membership have a positive impact on airline efficiency (Barros & Peypoch, 2009). In their 2014 study, Chai et al. examined the growth in Chinese aviation fuel demand. They found through regression analysis that a 1% increase in passenger occupancy results in a 0.8% increase in fuel demand. In comparison, a 1% increase in GDP per capita yields a 0.4% increase in fuel demand. Aviation fuel demand in China is projected to increase very rapidly (Chai et al., 2014).

Yılmaz and Atmanlı (2016) stated that the aviation sector has grown in tandem with the global economy and globalization, and as a result, fuel costs have become increasingly important. Furthermore, the use of petroleum-based fuels has led to an increase in pollutant emissions into the atmosphere. The study examined the necessity of using biofuels in the aviation sector, as well as the properties and environmental impacts of alternative fuel types.

In their 2016 study, Kousoulidou and Lonza presented a forecast for the future growth of the aviation sector in Europe, as well as the widespread use of biofuels. Based on 2010 predictions, changes in traffic volume, fuel consumption, and CO2 emissions were forecasted through three different scenarios until 2030. European and national policies, innovations, and the latest technological developments are discussed, and the role of biofuels in aviation to reduce environmental impact is evaluated (Kousoulidou & Lonza, 2016). To calculate the environmental impacts of new aircraft technologies and alternative fuels in the aviation sector, Moolchandani et al. utilized a simulation called FLEET (Fleet Level Environmental Assessment Tool), in accordance with the NASA program, to estimate future CO2 emissions. As a result of the study, it was concluded that there is an improvement in CO2 emissions; however, this alone is not sufficient (Moolchandani et al., 2017).

The study, prepared by Salih Aygün, Murat Sağbaş, and Fahri Alp Erdoğan, analyzes the development process and current status of sustainability research in the aviation sector by examining 123 academic articles published in the Web of Science database between 2001 and 2023. At the end of the study, it was determined that the USA contributed the most, with 29 publications, and Türkiye ranked second, with 19 publications. As a result of the research, the words "energy, aircraft, emissions, life cycle" were found to be the most used words in the research (Aygün et al., 2023).

Ozan Öztürk and Hülya Göktepe published a study in 2024 that examines alternative energy sources for the aviation sector. In the study, six different primary alternative energy sources were discussed, including synthetic carnosene (bio-jet fuels and PtL fuels, liquid hydrogen, liquid natural gas, ammonia, alcohol-based fuels and electrical systems, and the natural gas source came to the fore as it is the most suitable for the existing structure and provides up to 80% CO2 emission reduction. The research also suggests that other studies are not yet mature and that various energy sources should be used in combination instead of a single energy source (Öztürk & Göktepe, 2024).

3. Methods

Although the first studies on sustainable aviation fuels date back to the production of biodiesel, the issue has gained importance in recent years. In the database search, the keywords "sustainability" and "aviation fuel" were searched, and 480 works were found. Among these works, those irrelevant to the field of aviation were excluded, and 403 works were selected for use in the program. Works published between 2005 and 2025 were used.

In this study, a bibliometric analysis method was employed. Bibliometric analysis is a method used to systematically identify and analyze scientific studies published in a specific field and within a specific period, employing statistical, mathematical, and scientific methods (Broadus, 1987). Bibliometric analysis offers the opportunity to examine the current structure and dynamics of the research field from a macro-level perspective (Tomaž Čater, 2015). Bibliometric analysis is a widely accepted and commonly used form of analysis in many scientific disciplines (Abad-Segura et al., 2020).

Thanks to bibliometric analysis, influential authors, journals, and words related to the subject, as well as countries where the subject is studied more extensively, can be quantitatively analyzed. Additionally, it can reveal the connections between research and visual tools (Broadus, 1987). Bibliometric analysis methods are among the most frequently used methods in the field of aviation, as well as in many other scientific fields. In the field of aviation, bibliometric analysis methods are employed to track trends, identify collaborations, and provide a comprehensive overview of the studies as a whole. For example, there are many written works such as bibliometric measurement of risk management in aviation, bibliometric analysis of scientific publications on armed uncrewed aerial vehicles, bibliometric analysis of published works on sustainable fuel, bibliometric analysis on sustainability trends in aviation (Aydın, 2024; Kavak et al., 2022; Xu et al., 2025; Yaşar Dinçer et al., 2024).

