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The Development of Air Transport Between Growth and Sustainability

Abstract

Air transport constitutes a key component of the modern global transportation system due to its speed, accessibility, and capacity to connect geographically distant regions. However, the continuous growth in demand for air travel places increasing pressure on the environment, infrastructure, and regulatory frameworks, making the sustainable development of the sector one of its most critical future challenges. The aim of this paper is to examine the development of air transport in the context of the opposing demands of growth and sustainability, with particular emphasis on environmental challenges, infrastructural constraints, and technological adaptation options. The study is based on an analysis of recent scientific and professional literature, including international reports, regulatory documents, and relevant academic studies in the field of air transport.

The paper explores the role of air transport within the global transportation system, identifies the key challenges shaping its development, and analyzes technological and organizational responses, such as digitalization, the application of artificial intelligence, and sustainable practices in airport management. Special attention is devoted to market differentiation, airline reputation, and the influence of sustainable practices on passengers.

In conclusion, the paper argues that the long-term development of air transport requires an integrated approach that aligns technological innovation, regulatory measures, and market demands in order to ensure the sustainability, competitiveness, and resilience of the sector in the future.

Keywords: air transport, sustainable development, digitalization, artificial intelligence, market differentiation

1. Introduction

Air transport today constitutes one of the key components of global mobility, enabling rapid connections between geographically distant regions, facilitating international trade, tourism, and business flows, and playing a vital role in emergency situations such as medical and humanitarian transport. At the same time, the continuous growth in demand for air travel places mounting pressure on the environment and infrastructure. Greenhouse gas emissions and other pollutants continue to increase, congestion at airports and along air routes intensifies, and rising operational costs and regulatory requirements further challenge the financial sustainability of the sector. [7], [8], [10], [12], [13]

In the context of climate objectives, air transport is increasingly oriented toward emission reduction through a combination of regulatory frameworks, including international initiatives and decarbonization policies, technological innovations such as sustainable aviation fuels and alternative propulsion technologies, and organizational and operational measures. These measures include route optimization, improvements in air traffic management, and more efficient ground operations.

A key challenge lies in the differing implementation timelines of these measures. Certain actions, particularly operational improvements, can be introduced relatively quickly, whereas others, such as the transformation of propulsion systems and supporting infrastructure, are long-term and capital-intensive. Consequently, an integrated approach is required, one that simultaneously addresses environmental, infrastructural, and governance dimensions of air transport development. [9], [10], [12], [13], [14]

The objective of this paper is to analyze air transport from the perspective of its systemic importance within the global transportation system and the principal challenges shaping its development, with a particular focus on environmental pressures and regulatory requirements, capacity constraints at airports and within air traffic management systems, and the impact of global disruptions on sectoral stability. This leads to the central research question: how can the growth of air transport be aligned with sustainability objectives without compromising operational efficiency and system safety?

The paper is based on a review of recent professional and scientific literature in the fields of air transport and sustainable development. The literature increasingly conceptualizes the sustainable development of air transport as a combination of technological, operational, and infrastructural solutions. Special attention is devoted to sustainable aviation fuels, widely recognized as one of the key instruments for decarbonizing the sector due to their potential to reduce greenhouse gas emissions across the fuel life cycle. Although several certified and promising production pathways have been identified, their widespread adoption remains constrained by high production costs, limited feedstock availability, and regulatory and certification requirements. [1]

Beyond technological innovation, operational improvements that can be implemented relatively quickly within existing systems can also significantly reduce the climate impact of air transport. Such measures include optimized flight procedures, improved ground operations management, and more efficient use of existing capacity. Research indicates emission reductions do not depend solely on new propulsion technologies but can also be achieved through enhanced operational practices. [2]

Air traffic management is further examined in light of emission reduction policies, including carbon pricing mechanisms and the integration of sustainable fuels. These measures may influence traffic flows, delays, and overall system performance, underscoring the need for balanced solutions that simultaneously reduce emissions while preserving operational efficiency. [3]

Finally, the sustainable development of air transport must account for the role of airports as critical infrastructural nodes within the system. Particular emphasis is placed on airport sustainability and resilience, including their capacity to accommodate traffic growth, respond to crisis situations, and comply with increasingly stringent environmental requirements. In this context, emerging technologies and management approaches play an important role in the long-term development and stability of airports. [4]

Based on the reviewed literature and the defined thematic framework, the following section first examines the position and role of air transport within the global transportation system, followed by a systematic analysis of the key challenges shaping its prospects for sustainable development.

