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The Impact of Digitalization on Air Traffic Evolution and Measures of Reducing CO2 Emissions

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Abstract. *In the past couple of decades, the field of digitalization has grown in popularity. Given the substantial amount of research supporting its significance, it can be stated that this phenomenon manages to make its presence felt in any field at the moment, including the air traffic sector. The discussed effects may be seen in almost every element of air transport, whether it is the performance of the aircraft or the passengers' experience from the moment of ticket purchase to the completion of the flight. Between 2009 and 2019, air passenger revenue worldwide increased by 63%, from 374 billion $ to 612 billion $. Before COVID-19, air travel increased significantly. As part of the fourth industrial revolution, the digital transformation manages to change organizational paradigms and working practices while improving performance. Having this in mind, we aimed to identify the impact of digitalization in air flights domain, and what measures could be applied to reduce CO2 emissions. A bibliometric study of the previously conducted research in the area was performed using the Biblioshiny library, based on a set of extracted articles pertinent to the effects of digitalization on the aviation field. The viewpoints of this research emphasise the benefits of digital transformation and highlight the necessity of digitalization in all industries, particularly air traffic.*

Keywords: Digitalization, Bibliometrix, Air Traffic, CO2 emissions, Traffic Evolution.

Introduction

Aircraft domain is one of the major industries in the world, having the purpose of transporting fast, efficient, and more sustainable people, goods, and military equipment. The airplane domain appeared for the first time in 1903, when Orville and Wilbur Wright created for the first time a motor-operated airplane, called “Wright Flyer”, and in 1908, the first flight took place.

Digitalization, affecting more and more fields, can be analyzed from numerous perspectives. This continuous digital transition manages to have a strong impact on society as a whole. The study of the digitalization phenomenon is of particular importance, because through

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these changes we can anticipate the future course of the economic sectors of interest. Nowadays, digitalization is being encouraged on an extensive level. In this sense, an interest in digital development at the level of the European Union (EU) can be observed, both through the lens of numerous researches in the field and through the annual reports (Union, 2023). The importance of the digitalization study can also be highlighted by the results obtained from the research on the evolution of digitalization (*DESI*, 2022) The favorable results of the periodic reports imply the countries' interest in digital progress and the availability of improving digital aspects.

On the other hand, each field goes through specific changes in accordance with the market it activates and for an adequate technological advance it is necessary to follow the level of digitalization adopted by the area of interest. By analyzing the already published articles that are based on the study of digitalization in relation to the evolution of air traffic, the opportunity to establish the level reached by the research up to this moment is seized. Air transport evolved radically in the last decades, implementing new technologies which facilitate traffic control and reduced the costs for boarding process. The technological evolution provided the opportunity to predict using Artificial Intelligence solutions the number of flights per day, number of passengers, what is the operation program and other relevant features for transportation domain as (Paprocki, 2021) presented in his paper.

Greenhouse gas emissions could be reduced by 5% and the number of passengers could be the same, by digitalizing activities and processes. The creation of a one single airspace agency in Europe could reduce significantly the air traffic control costs (Paprocki, 2021).

Therefore, this paper aims to investigate the impact of digitalization on air traffic evolution and ways to reduce CO2 emissions, using a bibliometric analysis, therefore addressing research questions such as those about the authors who have made the largest contribution to the topic and the most common journals for the publishing of such articles.

The structure of the paper is the following. Section 2 is dedicated to the literature review in the field, while the methodology is briefly presented in Section 3. Next, the main results of the bibliometric analysis are discussed in detail, while the last section concludes.

Literature review

Metropolitan areas are forced to adapt to urbanization, investing considerable resources on transport, connecting air transport with public transport. Digitalization helped the process of transport and logistics, managing more and more complicating traffic facing limitations of resources and space (Richter et al., 2020). Thanks to technological evolution, private companies are more and more interested in new transportation solutions. The implementation of web applications helped clients identify the timetables and fares from different airlines and travel agencies (Jarach, 2002). Air carriers' growth significantly in online ticketing. The first step of digitalization on air transport appeared in 1990s, when asynchronous applications offered information for travelers such as flight frequencies, timetables, on-board services. There was limited interactivity on the web sites at that point. Internet of Things (IoT), Building Information Modeling (BIM) and Distributed Ledger Technologies (DLT) are the main tools which have been implemented, facilitating the air transport domain. Using IoT, various scenarios and parameters have been tested, finding the optimum components for pavement. Building Information Management is an important software which improved pavement management, integrating flows of digital information. Airport Pavement Management System (APMS) offered a more durable and sustainable airfield pavement (Pacios Álvarez et al., 2021).