The bibliometric analysis method can be visualized on a computer through programs such as R Studio, Citespace, and VOSviewer, and the links between journals, works, and authors can be presented more clearly with the help of visual maps (Guleria & Kaur, 2021). In this study, the Biblioshiny annex was created using version 4.4.1 of the RStudio program. The fact that the R Studio program is free of charge, easy to use, and can provide graphics in various formats makes it a preferred choice. Future trend and regression forecasts using R analysis are one of the most successful and widely used methods (Daswito et al., 2023).

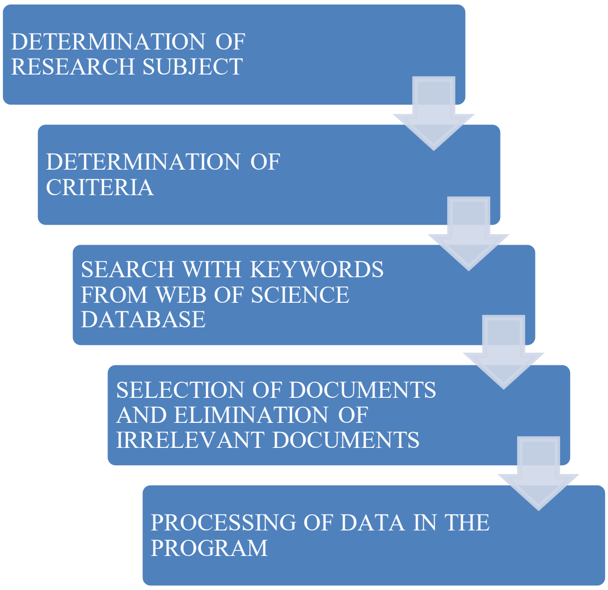

Figure 1. Steps of bibliometric analysis

The bibliometric analysis process consists of six basic stages (Figure 1). This process starts with the identification of the research topic and ends with the interpretation of the analysis results. Each stage builds upon the previous one and proceeds systematically.

4. Result and Discussion

4.1. Distribution of articles by year

While the number of articles published between 2005 and 2014 was less than 10 annually, this figure increased rapidly after 2014. According to the Web of Science database, 42 articles were published in 2021, 43 articles in 2022, 69 articles in 2023, and 89 articles in 2024. This increasing trend aligns with the 15% annual increase rate determined in the general aviation sustainability study conducted by Aygün et al. (2023). However, the 29% increase in SAF shows a faster growth trend than general sustainability studies. The quantitative increase in the number of scientific publications included in the printed literature over the following years demonstrates that SAF-related research is recognized as an emerging scientific trend within the academic community. In 2008, SAF fuels began to be tested, and SAFs were approved for use in commercial aircraft in 2011, which increased interest in this topic (Dodd, 2023).

In 2011, ASTM D7566 (Standard for Aviation Turbine Fuel Containing Synthetic Hydrocarbons) was revised to allow commercial airlines to blend up to 50% biofuel with conventional jet fuel. The ASTM D4054 evaluation process is used for the approval of new Safety Assessment Factors (SAFs). There are two traditional and two fast-track options to obtain ASTM D7566 approval. The traditional route is tested for 2-3 years, and up to 50% of the material can be used. The fast track is completed in 1-2 years and can be used up to a maximum of 10% (Hunt, 2023). With the impact of global warming, environmental awareness, and climate change, this issue is being studied by an increasing number of researchers (Abrantes et al., 2021; Sacchi et al., 2023; Watson et al., 2024). In addition, governments and aviation companies offer significant incentives for achieving the net-zero project in the aviation sector (Birpınar & Dinçbaş, 2022). The EU runs the Fit for 55 program to support sustainable aviation fuels, while in the US, the Inflation Act provides support of USD 1.25-1.75 per gallon of SAF. In Türkiye, the Microalgae-based Sustainable Biojet Fuel Project is being carried out in cooperation with Tübitak, Turkish Airlines, and Boğaziçi University. EasyJet, Air France-KLM, SAS, and Airbus are involved in and support initiatives such as Project Skypower. The expansion in the financial volume of the industry related to SAF production, the increase in resources allocated to research and development activities, the acceleration of technological innovations, competitive market dynamics and the steady growth trend of the sector encourage scientific interest in this field and contribute to the advancement of academic research (Özbay et al., 2024).