2. Air transport as a key element of the global transportation system

Air transport plays an important role in the modern transportation system, as it enables fast and efficient mobility of people and goods on a global scale. Its development is closely linked to economic growth, international trade, and globalization processes, making it one of the key factors supporting the functioning of contemporary society. In order to better understand its role and significance, the following sections examine the core functions of air transport as well as its development and current trends.

2.1. Role and importance of air transport

Air transport occupies a distinctive position within the global transportation system due to its capacity to connect distant regions of the world within extremely short timeframes. Speed constitutes its primary comparative advantage over other modes of transport, particularly in passenger travel and the movement of high-value or time-sensitive goods. Whereas maritime and rail transport remain indispensable for bulk cargo, air transport enables delivery within hours or days, thereby significantly reducing travel times and logistical cycles. [30], [31], [33], [34]

In addition to speed, global connectivity represents one of the most important functions of air transport. Air route networks connect major economic centers as well as geographically isolated or less accessible regions. In this way, air transport contributes to territorial cohesion, supports more balanced regional development, and facilitates access to international markets. Its role is particularly significant for island states and regions where alternative modes of transport cannot provide comparable levels of accessibility and service frequency. [30], [31], [33], [34]

The economic importance of air transport is reflected in its direct and indirect contribution to economic development. Air transport stimulates international trade, tourism, and business mobility, while generating employment within airlines, airports, and associated industries. Beyond its direct effects, air transport has a strong multiplier impact on other sectors of the economy, such as hospitality, logistics, and manufacturing. Consequently, the stability and efficiency of air transport constitute essential prerequisites for the functioning of the modern global economy. [30], [33], [34]

2.2. Development of air transport and contemporary trends

The historical development of air transport has been characterized by continuous growth in demand, driven by globalization, economic development, and increased population mobility. Over time, air transport has evolved from a specialized and relatively expensive mode of transport into a mass transportation system that now plays a central role in international connectivity and global mobility. A particularly significant transformation was enabled by the emergence of low-cost carriers, which expanded access to air travel and further stimulated passenger growth. [33], [34]

However, while the expansion of mass air transport has contributed to the democratization of travel, it has simultaneously raised concerns regarding sustainability and the long-term capacity of the system to respond to growing demand. A major challenge concerns the environmental impact of air transport, manifested in increased noise levels around airports, emissions of greenhouse gases and local air pollutants in airport areas, as well as nitrogen oxide emissions at higher altitudes that may adversely affect climatic processes and the ozone layer. [33], [34], [7], [8]

Alongside traffic growth, digitalization has emerged as one of the key drivers of contemporary air transport development. Digital technologies are applied across nearly all segments of the system, from ticket sales and passenger flow management to flight planning and air traffic management. The implementation of advanced information systems enables operational optimization, delay reduction, and more efficient use of existing capacity. Moreover, digitalization contributes to environmental performance by facilitating more precise route planning, reducing unnecessary fuel consumption, and improving coordination among system stakeholders. [7], [8], [10], [29]

As a result, the development of air transport currently unfolds under conditions of simultaneous demand growth and the need for systemic transformation. This

combination makes air transport one of the most dynamic yet most challenging segments of the global transportation system, while also creating a strong foundation for analyzing the principal challenges shaping its sustainable development.

3. Key challenges in the development of air transport

The development of air transport under contemporary conditions is shaped by a series of interrelated challenges that significantly affect its sustainability and long-term stability. While demand for air transport continues to grow, the sector simultaneously faces constraints arising from environmental requirements, infrastructural capacity limitations, and increased vulnerability to global disruptions. These challenges do not operate in isolation; rather, they interact and reinforce one another, creating a complex environment in which a careful balance between growth, efficiency, and sustainability is required. [7], [8], [10]