The main index used to monitor the level of digitalization at the EU level is the Digital Economy and Society Index (DESI), a composite index that brings together the most important dimensions of the digital transition: Human capital, Connectivity, Integration of digital technology and Digital public services (*DESI*, 2022). Considering these 4 categories of indicators, the overall picture of the level of digitalization is extended both at individual and at country level. The numerous research on the issue of monitoring the digitalization index suggests an interest in the digital transition. Furthermore, using this form of monitoring decisions are taken to improve each country's degree of digitalization based on the outcomes for each dimension and indicator. The relationship established between the digitalization phenomenon and the field of air traffic has become a focus in the research of specialists in recent years. Air transport was studied via the lens of digitalization, taking into consideration the complexity of current procedures in terms of passenger experience and flight itself. Thus, aspects such as reducing costs, improving the level of security, and connecting to passengers are just some of the key points targeted by digitalization in this field. In other words, all the areas where digitalization is involved lead to an increase in profit and the trust granted by customers. According to studies, in 2022, approximately 70% of passengers prefer the online purchase of plane tickets in favor of traditional methods and approximately 50% consider that self-service check-in methods are more advantageous than those at the airport. The results confirm that this phenomenon can be improved in order to make the entire boarding process more efficient for passengers as well as to increase airline profits, even though there are still some drawbacks to digitalization in the industry, such as potential security breaches or technical errors that can occur at self-check-in (Heiets et al., 2022).

Although over time, airlines have introduced digital measures to improve services, thus focusing on the well-being of passengers it is clear that there is potential for improvement (Heiets et al., 2022). Therefore, although the current level of digitalization in the field of air traffic is advanced, a common recommendation consists in focusing new digital measures on improving the level of Greenhouse gas (GHG) emissions, minimizing the negative impact on the environment (Paprocki, 2021). The GHG emissions, mainly consisting of CO2 emissions, represents the main concept when discussing air pollution. The smart airport concept, which has begun to be implemented in some geographical areas, aims both to digitize the passenger experience and to monitor how air traffic affects the environment. An example in this sense is represented by the fact that through the digitalization of the air sector, the consumption of energy, and in general of resources, is reduced in favor of the environment (Rodoplu et al., 2022). Since the early 2000s, digitalization concepts have been used to monitor GHG emissions through digital maps. The numerical results obtained from the digital monitoring of emissions can be used to mitigate the impact on the environment (Winther et al., 2006).

Methodology

Keeping in mind the focus of the paper on studying the impact of digitalization on air traffic evolution and ways to reduce CO2 emissions through a bibliometric analysis, the dataset was downloaded from ISI Web Of Science, and a series of filters have been applied. Using words related to digitalization and airlines, such as “Digital Public Services”, “Integration Digital Technology”, “Digitalization”, “airline”, “onboarding”, “airport”, “airline”, “flight”, “air transport”, it was possible to extract a set of research papers. After extracting the studies focused on digitalization and those focused on air transport, only the studies common to the two categories were selected.

The same approach was repeated for the titles, abstracts, and keywords, and 78 studies were discovered using all of these criteria. Therefore, the chosen terms can be found either in the keywords of the articles, in their title or in the abstract. Restricting the papers to article type and English language, the final number of papers got to 43. The explanation of each step is described in Table 1.