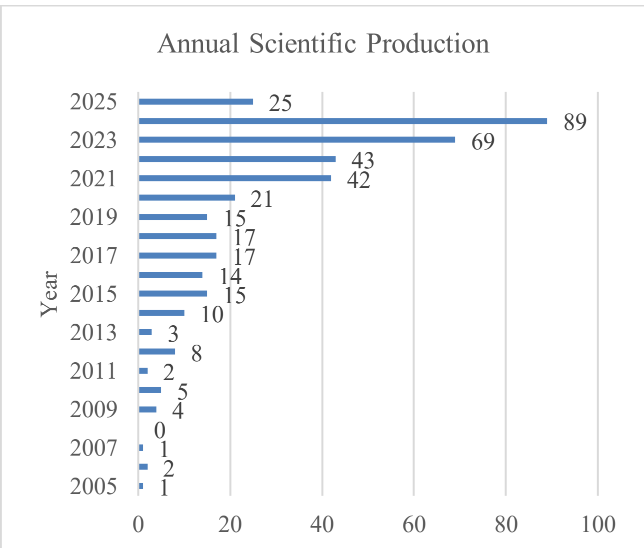

Figure 2. Number of articles by years

An analysis of the distribution of articles by year (Figure 2) shows that the number of studies on the subject has been steadily increasing. The impact of financial investments on academic research is an important factor. The fact that the global SAF market is expected to grow over time will contribute to strengthening industry-university collaborations and increasing the number of applied research projects (Pulidindi & Ahuja, 2024).

4.2. Distribution of academic publications by document type

The distribution of academic publications by type in the study, conducted using the Web of Science database, is shown in Table 2. Upon examination of the table, the vast majority of studies, at 70.72%, consist of research articles, followed by 12.90% of review articles and 12.90% of proceedings and other documents.

Table 2. Distribution of academic publications by document types

Document Type	Frequency	%
Research Articles	285	70,72
Review Articles	52	12,90
Proceedings Documents	52	12,90
Book Chapters	3	0,74
Early Access	5	1,24
Editorial Materials	6	1,49

The main reason for the predominance of research articles in Web of Science is that the database indexes high-quality peer-reviewed journals with high priority. Since research articles are published through a detailed peer-review process, they more easily meet Web of Science's quality standards (Bornmann & Daniel, 2008). Other types of documents have lower rates because review articles are less frequently written and are usually prepared by inviting abstracts, not all conference proceedings are indexed, and book chapters are not the primary focus of Web of Science. Editorial material is usually short and limited in content (Mongeon & Paul-Hus, 2016).

Therefore, the distribution of 70.72% of research articles, 12.90% of reviews and proceedings, and 12.90% of other documents in the table aligns with the structure and academic nature of the Web of Science.

4.3. Most cited authors and works (Citation of authors)

The number of citations for a scientific article increases as the article attracts attention and is recognized as a scientific work. Citation counts have a positive impact on the authors' recognition and reputation (Weihs & Etzioni, 2017). Citation counts are one of the key criteria used in ranking academic search engines. Authors with a high number of citations are ranked first and foremost in search results. In this way, they have the opportunity to receive more citations. This phenomenon is scientifically referred to as the Matthew Effect (Bol et al., 2018). When examining the top 3 most cited works, Sims et al. (Sims et al., 2010) attracted attention in academia with their work titled "Overview of 2nd Generation Biodiesel Technology" and received the most citations on this subject. In the study, instead of producing biodiesel from agricultural products, the authors discussed the production of ethanol-based biodiesel from secondary products such as bark. Since the use of agricultural products for fuel is not considered very appropriate by society, they tried to both reduce costs and use an unused material as a raw material. The desired result could not be achieved due to technological inadequacy and process difficulty. The second most cited work is Yusuf Chisti's (Chisti, 2013) "Barriers to the Commercial Use of Fuels Derived from Algae." The third most cited work is the 2014 study by Hari et al. on the direction, opportunities, and barriers to aviation biofuels from renewable resources, which examined alternative biofuel feedstocks, production techniques, and emerging biofuels, and evaluated the opportunities and challenges in the development of alternative fuels (Hari et al., 2015).

