Corporate sustainability models in airline business

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Abstract

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Facing the challenges of global climate change and environmental degradation, the aviation industry, as one of the important sources of global carbon emissions, urgently needs to explore new paths for sustainable development. This study explores the sustainable development model of the aviation business. The aviation industry faces increasing pressure for sustainable development due to its significant contribution to global greenhouse gas emissions. This study explores how airlines respond to environmental challenges by adopting sustainable strategies through literature review, case analysis, and SWOT and PEST analyses. The study found that despite cost and technical barriers, many airlines have taken proactive steps to reduce their environmental footprint, such as introducing sustainable aviation fuels, optimizing operational efficiency, improving aircraft fuel efficiency, and implementing circular economy practices. These measures not only help airlines reduce carbon emissions, but also enhance their market competitiveness and customer loyalty. Case studies highlight practical successes from companies such as KLM, American Airlines and Etihad Airways. This study concludes that through continued technological innovation and international cooperation, the aviation industry can further strengthen the implementation of sustainable development strategies. Future research could explore a wider range of technical solutions and policy support to promote industry-wide green transformation.

Key words
aviation industry, sustainable development, environmental strategy

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1 Introduction

1.1 Research background

In the process of globalization, aviation, as a key industry connecting the world, has an impact far beyond the transportation field itself. As global concerns about climate change grow, the aviation industry is under tremendous pressure to find a balance between growing market demand and environmental sustainability. This challenge is not only related to economic growth, but also involves multi-dimensional issues such as environmental protection and social responsibility.

The aviation industry is also one of the important sources of global carbon emissions. , aviation emissions have an important impact on the radiative forcing (RF) of the climate. In particular, increased cloud cover caused by carbon dioxide (CO2), nitrogen oxides (NOx), aerosols and their precursors (soot and sulfates), and induced cirrus clouds Climate change has a contribution that cannot be ignored. （David S. Lee et al,2009）

Additionally, there is a two-way relationship between aviation and climate change, with impacts of climate change on aviation including more frequent extreme weather events and changes in temperature extremes that may require longer takeoff distances and reduced climb rates. Additionally, extreme rainfall and rising sea levels could threaten airports in coastal and low-lying areas. （E. Paraschi,2023）

Currently, the aviation industry accounts for approximately 2% to 3% of global carbon emissions, a proportion expected to continue to rise as demand for air travel increases. Against this background, the international community is increasingly requiring airlines to take measures to reduce the negative impact of their operations on the environment. This is not only a regulatory pressure faced by airlines, but also part of the airline's own sustainable development strategy. The key to achieving this goal is to innovate and adopt new business models that optimize resource utilization and reduce environmental impact while ensuring the company's economic benefits.

Faced with this demand, the aviation industry began to explore how to build a new business model for sustainable development through technological innovation, service model improvement and operational efficiency improvement. From using biofuels to promoting e-ticketing to implementing carbon offset schemes, airlines are answering the call for sustainability through a range of innovative practices. These changes not only help airlines improve their environmental performance, but are also key to gaining consumer trust and improving market competitiveness.

Therefore, this study aims to conduct an in-depth analysis of the implementation strategies and effects of sustainable business models in the aviation industry, and explore how these models help airlines improve their environmental and social responsibilities on a global scale.

1.2 Research purpose

This study aims to systematically explore the effectiveness and innovation of sustainable business models in the aviation industry. Facing the dual challenges of global climate change and environmental degradation, the aviation industry, as an important source of global carbon emissions, urgently needs to develop and implement business strategies that can reduce environmental impacts while improving economic benefits. The main objectives of this study include:

Review analysis: Through an extensive literature review, we evaluate the sustainable business models currently adopted in the aviation industry and explore the application status of these models among different airlines around the world.

Case studies: Select a number of domestic and foreign airlines as cases to analyze in detail their successful experiences and challenges in implementing sustainable development strategies.

Strategy evaluation: Use SWOT and PEST analysis methods to compare the sustainable development strategies adopted by different airlines to evaluate the actual effectiveness of each strategy in terms of environmental protection and economic benefits.

Innovation promotion: Explore innovative technologies and business models that the aviation industry may adopt in promoting sustainable development, such as the use of biofuels and the development of electric aircraft technology.

Policy Recommendations: Based on the research findings, specific policy recommendations are proposed to promote the wider adoption and implementation of sustainable business models in the aviation industry.

Through these research activities, this study hopes to provide an empirical basis for the sustainable development of the aviation industry to cope with the challenges brought by environmental changes while achieving dual benefits of the economy and the environment. This study provides strong evidence and profound insights, provides practical guidance and strategic reference for the sustainable development of the aviation industry, and helps the industry and policymakers better understand and promote the green transformation of the aviation industry. This will provide value to

airline management, academia, and contribute to the sustainable development of the global aviation industry.

1.3 Research problem

This article aims to answer the following core research questions, deeply explore the progress and challenges of sustainability in the aviation industry, deeply explore the sustainable development business model of the aviation industry, and evaluate its application effect in actual business:

1. Pattern recognition: Which sustainable business models are currently being adopted by global airlines? What are the main characteristics and operating mechanisms of these models?