Table 1. Data selection steps

Exploration steps	Questions on Web of Science	Description	Query	Query number	Count
1	Title	Contains one of the digitalization specific keywords	((TI=(Digital_Public_Services)) OR TI=(Integration_Digital_Technology)) OR TI=(digitalization)	#1	5,075
2	Title	Contains one of the air transport specific keywords	(((((((TI=(airline)) OR TI=(onboarding)) OR TI=(airport)) OR TI=(airline)) OR TI=(flight)) OR TI=(airlines)) OR TI=(airports)) OR TI=(flights)) OR TI=(air_transport)	#2	81,121
3	Title	Contains the specific keywords related to digitalization and air transport	#1 AND #2	#3	3
4	Abstract	Contains one of the digitalization specific keywords	((TI=(Digital_Public_Services)) OR TI=(Integration_Digital_Technology)) OR TI=(digitalization)	#4	18,203
5	Abstract	Contains one of the air transport specific keywords	(((((((TI=(airline)) OR TI=(onboarding)) OR TI=(airport)) OR TI=(airline)) OR TI=(flight)) OR TI=(airlines)) OR TI=(airports)) OR TI=(flights)) OR TI=(air_transport)	#5	242,464
6	Abstract	Contains the specific keywords related to digitalization and air transport	#4 AND #5	#6	70
7	Keywords	Contains one of the digitalization specific keywords	((TI=(Digital_Public_Services)) OR TI=(Integration_Digital_Technology)) OR TI=(digitalization)	#7	8,354
8	Keywords	Contains one of the air transport specific keywords	(((((((TI=(airline)) OR TI=(onboarding)) OR TI=(airport)) OR TI=(airline)) OR TI=(flight)) OR TI=(airlines)) OR TI=(airports)) OR TI=(flights)) OR TI=(air_transport)	#8	40,724
9	Keywords	Contains the specific keywords related to digitalization and air transport	#7 AND #8	#9	12

Exploration steps	Questions on Web of Science	Description	Query	Query number	Count
10	Title/Abstract/Keywords	Contains the specific keywords related to digitalization and air transport on title or abstract or keywords	#3 OR #6 OR #9	#10	78
11	Language	Contains one of the grey systems specific keywords*	(#10) AND LA=(English)	#10	73
12	Document Type	Limit to Article	(#11) AND DT=(Article)	#11	43

Source: Authors' own research.

Figure 1 presents Bradford's law, showcasing the most cited journals on air transport and digitalization domains, sorting the journals on three different categories based on the number of published documents (Wardikar, 2013). If each category contains one-third of all articles, then the total number of journals from each group is proportional to 1:n:n2. There are 8 relevant journals determined by Bradford's law, Journal of Air Transport, Aerospace, Computers in Industry, Sustainability, Technological Forecasting, Aircraft Engineering and Aerospace Technology, Applied Energy, Applied Sciences-Basel.

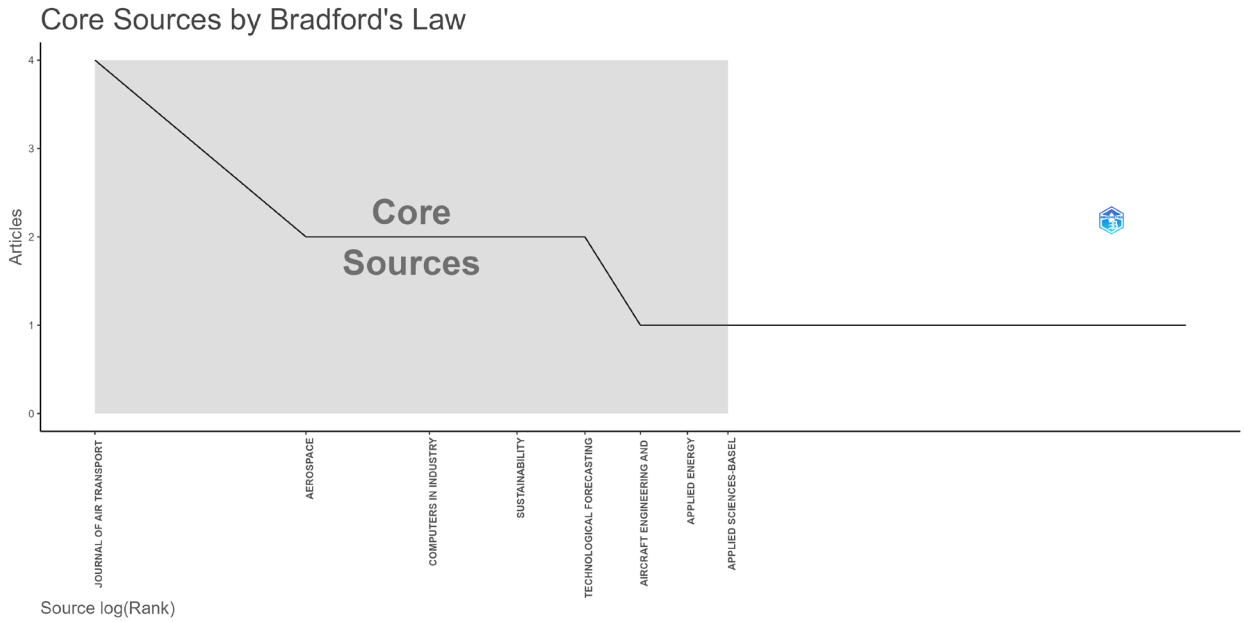


Figure 1. Bradford's law sources clusterization

Source: Authors' own research.