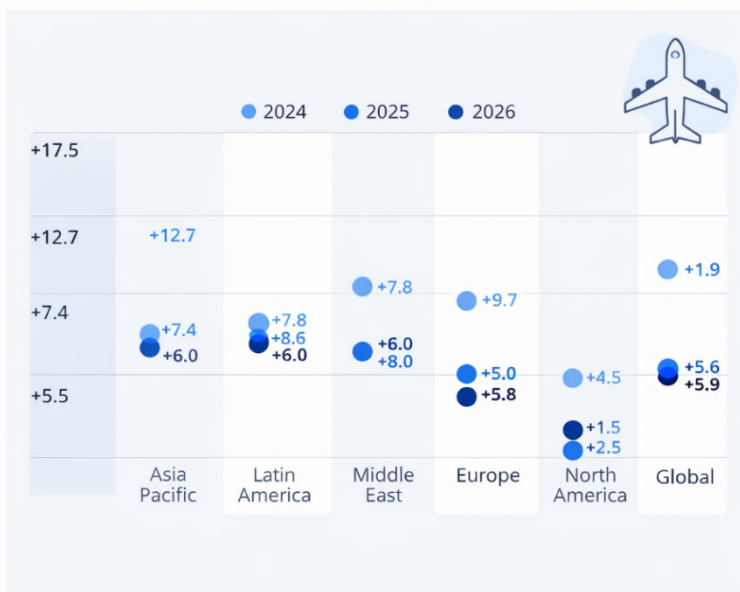


Figure 1. Projected growth in air passenger traffic by world region
Source: International Air Transport Association (IATA), World Air Transport Statistics; graphical processing: Statista.

<https://www.statista.com/statistics/1385780/global-air-passenger-traffic-growth-by-region/>

The presented passenger growth trends indicate a continuation of strong expansion in air transport across all world regions, albeit with pronounced regional differences.

Such dynamics further emphasize the need for a systematic approach to addressing environmental and regulatory challenges, which become increasingly significant as traffic volumes grow. In this context, the sustainable development of air transport emerges as a key prerequisite for its long-term viability. [7], [8], [10], [13]

3.1. Environmental challenges and regulatory pressures

Among the most pressing challenges is the environmental impact of aviation. Air transport constitutes a significant source of carbon dioxide (CO₂) emissions, as well as other pollutants such as nitrogen oxides (NO_x) and particulate matter, which exert additional climate effects, particularly due to emissions at higher altitudes. Although the share of air transport in total global greenhouse gas emissions is lower compared to some other sectors, its rapid growth places it among the key focal points of climate policy. [10], [11], [14]

Pressure to reduce emissions has been further intensified by international climate commitments, most notably the objectives of the Paris Agreement and initiatives aimed at achieving carbon neutrality in international aviation. In this context, regulatory mechanisms such as the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) have introduced new requirements for airlines. While such mechanisms encourage more responsible emission management, they also increase operational costs and require adjustments to existing business models. [5], [6], [7], [8], [9], [13]

Environmental challenges therefore extend beyond purely technical issues related to emission reduction and encompass the need to comply with rapidly evolving regulatory frameworks. Air transport must simultaneously respond to growing demand and increasingly stringent environmental standards, which necessitates a systematic and long-term approach to sustainable development. [5], [9], [12], [13]

3.2. Infrastructural constraints and capacity management

The growth of air transport is directly reflected in increasing pressure on infrastructure, particularly airports and air traffic management systems. Many airports, especially those located in major urban areas, are already operating close to their maximum capacity. Overcrowding leads to delays, reduced service quality, and higher operational costs, while also contributing to additional emissions caused by inefficient aircraft movement both on the ground and in the air. [7], [8]

The expansion of infrastructural capacity is often constrained by spatial, environmental, and social factors. The construction of new runways or terminal facilities requires substantial financial investment and lengthy administrative procedures and frequently encounters resistance from local communities due to concerns related to noise and environmental impacts. As a result, increasing emphasis is being placed

on the more efficient management of existing capacity rather than solely relying on physical infrastructure expansion. [10]

Air traffic management (ATM) plays a crucial role in optimizing aircraft flows and reducing congestion. The modernization of ATM systems, including the application of digital technologies and advanced flight-planning algorithms, enables better utilization of airspace and reductions in delays. However, the implementation of such systems requires a high level of coordination among states, airports, and airlines, which represents an additional organizational and institutional challenge. [6], [24]

3.3. The impact of global disruptions on sector stability

In addition to long-term structural challenges, air transport is highly sensitive to global disruptions such as pandemics, economic crises, and geopolitical tensions. The COVID-19 pandemic exposed the sector's vulnerability, resulting in a sharp decline in passenger numbers, border closures, and substantial financial losses for airlines and airports. Traffic recovery was uneven, with domestic and regional travel rebounding more quickly than international operations.

Global disruptions have further highlighted the need to enhance the resilience of air transport systems. This includes the ability to rapidly adapt to changes in demand, the flexibility of business models, and the strengthening of crisis management and contingency planning. At the same time, such disruptions often delay investments in new technologies and infrastructure, thereby complicating the implementation of long-term sustainability objectives.

