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Bibliometric Analysis of Studies on Emissions from Air Transportation Sector: The Case of Journal of Air Transport Management

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Abstract

***Keywords**:*
Air transportation, Carbon emission, Bibliometric analysis, Performance analysis, Science mapping analysis

One of the biggest challenges of our time is global warming. Increasing global warming causes climate change and makes our world a less habitable place. The most important greenhouse gas that causes global warming is carbon dioxide, and one of the sectors that cause carbon dioxide emissions is the air transportation sector. This study aims to analyze the literature published in JATM on the carbon emissions caused by the air transport sector by using the bibliometric analysis method and to provide a perspective on the course. In this context, performance and science mapping analyses were applied to 126 studies published in JATM between 2000 and 2022. The findings show that China is the most productive country in studies on carbon emissions in JATM, while the UK has the highest citation productivity. The findings show that the most collaboration is realized by the USA. On the other hand, it was revealed that the rate of both national and international collaboration in studies on carbon emissions is quite high. It is expected that understanding the themes revealed by thematic analysis and the network structures revealed by science mapping analysis will shed light on future research..

Hava Taşımacılığı Sektöründen Kaynaklanan Emisyonlar Üzerine Yapılan Çalışmaların Bibliyometrik Analizi: Journal of Air Transport Management Örneği

Özet

Anahtar Kelimeler:
Hava taşımacılığı, Karbon emisyonu, Bibliyometrik analiz, Performans analizi, Bilim haritalama analizi

Çağımızın en büyük sorunlarından biri küresel ısınmadır. Artan küresel ısınma iklim değişikliğine neden olmakta ve dünyamızı daha az yaşanabilir bir yer haline getirmektedir. Küresel ısınmaya neden olan en önemli sera gazı karbondioksittir ve karbondioksit emisyonuna neden olan sektörlerden biri de hava taşımacılığı sektörüdür. Bu çalışmanın amacı, hava taşımacılığı sektörünün neden olduğu karbon emisyonları ile ilgili JATM'da yayınlanan literatürü bibliyometrik analiz yöntemini kullanarak analiz etmek ve gidişata dair bir bakış açısı sunmaktır. Bu kapsamda, 2000-2022 yılları arasında JATM'da yayımlanan 126 çalışmaya performans ve bilim haritalama analizleri uygulanmıştır. Bulgular, JATM'da karbon emisyonları üzerine yapılan çalışmalarda Çin'in en üretken ülke olduğunu, İngiltere'nin ise en yüksek atıf üretkenliğine sahip olduğunu göstermektedir. Bulgular, en fazla işbirliğinin ABD tarafından gerçekleştirildiğini göstermektedir. Öte yandan, karbon emisyonları ile ilgili çalışmalarda hem ulusal hem de uluslararası işbirliği oranının oldukça yüksek olduğu ortaya çıkmıştır. Tematik analiz ile ortaya çıkan temaların ve bilim haritalama analizi ile ortaya çıkan ağ yapılarının anlaşılmasının gelecekteki araştırmalara ışık tutması beklenmektedir.

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INTRODUCTION

The steady increase in air travel almost every year has led to an increase in environmental concerns. According to the International Civil Aviation Organization (ICAO) data, the number of airline passengers has increased continuously since 1970, reaching 4.56 billion by 2020, when the effects of COVID-19 were felt. In 2040, this number is estimated to be around 10 billion passengers (ICAO, 2020). Similarly, when the number of aircraft takeoffs is analyzed, approximately 39 million aircraft took off in 2019, and this number is expected to increase to 90 million in 2040 (ICAO, 2020). According to Airbus estimates, about 39,000 new aircraft will be needed by 2041. Of this number, about 24,000 will be needed to meet the new traffic volumes (Airbus, 2022). Boeing's forecasts are no different from Airbus'. Therefore, in the coming years, we will see more airplanes in the air and we will witness a further increase in environmental concerns. However, regulators, aircraft and engine manufacturers, airports, airlines, ground handling companies, air traffic service providers, and all other air transport stakeholders are working to address environmental concerns.

ICAO, which is the regulator of international aviation, carries out studies on environmental problems arising from air transportation through the Committee on Aviation Environmental Protection (CAEP). In this context, CAEP sets standards for noise generated by aircraft with Annex 16 Volume I, emissions from aircraft engines with Annex 16 Volume II, aircraft emissions with Annex 16 Volume III, and Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) with Annex 16 Volume IV. While aircraft manufacturers are improving the aerodynamic structures and technologies of aircraft to support emission reduction (Airbus, 2023; Boeing, 2022; Embraer, 2022), engine manufacturers are trying to produce engines with lower emission values and develop engines powered by alternative energy sources, especially electricity, hydrogen and sustainable aviation fuel (SAF) (Pratt&Whitney, 2023; RollsRoyce, 2023; Worley & Palmet, 2022). Airline companies are trying to reduce their emissions by using SAF in their operations (Ahlgren, 2020).

According to the Federal Aviation Administration (FAA), airport operators can reduce emissions by insulating buildings, improving energy efficiency, using renewable energy sources, and using low- or zero-emission vehicles and equipment (FAA, 2022). When they fulfill these processes, they are entitled to receive the Airport Carbon Accreditation certificate. Ground handling companies are also trying to reduce their emissions by replacing their ground handling equipment with electric vehicles, using renewable energy sources, and constructing their buildings and facilities with Leadership in Energy and Environmental Design (LEED) certification (Southwest, 2021; TAV, 2022). Finally, air traffic service providers strive to reduce aircraft emissions by using airspace capacity efficiently, minimizing air and ground delays, and providing optimal routes (Kale et al., 2021).

According to the Air Transport Action Group (ATAG), the air transport sector has spent more than $150 billion on research and development to reduce emissions (ATAG, 2021). Two important factors can be considered to underlie these efforts of air transportation stakeholders. The first is the genuine sharing of environmental concerns, while the second is the desire to be perceived as a socially responsible business in the eyes of society. Regardless of what businesses think, it is believed that the activities carried out for the protection of the environment have positive effects.

In parallel with the efforts of air transportation stakeholders to reduce emissions, many studies on emissions have been carried out in the academic community. In the Scopus database, it is seen that the first study on emissions with environmental impact in the category of Business, Management, and Accounting (BMA) was conducted by Gellhorn and Joslyn (1937). Although the first study was very early, it can be mentioned that studies on emissions remained limited until the 1990s. As a matter of fact, as of February 2023, while there are 82,149 academic studies on emissions in the BMA category in the Scopus database, only 475 of them were conducted until the 1990s. After the 1990s, it can be mentioned that studies on emissions have increased in the academic community in parallel with the increase in technological developments and the increase in environmental awareness in society.

The first study on air transportation emissions in the BMA category in the Scopus database is Guild (1996), published in Airline Business. Guild's study discusses emissions and noise pollution, CAEP's work on the subject, the environmental concerns of countries, and the effects on the costs of methods applied to reduce environmental concerns. In the Web of Science Core Collection, the first study in the Trasportation category was published in Transportation Research Part D-Transport and Environment by Perl et al. (1997). The study of Perl et al. focuses on the calculation of the cost of environmental pollution caused by aviation at Lyon-Satolas airport. The first study on emissions in the Journal of Air Transport Management (JATM), which constitutes the sample of the study, was conducted by Olsthoorn (2001). Olsthoorn (2001)'s study reveals the relationship between international carbon dioxide (CO2) emissions and world crude oil prices and global gross domestic product (GDP). Another article published in the same year as Olsthoorn (2001)'s article but in the next issue is the article by Schipper et al. (2001). In this article, the environmental externalities of the air transportation sector are mentioned, and emissions are discussed as negative externalities.

This study aims to examine the studies published in JATM on carbon emissions in air transportation through bibliometric analysis and to retrospectively identify the trajectory of the literature. In this context, 126 articles published in JATM between 2000 and 2022 were analyzed with R-based bibliometrix software. The study also analyzed the relationships between authors, countries, and keywords using VosViewer software with a scientific mapping approach. On the other hand, research themes were also identified within the scope of the keywords used by the authors. It is thought that the emerging themes will guide the researchers for their future studies. Finally, it is thought that the lack of bibliometric analysis on carbon emissions from air transportation in the existing literature makes this study important.

LITERATURE REVIEW

Carbon emissions

Global warming caused by greenhouse gases has become one of the most important problems of today's world. Global warming has reached a position that jeopardizes the ecological system, human life, and the development of the social economy (Ballantyne et al., 2016; Chen et al., 2023; Saunois et al., 2020; Shuai et al., 2017). The greenhouse gas component that makes the biggest contribution to global warming is CO2. CO2 is being released in excess from the burning of fossil fuels and growing populations, causing serious environmental problems such as acidification of the oceans and major climate change (Podrojková et al., 2020; Sun et al., 2023). According to International Energy Agency (IEA) data, CO2 emissions from oil in 2022 increased by 2.5% compared to the previous year, reaching 11.2 Gt (IEA, 2023). However, this increase should be evaluated together with the restrictions, production losses, and decreases in the transportation sector during the COVID-19 period. As a matter of fact, the IEA states that half of the 2.5% increase in oil in 2022 is due to the transportation sector, and this is due to the recovery in the transportation sector in the post-COVID-19 period (IEA, 2023). The massive consumption of fossil fuels in the electricity generation and transportation sector contributes to more than 90% of total CO2 emissions in the atmosphere (Khawaja et al., 2023; Umar et al., 2021). In this context, many studies have been carried out on how CO2 reduction can be realized in various sectors.