2. Implementation impact: How effective are these sustainable business models in reducing environmental impacts (e.g. reducing greenhouse gas emissions) and improving economic performance? What notable success stories or failures exist?

3. Strategy comparison: What are the similarities and differences in the strategies of different airlines to implement sustainable development models? How do these strategies perform in different market and operating environments?

4. Technological innovations and challenges: Which innovative technologies have proven effective in advancing sustainable business models? What are the key challenges and barriers airlines face in adopting these technologies?

5. Policy and regulatory environment: How does the current policy and regulatory framework affect airlines' implementation of sustainable development strategies? What policy improvements are needed to support the green transition of the aviation industry?

This article hopes to reveal the successful experiences and challenges faced by airlines in promoting sustainable business models through systematic research on these issues, provide reference for other companies in the industry, and provide scientific basis for policy formulation. These research questions will guide the entire research. The choice of framework and methodology ensures the practicality and scientificity of research results

1.4 Paper structure introduction

This article is divided into 6 chapters, each chapter is organized as follows:

Introduction: This chapter introduces the research background, research purpose, main research questions of this article, and outlines the research method and overall structure of this article.

Literature review: Chapter 2 reviews relevant literature and discusses the theoretical basis of sustainable development of the aviation industry and previous research results. This chapter will also review the theoretical frameworks and practical cases of various sustainable business models. In this section, relevant theories and previous research will be reviewed, especially on the sustainable development model of the aviation industry. Analyze how different authors and researchers define sustainable development and explore the business models and strategies that have been implemented.

Research Methods and Case Studies: Describe the specific methods used in this study, including literature review, SWOT analysis, PEST analysis, case study selection, data collection and analysis techniques. Describe in detail the steps used to conduct the study and the analytical tools chosen. Analyze the implementation and effectiveness of sustainable business models through specific airline cases. This chapter will provide an in-depth look at how different airlines are addressing the challenges of sustainability and their strategic innovations. Each case will evaluate the actual performance of the model and compare its environmental and economic benefits.

Research Results: Chapter 4 presents the research results, compares the sustainability performance of different airlines, and discusses the implications of these results for sustainability practice and theory in the aviation industry.

Research summary: Chapter 5 summarizes the research results, puts forward practical suggestions for the sustainable development of the aviation industry, discusses the limitations of the research and future research directions, and proposes policy recommendations and recommendations for the sustainable development of the aviation industry. Strategic Direction.

References and Appendices: This section lists all sources cited in the paper, as well as relevant materials consulted during the research. This is intended to provide sufficient contextual support to ensure verifiability and transparency of the research.

2 Literature review

2.1 The importance of sustainability in aviation

The aviation industry has become an indispensable part of modern society due to its huge role in promoting economic globalization. At the same time, however, the aviation industry is also a significant source of global greenhouse gas emissions. As the world becomes increasingly concerned about the impact of climate change, sustainability has become a core issue that cannot be ignored in the development of the aviation industry. Research shows that if the rapid growth of the aviation industry is not subject to sustainable management and technological innovation, its environmental impact may gradually increase, thereby affecting society's demand for sustainability in the aviation industry. Many airlines around the world have begun to implement sustainable development strategies, such as improving flight operation efficiency and enhancing aircraft fuel efficiency to reduce carbon emissions per flight. In addition, airlines are also actively exploring circular economy models, including waste management and reuse within aircraft. These measures will help promote the green transformation of the industry.（Gang, W,2003)

International passenger aviation has tripled over the past 25 years and is expected to continue a similarly rapid expansion over the next 25 years. While the aviation industry brings huge economic benefits, its growth may also bring greater social and environmental impacts. To address these issues, sustainable aviation policy is defined as a “balanced strategy” that, while emphasizing the economic benefits of aviation, also aims to address the environmental and social impacts that its expansion may bring.(Walker & Cook, 2009)

Sustainability in the aviation industry involves integrating economic, environmental and social performance indicators (the triple bottom line) into business management and reporting processes. The long-term goal is to establish an airport with a strong economic structure while meeting the social expectations of stakeholders and minimizing environmental impact. In the short term, companies should provide competitive products and services to remain economically sustainable while protecting natural and human resources to meet the needs of future generations.（Koç, S. & Durmaz, V, 2015)

The goals and commitments set by the Aviation Industry Corporation of China (AVIC) to achieve green aviation. With the rapid development of science and technology and the popularization of environmental awareness, energy conservation, emission reduction, and response to climate change have become global goals. As part of the manufacturing industry, China's aviation industry is a

major consumer of natural resources and energy, so the development of green technology will have a significant impact on air transportation.（(Zuo Lin, 2013)