The stability of air transport thus depends not only on technical and operational efficiency, but also on the system's capacity to respond to unpredictable external shocks. In this context, environmental sustainability challenges, infrastructural constraints, and global disruptions form an interconnected set of issues that require an integrated approach in planning the future development of the sector. [7], [10], [13]

4. Technological and organizational responses to the challenges of air transport

Given the complex challenges facing air transport, the sustainable development of the sector requires the application of a combination of technological innovations and organizational adjustments. The objective of such an approach is not limited to reducing environmental impacts, but also includes improving operational efficiency, system resilience, and long-term competitiveness. In this context, digitalization, operational optimization, and the introduction of advanced technologies represent key tools for adapting air transport to contemporary demands.

4.1. Digitalization and operational optimization

Digitalization in air transport enables significant improvements in the planning, management, and monitoring of operations across all levels of the system. The application of advanced information systems in flight planning, traffic management, and coordination among airlines, airports, and air navigation service providers contributes to more efficient use of available capacity. As a result, delays are reduced, unnecessary aircraft holding in the air and on the ground is minimized, and overall fuel consumption decreases. [7], [8], [29]

The optimization of flight routes and procedures, facilitated by digital tools, has a direct positive impact on environmental performance, as it reduces greenhouse gas emissions without requiring major infrastructural interventions. In addition, digital solutions improve the accuracy and timeliness of information, thereby supporting real-time decision-making and enhancing overall traffic safety. Digitalization thus emerges as one of the most rapidly deployable solutions in the transition toward more sustainable air transport. [7], [8], [29]

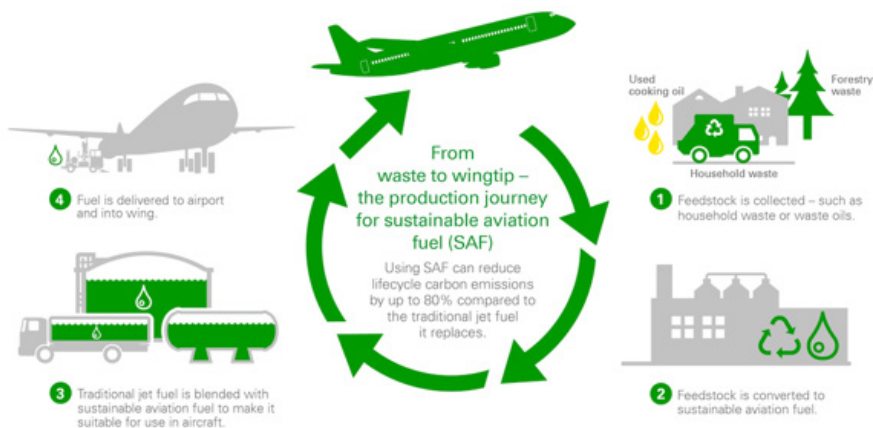


Figure 2. Sustainable aviation fuel (SAF) production pathways

Source: International Air Transport Association (IATA), Sustainable Aviation Fuel – production pathway;

Based on the presented production process, sustainable aviation fuels demonstrate significant potential for reducing the environmental impact of air transport. However, their broader implementation in practice depends on a range of technological, economic, and regulatory factors, which largely determine the pace and scale of their adoption.

4.2. Sustainable airport management practices and the application of artificial intelligence

Airports represent key nodes within the air transport system, and their role in achieving sustainability has become increasingly prominent. Sustainable airport management practices encompass a wide range of measures, from energy efficiency improvements and emission reductions on the ground to the optimization of passenger and operational flows. The introduction of automated systems for passenger and baggage handling, as well as smart infrastructure management systems, enables congestion reduction, shorter processing times, and more efficient use of existing capacity. [23], [24], [4], [6]

A major advancement in this context is the application of artificial intelligence (AI), which is increasingly being adopted in air transport planning and management. AI-based algorithms enable advanced flight planning through the analysis of large volumes of data related to weather conditions, traffic flows, and available capacity. This approach allows for more accurate determination of optimal routes and departure and arrival times, thereby reducing delays and unnecessary fuel consumption. [27], [29], [7], [8]

Beyond flight planning, artificial intelligence plays an important role in predictive maintenance of aircraft and infrastructure. By analyzing data collected through sensors and operational systems, potential failures can be identified before they occur. This enhances safety, reduces the number of unplanned disruptions, and extends the service life of equipment and infrastructure. Predictive maintenance also supports more efficient resource allocation and reduces the need for costly emergency interventions. [28], [27]

The application of AI technologies also has a direct impact on reducing the operational costs of airports and airlines. Process automation, improved planning accuracy, and fewer delays result in lower fuel consumption, reduced maintenance costs, and more efficient use of labor resources. As a result, artificial intelligence contributes not only to environmental objectives but also to the financial sustainability of the sector. [27], [28], [29]