Figure 2 presents the most relevant countries which have articles on the analyzed domain. What stands out in this graph is the disparity in article frequency between the first-place country and the other four countries. German authors have the most significant impact, the majority of their research being made by Multiple-Country Publication or MCP (9 papers out of 12), and only

3 documents were Single-Country Publication or SCP. The frequency of Germany is 27.9% of the total number of articles, with almost 21% higher than second place. On second place is China, with only 3 articles published, 2 of them are SCP, and only 1 MCP, representing 7% of the total documents.

The same importance was discovered also for Sweden and United Kingdom, which have only 3 SCP documents and 0 MCP. Australia have only 2 articles, both SCP, representing 4.7% of the total papers. In addition, German authors have published 12 articles, more than China, Sweden, UK, and Australia combined, which is a significant difference when considering the average of the four nations in the hierarchy, enhancing the major discrepancy present on the field of digitalization and air traffic.

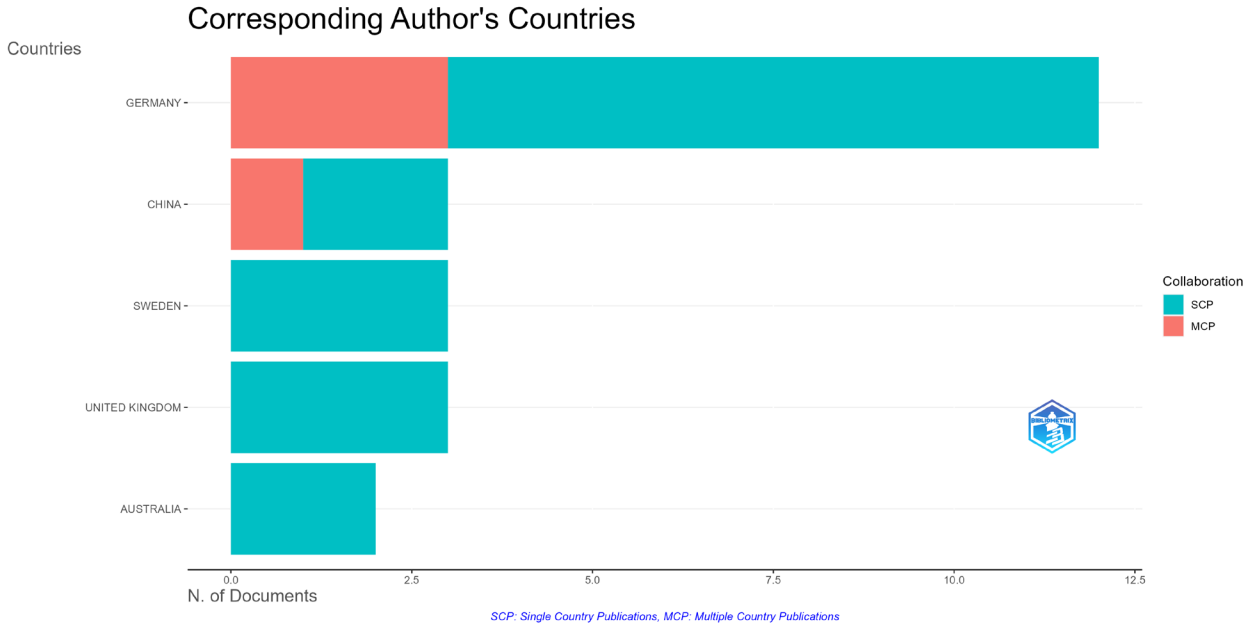
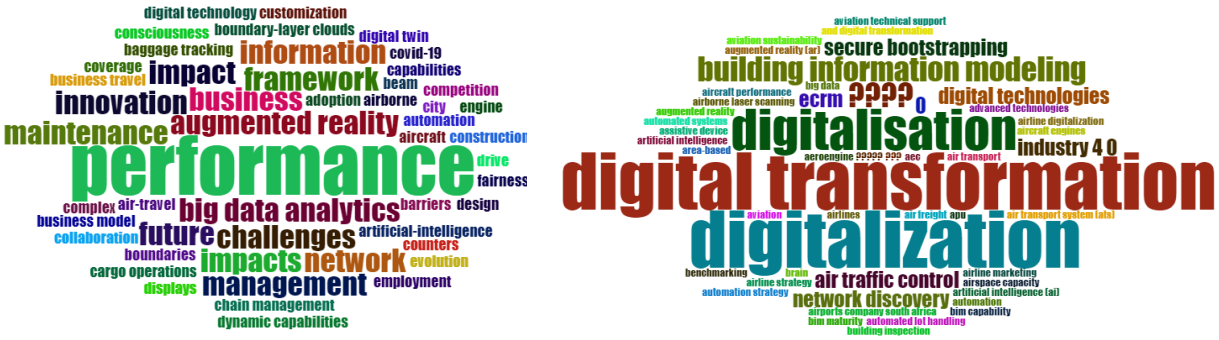