2.2 The state of sustainable business models in aviation

Southwest Airlines is increasing recycling across its operations by expanding recycling coverage, improving the quality of data collection, and increasing education and consistency. Their goal is to reduce single-use plastic on board by 50% by 2025 and eliminate it wherever possible by 2030. In addition, they have launched a "Repurpose with Purpose" project to upcycle old aircraft seat leather into new products. Many airlines are applying recycling by focusing on the sustainable design, maintenance and recycling of aircraft materials. economic principles. Initiatives include using recycled materials for aircraft interiors and other onboard items, promoting component repair and refurbishment, and implementing end-of-life product recycling processes.(Southwest Airlines)

As a clean energy source, algae biofuel's application in the aviation industry is being viewed as an effective way to reduce reliance on traditional fuels and reduce greenhouse gas emissions. Explores how algae biofuels can provide the aviation industry with a sustainable fuel alternative that reduces environmental impact while enhancing airlines' market competitiveness.（Nair & Paulose,2014）

In the case of the development of the Zhengzhou Aviation Metropolitan Area, the synergy and sustainability of the airport, industry and city (AIC) system are discussed. By constructing and evaluating the collaborative development model of the AIC system, the study points out that there are significant sustainable development prospects in strengthening internal mechanisms and optimizing the relationship with the regional environment. The implementation of this model provides a new perspective for understanding the interaction between the aviation industry and regional economic and social development.（Bai Yangmin,2021)

This chapter mainly introduces and evaluates current and future technologies for sustainable development in the aviation industry. The article provides an in-depth look at how technological advancements are shaping sustainable practices in the aviation industry, detailing topics including biofuels, energy efficiency improvements, waste reduction strategies, and advances in aircraft design and operations. Overall, the literature review on sustainability in the aviation industry may emphasize a multifaceted approach that combines technology assessment, policy implications and industry adaptation strategies. It may call for continued innovation and collaboration between different sectors to achieve aviation's sustainability goals, reflecting a dynamic development sector that seeks to meet environmental, economic and social objectives .(Gu Mengqi ,2023)

Currently, the aviation industry has made significant progress in promoting sustainable development. Especially in terms of innovative power technology, research on hydrogen fuel engines and hybrid power architecture is gradually moving from theory to practical application. Many companies are exploring different technical paths based on their own research and technology accumulation. These efforts reflect the industry's commitment to reducing environmental impact and improving energy efficiency. Although the technical routes of each company are different, the common goal is to contribute to the environmental sustainability of the aviation industry. The development and testing of these technologies is an exploration of future clean aviation power technologies, paving the way to achieve an ambitious blueprint for reducing greenhouse gas emissions and other environmental goals. In addition, as policies, regulations and market demands continue to drive forward, it is expected that these technologies will further accelerate their transformation to commercialization. The roadmap for sustainable development in the aviation industry is becoming increasingly clear, demonstrating a comprehensive development strategy that takes into account environmental, economic and social factors. (Debois, T. & Macy-Beresford, H,2023)

2.3 Innovation strategy and sustainable development

The aviation logistics industry is improving service efficiency through technological innovation and resource integration. For example, modern information technology is used to integrate multiple transportation modes and related resources to improve the flow efficiency of raw materials, finished products and related information. And we are discussing how to enhance the market competition of aviation logistics through strategic alliances and cooperation in the context of market opening and intensified competition. It provides a comprehensive perspective on sustainable development for China's aviation logistics industry, demonstrating how the industry responds to the rapidly changing market environment and seeks sustainable development through innovative strategies.（Cao, X. & Wang, X,2009）

Promotion and implementation of low-carbon policies: The Chinese government actively responds to climate change and launches low-carbon economic pilots to promote the low-carbon development of the tourism industry. Research shows that low-carbon tourism not only helps reduce carbon emissions, but also promotes the purpose of tourism. The local economic and social development has enhanced the sustainability of tourism through the promotion of low-carbon production and lifestyle, emphasizing that the connotation of low-carbon tourism includes energy conservation and emission reduction, low-carbon technological innovation, clean energy utilization, etc., which are all As a key aspect of promoting the sustainable development of the tourism industry, government departments hope to promote innovative strategies in various industries in sustainable development.（Tang, Cheng-cai,&Zhong, Lin-sheng,2011）

In summary, the aviation industry’s sustainable development strategy encompasses efforts ranging from fleet modernization and fuel efficiency improvements to the full adoption of sustainable aviation fuels. These measures not only address the challenge of global climate change, but also reflect the aviation industry's commitment to environmental protection and social responsibility. In the future, the sustainable development of the aviation industry will rely on continued technological innovation, effective policy implementation, and industry-wide cooperation. These focused efforts are directed towards a common goal: reducing the environmental impact of aviation while ensuring the continued growth of its economic and social value.

3 Research methods and case analysis

3.1 SWOT analysis

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Airlines have begun to align emissions reduction targets with their bottom-line benefits by investing in new technologies and improving operational efficiencies. For example, airlines have achieved carbon emissions reductions of up to 30% by using engines with more efficient aerodynamic designs and lightweight materials. In addition, airlines can further improve fuel efficiency by improving fuel efficiency in flight, taxiing and airport operations, and by changing the behavior of frontline employees through behavioral science programs. A case study from Virgin Atlantic shows that through feedback and evaluation of pilots' fuel usage, it successfully prompted pilots to reduce fuel usage while increasing job satisfaction .(McKinsey,2020).