The integration of sustainable practices, digitalization, and artificial intelligence into airport and air traffic management represents a crucial step toward creating a more efficient and resilient system. Such an approach enables air transport to respond to growing demand and increasingly stringent environmental requirements, while maintaining high levels of safety and competitiveness. [24], [4], [27], [29]

5. The future of air transport and strategic development implications

In order to assess the future development of air transport, it is necessary to integrate the previously analyzed challenges and technological responses into a broader strategic context. The sector's development in the coming period will be shaped by the simultaneous growth in demand, the strengthening of regulatory requirements, and the

need to adapt to new market and technological conditions. Within this framework, it is important to consider the competitive position of air transport, its relationship with service users, and the possibilities for long-term sustainable growth. [7], [8], [10], [13]

This chapter first presents a SWOT analysis of air transport as a tool for systematically assessing internal and external factors influencing sector development. It then examines issues of market differentiation and passenger impacts, with particular emphasis on changes in user expectations and competitive strategies adopted by airlines. Finally, potential directions for the future development of air transport and the strategic implications arising from identified trends are discussed.

5.1. SWOT analysis of air transport

In this context, SWOT analysis provides a structured overview of the internal strengths and weaknesses of the air transport sector, as well as the external opportunities and threats shaping its future development. Key strengths of air transport include a high level of global connectivity, transport speed, and its strong role in international trade and tourism. These advantages enable air transport to maintain a central position within the global transportation system.

At the same time, the sector faces several weaknesses, most notably high operational costs, sensitivity to external disruptions, and a significant environmental footprint. External opportunities for further development include technological progress, the adoption of sustainable aviation fuels, digitalization, and growing demand in emerging markets. Conversely, threats arise from increasingly stringent regulatory requirements related to emissions, volatility in fuel prices, infrastructural constraints, and intensified competition from other modes of transport on shorter routes.

Table 1. SWOT analysis of air transport

<p>Strengths:</p> <ul style="list-style-type: none"> • High transport speed and global connectivity • Developed network of airports and airlines • High levels of safety and reliability • Key role in international trade and tourism 	<p>Weaknesses:</p> <ul style="list-style-type: none"> • High energy intensity and greenhouse gas emissions • Dependence on fossil fuels • High operational and investment costs • Sensitivity to global disruptions
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<p>Opportunities:</p> <ul style="list-style-type: none"> • Development of sustainable aviation fuels and new propulsion technologies • Digitalization and application of artificial intelligence • Operational optimization and smart airports • Growing passenger awareness of sustainability 	<p>Threats:</p> <ul style="list-style-type: none"> • Stricter emission-related regulatory requirements • Geopolitical instability and global crises • Competition from other transport modes on short-haul routes • Risk of slow adoption of new technologies
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Based on the conducted SWOT analysis, it can be concluded that air transport possesses significant internal strengths, particularly in terms of speed, global connectivity, and its essential role in international mobility of people and goods. These characteristics make air transport an indispensable component of the modern transportation system and provide a solid foundation for its further development. At the same time, identified weaknesses, such as high operational costs, energy dependence, and environmental impacts, indicate the need for systematic adjustments to business and operational models.

The analysis of the external environment reveals numerous opportunities that may contribute to the long-term sustainability of air transport, particularly through technological progress, digitalization, the adoption of sustainable aviation fuels, and strengthened regulatory and financial incentives for emission reduction. On the other hand, threats related to stricter environmental requirements, energy price volatility, infrastructural limitations, and uncertainty caused by global disruptions highlight the need for careful strategic planning.

In this context, the results of the SWOT analysis suggest that the future development of air transport should focus on maximizing identified strengths and opportunities, while simultaneously mitigating weaknesses and threats through innovation, regulatory adaptation, and improved governance practices. Such a balanced approach creates the conditions for sustainable and competitive long-term development of air transport.

5.2. Market differentiation and passenger impacts

Under conditions of intensifying competition and increasingly stringent regulatory requirements, air transport faces the need to redefine market strategies. Market differentiation has become a key instrument through which airlines and airports seek to distinguish themselves, with sustainability, technological advancement, and service quality gaining growing importance. In this context, sustainable development is no longer viewed solely as a cost or regulatory obligation, but also as a potential source of competitive advantage.

Airlines that invest in emission reduction, operational optimization, and digital technologies can improve their market position and strengthen brand recognition.

Sustainability is increasingly used as an element of differentiation, particularly in markets where passengers are sensitive to environmental issues and corporate social responsibility. Such an approach allows carriers to compete not only in price, but also on the values they offer to customers.