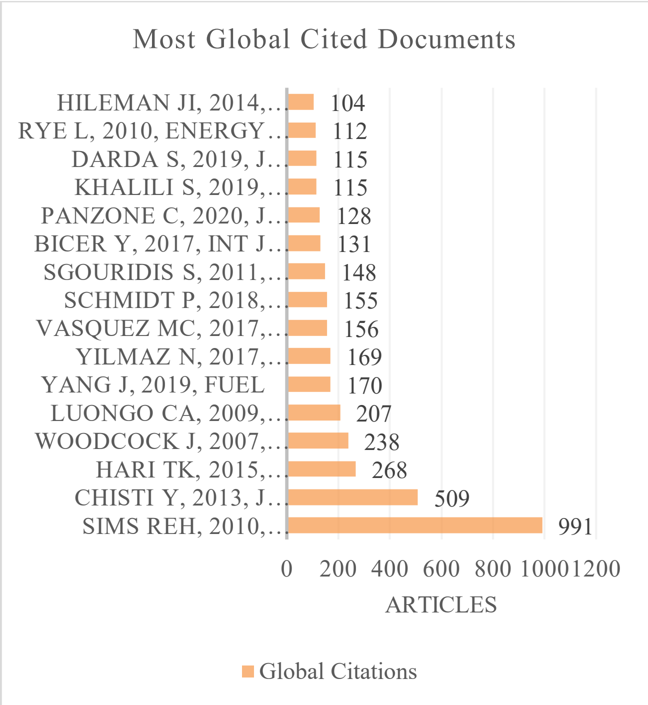

Figure 3. Most cited authors and works

Figure 3 shows the works and authors with 100 or more citations globally. Since studies with 100 or more citations account for only 1.8% of all publications worldwide, the works that exceed this threshold are among the most influential in the scientific literature, demonstrating the academic importance of the topics. It demonstrates that these studies are widely accepted within the scientific community and that SAF research is grounded in a strong theoretical foundation. A common feature of highly cited papers is that they address the SAF field in an integrated manner across different dimensions (technical, economic, environmental, and policy) and provide concrete examples of practical applications. This is evident when the three most cited papers are analyzed.

The so-called H-index, also known as the Hirsch index, is an indicator that reveals the impact and productivity of scientific journals and researchers. It was first proposed by Jorge E. Hirsch in 2005 to reveal the scientific impact of articles (Gasparyan et al., 2018). The h-index of a researcher is determined if that researcher's article is cited at least h times in h number of times. Local H-index values (Figure 4) of the authors examined within the scope of the research are presented.

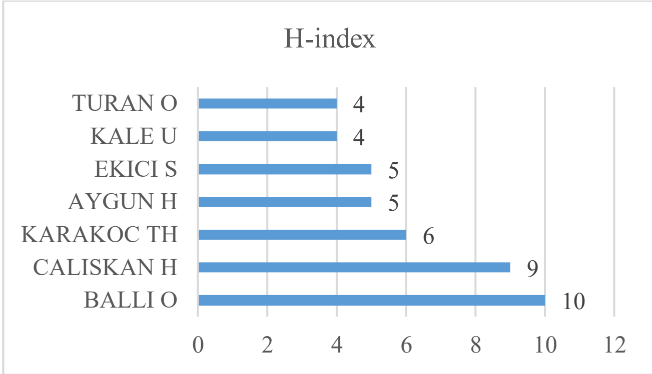

Figure 4. Local H-index and impact factor

According to the results of bibliometric analysis in the field of sustainable aviation fuels, the authors with the highest h-index have made significant scientific contributions in the field. The institution with the highest number of publications is considered the local h-index in this study. This is an indicator not only in terms of the number of articles of these researchers, but also in terms of the impact of their work in the scientific world.