Biofuels are one of the important ways for the aviation industry to reduce its carbon footprint. For example, airlines can significantly reduce their carbon emissions compared to traditional fossil fuels by using biojet fuel made from vegetable oils or other renewable resources. The use of this type of fuel not only supports environmental sustainability, but also demonstrates the aviation industry's enthusiasm for adopting emerging environmentally friendly technologies. A key advantage of biofuel is that it is compatible with existing fuel infrastructure and aircraft engines, reducing additional retrofit costs. (McKinsey,2020).

In airlines, the implementation of product service systems (PSS) has brought significant benefits to enhance market competitiveness and customer loyalty. For example, during the migration to Amadeus Altea's PSS, a large Australian airline achieved process optimization in multiple business areas including reservations, ticketing, seat allocation, customer processing, etc. through comprehensive system integration services. This change not only improves business efficiency, but also reduces call handling time and significantly improves customer service quality by automating and optimizing business processes.

The benefits of the shared consumption model for airlines include improved resource utilization efficiency and increased consumer satisfaction. In the aviation industry, airlines are able to optimize operating costs and increase service flexibility by sharing resources such as aircraft, crew or airport facilities. In addition, this model meets consumer demands for economic and environmental sustainability because it reduces the resource requirements of individual companies, thereby reducing overall environmental impact.

For example, research points out that the sharing economy model has had a positive impact on both society and the economy by enhancing the accessibility of services and reducing costs. Examples of this in the aviation industry may include sharing flight data and resources to enable airlines to more effectively plan routes and adjust flight plans to adapt to changes in market demand.

W

While the use of sustainable technologies in the aviation industry has many advantages, there are also some disadvantages. Especially for the integration and production of sustainable aviation fuel (SAF), the main challenges they face include uncertainty of economic benefits and high initial investment costs. The economic feasibility of these technologies is affected by a variety of market conditions and will require greater capital investment to meet rising jet fuel demand than conventional fuels. For example, the study notes that incorporating SAF into the refining process requires significant capital investment and requires high marginal abatement costs to incentivize its integration. In addition, the financial return of such investments often carries high risks for investors, as uncertainty in oil prices and the aviation industry can significantly affect the returns of investments.（Capaz, R., Carlson, E., & Jiang, K,2021）

Infrastructure adaptability and investment requirements: Airlines and airports generally do not require large-scale modifications to existing fuel supply systems when using SAF, which is an advantage. However, ensuring that biofuels are efficiently supplied through existing systems, such as through blending storage or book and claim systems, requires sophisticated logistics and efficient management. These systems allow airlines to purchase and use SAF at different locations while ensuring biofuel traceability and accurate attribution of environmental benefits.（international airport magazine）

In addition, from a technical perspective, although electrified aircraft have the potential to reduce greenhouse gas emissions to zero, the energy density and cost of batteries under current technology are still major obstacles. Battery technology needs further development to support long-distance flights, but this technology is currently immature, limiting the widespread application of electric aircraft

O

The use of sustainable technologies by airlines offers a range of opportunities, particularly in terms of environmental protection and compliance with future market demands. For example, Bio-Aviation Fuel (BAF), as a renewable fuel, releases the same amount of carbon dioxide as traditional fuel during the production process, but its growth process that absorbs carbon dioxide from the

atmosphere makes its entire life cycle Carbon emissions are significantly reduced. This not only helps airlines achieve their carbon neutrality goals, but also helps improve the brand's environmental image and attract more environmentally conscious consumers.（Bosch, G., Yang, Z., & Wilbrand, J,2019）

In addition, continued technological innovation offers airlines the possibility to shift to more environmentally friendly operations. New aviation technologies, such as electric and hybrid aircraft, have huge potential to reduce greenhouse gas emissions and operating costs, despite technical and cost challenges. For example, small hybrid aircraft have been used on some short-haul routes, demonstrating the practical application prospects of new technologies.

These opportunities not only help airlines improve their environmental performance, but also enhance the company's market competitiveness in a context where policy and consumer trends are increasingly geared toward sustainability. Nonetheless, airlines still need to overcome challenges such as high initial costs, technology maturity, supporting infrastructure and policy support when moving to these new technologies.（McKinsey & Company,2021）

T

The financial instability of the aviation industry stems primarily from the high degree of fixed costs within the industry and its sensitivity to external economic factors. In the study, they noted how the recent financial crisis had a profound impact on the aviation industry. For example, both the 2008 global financial crisis and the subsequent COVID-19 pandemic put enormous financial pressure on airlines, leading to multiple airlines going bankrupt or being forced to merge.These financial crises affect airlines' sustainability strategies, as they require significant capital to maintain daily operations while also investing in environmentally friendly technology and service upgrades. In addition, airlines often require government bailouts in order to survive, which increases their dependence on strategic decisions and may make it difficult for companies to adopt more environmentally friendly and sustainable measures autonomously.（Markovskaya et al,2023)