Figure 2. Top 5 Most important corresponding authors' countries

Source: Authors' own research.

WordClouds combines the most used words by the authors, the size of the words representing the frequency of appearance. Figure 3 includes two graphs, one for the most used 50 keywords plus and the second one for the most used 50 authors' keywords. For keywords plus, the most frequently used word is "performance" appearing 5 times, indicating the increased performance provided by digitalization on air transport. The rest of the words, "augmented reality", "big data analytics", "future", "impact", "challenges" appeared twice or less, referring to future or actual tools which can be implemented and facilitate air transport. The first WordCloud shows how the keywords emphasize performance, and it is intuitive that performance is tied to certain concepts of technical development and innovation.

The topics of digitalization and air traffic are the major emphasis of the second WordCloud, since digitalization ideas appear first, followed by phrases relating to air transport, such as "air traffic control". This way, for authors' keywords, the most used word is "digital transformation", a crucial step for implementing digitalization, appearing 7 times, similar with "digitalization", both referring to the same idea. Another frequently used word is "digitalisation". The rest of the words such as "air traffic control", "industry 4.0", "ecrm", "building information modeling" appeared three or two times, having a smaller impact.



(A) Top 50 words based on keywords plus (B) Top 50 words based on authors' keywords

Figure 3. WordClouds for keywords plus and authors' keywords

Source: Authors' own research.

Table 2 summarize the main information extracted from the dataset. The documents were published between 1997 and 2023. There are 36 different sources, with 43 documents, having an average of 13.93 citations each paper. The average year from publication for the documents is approximately 4.3, and the average citations per year for each paper is 2.24. Authors' keywords used on the analyzed papers are 241, and 131 keywords plus, and 2113 references.

Table 2. Main information about the data

Indicator	Value
Timespan	1997-2023
Sources	36
Documents	43
Average years from publication	4.3
Average citations per documents	13.93
Average citations per year per document	2.24
Keywords plus	131
Author's keywords	241
References	2113

Source: Authors' own research.

The collaboration between countries is presented on Table 3. The most important collaboration was between Germany and 2 different countries: Switzerland and United Kingdom, with 2 papers written in each case. The rest of the countries collaborated only once, such as between China-Japan, Finland-Norway, Finland-Switzerland.

Table 3. Top-5 Countries collaboration

Countries	Frequency
Germany-Switzerland	2
Germany-United Kingdom	2
China-Japan	1
Finland-Norway	1
Finland-Switzerland	1

Source: Authors' own research.

Results and discussions

The bibliometric analysis provided a complete perspective of the evolution of air transport and digitalization domains, presenting the most relevant journals, articles, authors, which are the most frequently used words when both domains are combined, and the impact of the technological evolution between 1997 and 2023. The focus of digitalization was to improve the productivity and performance of air transport processes, by implementing various software tools (Building Information Modeling, improving air traffic control, secure bootstrapping, implementing augmented reality, artificial intelligence, and other tools). Germany is the most influential country, with almost 28% of the total documents published, highlighting the significant interest among German authors.

The document has a series of limitations, mainly appearing on dataset selection step. Web of Science is one of the most known databases in the academic community, but the decision of not including other databases could impact the variety and number of documents selected. As Liu (Liu, 2021) described the process of filtering the Web of Science database, searching after relevant terms has some limitations. For some articles, there might be cases of missing abstracts, author keywords, or keywords plus, caused by the process of collecting information from journals. The availability rate has significantly improved in the last decades. In the actual database, there are only 2 keywords missing, 13 keywords plus missing, representing 4.65% of the total data, and 30.23% of the total data respectively. The predefined searching criteria which are applied to the documents represents another limitation, containing only documents written in English, which are articles, excluding other type of papers, such as conferences. Vera-Baceta et al. (Vera-Baceta et al., 2019) presented a disparity of articles between Web of Science and Scopus journals for non-English paper language, but for English, the extracted database is not affected.