When the literature is examined, it is seen that studies have been carried out in many sectors such as fuel technologies such as biofuels and hybrids (Fu et al., 2023; Lee et al., 2023; Shukla et al., 2023), transportation sector (Joshi et al., 2023; Law et al., 2023; Matusiewicz et al., 2023; Nie & Zhang, 2023;

Opoku et al., 2023; Torvanger et al., 2023; Zhang et al., 2023), renewable energy sources (Kaiprath, 2023; Khan et al., 2023; Olabi et al., 2023), engine technology (Dinani et al., 2023; Kim et al., 2023; Yadav et al., 2023), coal-based enterprises (Liu et al., 2023), air conditioning systems (Zou et al., 2023), automotive sector (Dinani et al., 2023; Hossain et al., 2023) and construction sector (Guo et al., 2023; Luo et al., 2023; Rangrazian et al., 2023; Shang & Lv, 2023).

One of the sectors where studies on carbon emissions are carried out is the transportation sector. One of the modes in the transportation sector that emits a significant amount of carbon emissions is air transportation (Dahal et al., 2021). In 2018, air transportation accounted for 2.4% of global carbon emissions (Graver et al., 2019). In 2019, global CO2 emissions from aviation were realized at 2.0% (Hasan et al., 2021). In 2021, with the recovery in the aviation sector after the COVID-19 pandemic, it started to rise again and reached 2.1% (Fageda & Teixidó, 2022). The fact that the air transportation sector has returned to the pre-COVID-19 period, even surpassing the statistics of that period, suggests that carbon emissions will increase.

When the academic studies conducted in the air transportation sector are examined, it is seen that most of the studies can be categorized under five groups: technology and innovation, climate change, CO2 policies, operational processes, and historical statistics of CO2. Technology and innovation-oriented studies have been conducted on a wide range of topics, and these include hydrogen-fueled aircraft (Boretti, 2021; Victor, 1990), next-generation jet engine designs (Langmaak et al., 2011; Langmaak et al., 2016), fuselage and wing designs (Cansino & Román, 2017; Linke et al., 2020; Moolchandani et al., 2013; Proesmans & Vos, 2022; Variyar et al., 2014), use of composite materials (Timmis et al., 2015), new generation fuels such as sustainable aviation fuel (Feser & Gupta, 2021; Jain et al., 2021; Kieckhäfer et al., 2018; Lim et al., 2021; Ploetner et al., 2018; Romero-Izquierdo et al., 2021; Scheelhaase et al., 2019; Undavalli et al., 2023; Wang et al., 2019) and aircraft with electric engines (Barelli et al., 2022; Baumeister et al., 2020; Hendricks et al., 2021; Hoelzen et al., 2018; Staack et al., 2021; Strathoff et al., 2022).

When the climate change-focused studies are examined, it is seen that the studies are carried out on topics such as European Union Emissions Trading System (EU-ETS) (Wall et al., 2008), comparing transportation modes and sectors and developing recommendations (Bows, 2010; Chapman, 2007; Hasan et al., 2021), statistical values of the effects of aviation on the atmosphere (Lee et al., 2010), the relationship between aviation and tourism (Bows et al., 2009; Gössling & Freytag, 2012), the relationship between travel behavior and climate change (Gössling & Dolnicar, 2023), developing scenarios for the future to reduce carbon emissions (Bernabeo et al., 2018), and the costs incurred to prevent climate change (Dray et al., 2022).

Another category of academic studies on carbon emissions in the air transportation sector is those on CO2 policies. This category includes policies implemented in different modes of transportation (Han et al., 2008), studies examining what should be done in the near, medium and long term (Kar et al., 2009; Sgouridis et al., 2011), policies that should be implemented for emission reduction (Bergero et al., 2023; Dray & Doyme, 2019; Dray et al., 2008; Nick & Thalmann, 2022), studies on emission trading policies (Leggett et al., 2012; Yoon & Jeong, 2016 and studies on the legal basis for emission reduction (Green & Jupp, 2016; Scheelhaase, 2014).

Another category of research on carbon emissions in the air transportation sector is studies on operational processes. In this category, studies on parameters such as flight time, thrust, fuel flow, long-haul flights, and aircraft size (Montlaur et al., 2021; Morrell, 2009; Morrison et al., 2012; Pukhova et al., 2021; Tanveer et al., 2014; Tyagi & Crossley, 2009; Zhi-Qiang & Chao, 2010), studies on changing routes (Derigs & Illing, 2013; Wells et al., 2023), studies on emissions during taxiing and take-off (Christien et al., 2022; Duinkerken, 2013; Pukhova et al., 2021; Vaishnav, 2012, 2014; Wei et al., 2019) and studies on fleet planning (Cui et al., 2022; Müller et al., 2018; Yin et al., 2016) are carried out to reduce carbon emissions.

The last category in the studies on carbon emissions is the category related to CO2 statistics. This category includes the following studies; A study analyzing the 2004-2006 global commercial aircraft emission data provided by the Volpe National Transportation Systems Center (Wilkerson et al., 2010), a study analyzing the emission values of airline companies operating in the USA domestic routes between 2010-2012 (Kwan & Rutherford, 2015), a study calculating the carbon emissions of airline companies operating in China between 2005-2014 (Sun et al., 2016), a study analyzing the carbon emission data between 1985-2013 among the transportation modes in China by time series analysis method (Li et al., 2017), a study analyzing the static and dynamic efficiencies of carbon emissions in China between 2009-2013 (Z. Wang et al., 2020), a study examining carbon emissions in the Lombardy region of Italy between 1997 and 2011 with an econometric model (Lo et al., 2020), a study calculating the effects of global carbon emissions between 2000 and 2018 (Lee et al., 2021), a study investigating the effects of the EU emissions trading system between 2010 and 2016 (Fageda & Teixidó, 2022), a study on the inventory of emissions from aircraft operations between 2017 and 2020 (Quadros et al., 2022), and a study examining the impact of fuel tax increase on fuel consumption and carbon emissions between 1995 and 2013 (Fukui & Miyoshi, 2017).

To the best of the author's knowledge, a limited number of bibliometric studies on carbon emissions have been conducted. Although bibliometric studies on emissions started in 2018, their intensity increased after 2022. Tian et al. (2018) studies on carbon emissions in the transportation sector between 1997-2016, Zhao et al. (2020) studies on sustainability between 2000-2019, Mahi et al. (2021) studies on energy efficiency between 1990-2019, Verma et al. (2021) research on the conceptual structure and typological thematic areas of carbon emissions from urban households between 1991-2019, Zhang et al. (2021) studies on the transition to clean energy between 1950-2020, Mishra et al. (2022) studies on the relationship between tourism and carbon emissions between 1990-2021, Wu et al. (2022) studies on carbon footprint in China and outside China between 2007-2020, Xia et al. (2022) analyzed the studies on Environmental Kuznets Curve (EKC) between 2010-2020, Maier (2022) analyzed the studies on sustainable biofuels that can be produced from wood waste between 2012-2021, Zhang et al. (2022) studies on forest management to achieve carbon neutrality between 2002-2022, Ritchie and Tsalaporta (2022) studies on carbon capture technology between 1997-2020, Yu and Song (2023) studies on the effects of land use changes on carbon capture between 1985-2021, Wang et al. (2023) studies on carbon neutrality between 1991-2022, de Oliveira Dias et al. (2023) studies on Carbon Credits between 2012-2022, Padhan and Bhat (2023) studies on the relationship between trade and environment between 2000-2021, Sudarsan et al. (2023) studies on renewable energy until 2021 and Zhong et al. (2023) studies on blue carbon sequestration between 2003-2021 by bibliometrics method. A review of the literature reveals that there is no bibliometric study on carbon emissions caused by air transportation. In this context, it is considered that this study can contribute to this gap in the literature.

Bibliometric analysis

The term bibliometrics was first used by Pritchard (1969) instead of "statistical bibliography". Pritchard stated that bibliometrics can be used in almost all studies aimed at quantifying written communication processes. As a matter of fact, there are bibliometric studies in many disciplines or sectors such as finance (Kumar et al., 2021; Qing et al., 2022), management (Smith & Sarabi, 2021; Vogel, 2014), marketing (Maucuer et al., 2022), production (Silva et al., 2022), tourism (Pahrudin et al., 2022), technology (Dadkhah et al., 2020) and agriculture (Bertoglio et al., 2021).

Bibliometric studies have become very popular in recent years in parallel with the expansion of the literature (Bakır et al., 2022; Donthu et al., 2020). Bibliometric analysis is one of the critical tools for meticulously processing large volumes of scientific material and obtaining important outputs (Donthu et al., 2021), and it enables the evaluation of scientific studies in terms of both quantity and quality (Al & Soydal, 2012).