It has been observed that after the financial crisis, some European airlines began to predict and prepare for possible future financial risks through risk assessment models. This model was developed to better understand which factors are most likely to affect a company's financial stability under various economic and market conditions and to adjust management strategies accordingly. However, despite this, the industry's financial instability remains an issue that is difficult to fully overcome and poses a threat to the long-term sustainability of airlines.By better understanding and

addressing these financial risks, airlines can more robustly advance their sustainability goals. Specific strategies may include diversifying revenue sources, strengthening financial risk management capabilities, and seeking collaboration between government and the private sector to share risks and resources. （Markovskaya et al,2023)

Aviation industry’s environmental challenges

Environmental challenges in the aviation industry mainly include emissions issues, energy consumption and impact on ecosystems. The study highlights important environmental protection issues for the aviation industry, including noise pollution at airports, energy consumption and the impact of climate change. These environmental problems not only impact local communities but are also an important factor in global climate change.

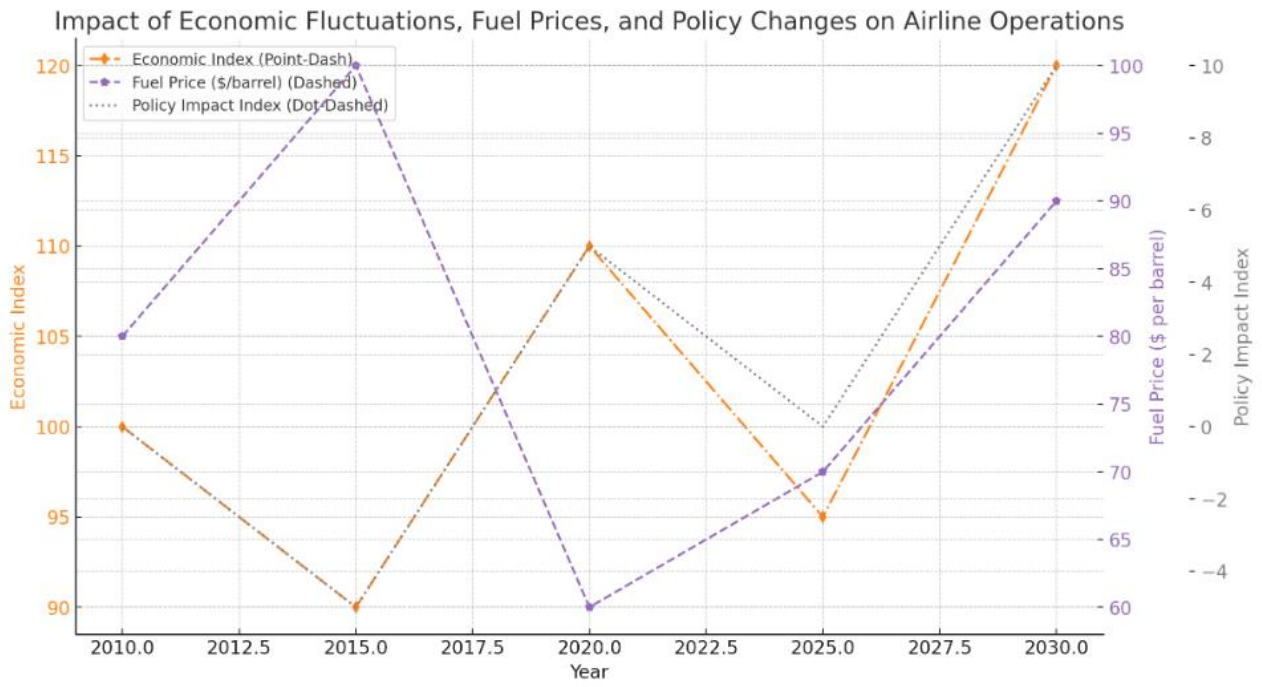
Carbon emissions and climate change: The aviation industry is one of the significant sources of global greenhouse gas emissions. Carbon dioxide and other greenhouse gases produced by burning fuel in aircraft have a direct impact on climate change. Therefore, reducing aviation emissions is key to achieving sustainable development of the industry.Energy Use: The aviation industry has a huge demand for energy, especially its reliance on petroleum products. As global oil resources dwindle and energy prices become unstable, airlines are under pressure to find sustainable energy alternatives.Noise pollution: Aviation noise pollution is another serious environmental problem, especially in residential areas near large airports. Noise pollution not only affects the quality of residents' daily lives, but may also have long-term effects on human health.Water management: The large amounts of water used during aircraft maintenance and cleaning and the disposal of its contamination is another environmental issue that the aviation industry needs to pay attention to. Effective management of water resources and wastewater treatment are key measures to reduce environmental impact. （Thomas,2016)

To address these environmental challenges, airlines need to take a range of measures, including improving fuel efficiency, investing in renewable energy, implementing stricter emissions standards and adopting advanced noise mitigation technologies. These measures not only help reduce environmental impact, but also enhance the company's competitiveness in the market.（Thomas,2016)