A high h-index indicates the author's academic productivity and reputation in their field. Especially in an interdisciplinary field such as sustainable aviation fuels, researchers with a high h-index are usually people who synthesize knowledge from different disciplines and produce innovative solutions. Moreover, studies published in high-impact-factor journals influence global research trends in sustainable aviation fuels. In particular, SAF studies published in prestigious journals in the fields of energy, environmental engineering, and aerospace technologies are of great academic and industrial interest.

4.5. The institutions that publish the most on the subject

Identifying the institutions that publish the most articles in various fields helps pinpoint some of the most nationally and internationally influential institutions, providing valuable data on the scientific productivity of these institutions. Developed and developing countries offer incentives to universities, industrial organizations, research centers, and other institutions to produce high-quality, qualified information, thereby advancing progress in various disciplinary fields (Çizmecioğlu et al., 2023). Universities play an active role in knowledge production and dissemination. Universities have the responsibility of disseminating accurate information to society and producing optimal solutions to current situations (Gürpınar & Aydoğmuş, 2022). Universities play a significant role in shaping society by educating current and future managers (Godemann et al., 2015). The study by Arısoy et al. highlights the responsibilities of universities to train qualified individuals and conduct research for the benefit of society (Arısoy et al., 2024). Figure 5 illustrates the institutions with the highest number of publications on the subject, along with the corresponding publication count. Eskişehir Technical University, the institution with the highest number of publications, was separated from Anadolu University in 2018 and established as a research university. Eskişehir Technical University ranks high in quantitative publication production. Behind this success lies the presence of academic staff with expertise in their fields (Tolga Baklacıoğlu, Tahir Hikmet Karakoç, Önder Altuntaş, etc.) and the strategic approach of the institution towards research and development activities with biodiesel and aircraft engines.

When the data from the Council of Higher Education Thesis Center are examined, it is revealed that the institution exhibits a periodic upward trend in the number of doctoral theses (65 in 2022, 70 in 2023, and 87 in 2024) (UTM | Statistics, 2025). This indicates that the university's graduate education activities are continually evolving. In light of the information presented on the institution's electronic web page, the cooperation mechanisms established by the university with industrial stakeholders draw attention (Eskisehir.edu.tr, 2022).

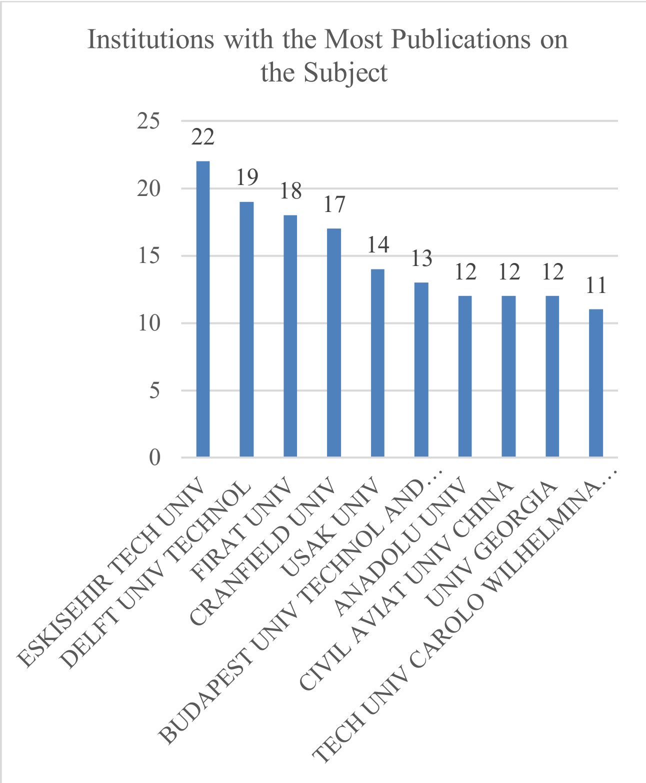

Figure 5. Institutions with the most publications on the subject and the number of publications

Within the framework of this cooperation, it is ensured that academic knowledge is integrated with sectoral practices, aiming to enhance the competencies of graduates.