Bibliometric analyses are performed for a variety of reasons, such as uncovering emerging trends in article or journal performance, collaboration patterns, and research components, and exploring the intellectual structure of a particular field in the existing literature (Donthu et al., 2020). In this context, bibliometric studies help to obtain an overview of a particular field, identify knowledge gaps, derive new ideas, and make intended contributions to the field (Donthu et al., 2021). Bibliometric methods have the potential to provide a systematic, transparent, and reproducible review process and thus improve the quality of reviews (Zupic & Čater, 2015). Bibliometric analyses make an important contribution to the evaluation of the existing literature by enabling analyses such as performance analysis, citation analysis, co-citation analysis, bibliographic matching, co-author analysis, and co-word analysis.

There are several other methods for reviewing, organizing, and evaluating the existing literature. For example, meta-analysis examines the overall strength and direction of effects and associations, variances, and the factors that explain them. Systematic literature reviews, on the other hand, examine the existing literature using procedures such as content and thematic analysis. However, although such descriptive literature reviews allow for retrospective research, they are subjective and may focus on a limited number of studies (Tanrıverdi et al., 2020). Bibliometric analyses are more reliable because they have a strong mathematical basis, provide quantitatively accurate findings, and reduce subjectivity bias (Donthu et al., 2021). Therefore, this study attempts to fill this gap by using bibliometric analysis to provide a more objective and in-depth view of the relevant literature.

METHODS AND MATERIALS

In this study, a bibliometric analysis of the studies on carbon emissions published in the Journal of Air Transport Management between 2000 and 2022 was conducted, and the findings obtained were tried to be quantified and visualized. Data collection and data analysis processes are detailed below.

Data collection

The data within the scope of the study were obtained from the widely used Scopus database. Scopus database was preferred for bibliometric analysis in social sciences because it contains more scientific articles than Web of Science, can present many data together, and is a comprehensive database (Falagas et al., 2008; Singh et al., 2021). The article search in the Scopus database was carried out with the following limitations and terms;

TITLE-ABS-KEY (carbon) OR (“carbon tax”) OR (“carbon emission”) OR (“carbon dioxide”) OR (“carbon footprint”) OR (emission) OR (“emission trading”) OR (“emission control”) OR (“emission inventory”) OR (“greenhouse gas”) OR (“gas emission”) OR (“climate footprint”) OR (corsia) OR (“traffic emission”) OR (biofuel) OR (SAF) OR (“pollution tax”) OR (“aircraft emission”) AND (LIMIT-TO(SUBJAREA,"BUSI")) AND (LIMIT-TO (EXACTSRCTITLE, "Journal Of Air Transport Management"))

As a result of the search, 218 studies published in the Journal of Air Transport Management were found. Abstracts of all 218 publications were analyzed and 126 studies on carbon emissions were identified. The bibliometric material used in the study can be found in the Open Science Framework: https://osf.io/q872v/. On 126 studies, bibliometric aspects such as number of citations, average number of citations per study, h-index values, most cited studies, worldwide distribution of studies, most productive countries, collaborations between countries, and most frequently used terms in titles and abstracts were investigated. The research design is summarized in Figure 1.

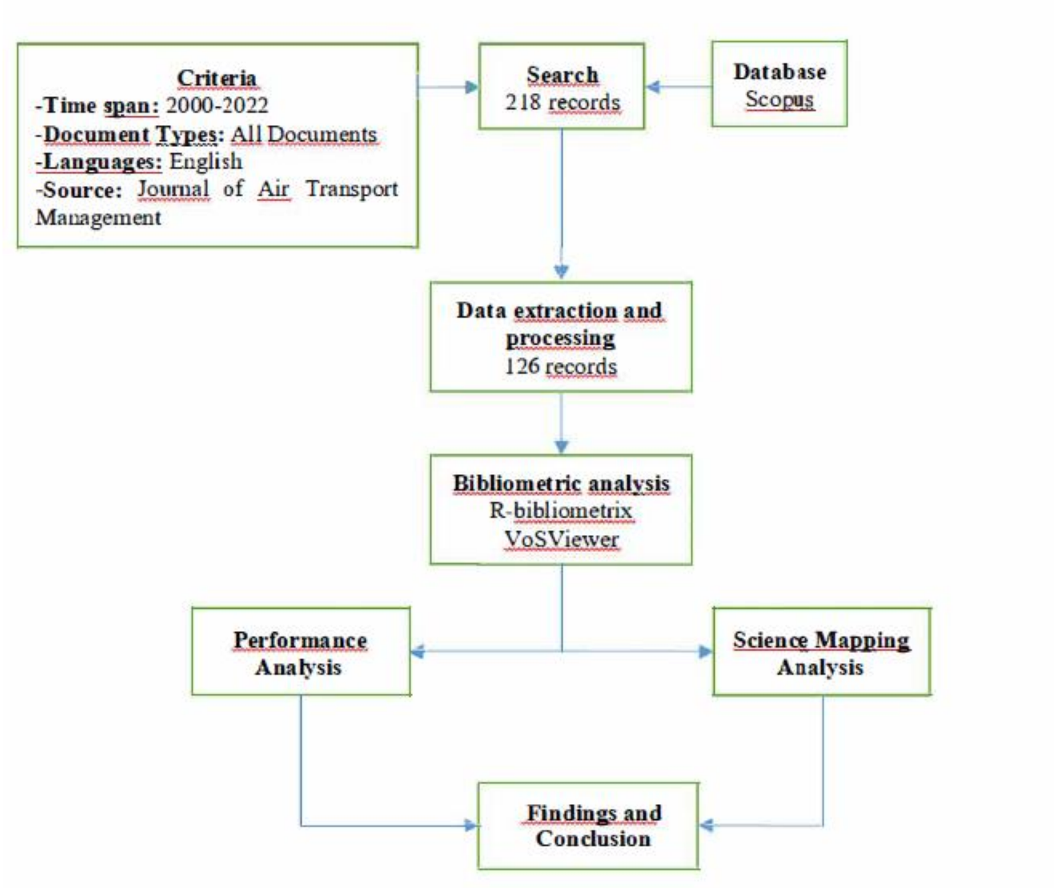


Figure 1. Bibliometric analysis flow chart.

Data analysis

Bibliometric analysis is based on the analysis of bibliographic characteristics of a publication, such as authors, collaborations, citations, keywords, etc., to learn about the structure of a scientific field, its social networks, and themes in the field (Zupic & Čater, 2015). In this study, R-bibliometrix, a free open-source software, and VoSViewer for visualizations were used to reveal these features. In the study, first performance analyses and then science mapping analyses were performed.

Performace analysis

Performance analysis is a type of bibliometric analysis in which several quantitative data can be obtained, such as the number of publications, the number of citations, the most prolific authors and countries, associated organizations, and the journals with the most publications (Fusco et al., 2020). In this study, the most productive author, the most productive countries and h-indexes, the most cited countries and authors, the countries of responsible authors, and the most cited publications were analyzed within the scope of performance analysis. R-bibliometrix software, which is frequently used in bibliometrics studies, was used for the analysis.

Science mapping analysis

Science mapping analysis is a graphical representation of how fields of knowledge, countries, articles, or authors are related to each other (Small, 1999). When the literature is examined, some studies use science mapping analysis, while some sources use the concept of collaboration analysis. However, both concepts have the same meaning. In this context, it was deemed appropriate to use science mapping analysis in this study. Science mapping analysis is a method that presents countries, institutions, authors, and keywords as a node in the context of bibliometric analysis (Wang et al., 2016). In other words, science mapping analysis provides an overview of collaboration and research communities, focusing on coming together at different levels (Fusco et al., 2020). Science mapping analysis is based on network analysis. Network analysis allows us to perform statistical analysis on the generated maps to show different measurements of the whole network, measurements of relationships, or overlap of different clusters detected (Aria & Cuccurullo, 2017). In this study, authors and countries were taken as the unit of analysis within the scope of science mapping analysis. VoSViewer software, one of the most widely used software, was used for science mapping.

RESULTS

Performance analysis findings

In this study conducted with the data obtained from the Scopus database, 126 (n=126) studies on carbon emissions from air transportation between 2000 and 2022 were accessed. While 125 of these studies are articles, 1 is a conference paper. The first study on emissions was conducted in 2001. Table 1 presents an overview of the 126 studies. While the authors used 451 keywords to accurately reflect their studies, the number of keywords plus determined by Scopus is 319. There were only 21 single-author studies, while the rate of international author collaboration was 31.75%.

Table 1. Descriptive statistics for bibliometric data.