The sustainable development of the aviation industry relies heavily on technological innovation and continuous improvement. However, rapid changes in technological development also bring many challenges:

Rapidly changing market demands: With the rapid advancement of technology, the market demand for new technologies is also constantly changing. Airlines must constantly update their technology infrastructure to remain competitive. This rapid technological change can lead to huge capital expenditures and increase the financial pressure on enterprises. Difficulty in adopting and implementing environmentally friendly technologies: Environmentally friendly technologies, such as new generation low-emission aircraft and technologies that use alternative fuels, may help reduce environmental impact in the long run, but the initial development and implementation costs are very high. In addition, there is no unified environmental protection technical standard in the world, which further increases the difficulty of implementation by airlines. Impact on the existing social structure: Although technological progress promotes efficiency improvements and cost reductions, it may also destroy the existing labor market. For example, the introduction of automation and artificial intelligence may reduce the number of jobs requiring human workers, which may cause employment problems and a decrease in job security at a social level.Increased dependence on technology: As the aviation industry's dependence on complex technologies increases, any technical failure can have serious consequences. This requires airlines to invest more resources in ensuring technical safety and reliability. Cybersecurity risks: As the aviation industry increasingly adopts digital and internet technologies, cybersecurity is a significant concern. Data breaches or system hacks can seriously impact an airline's operational security and customer trust. （Wierzbicki ,2017)

The study highlights that while technological developments have brought unprecedented opportunities to the aviation industry, they have also introduced new challenges and risks, which need to be properly addressed through comprehensive strategies and adaptive management.
（Wierzbicki ,2017)



3.2 PEST analysis

P

Environmental regulations:The government directly affects the operating costs of airlines through environmental regulations such as carbon taxes and emissions trading systems. For example, the EU's Emissions Trading System (ETS) requires airlines to purchase emission rights to cover the CO2 emissions generated by their flight activities. Such policies push airlines to adopt greener operating practices, such as using biofuels or newer, more efficient aircraft.

International Agreements and Policies:The global Carbon Offset and Reduction Scheme (CORSIA) developed by the International Civil Aviation Organization (ICAO) aims to reduce carbon emissions in the aviation industry. Such international agreements impact airlines' global operations, prompting them to invest in cleaner technologies and improve operational efficiency.

Government support and subsidies:Government financial support and subsidies are critical to airlines' continued operations in the face of economic hardship or environmental challenges. For example, many governments provided emergency financial assistance during the epidemic to help airlines cope with the collapse in travel demand.

In D. Chang's research, they analyzed the strategic factors of airlines in the Asia-Pacific region in implementing corporate social responsibility (CSR), pointing out that political factors and corporate

governance are key strategic factors affecting the sustainable development of airlines. Furthermore, the study highlights the importance of risk management and brand management in improving sustainability in the aviation industry through the Decision Making Trial and Evaluation Laboratory (DEMATEL) methodology. Research shows that Western airlines generally outperform airlines in the Asia-Pacific region on CSR performance, partly due to differences in the political and policy environment.（D. Chang et al,2015)

E

In the sustainable development of the aviation industry, economic factors play a decisive role, especially in influencing consumer behavior, airline cost structures and the overall performance of the industry. Here are several key economic factors and their impact on the sustainable development of the aviation industry:

Global Economic Conditions: The performance of the aviation industry is closely related to global economic conditions. Aviation industry growth is driven by increased demand for tourism and business travel during economic booms. An economic recession can lead to a sharp drop in demand, as seen during the 2008 global financial crisis. This volatility has profound consequences for airlines' financial performance and sustainability strategies.

Fuel Price Fluctuation: Fuel costs are one of the largest operating costs for airlines. Fluctuations in oil prices directly affect airlines' profit margins and fare strategies. When oil prices rise, airlines may need to raise fares or take other measures to stay profitable, which could impact consumer demand.

Policy and regulatory changes: Economic policies, such as taxes, subsidies and environmental regulations, have a significant impact on the aviation industry's operating costs and market opportunities. For example, biofuel subsidies provided by some countries can help airlines reduce their dependence on traditional fuels and support the implementation of sustainable development strategies.

How these economic factors specifically affect the sustainable development of the aviation industry can be referred to J. Brueckner's 2003 study. His research shows that improvements in aviation service levels and frequent flight services have a significant role in promoting urban economic development. Specifically, for every 10% increase in passenger occupancy, the employment rate in related service industries increases by approximately 1%. This finding highlights the important role of the aviation industry in global and local economies and the importance of maintaining industry competitiveness and sustainable development.(J. Brueckner,2003)

S

In the aviation industry, social factors have a significant impact on a company's sustainability strategy. Here are a few key social factors and their impact on the aviation industry:

Public concern about environmental protection: As society pays increasing attention to environmental issues, more and more consumers tend to choose airlines that implement sustainable development measures. This has driven airlines to invest more in environmentally friendly technologies and sustainable practices. For example, many airlines are increasing their use of biofuels to reduce greenhouse gas emissions.