Table 3. Distribution of the most active countries in academic publications

Country	Frequency	Country	Frequency
USA	240	ITALY	57
UK	125	AUSTRALIA	48
TÜRKİYE	124	NETHERLANDS	38
CHINA	112	INDIA	36
BRAZIL	91	FRANCE	28

The United States allocates a significant portion of its resources to military expenditures and research and development (R&D). The US allocates approximately half of its defense budget to personnel costs and the other half to procurement, research and development, and testing activities. The US Department of Defense and universities in the US attach great importance and support R&D activities (O'Hanlon, 2024). In particular, factors such as the cooperation between research universities and industry, as well as legal sanctions on patents and intellectual property rights, make it attractive for researchers. Researchers are also supported because the US aims to establish a competitive advantage over countries that can rival it, such as China and Russia (Mowery, 2012).

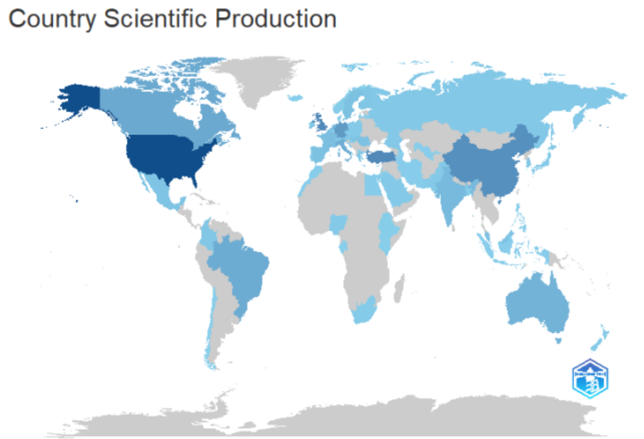

Figure 6. Map of Countries by Scientific Publications

4.6. Co-authorship relationship by country

Although it shows the amount of cross-country collaboration, the proportions may vary by subject. SCP (shown in green - single country participant) indicates work written in a single country, while the indicators in red show how much of the work is international (Figure 7). When examining the United States, Türkiye, the United Kingdom, and Germany, which are among the countries with the highest number of studies, it is evident that the majority of studies are conducted within these countries. In the aforementioned countries, the aviation industry has a distinct advantage, as it hosts the leading organizations in the sector on a global scale. Delta Air Lines, United Airlines, Southwest Airlines, Lufthansa Group, Turkish Airlines, UPS Cargo, and FedEx Express, on the cargo side, cooperate with universities, especially in personnel training. This strategic cooperation paves the way for a significant increase in aviation-oriented academic publications in these countries and privileges staff training opportunities. The primary reason for the tendency of authors of scientific studies to originate from a single country rather than a multinational structure is that research grants are typically allocated within national and regional borders, rather than being international in scope. According to Rand Corporation reports, organizations such as the US Department of Defense, the French National Research Agency (ANR), and the National Natural Science Foundation of China (NSFC) allocate a large portion of their basic research budgets to organizations in their own countries, while the budget allocated to foreign organizations is at most 3% of the total, which is insufficient (Hottes et al., 2023). This situation leads to the shaping of scientific production within geographical limitations.