Description	Frequency
Period	2000:2022
Documents	126
Annual Growth Rate %	9,71
Document Average Age	7,29
Average citations per doc	29,37
References	5884
Keywords Plus	319
Author's Keywords	451
Authors	346
Authors of single-authored docs	18
Single-authored docs	21
Co-Authors per Doc	3,04
International co-authorships %	31,75

Figure 2 shows the historical development of scientific studies in the literature. Accordingly, although the first study was conducted in 2001, the number of publications has been increasing since 2009. This is thought to be due to the EU-ETS launched by the European Union (EU) in 2005. As can be seen in the graph, although there has been a decline in some periods, the number of studies on carbon emissions and the average number of citations per year has been on an upward trend. On the other hand, 53.9% (n=68) of the publications were published after 2017. This is thought to be due to the signing of the Paris Agreement in December 2015 and ICAO's plan to introduce CORSIA in 2016, requiring member airlines to purchase carbon offsets to cover their emissions above 2020 levels from 2021 (ICAO, 2023b).

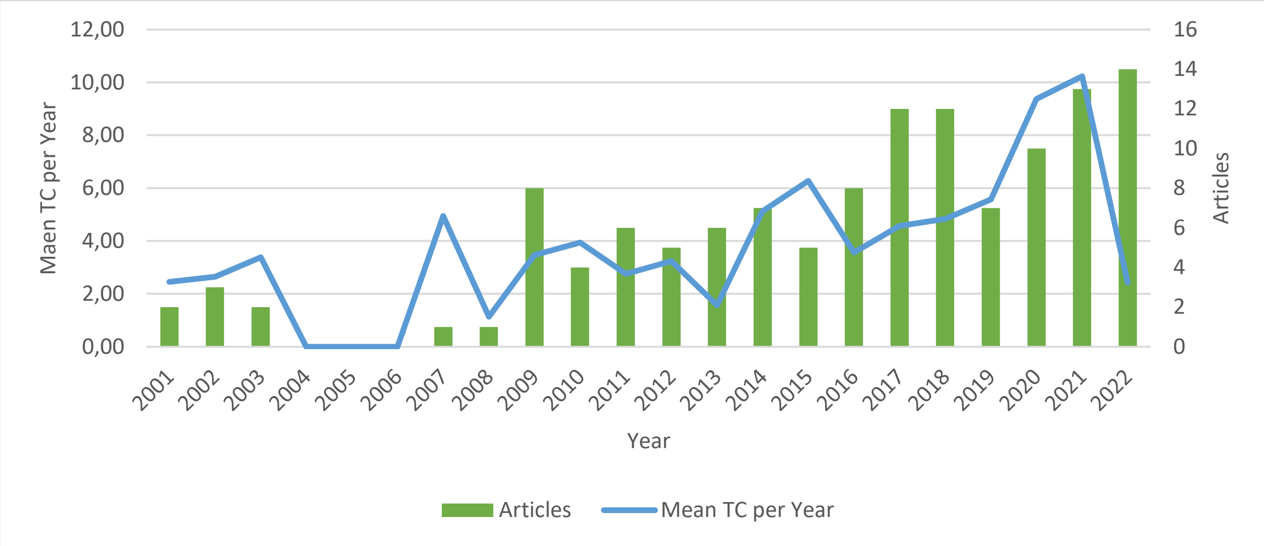


Figure 2. Number of publications and mean total citations by year.

Another performance analysis carried out in the study concerns the most productive authors. Progress in a research field depends on the authors who undertake scientific production and contribute to a better understanding of the current limits of the scientific field (Bakır et al., 2022). Table 2 shows the most prolific authors, their total citations, and h-index values. When Table 2 is examined, it is seen that Wang Q is the most productive author (A: 4) and the author who contributed the most to the expansion of the field (h-index: 4). On the other hand, the most cited author with 2 studies is Waitz IA with 184 citations. In terms of citation efficiency of the publications, it is seen that the most efficient authors are Chikodzi D, Dube K, and Nhamo G. When the data set is analyzed, it is seen that these authors were involved in the same study. In addition, when the author productivity was analyzed with Lotka's Law analysis, it was seen that 315 authors were involved in a single study (91%), 26 authors were involved in two studies (7.5%), 4 authors were involved in three studies (1.2%) and 1 author was involved in four studies (0.3%) among 346 authors. The reason why many researchers are included in only one study can be interpreted as that most of the publications are after 2017 and that they continue their follow-up research on the subject and will publish new studies in the coming years.

Table 2. Most productive and most cited authors.

R	Authors	A	TC	TC/A	h-index	R	Authors	A	TC	TC/A	h-index
1	Wang Q	4	83	20,75	4	1	Waitz IA	2	184	92	2
2	Liu X	3	88	29,33	3	2	Gössling S	2	161	80,5	2
3	Scheelhaase JD	3	108	36	3	3	Chikodzi D	1	142	142	1
4	Wang C	3	18	6	3	4	Dube K	1	142	142	1
5	Zhou D	3	78	26	3	5	Nhamo G	1	142	142	1
6	Alonso G	2	69	34,5	2	6	Semejn J	2	133	66,5	2
7	Becken S	2	59	29,5	2	7	Babikian R	1	122	122	1
8	Benito A	2	69	34,5	2	8	Lukacko SP	1	122	122	1
9	Button K	2	62	36	2	9	Gillingwater D	2	116	58	2
10	Chen L	2	52	21	2	10	Williams V	2	110	55	2

Notes: R: Rank, A: Articles, TC: Total Citations

Another issue investigated in the study is the most cited studies on carbon emissions published in JATM. Table 3 shows the most cited studies on carbon emissions published in JATM. The most cited article is "COVID-19 Pandemic and prospects for recovery of the global aviation industry" by Dube et al. (2021) with 142 citations.

It is seen that the same study ranks first in the average number of citations per year. It is thought that the reason for the high number of citations and the average number of citations per year of this study, which is newer than all of the studies in Table 3, may be because all researchers want to conduct studies on COVID-19 during the COVID-19 period and the number of studies on COVID-19 is high. A similar situation can be said for the study by Abate et al. (2020), which is ranked 6th in Table 3. Although these studies are not directly related to carbon emissions, they provide various information on the effects of the COVID-19 period on carbon emissions. The most cited study on direct carbon emissions (TC: 121) is by Babikian et al. (2002), while the most cited study on average per year (TCPY: 18) is by Scheelhaase et al. (2018).

Table 3. Top 20 most cited studies in JATM from 2000 to 2022.

Rank	Title	Author(s)	Year	TC	TCPY
1	COVID-19 pandemic and prospects for recovery of the global aviation industry	Dube et al.	2021	142	47,33
2	The historical fuel efficiency characteristics of regional aircraft from technological, operational, and cost perspectives	Babikian et al.	2002	121	5,55
3	Evaluating energy efficiency for airlines: An application of VFB-DEA	Cui Q. and Li Y.	2015	107	11,89
4	Environmental capacity and airport operations: current issues and future prospects	Upham et al.	2003	103	4,90
5	Including aviation in the European emissions trading scheme: Impacts on the industry, CO2 emissions and macroeconomic activity in the EU	Anger A.	2010	100	7,14
6	Government support to airlines in the aftermath of the COVID-19 pandemic	Abate et al.	2020	97	24,25
7	Can we fly less? Evaluating the ‘necessity’ of air travel	Gössling et al.	2019	89	17,80
8	Exploring the green image of airlines: Passenger perceptions and airline choice	Hagmann et al.	2015	84	9,33
9	The market development of aviation biofuel: Drivers and constraints	Gegg et al.	2014	83	8,30
10	Carbon dioxide emissions from international aviation: 1950–2050	Olsthoorn, X.	2001	83	3,61
11	Dynamic cost indexing – Managing airline delay costs	Cook et al.	2009	82	5,47
12	EU ETS versus CORSIA – A critical assessment of two approaches to limit air transport's CO2 emissions by market-based measures	Scheelhaase et al.	2007	79	4,71
13	The environmental implications of airlines' choice of aircraft size	Givoni, M. and Rietveld, P.	2010	77	5,50
14	Emissions trading for international aviation—an estimation of the economic impact on selected European airlines	Scheelhaase, D. J. and Grimme G. W.	2018	71	18,00
15	Risks, resilience, and pathways to sustainable aviation: A COVID-19 perspective	Gössling, S.	2020	69	11,83

16	Air travel attitudes and behaviors: The development of environment-based segments	Davison et al.	2014	68	6,80
17	A dynamic network efficiency measurement of airports performance considering sustainable development concept: A fuzzy dynamic network-DEA approach	Olfat et al.	2016	64	8,00
18	Fully solar powered airport: A case study of Cochin International airport	Sukumaran, S, and Sudhakar, K.	2017	63	9,00
19	The impact of the European Union Emissions Trading Scheme on US aviation	Malina et al.	2012	62	5,17
20	The carbon emissions of selected airlines and aircraft types in three geographic markets	Miyoshi, C. and Miyoshi J. K.	2009	60	4,00

Notes: TC: Total Citations, TCPY: Total Citations per Year

Another issue examined in the study is the organizations that support research on carbon emissions and the countries in which the research is conducted. Table 4 shows the top ten organizations supporting the studies and the top ten countries where the studies were conducted. The Nanjing University of Aeronautics and Astronautics with 7 studies, and Cranfield University and Griffith University with 5 studies are the institutions where studies on carbon emissions are supported the most. On the other hand, when the studies conducted are evaluated in terms of countries, China ranks first with 38 studies, followed by the UK with 32 studies. When the citation efficiency of the number of publications of the countries is analyzed, the UK ranks first (TC/TS: 25.03), while the Netherlands ranks second (TC/TS: 16.71).