An important aspect of market differentiation also relates to the reputation of airlines and airports. In an environment characterized by increased transparency and information availability, public perception of environmental responsibility and reliability has a growing impact on business performance. Negative events or failure to comply with sustainability practices may have long-term reputational consequences, while consistent implementation of sustainable solutions can strengthen passenger trust and regulatory credibility.

Changes in business strategies and technological solutions are directly reflected in passenger experience. The digitalization of processes, such as automated passenger handling, more accurate flight planning, and reduced delays, contributes to higher reliability and service quality. Passengers increasingly value punctuality, simplicity, and transparency, as well as the environmental aspects of travel, which further influences their choice of airline.

The impact of sustainable practices on passengers is also evident through changes in travel behavior. Growing awareness of climate change encourages some passengers to consider alternative modes of transport or to prefer airlines that actively invest in reducing their environmental footprint. Although price remains a key decision factor, sustainability is gradually becoming an additional criterion that may be decisive when competing offers are otherwise similar.

Market differentiation in air transport is therefore increasingly based not only on operational efficiency and price competition, but also on the ability to integrate sustainability, technology, and service quality. Such an approach enables airlines and airports to respond to evolving market and passenger expectations, while simultaneously strengthening the long-term competitiveness of the sector. [33], [34], [13]

5.3. Future development of air transport under conditions of sustainability and technological change

The future development of air transport will take place under conditions of continued demand growth and the need to reduce environmental impacts. Passenger numbers are expected to increase in the coming decades, particularly on international and intercontinental routes, which further underscores the importance of aligning sector expansion with sustainable development objectives. In this context, sustainability becomes a key prerequisite for the long-term competitiveness and stability of air transport.

Technological innovation will play a decisive role in shaping the future air transport system. The development and wider adoption of sustainable aviation fuels,

new propulsion technologies, and advanced digital solutions will enable gradual emission reductions and improvements in operational efficiency.

Although a complete transformation of propulsion systems cannot be expected in the short term, a combination of existing and emerging technologies represents a realistic pathway toward the gradual decarbonization of the sector.

In addition to technological progress, institutional and regulatory frameworks will represent an important factor in future development. International organizations and national authorities will continue to design policies aimed at reducing emissions and promoting sustainable practices, requiring continuous adaptation of airline and airport business models. The effectiveness of these policies will largely depend on the level of international cooperation and regulatory alignment, given the global nature of air transport.

System resilience will also play a central role in future development. Experiences from global crises have demonstrated the need for more flexible and adaptive systems capable of responding quickly to changes in demand and operational conditions. Investments in digitalization, automation, and smart infrastructure will contribute to strengthening the resilience of air transport and reducing the risk of long-term disruptions.

The future of air transport will therefore be defined by a balance between growth, sustainability, and technological advancement. The sector's ability to integrate innovation, regulatory requirements, and market expectations will be crucial for its successful long-term operation. Such an integrated approach will ensure that air transport continues to play a vital role in the global transportation system, while reducing its negative impacts on the environment and society.

6. Conclusion

Air transport plays an indispensable role in the modern global transportation system by enabling the rapid movement of people and goods and by significantly contributing to economic development and international connectivity. However, its future development is confronted with a range of challenges arising from growing demand, increasingly stringent environmental requirements, infrastructural constraints, and heightened vulnerability to global disruptions. These factors underscore the need for a fundamental transformation of the sector, in which sustainability becomes a central element of long-term stability and competitiveness.

The analysis demonstrated that environmental pressures and regulatory requirements cannot be considered independently of operational efficiency and capacity management. Constraints related to airport infrastructure and air traffic management systems further emphasize the need to optimize existing resources rather than relying exclusively on physical capacity expansion. At the same time, experiences from global disruptions, such as the COVID-19 pandemic, have exposed the vulnerability of the

sector and emphasized the necessity of strengthening its resilience to unpredictable external shocks.

Technological and organizational responses, particularly digitalization, the application of artificial intelligence, and the implementation of sustainable airport management practices, represent realistic and effective pathways for reducing the environmental impact of air transport. The optimization of flight planning, predictive maintenance, and cost-efficiency measures contribute not only to environmental objectives but also to enhanced safety, reliability, and financial sustainability. This confirms that sustainability and operational efficiency should not be viewed as competing goals, but as mutually reinforcing elements of sector development.

From a strategic perspective, the sustainable development of air transport creates new opportunities for market differentiation and for strengthening the reputation of airlines and airports. Growing passenger awareness and public expectations further encourage the integration of sustainability into business models and operational strategies. The future of air transport will therefore largely depend on the sector's capacity to align technological innovation, regulatory frameworks, and market demands, while maintaining high levels of safety and accessibility.