Since the number of papers was small, a detailed analyses of each document have been done on Table 4 (Appendix) where a full list of the documents can be found, grouping documents by relevant key elements. The entire dataset has been analyzed, in order to identify the elements which captured the attention of authors regarding air transport and digitalization domains. Examining all 43 papers, two big categories were created, Technological Development and Ecosystem Evolution, each one with subcategories, reflecting the main topics discussed in the articles. For instance, 3D Technology, which is one of the most revolutionary technologies, appeared in 9 different documents, representing 20.93% frequency of total papers. Machine Learning Technologies appeared 16 times, representing 37.21% of total documents. Sustainability, which is one of the key topics in the last years, has 16 paper occurrences, 37.21% frequency. Various tools have been discovered on papers, such as Video Feeds of Drones, Photon Lidar System, Mobile Robotic Systems, which appeared rarely, specifically on one or two documents, but are relevant for the analyzed domains.

Conclusion

In conclusion, this article highlights the importance of the effects of digitalization on air traffic and summarizes the methods for reducing CO2 emissions that have been researched to this point, therefore achieving the main purpose of the research.

The article elaborates a bibliometric analysis of air transport and digitalization, taking into consideration 43 papers downloaded from Web of Science database, which were analyzed in detail, extracting the main elements described by the authors, identifying the collaboration network,

citations, and research patterns. Following the bibliometric analysis, relevant information was extracted regarding the previous publications of this field about the authors and the field of study.

Concerning the author information, it was noted that the corresponding authors are predominantly based in Germany, with 12 published articles out of the 43 extracted. With a significant difference from the first-place country, China, Sweden, and the United Kingdom are rated second in the top countries that contribute to the study of the effects of digitalization in aviation.

Given the nature of the research topic, it is not surprising that technological performance and innovation are the most frequently utilized phrases in these studies. Digitalization had a crucial role in the evolution of air transport, facilitating a variety of processes, making faster and more sustainable one of the main industries on CO2 emissions.

The results of this paper provided an overview of the current state of research across the implications of digitalization on air traffic, highlighting the main characteristics of the authors with the most publications as well as the most frequently chosen journals in this field of study.

Future analysis should include more documents, taking into consideration also the Scopus database, and discovering more correlations between digitalization and air transport, identifying the benefits for cargo and human transport.

By considering these aspects, a deeper understanding of the effects of digitalization on air traffic could be achieved in future publications.

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Appendix

Table 4. Brief overview of the documents included in the dataset

No.	Reference	Technological Development				Ecosystem Evolution					DOI
		3D Technology	Systems	Industry Evolution	Machine Learning Technologies	Sustainability	Transport	Survey	Experiment	Other*	
1	(Kohtamäki et al., 2019)		✓	✔		✔					10.1016/j.jbusres.2019.06.027
2	(Niitsoo et al., 2019)				✔				✔	✔	10.3390/s19051064
3	(Jarach, 2002)		✓	✓			✓				10.1016/S0969-6997(01)00039-4
4	(Richter et al., 2020)	✓	✓								10.1016/j.techfore.2020.119970
5	(Wästlund et al., 2018)	✓								✔	10.3390/rs10091422
6	(Guillaume et al., 1997)						✔		✔	✔	10.1016/S0021-9290(96)00153-4