Table 4. Most productive institutions and countries that contribute to JTAM.

Institutions	S	Country	TS	TC	TC/TS
Nanjing University of Aeronautics and Astronautics	7	China	38	461	12,13
Cranfield University	5	UK	32	801	25,03
Griffith University	5	Germany	31	355	11,45
Allameh Tabataba'i University	4	USA	27	386	14,29
Loughborough University	4	Netherlands	14	234	16,71
German Aerospace Center (DLR)	3	Spain	12	111	9,25
Maastricht University	3	Australia	11	65	5,90
Massachusetts Institute of Technology	3	Turkey	11	12	1,09
Nazarbayev University	3	Canada	7	63	9
Technical University of Munich	3	India	7	12	1,71

Notes: S: Studies; TS: Total Studies; TC: Total Citations

Figure 3 shows the number of publications produced by the top five countries over a 4-year period. While the UK and Germany seem to have published for longer periods, China and the USA have contributed to the aviation carbon emissions literature in JATM by publishing more studies in recent years.

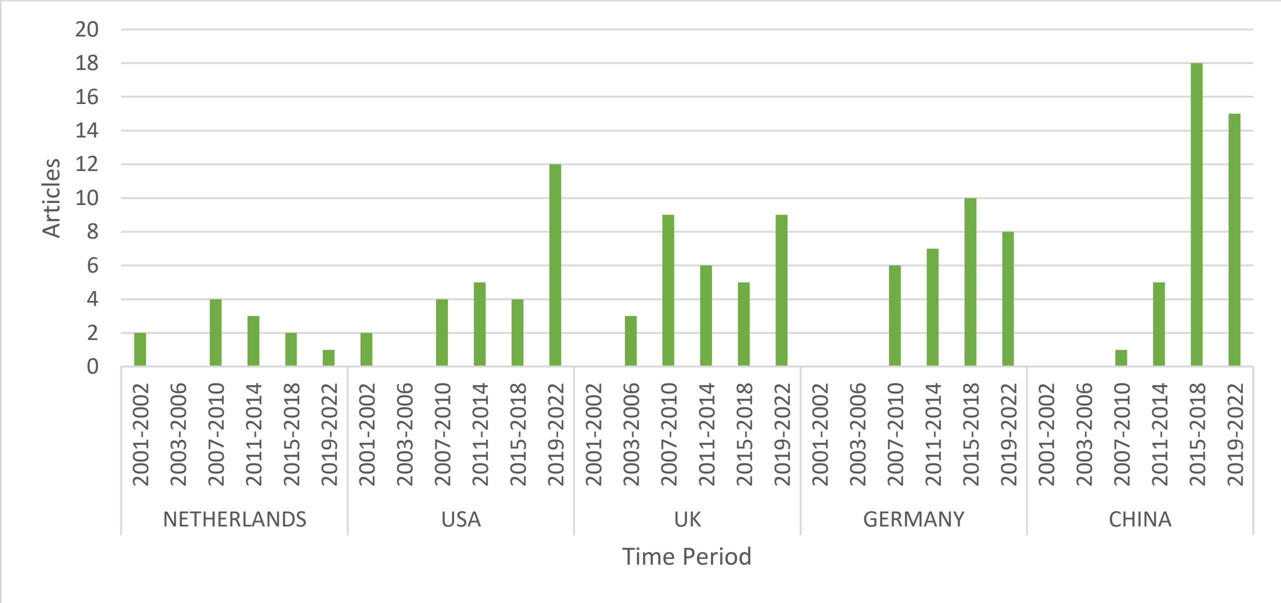


Figure 3. Publication production of countries in JATM in 4-year periods

In addition to Figure 3, Table 5 shows the countries of the corresponding author of the publications and the international collaborations in the studies. When Brazil and France are excluded because they have 2 publications each, it is seen that the USA is the country with the highest number of publications (46%) in the context of international collaboration. Spain is in second place with 33%. Authors from China, on the other hand, have the highest number of publications, but relatively low international collaboration (20%).

Table 5. Corresponding author countries and international collaborations

Country	Articles	SCP	MCP	MCP %
China	20	16	4	20
UK	16	12	4	25
Germany	15	14	1	6
USA	13	7	6	46
Spain	6	4	2	33
Netherlands	4	3	1	25
Australia	3	2	1	33
Canada	3	3	0	0
Brazil	2	1	1	50
France	2	1	1	50

SCP: Single Country Production, MCP: Multi Country Production

One of the most powerful tools used to illustrate the thematic development of a study area is thematic maps (Bakır et al., 2022). Furthermore, the creation of a thematic map provides more unbiased insight by identifying themes based on the clustering of recurring keywords (Bajaj et al., 2022; Rejeb et al., 2022). The thematic map is framed on centrality (x-axis) and density (y-axis) (Sharma et al., 2021). Intensity is a measure of the development of the chosen theme, while centrality measures the importance of the theme. The thematic map has four quadrants. The themes in the upper right quadrant are both well-developed and important for structuring a research area. The themes in this section are known as the motor themes of the field. The placement of themes in this quadrant indicates that they are externally related to concepts applicable to other themes that are conceptually closely related. The themes in the upper left quadrant have well-developed internal ties, but only marginal importance for the field as they have insignificant external ties. In other words, the upper left quadrant represents niche themes, developed but isolated. The themes in the lower left quadrant are both poorly developed and marginal. The themes of this quadrant have low intensity and low centrality and represent themes that are either emerging or declining. The themes in the lower right quadrant are important for a research area. Much research has been done on these themes, but they are constantly evolving (Bakır et al., 2022; Cahlik, 2000; Cobo et al., 2011; Sharma et al., 2021). The size of the bubbles in the thematic map is determined by the number of publications in which the keyword appears (Rejeb et al., 2022).

Before the thematic map analysis of carbon emissions in air transportation, it was considered that some keywords should be removed from the analysis and some should be combined to provide more accurate results. In this context, the keywords air transportation, air transport, and aviation were removed, and carbon emission, carbon emissions, co2 emissions, carbondioxide emissions, carbon dioxide emissions, and carbon footprint were combined as one group and greenhouse gases, greenhouse gas emissions were combined as another group. As a result of the analysis, it is seen that themes emerged in each quadrant.

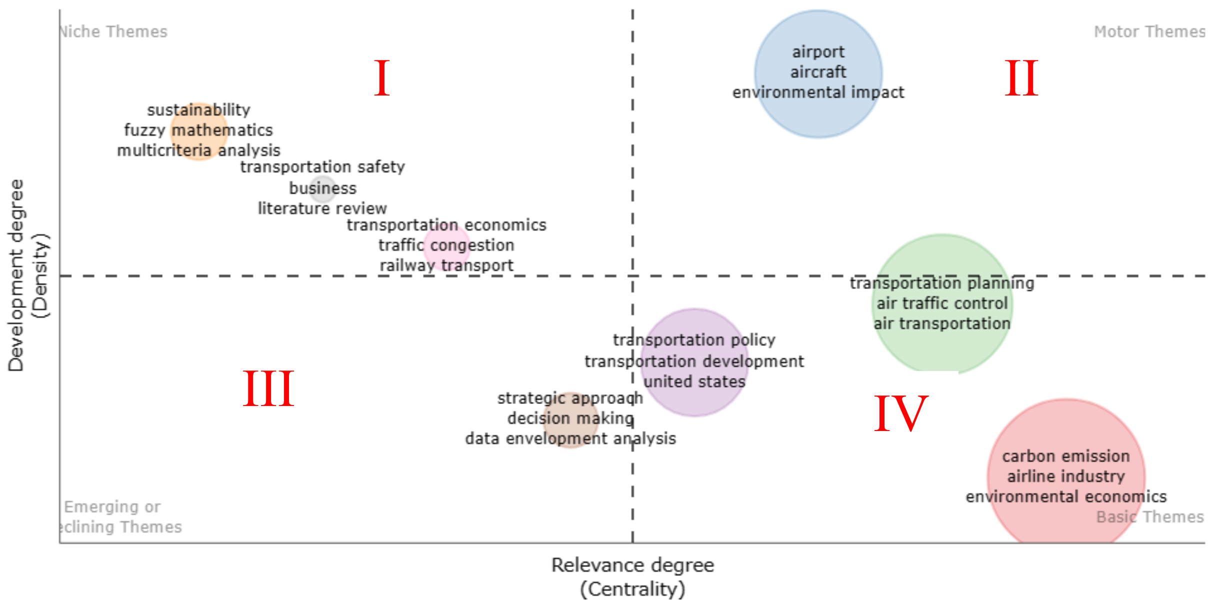
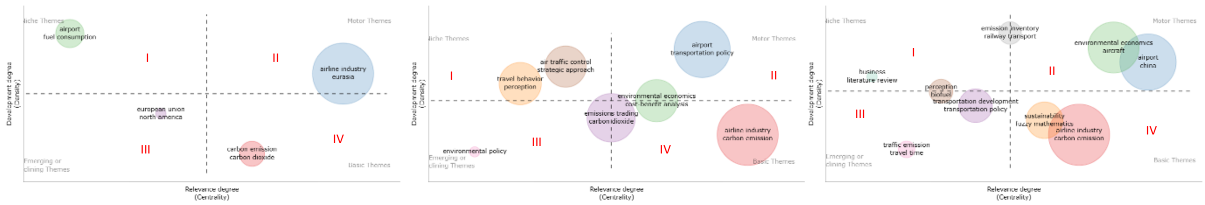


Figure 4. Thematic map

According to Figure 4, the motor themes related to carbon emissions (quadrant II) are airport, aircraft, and environmental impacts. The basic themes in the study (quadrant IV) are transportation policies, transportation development, carbon emissions, the airline industry, and environmental economy. Strategic approach, decision making, and data envelopment analysis have either emerging or declining themes (quadrant III). Finally, sustainability, fuzzy mathematics, multi-criteria analysis, transportation safety, literature review, transportation economics, traffic congestion, and railway transport represent niche themes (quadrant I).