Labor Practices and Corporate Social Responsibility (CSR):

Good labor practices and active social responsibility activities can enhance an airline's brand image and consumer trust. For example, airlines in the Asia-Pacific region perform less well than Western countries in implementing CSR, indicating the need for improvement in this area.

Changes in culture and consumer behavior:

Cultural differences and changes in consumer behavior in different regions will also affect airline service models and market strategies. For example, in some cultures expectations for flight service may be more focused on comfort and personalized service, while in other cultures they may be more focused on cost-effectiveness.

The strategic factors of airlines in the Asia-Pacific region in implementing CSR were analyzed through the Decision Testing and Evaluation Laboratory (DEMATEL) method. This study shows that political factors and corporate governance are key strategic factors affecting the sustainable development of airlines. Research also highlights the importance of risk management and brand management in improving sustainability in the aviation industry (D. Chang et al,2015)

Airlines are working with the automotive and energy industries to drive the development and commercialization of sustainable aviation fuels (SAF). For example, the U.S. aviation industry has played a leadership role in the development and deployment of SAFs and continues to advance the commercialization and deployment of SAFs by working with energy companies to achieve its emission reduction goals, increase the diversity of fuel supplies, and enhance energy security. sex. These collaborations help drive technological innovation and enhance the economic viability and market acceptance of sustainable fuels（American Airlines Association）

T

In discussing the sustainable development of the aviation industry, technological factors play a central role, especially in promoting environmental protection and improving economic efficiency. Here is a detailed analysis of several key technological developments and their impact on the aviation industry:

Flight efficiency technologies: Flight efficiency technologies are critical to achieving sustainability goals, helping airlines meet their environmental goals by reducing carbon emissions and noise pollution. For example, Boeing has studied techniques to improve the efficiency of flight operations, including predicting and optimizing flight routes and dynamically correcting flight profile predictions to enable adjustments based on changing weather, airspace user preferences, and fuel usage history [Louis Bailey et al. (Louis Bailey et al,2023)

Information Communication Technology (ICT): The application of ICT in the aviation industry has significantly transformed airline operations and strategic management. These technologies include the Internet, internal systems and external communication platforms, helping airlines improve the efficiency of distribution strategies, reduce costs, and optimize flight efficiency through tools such as electronic flight bags.(Dimitrios Buhalis,2004)

Sustainable aircraft design: In terms of aircraft design, exploring new technical systems is the key to achieving long-term sustainable air transportation. The current technology system mainly develops in an incremental manner to improve efficiency, but in order to truly achieve sustainability, more radical technology options need to be adopted, such as Blended Wing Body design and Flying V design, these designs help increase passenger capacity and reduce fuel consumption(A. D. Haan & K. Mulder,2002)

3.3 Case study

KLM is one of the first airlines in the world to use sustainable aviation fuel. KLM is working with fuel suppliers and other industrial partners to introduce biofuels and synthetic fuels on a large scale to reduce carbon emissions during flight. This strategy by KLM is part of its response to environmental regulations in the aviation industry and also demonstrates the company's commitment to sustainable development. Unfortunately, sustainable aviation fuel is not yet available on a large scale. This means SAF is at least 3 to 4 times more expensive. Today, SAF accounts for only a tiny fraction of the millions of tons of kerosene used by commercial airlines. To significantly impact the aviation industry’s overall carbon emissions（KLM）

U.S. airlines are reducing their carbon emissions by setting science-based baseline targets (SBTi). According to McKinsey's analysis, 25 major airlines, including American Airlines, have pledged to reduce carbon emissions by more than 30% by 2030 compared with 2019 and by more than 50% by 2035. The companies' strategies include improving fuel efficiency, introducing a new generation of greener aircraft, and using sustainable aviation fuels. These initiatives demonstrate the aviation industry's active participation in global environmental initiatives. Airlines that integrate decarbonization efforts into their long-term business planning cycles can reduce the risks of their sustainable transition and achieve optimized decarbonization costs. While decarbonizing aviation is one of the biggest challenges the industry has ever faced, the long lead times for some investments make it urgent for companies across the aviation value chain to act quickly to better position themselves for the future. The future of green aviation can be determined by airlines adopting radical transparency on their decarbonization options and investigating partnerships with other aviation value chain players.(McKinsey & Company,2023)

Etihad Airways claims to have become the first airline in the United Arab Emirates to not use any single-use plastic on flights to raise awareness of plastic pollution, with the landmark flight being part of Etihad's commitment to the environment As part of an ongoing commitment that extends beyond Earth Day celebrations, the company has pledged to reduce single-use plastic use by 80% by the end of 2022, not just in flight but across the organization. Aiming to reduce plastic pollution and enhance customers' eco-friendly travel experience, Etihad Airways announced in its sustainability report that it has achieved a 26% reduction in CO2 emissions per revenue tonne kilometer (RTK). This achievement is driven by its flagship sustainability initiatives, including its Green Fleet Initiative using its fleet of Boeing 787 Dreamliners.(Future Travel Experience,2019)