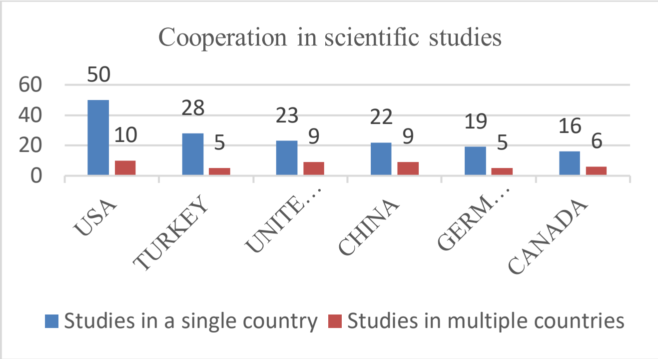

Figure 7. Co-authorship relationship by country

The global dissemination of scientific research is one of the most important academic goals of our time. To achieve this goal, national governments and private sector organizations must significantly increase their financial support for research and development activities. The inadequacy of existing funding models restricts scientific research, particularly in developing countries. In addition to strengthening financial support mechanisms, it is crucial to restructure research in a direction that promotes open access. This approach enables research results to reach a wider audience and facilitates the sharing and development of scientific knowledge. Establishing multinational participation models that bring together experts from different disciplines to collaborate on joint projects can enhance the quality of research and increase the number of outputs. To change the current situation, international academic networks should be strengthened, international projects should be expanded, and sectoral cooperation and open-access policies should be supported.

4.7. Keyword analysis (Word cloud)

The word cloud is a visual graphic in which words are sized according to the number of occurrences in the relevant articles, with the most frequently occurring word displayed in the central area in the largest size. In this study, the words "emission," "energy," "performance," and "aircraft" were mentioned 46, 44, 42, and 40 times, respectively (Figure 8). Through keyword analysis, a particular topic can be scanned in the database over various periods to reveal the area in which the topic has evolved, experienced congestion, and created research opportunities for researchers (Zubaidi, 2024).

Figure 8. Word cloud

When the word cloud in this study is analyzed, it can be observed that researchers focus most on reducing environmental impact and improving energy efficiency, with the words emission," energy,' and 'performance' being repeated the most. The prominence of terms such as life cycle, biodiesel, biofuels, biomass, and hydrogen, along with techno-economic analysis, addresses the research on next-generation fuels. In addition, the high frequency of the words aircraft, optimization, design, and aviation indicates that there are alternative searches. Additionally, thanks to this method, studies on a topic can be examined at a national level, creating an opportunity for researchers to initiate similar research in their regions.

4.8. Other related terms

A CoWordNet graph is provided to illustrate the common words used in conjunction with each other in the studies. Sustainable aviation fuel studies are represented by three different colors in the link map, indicating that they are distributed across three distinct areas. The visual obtained as a result of the analysis (Figure 9) indicates that the subject is multifaceted, as evidenced by its occurrence in three different regions.