In conclusion, the sustainable development of air transport requires an integrated approach that connects environmental, infrastructural, technological, and socio-economic dimensions. Only through such a comprehensive framework can air transport continue to function as a reliable, competitive, and socially responsible pillar of global mobility in the long term.

References:

1. Klimczyk, W., Jasiński, R., Niklas, J., Siedlecki, M., & Ziółkowski, A. (2025). Sustainable Aviation Fuels: A Comprehensive Review of Production Pathways, Environmental Impacts, Lifecycle Assessment, and Certification Frameworks. *Energies*, 18(14), 3705. <https://doi.org/10.3390/en18143705>
2. Zengerling, Z. L., Dal Gesso, S., Linke, F., Clococeanu, M., Gollnick, V., Peter, P., Matthes, S., Baspinar, B., Ozkol, I., Noorafza, M., Roling, P., Branchini, E., Grampella, M., Abate, C., & Tedeschi, A. (2023). Operational Improvements to Reduce the Climate Impact of Aviation—A Comparative Study from EU Project ClimOP. *Applied Sciences*, 13(16), 9083. <https://doi.org/10.3390/app13169083>
3. Hamdan, S., Jouini, O., Cheaitou, A., Jemai, Z., Granberg, T. A., & Josefsson, B. (2022). *Air traffic flow management under emission policies: Analyzing the impact of sustainable aviation fuel and different carbon prices. Transportation Research Part A: Policy and Practice*, Volume 166. <https://doi.org/10.1016/j.tra.2022.09.013>.
4. Ammourey, S., & Salman, A. (2024). Advancing Sustainability and Resilience of Airports through Deployment of New Technologies in the Aftermath of the COVID-19 Pandemic. *Multidisciplinary Journal of Civil Engineering* 2(1). <https://doi.org/10.1061/AOMJAH.AOENG-0027>
5. International Civil Aviation Organization (ICAO). (2022). *Environmental Report 2022*. <https://www.icao.int/CORSIA> [Accessed 19 February 2026]
6. International Civil Aviation Organization (ICAO). (2025). *CORSIA Annual Sector's Growth Factor (SGF), 4th edition (2024)*. <https://www.icao.int/sites/default/files/environmental-protection/CORSIA/Documents/CORSIA%20Central%20Registry/CORSIA-Annual-SGF-4ed-2025-web.pdf> [Accessed 19 February 2026]