Evaluating thematic development in the context of time periods is important for understanding how the field has developed in the historical process. The thematic evolution of the field examines the broad picture of the field's development in a given period of time, dividing the entire time frame into different time periods

(Ingale & Paluri, 2022). In terms of time periods, the first period (Figure 5a) is 2000-2008, the second period (Figure 5b) is 2009-2015 and the last period (Figure 5c) is 2016-2022. The main reason why the first period in the study was determined between 2000-2008 is that it includes the years when studies on carbon emissions were not yet intensive. Figure 5a shows that in the first studies on carbon emissions, the motor themes were airline industry and Eurasia, the niche themes were airport and fuel consumption, the basic themes were carbon emission and carbon dioxide, and the finally emerging or declining themes were European Union and North America. The next period is the period covering the years 2009-2015. This is the period when the studies started to intensify, and it is thought that the signing of the Paris Agreement may change the course of the studies. When Figure 5b is analyzed, it is seen that the airport, which was in quadrant I in the previous period, has now become a motor theme in quadrant II. Another motor theme in this period was transportation policy. The airline industry became the basic theme in this period. The themes of environmental economy and cost-benefit analysis remained between quadrants II and IV, while emission trading and carbon dioxide remained between quadrants III and IV. Environmental policy is seen as an emerging or declining theme. On the other hand, air traffic control, strategic approach, travel behavior, and perception emerged as niche themes in this period.



2000-2008 2009-2015 2016-2022

Figure 5. Thematic evolution by time slice

The last period of thematic development is the period covering 2016-2022. This time period was chosen because it is both the period when the studies are at their peak and the period when both the Paris Agreement and CORSIA have their effects. When Figure 5c is analyzed, it is seen that environmental economics, aircraft, airport, and China were the motor themes in this period, while sustainability, fuzzy mathematics, airline industry, and carbon emission were the basic themes. In this period, transportation policy, which was the motor theme in the previous period, is seen as a disappearing theme, while transportation development is an emerging theme. Traffic emission and travel time appear to be themes that emerging or declining in this period. While perception was a niche theme in the previous period, it is seen as a disappearing theme in this period. Biofuel took place between quadrants I and III. The themes that declining or emerging in this period were business and literature review. Finally, emission inventory and railway transport were included between quadrants I and II in this period.

Science mapping analysis findings

Science mapping analyses are widely used in bibliometrics studies. In this study, co-occurrence, co-citation, and collaboration network analyses were performed. VoSViewer software was used to visualize the analyses.

Co-occurrence analysis

Co-occurrence analysis is one of the most important analyses to support knowledge mining and to gain insight into knowledge structure and research trends (X. Wang et al., 2020). In the study, the analysis was conducted using the most frequently used author keywords. In the literature, it is recommended to use 50 keywords with the highest rank in some studies (Ingale & Paluri, 2022) and 40 keywords in some studies (Aria & Cuccurullo, 2017) for co-occurrence analysis. In this context, an analysis of 50 keywords was performed for a more comprehensive analysis. Figure 6 shows the results of the co-occurrence analysis.

As a result of the analysis, eight different clusters were formed from the most frequently used keywords. The most frequent keyword in the first cluster, shown in red, is transport and this cluster includes the keywords carbon emissions, carbon footprint, civil aviation, environmental impact, flight shame, sustainable development, and tourism. This cluster integrates the environmental impacts of carbon emissions from air transportation, flight shame, and carbon footprint from tourism. The second cluster, shown in green, includes the keywords aircraft emission, air transport policy, airline fleet planning, emission trading, airline competition, environmental economy, and CORSIA. In this cluster, aircraft emissions are associated with airline fleet planning and air transport policy. On the other hand, aircraft emissions are associated with emissions trading under EU legislation and CORSIA, an ICAO scheme. The third cluster, shown in blue, includes the keywords CO2 emission, airline operation, European Union, flight delays, fuel consumption, and game theory. In this cluster, CO2 emissions are integrated with fuel consumption, flight delays, and airline operations. The fourth cluster, shown in yellow, includes the keywords aviation, airport, air traffic management, environment, sustainability, and systematic literature review. In this cluster, aviation is integrated with airports and air traffic management and associated with environmental and sustainability efforts. The fifth cluster, shown in purple, includes the keywords carbon dioxide emission, climate policy, externalities, international tourism, and open skies agreement. In this cluster, carbon dioxide emissions are associated with climate change and externalities. On the other hand, the effects of the Open Skies Agreement and international tourism on carbon emissions are associated. The sixth cluster, shown in light blue, includes the keywords climate change, COVID-19, greenhouse gas emission, and resilience. The impacts of COVID-19 on climate change and greenhouse gas emissions are associated. The seventh cluster, shown in orange, includes the keywords international aviation, greenhouse gases, environmental regulation, and environmental cost. In this cluster, the environmental costs of greenhouse gases generated by international aviation and environmental regulations are integrated. Finally, in the eighth cluster, shown in brown, aircraft size and airline operation are associated.

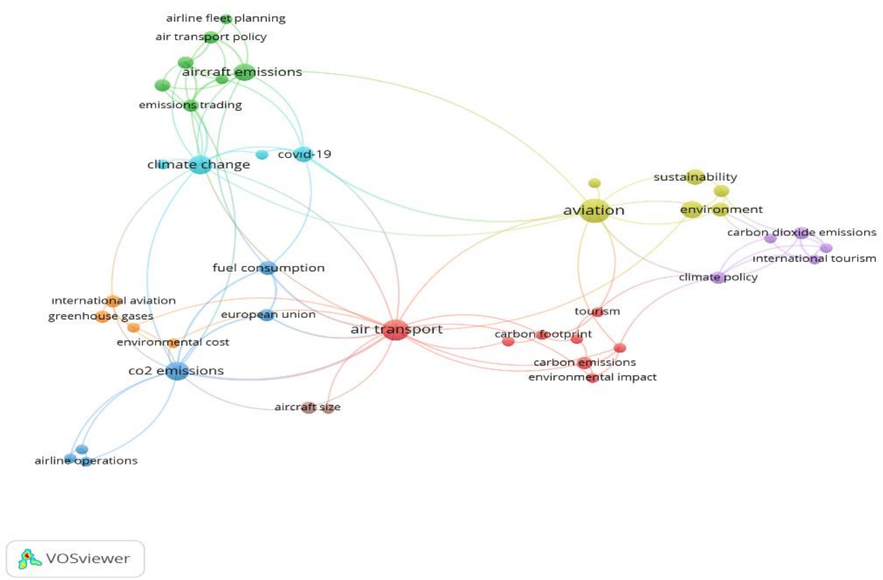


Figure 6. Co-occurrence analysis

Co-citation analysis

Another widely used method in bibliometric analysis is co-citation analysis, which enables the discovery and mapping of intellectual connections between influential articles in any field (Hota et al., 2020). In other words, co-citation analysis refers to the study of relationships between journals, articles, or authors to discover patterns within a particular intellectual tradition. (Köseoğlu et al., 2015). Co-citation means that two previously published articles are cited together in a subsequent study. The more these two articles are cited together, the closer the relationship between them is assumed to be. (Vogel & Güttel, 2013). Within the scope of the study, a co-citation analysis of the 25 most cited references was conducted to ensure the comprehensibility of the analysis. As a result of the co-citation analysis, three different clusters were formed as shown in Figure 7.