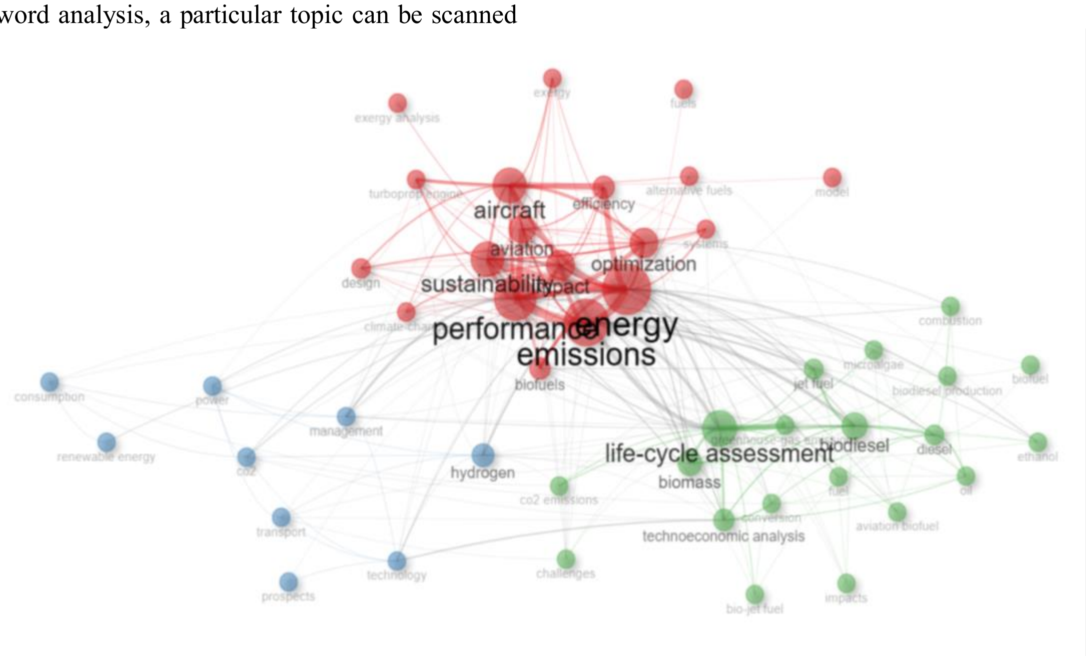

Figure 9. CoWordNet (connected words)

Three different thematic regions were identified in the CoWordNet visual graph. The first region, coded in green, comprises word groups that focus on emissions, the carbon life cycle, and biodiesel. Szyc and Lenort's (2024) study, titled "Sustainable Aviation Fuels as the Path to Carbon Neutrality in Air Transport," is an example in this thematic area. The second region, colored in red, shows terminological clusters related to aircraft, energy, and performance evaluations. Liu and Yang's (2024) "Analyzing Engine Performance and Combustor Performance to Assess Sustainable Aviation Fuel Blends" can be included in this category. The third region, marked in blue, contains conceptual groupings in the fields of the aviation industry, hydrogen technologies, and systems. The study by Yelugoti and Wang (2023) is representative of this last category (Liu & Yang, 2024; Szyc & Lenort, 2024; Yelugoti & Wang, 2023).

The three thematic areas identified in our CoWordNet analysis (emissions-biodiesel, aircraft-energy-performance, aviation-hydrogen) confirm the six main categories of alternative energy sources identified by Öztürk and Göktepe (2024). In particular, the fact that hydrogen technologies are a distinct cluster indicates that this technology is becoming increasingly important in the SAF literature.

5. Conclusion

The aviation sector is a strategic industry of great importance for the global economy and international connectivity. Various reasons prevent the aviation sector from reaching its targeted point. The primary problems are economic fluctuations, environmental concerns, passenger expectations, lack of adequate technological infrastructure, incomplete adaptation of sustainable fuels to existing systems, adaptation of renewable energy sources to the aviation sector, and the extended return on investment in the sector, fossil-based jet fuel prices being cheaper than sustainable fuels, etc. These factors make the transition to sustainable aviation fuels difficult. Secondary problems are inadequate aviation infrastructure and capacity constraints. Failure to expand airport capacity in parallel with the increase in air traffic, problems with slot allocations, issues in airspace management, and employee strikes reduce the profitability of companies (Doganis, 2019). Environmental sustainability is another major challenge facing the industry. The contribution of aviation activities to carbon emissions and environmental impacts, including noise pollution, is widely criticized by society. Regulatory differences between countries can significantly impact international operations and limit market access. Increasing carbon taxes also affect the economic performance of the sector.

The multidimensional nature of the problems faced by the sector hinders its growth and prevents it from achieving the desired results. A holistic approach should be taken to solve these problems, and the ties between stakeholders should be strengthened. The Net Zero Emission program, the largest project in the sector, should receive the necessary support. The most significant breakthrough will be the replacement of fossil fuels with aviation fuels, which are the largest expense item for the sector within the scope of sustainability. As a result of increasing technological developments and the integration of various alternative raw material resources in sustainable fuel production, the aviation sector will gradually achieve the Net Zero Emission target with aviation engine systems with higher efficiency coefficients and minimized emission emissions, advanced energy storage systems and the widespread use of renewable energy systems in airport infrastructures.

This research aims to review scientific studies on sustainable aviation fuels systematically and to provide a methodological framework for future research. The number of publications in this field is expected to increase exponentially if industry and government support continue to be provided. In this study, only articles from the Web of Science were analyzed, and studies from other databases constitute a limitation of this study. Other researchers working on this subject can focus on hydrogen fuel, engine technologies, or, similar to this study, articles in other databases.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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