7. International Civil Aviation Organization (ICAO). *Standards and Recommended Practices (SARPs) – Annex 16, Volume IV (CORSLA)*. <https://www.icao.int/CORSIA/sarps-annex-16-volume-iv> [Accessed 19 February 2026]
8. International Air Transport Association (IATA). (2024). *CORSIA Handbook*. <https://www.iata.org/contentassets/fb745460050c48089597a3ef1b9fe7a8/corsia-handbook.pdf> [Accessed 19 February 2026]
9. European Union. (2023). *Regulation (EU) 2023/2405 on ensuring a level playing field for sustainable air transport (ReFuelEU Aviation)*. *Official Journal of the European Union*. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ%3AL_202302405 [Accessed 19 February 2026]
10. European Union Aviation Safety Agency (EASA), European Environment Agency (EEA), & EUROCONTROL. (2025). *European Aviation Environmental Report 2025*. <https://www.eurocontrol.int/sites/default/files/2025-01/eurocontrol-easa-eaer-2025.pdf> [Accessed 19 February 2026]
11. EUROCONTROL. (2022). *Aviation Outlook 2050: Main Report*. <https://www.eurocontrol.int/sites/default/files/2022-04/eurocontrol-aviation-outlook-2050-main-report.pdf> [Accessed 19 February 2026]
12. EUROCONTROL. (2024). *Aviation long-term outlook: Flights and CO₂ emissions forecast 2024–2050*. <https://www.eurocontrol.int/publication/eurocontrol-forecast-2024-2050> [Accessed 19 February 2026]
13. International Civil Aviation Organization (ICAO). (2022). *ICAO Environmental Report 2022*. <https://www.icao.int/icao-environmental-report-2022> [Accessed 19 February 2026]
14. Intergovernmental Panel on Climate Change (IPCC). (2021). *Sixth Assessment Report (AR6), Working Group I: Chapter 7*. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter_07.pdf [Accessed 19 February 2026]
15. Intergovernmental Panel on Climate Change (IPCC). (2021). *AR6 Working Group I: Figure 7.6 – Effective radiative forcing including contrails and aviation-induced cirrus*. <https://www.ipcc.ch/report/ar6/wg1/figures/chapter-7/figure-7-6/> [Accessed 19 February 2026]
16. Air Transport Action Group (ATAG). (2021). *Waypoint 2050* (2nd ed.). https://aviationbenefits.org/media/167417/w2050_v2021_27sept_full.pdf [Accessed 19 February 2026]
17. International Air Transport Association (IATA). (2021). *Fly Net Zero by 2050*. <https://www.iata.org/contentassets/b3783d24c5834634af59148c718472bb/net-zero-tracking-progress-methodology.pdf> [Accessed 19 February 2026]
18. ASTM International. *ASTM D7566 – Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons*. <https://www.astm.org/d7566-24d.html> [Accessed 19 February 2026]
19. ASTM International. *ASTM D1655 – Standard Specification for Aviation Turbine Fuels*. <https://www.astm.org/d1655-22a.html> [Accessed 19 February 2026]
20. P. Kurzawska-Pietrowicz and R. Jasiński, “A Review of Alternative Aviation Fuels,” *Energies*, vol. 17, no. 16, p. 3890, 2024. <https://www.mdpi.com/1996-1073/17/16/3890>
21. Wandelt, S., Zhang, Y., Sun, X. (2025). *Sustainable aviation fuels: A meta-review of surveys and key challenges*. *Journal of the Air Transport Research Society* 4. <https://doi.org/10.1016/j.jatrs.2024.100056>
22. Uddin, M. N., & Wang, F. (2025). Sustainable Aviation Fuels: A Review of Current Techno Economic Viability and Life Cycle Impacts. *Energies*, 18(20), 5510. <https://doi.org/10.3390/en18205510>
23. Sreenath, S., Sudhakar, K., Yusop, A.F. (2021). *Sustainability at airports: Technologies and best practices from ASEAN countries*. *Journal of Environmental Management*, Volume 299. <https://doi.org/10.1016/j.jenvman.2021.113639>.
24. Raimundo, R. J., Baltazar, M. E., & Cruz, S. P. (2023). Sustainability in the Airports Ecosystem: A Literature Review. *Sustainability*, 15(16), 12325. <https://doi.org/10.3390/su151612325>
25. Poo, M., Yang, Z., Dimitriu, D., Qu, Z. (2021). *An advanced climate resilience indicator framework for airports: A UK case study*. *Transportation Research Part D: Transport and Environment*, Volume 101. <https://doi.org/10.1016/j.trd.2021.103099>.
26. Wandelt, S., Zhang, A., Sun, X. (2025). *Global Airport Resilience Index: Towards a comprehensive understanding of air transportation resilience*. *Transportation Research Part D: Transport and Environment*, Volume 138. <https://doi.org/10.1016/j.trd.2024.104522>.

27. Geske, A. M., Herold, M. D., Kummer, S. (2024). Artificial intelligence as a driver of efficiency in air passenger transport: A systematic literature review and future research avenues. *Journal of the Air Transport Research Society*, Volume 3. DOI: <https://doi.org/10.1016/j.jatrs.2024.100030>.
28. Xue, F., Jin, G., Tan, L. et al. (2025). Predictive maintenance programs for aircraft engines based on remaining useful life prediction. *Sci Rep* **15**, 41756. <https://doi.org/10.1038/s41598-025-19957-w>
29. SESAR Joint Undertaking. (2024). *Sustainable flights start with efficient ground movements*. URL: <https://www.sesarju.eu/news/sustainable-flights-start-efficient-ground-movements> [Accessed 19 February 2026]
30. Belobaba, P., Odoni, A., & Barnhart, C. (2015). *The global airline industry* (2nd ed.). Wiley. ISBN: 978-0-470-74077-4
31. Wensveen, J. (2023). *Air transportation: A global management perspective* (9th ed.). Routledge. <https://doi.org/10.4324/9780429346156>
32. Kazda, A., & Caves, R. E. (2015). *Airport design and operation* (3rd ed.). Emerald. <https://doi.org/10.1108/9781784418694>
33. Doganis, R. (2005). *Airline business in the 21st century (1st ed.)*. Routledge. <https://doi.org/10.4324/9780203991916>
34. Doganis, R. (2002). *Flying off course: The economics of international airlines* (3rd ed.). Routledge. URL: http://ndl.ethernet.edu.et/bitstream/123456789/7708/1/197%20.%20Rigas_Doganis.pdf [Accessed 19 February 2026]