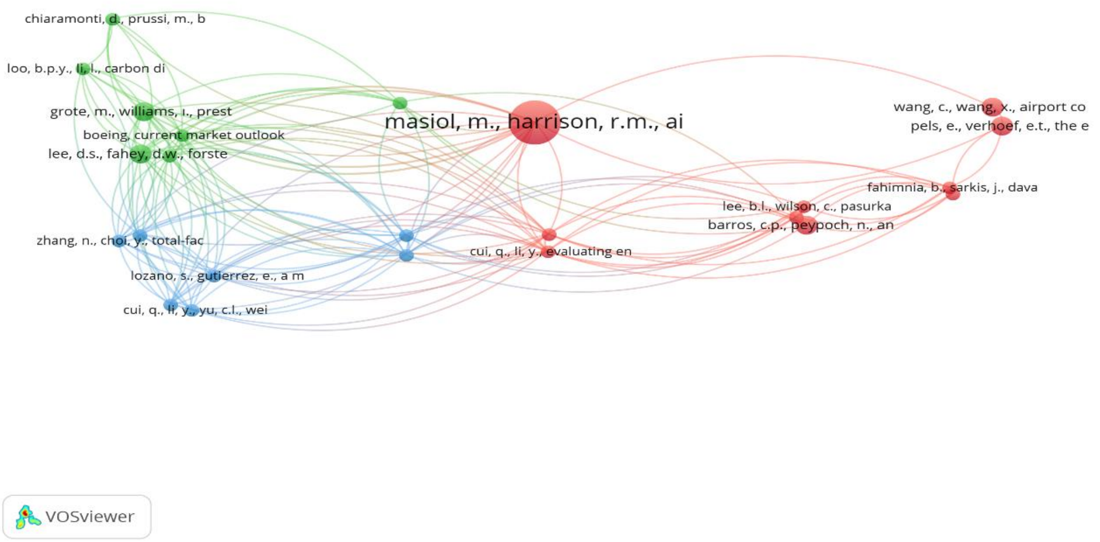


Figure 7. Co-citation Analysis

As a result of the analysis, Masiol and Harrison (2014) article "Aircraft engine exhaust emissions and other airport-related contributions to ambient air pollution: A review" was the most co-cited publication in JATM. The research clusters and themes derived from the co-citation analysis are shown in Table 6. As can be seen in Table 6, most of the co-cited studies are related to aviation emissions, while the most commonly used methods are data envelopment analysis (DEA) and review.

Table 6. Research clusters derived from co-citation analysis.

Cluster	Theme and Method	Related publication	Journal
1	Aircraft and airport emissions /Review	Masiol and Harrison (2014)	Atmospheric Environment
	Airline operational efficiency / Data envelopment analysis (DEA)	Barros and Peypoch (2009)	International Journal of Production Economics
	Carbon reduction efficiency /Stochastic network DEA	Chen et al. (2017)	Energy Economics
	Airline energy efficiency /Virtual Frontier Benevolent DEA	Cui and Li (2015)	Journal of Air Transport Management

	Green supply chain management/ Bibliometric analysis	Fahimnia et al. (2015)	International Journal of Production Economics
	Organizational studies/Co-citation analysis	Gmür (2003)	Scientometrics
	Airline carbon efficiency/Luenberger productivity indicator	Lee et al. (2017)	Journal of Productivity Analysis
	Airline performance efficiency /DEA	Lee and Worthington (2014)	Journal of Air Transport Management
	Airports congestions prices/Model development	Pels and Verhoef (2004)	Journal of Urban Economics
	Airport congestions/Wellfare analysis	Wang and Wang (2019)	Transportation Research Part E: Logistics and Transportation Review
2	Aircraft emission/ Review	Grote et al. (2014)	Atmospheric Environment
	Aviation emission/ Review	Lee et al. (2009)	Atmospheric Environment
	Biofuels/ Review	Chiaramonti et al. (2014)	Applied Energy
	Market Outlook/Forecasting	Boeing (2012)	
	Emissions from transport/ Forecasting	Loo and Li (2012)	Energy Policy
	Aviation emission/ Review	Lee et al. (2010)	Atmospheric Environment
	Greenhouse gases/ Guidelines	IPCC (2006)	
3	Emission reduction/ Malmquist index analysis and DEA	Zhou et al. (2016)	Applied Energy
	Emissions from transport/ Malmquist index analysis and DEA	Zhang et al. (2015)	Renewable and Sustainable Energy Reviews
	Airlines energy efficiency/ Virtual Frontier Dynamic Slacks Based Measure	Cui, Li, et al. (2016)	Energy
	EU-ETS emission/ Dynamic Environmental DEA	Cui, Wei, et al. (2016)	Applied Energy
	Airlines fuel and operating cost efficiency/ Multiobjective DEA	Lozano and Gutiérrez (2011)	Computers & Industrial Engineering
	CO2 emission performance/Malmquist index analysis and DEA	Zhou et al. (2010)	Energy Economics
	Carbon emission performance/Non-radial Malmquist index analysis and DEA	Zhang and Choi (2013)	Energy Economics

Collaboration analysis

In the last step of the scientific mapping analysis, collaboration networks between units in the research field were analyzed. In this context, author and country level analyses were conducted. Figure 8 shows the results of the analysis of author collaborations.

As seen in Figure 8, three different clusters emerged in the authors' collaboration network analysis. The most striking and largest network is the cluster shown in red, which includes Wang Q, Zhou D, Liu X, Hang Y, Hu JL, Zhou P, Huang F and Madlener R. At the center of the red cluster are Wang Q, Zhou D and Liu X. The second cluster is shown in green and includes Kelly KJ, Kotz A, Lunacek M, Garikapati V, Phillips C and Sigler D. The last cluster is shown in blue and includes Wang B, Yang J, Xue B and Liu Z.

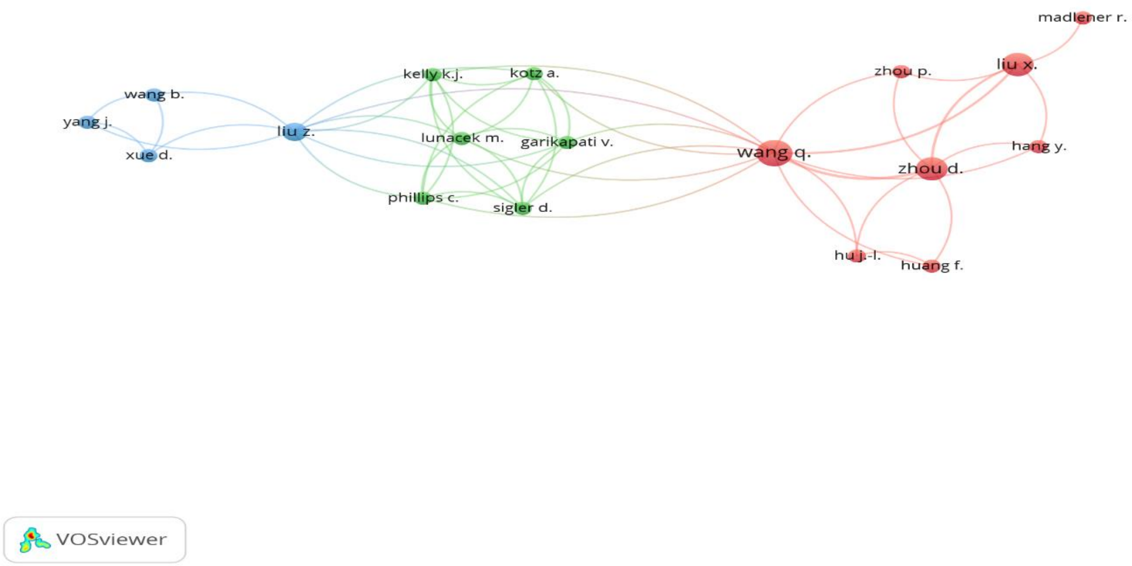


Figure 8. Authors' collaboration network map.

Another analysis within the scope of collaboration analysis is the collaboration between countries. Studies conducted by countries that do not collaborate with countries were not included in the collaboration analysis. As can be seen in Figure 9, eight different clusters emerged in collaborations between countries. The first cluster shown in blue includes the UK, Germany, France, Kazakhstan, and Singapore, while the cluster shown in brown includes the USA and Israel. The orange cluster includes China, Taiwan, and Hong Kong, while the yellow cluster includes Croatia, Lithuania, Ireland, the Netherlands, and Vietnam. The cluster in light blue includes Australia, Belgium, Greece, and Italy, while the cluster in purple includes Spain, Brazil, Turkey, Portugal, and Russia. The cluster in green includes Norway, Sweden, New Zealand, Canada, Japan, and South Korea, while the cluster in red includes Egypt, India, Indonesia, Malaysia, Pakistan, and Saudi Arabia. The collaboration network map obtained as a result of the analysis shows that USA, UK, Germany, and China are effective in collaboration with other countries in studies on carbon emissions.