No.	Reference	Technological Development				Ecosystem Evolution					DOI
		3D Technology	Systems	Industry Evolution	Machine Learning Technologies	Sustainability	Transport	Survey	Experiment	Other*	
7	(Zhao et al., 2016)								✔	✔	10.1016/j.nima.2016.03.106
8	(Ehrlich & Wendisch, 2015)		✓	✔	✔					✔	10.5194/amt-8-3671-2015
9	(Kovynyov & Mikut, 2019)			✔	✔	✔	✔	✔	✔		10.1007/s11066-019-09132-5
10	(Winther et al., 2006)						✔	✔	✔	✔	10.1016/j.scitotenv.2005.08.015
11	(Pacios Álvarez et al., 2021)		✓		✔	✔	✔				10.1016/j.jairtraman.2020.101941
12	(Wolf et al., 2014)		✓	✔		✔	✔		✔	✔	10.2514/1.I010156
13	(Paprocki, 2021)		✓	✔	✔	✔	✔			✔	10.3390/su13095076
14	(Dudzevičiūtė et al., 2017)		✓	✔		✔	✔				10.14807/ijmp.v8i4.659
15	(Katsoni & Poulaki, 2021)				✔	✔				✔	10.1108/JHTT-12-2019-0145
16	(Daft et al., 2021)		✓	✔			✔	✔	✔	✔	10.1057/s41272-021-00345-8
17	(Schmalz et al., 2021)			✔	✔		✔	✔		✔	10.1016/j.jairtraman.2021.102040
18	(Yilmaz et al., 2023)	✓	✓	✔	✔	✔				✔	10.1016/j.compind.2023.103861
19	(Heiets et al., 2022)			✔	✔			✔			10.1016/j.retrec.2022.101186
20	(Diefenbach et al., 2023)		✓	✔	✔		✔		✔	✔	10.1080/13675567.2021.1958305

No.	Reference	Technological Development				Ecosystem Evolution					DOI
		3D Technology	Systems	Industry Evolution	Machine Learning Technologies	Sustainability	Transport	Survey	Experiment	Other*	
21	(Menon et al., 2021)		✓	✔	✔	✔	✔	✔			10.1080/23311886.2021.1903149
22	(Kholod et al., 2021)		✓		✔						10.25115/eea.v39i6.5015
23	(Liao et al., 2023)		✓	✔	✔	✔	✔	✔			10.3390/systems11020088
24	(Heinrich et al., 2019)	✓	✓	✔	✔		✔		✔	✔	10.1109/TSM.2019.2945352
25	(Niemi & Komp-Leukkunen, 2021)		✓				✔				10.1108/IJSSP-06-2021-0153
26	(Sani et al., 2022)							✔		✔	10.1108/MD-11-2021-1528
27	(Huang et al., 2023)	✓	✓							✔	10.1016/j.compind.2023.104019
28	(Delke et al., 2023)		✓	✔		✔		✔			10.1016/j.techfore.2023.122847
29	(Seidel et al., 2023)	✓	✓							✔	10.1016/j.techfore.2023.122847
30	(La & Heiets, 2021)		✓	✔			✔				10.3846/aviation.2021.15336
31	(Colak et al., 2023)		✓	✔		✔	✔				10.1016/j.jairtraman.2022.102337
32	(Rodoplu et al., 2022)		✓	✔		✔	✔			✔	10.1504/IJSA.2023.127488
33	(Martin et al., 2023)		✓	✔		✔	✔		✔		10.3390/aerospace10100847

No.	Reference	Technological Development				Ecosystem Evolution					DOI
		3D Technology	Systems	Industry Evolution	Machine Learning Technologies	Sustainability	Transport	Survey	Experiment	Other*	
34	(Kabashkin & Perekrestov, 2023)		✓	✔		✔				✔	10.2478/ttj-2023-0037
35	(Elmquist et al., 2023)	✓								✔	10.17059/ekon.reg.2022-3-13
36	(Moruzzi et al., 2023)	✓	✓						✔		10.1007/s12193-023-00404-x
37	(Korba et al., 2023)		✓	✔			✔		✔		10.1007/s12008-023-01288-7
38	(Wang et al., 2023)		✓		✔					✔	10.3390/app13063824
39	(Motaung & Sifolo, 2023)	✓	✓	✔		✔					10.3390/aerospace10090789
40	(Mirosavljević et al., 2018)			✔						✔	10.3390/su15054610
41	(Finster et al., 2023)		✓				✔			✔	10.1108/AEAT-05-2016-0070
42	(Martinsen et al., 2023)		✓	✔	✔		✔				10.1515/auto-2023-0074
43	(Matushkina et al., 2022)		✓				✔				10.1016/j.apenergy.2023.120988

*Photon Lidar System; Radio-Based Real-Time locating systems; Medicine; Time-Of-Flight; Emission Measurement; Video Feeds of Drones; Greenhouse Gas Emissions; Revenue Management; Railway Transport; Building Information Management; Manual Materials Handling; Mobile Robotic Systems; Digital Ecosystem; The effect of digitalization

Source: Authors' own research.