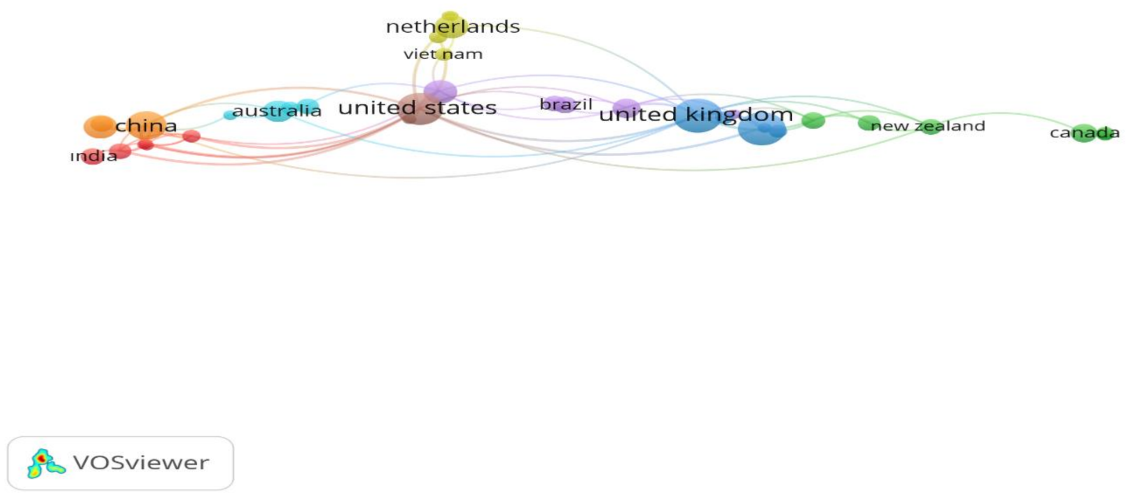


Figure 9. Countries collaboration network map.

DISCUSSION AND CONCLUSION

With the beginning of the effects of global warming, interest in greenhouse gases is increasing day by day in the academic community. The air transportation sector also contributes to climate change with greenhouse gases (Anger, 2010). It is stated that the most important anthropogenic greenhouse gas emitted in the sector is CO2 (Grote et al., 2014). In this context, the retrospective analysis of the literature on carbon emissions in JATM between 2000 and 2022 was evaluated using bibliometric analysis. Within the scope of bibliometric analysis, performance analysis and scientific mapping analysis were performed. In the study, 126 publications were used for analysis.

According to the results of the analysis, the first study on carbon emissions in JATM was published by Olsthoorn (2001). 346 authors contributed to the development of the field. The analysis revealed that the collaboration rates in the studies are quite high (83.3%). The number of single-author studies is only 21. The number of authors per document is 3.04. When international collaboration rates are analyzed, 31.75% of the studies show collaboration. In this context, it can be said that there is a culture of cooperation in the literature on carbon emissions. It is stated in the literature that the increase in both national and international collaboration increases the impact of the publication, in other words, the possibility of citation (Glänzel et al., 1999; Polyakov et al., 2017; Teodorescu & Andrei, 2011). On the other hand, it would not be wrong to say that collaborations increase learning together (Laal & Ghodsi, 2012), thus contributing to the development of the field by adding different perspectives.

Although the first of the studies on carbon emissions in JATM was published in 2001, it can be said that the field did not grow much until 2009, but it has gained increasing momentum after 2009. Approximately 54% of the publications in the JATM literature were published between 2017 and 2022, with the highest number of publications (n=14) published in 2022. It can be mentioned that there are various reasons for the increase in publications especially after 2009. The first of these reasons is the emergence of the EU-ETS in 2005. EU-ETS can be defined as a system that works on the principle of "cap and trade", determines the maximum greenhouse gas upper point that enterprises can emit, and rewards enterprises that reduce greenhouse gas emissions. One of the sectors defined in the EU-ETS is the air transportation sector. In this context, such regulation seems to have triggered studies on greenhouse gases, and more narrowly on CO2 emissions. The reason for the increase in publications after 2015 may be the Paris Agreement, which was signed in 2015 and entered into force in 2016. The Paris Agreement establishes the framework of the climate change regime and aims to keep the increase in global warming caused by anthropogenic greenhouse gases below 2 degrees Celsius compared to the pre-industrialization period. (MFA, 2022). This agreement can also be considered to have triggered studies on carbon emissions. CORSIA can be mentioned as another trigger for the increase in the number of publications. While the EU-ETS and the Paris Agreement set the general framework for almost all sectors, CORSIA, announced by ICAO in 2016, is a program specific to the air transport system that seeks to reduce emissions from aviation and minimize market distortion. (ICAO, 2023a). ICAO has defined three phases for the implementation of CORSIA: pilot phase (2021-2023), phase one (2024-2026), and phase two (2027-2035). Participation in the pilot phase and phase one is voluntary, while participation in phase two will be based on 2018 RTK data starting in 2027. As a result, the emergence of a sector-specific regulation on carbon emissions by the international authority seems to have triggered studies on carbon emissions. Finally, the increase in emissions from air transportation and the fact that emission values are expected to increase further (Perryman et al., 2022) may also have triggered an increase in studies on carbon emissions.

When the literature on carbon emissions in JATM is evaluated in terms of authorship, it is seen that the most productive author (n=4) is Wang Q, who examines aviation carbon emissions in aviation components such as airports and airlines. The most cited author (n=184) in the field is Waitz IA, who studies fuel efficiency and EU-ETS. Waitz IA's "The historical fuel efficiency characteristics of regional aircraft from technological, operational, and cost perspectives" is an early study published in 2002. The Scopus database shows that this study has 122 citations. It can be mentioned that the early period of the study increased the number of citations. When we look at the contributions of countries to the field, it is seen that China (n=38), the UK (n=32) and Germany (n=31) stand out. Of course, it is not surprising that China ranks first. When scientific academic journals are analyzed, it is known that Chinese authors have published a lot in the last 20 years. There are various reasons for this. The first is the requirement to publish in the Science Citation Index (SCI) to obtain a Ph.D. degree, which has become established in many universities in China. (Li, 2016). Second, in parallel with China's economic development, Chinese scholars living overseas are returning home, both as academics and practitioners. (Zhou & Leydesdorff, 2006). As a matter of fact, these repatriations have been reflected in the number of publications by academics and researchers based in China through collaborations and learning from returnees. Third, China sees research productivity as central to economic competitiveness, increasing research expenditures and thus putting pressure on research staff to publish in SCI or Social Science Citation Index (SSCI).

The keywords used by the authors of academic studies in a scientific field are very important for understanding the current situation in that field. In this study, thematic analysis and co-occurrence analysis were conducted using the keywords used by the authors. As a result of these analyses, trending topics and concepts in the past and current situations were revealed. According to the results of the thematic analysis (see Fig 4), the motor themes that have contributed the most to the development of the literature are aircraft, airports, and environmental impact. The niche themes are traffic congestion, railway transport, transportation safety, and transportation economics. It can be evaluated that these themes will become more prominent in the future. As a matter of fact, in recent years, some of the studies in JATM (Chen et al., 2022; Erdogan et al., 2020) have compared high-speed trains with air transportation and presented these comparisons through economic evaluations. When the publications in JATM are thematically analyzed in three periods (see Fig 5), it is seen that the motor themes are airline industry and Eurasia in the period 2000-2008, airport and transportation policy in the period 2009-2015, and environmental economics, airport, aircraft and China in the last period 2016-2022. In this context, it would not be wrong to say that the first studies in JATM examined the emissions of airline companies, but in the following periods, they focused on the impacts of the air transportation system as a whole.

As a result of the co-citation analysis (see Fig 7), which is one of the science mapping analyses performed, three different clusters emerged. Table 6 shows the themes and methods of the studies in the clusters. Accordingly, while most of the studies in the first cluster were efficiency studies, many of them used data envelopment analysis (Barros & Peypoch, 2009; Chen et al., 2017; Lee & Worthington, 2014). Most of the studies in the second cluster are review studies that examine aviation-related emissions (Chiaramonti et al., 2014; Grote et al., 2014; Lee et al., 2010). Finally, the studies in the third cluster are those that focus on emission performance and mitigation and use both the Malmquist index analysis and DEA (Zhang & Choi, 2013; Zhang et al., 2015; Zhou et al., 2016). The last of the scientific mapping analyses was carried out for collaborations. The author’s collaboration analyses produced three different clusters (see Fig 8). In the clusters shown in red and blue, the collaborations of Chinese authors stand out. When the collaboration network between countries is analyzed (see Fig 9), it is seen that USA, UK, Germany, and China come to the fore.

This study aims to provide an overview of the historical development of studies on carbon emissions published in JATM and to describe the structure of the research field. The main contribution of this study is that it is the first bibliometric analysis of the existing literature on carbon emissions published in JATM. In this context, in terms of revealing the general structure of the research field, the study can be considered a guide for researchers who want to get to know the existing literature. Through the study, researchers can obtain statistical information such as the most prolific authors, countries, and the most cited studies in the field, as well as identify gaps by monitoring the development direction of the literature.

Sustainability and environmental issues are important themes in air transportation management. (Merkert, 2022). Therefore, JATM, the leading journal of air transportation management, also publishes various studies on these themes. In this context, learning the historical development and existing status of the JATM literature will guide future studies. For these reasons, in this study, a bibliometric analysis of the studies published in JATM on carbon emissions was conducted. On the other hand, the main objective has also emerged as a limitation. The exclusion of studies published in other journals on carbon emissions from air transportation is considered an important limitation. In future studies, it is thought that analyzing carbon emission studies on air transportation in all journals in indexes such as Scopus or WoS will contribute to a more comprehensive perspective on the field. Finally, in this study, a bibliometric analysis of carbon emissions from the air transportation sector was conducted. In future studies, a more comprehensive perspective can be obtained by including all emissions generated by air transportation in the analysis.

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