Delta Air Lines has launched its first aviation innovation lab to accelerate research, design and testing for a more sustainable future of air travel. The Delta Sustainable Sky Lab will showcase the work Delta is currently doing to spark disruptive industry innovation and expand known technologies and actions to achieve Delta’s goal of net-zero emissions by 2050. Delta Air Lines has joined a sustainable flight demonstration program supported by Boeing and NASA to research and develop new aircraft designs to improve the environmental performance of flying. The airline has an advisory role in the design of new aircraft, specifically the Transonic Truss-Braced Wing, which will be the first X-Plane to focus on sustainability.(Delta News,2019)

Boeing expands its global efforts at the 2023 Dubai Air Show, signing a cooperation agreement with Zero Corporation to focus on three key strategies on the path to aviation sustainability - fleet renewal, sustainable aviation fuels and operational efficiency . The exhibition also discusses low-carbon technologies as an important part of the journey towards decarbonization by 2050 and the advancement of sustainable aviation fuels. This collaboration marks Boeing's further commitment and actions in the area of sustainable aviation fuels, focusing on three key strategies on the path to aviation sustainability – fleet renewal, sustainable aviation fuels and operational efficiency. The exhibition also discusses low-carbon technologies as an important part of the journey towards decarbonization by 2050.(Boeing.2022)

Across the global aviation industry, several airlines are taking innovative and proactive steps to advance their sustainability strategies, with these efforts focused on reducing environmental impact and enhancing energy efficiency. From KLM's large-scale use of sustainable aviation fuel (SAF), to American Airlines' systematic efforts to reduce carbon emissions through Science Baseline Targets (SBTi), and Etihad Airways' move to eliminate single-use plastic products Breakthroughs, these initiatives all reflect the airline's commitment to environmental protection and its active participation in global environmental initiatives. In addition, Delta's Innovation Lab and Boeing's collaboration in promoting sustainable fuel technologies further demonstrates the aviation industry's efforts in technological innovation and collaboration to reduce the negative impact of flying activities on the environment while ensuring business continuity. Sustained growth and competitiveness.

Overall, these cases show that despite high costs and technical challenges, airlines are moving effectively towards net-zero emissions targets by implementing diverse sustainability strategies. This not only helps improve its environmental performance but also enhances corporate social responsibility, creating a more positive brand image among consumers around the world. This trend heralds a future in which aviation will continue to play an important role in global efforts to reduce carbon emissions.

3.4 Overlay matrix method

Research dimensions:

1. Sustainability strategy: This dimension can include various sustainability measures, such as using sustainable aviation fuel, improving operational efficiency, implementing circular economy practices, etc.

2. Environmental Impact: Analyze the effectiveness of different sustainability strategies in reducing carbon emissions, improving fuel efficiency and other environmental impacts.

3. Economic performance: Examine the financial impact of implementing sustainability strategies

4. Technological Innovation: Consider the role of new technologies in advancing the Sustainable Development Goals

5. Policy and regulatory impacts: Assess how different airlines adapt to and benefit from various international and local environmental regulations and policies.

6. Market Competitiveness and Consumer Loyalty: Explore how sustainability initiatives impact an airline's ability to compete in the marketplace and attract or retain consumers who value environmental responsibility.

Based on the details of the four airline cases, we can construct an overlay matrix based on the study dimensions:

Dimension / Company	KLM Royal Dutch Airlines (KLM)	American Airlines	Etihad Airways	Delta Airlines
Sustainability strategy	Introduction of biofuels and synthetic fuels	Set science-based targets (SBTi) to reduce carbon emissions	Do not use single-use plastics and reduce plastic pollution	Create a Sustainable Sky Lab and join the Sustainable Flight Demonstration Program
Environmental impact	Significantly reduce carbon emissions during flights	Pledge to reduce carbon emissions by more than 50% by 2035	26% reduction in CO2 emissions per tonne-kilometer of revenue	Improving the environmental performance of flights through new technologies
Economic performance	SAF is expensive, but it raises environmental profile and responsibility	Long-term investment in environmentally friendly aircraft and fuel efficiency improvements	Enhance your customers' eco-friendly travel experience and enhance your brand image	Drive industry innovation and long-term net-zero emissions goals
Technological innovation	A pioneer in biofuels and synthetic fuel technologies	Introducing a new generation of greener aircraft	Green fleet plan with Boeing 787 Dreamliner	Development of new aircraft designs, particularly the Transonic Truss-Braced Wing
Policy and regulatory implications	Respond to environmental regulations in the aviation industry and actively participate in the formulation of international standards	Actively respond to international carbon emission standards and policies	As part of our ongoing commitment to the environment, participate in Earth Day activities	Cooperate with Boeing and NASA to meet the requirements of future environmental protection policies
Market competitiveness and consumer loyalty	Strengthen market competitiveness and customer loyalty	Reduce operating costs and attract environmentally conscious consumers	Eco-friendly measures increase customer satisfaction and loyalty	Innovation leads the industry, enhances brand value and customer trust

KLM has excelled in promoting biofuels and synthetic fuels that significantly reduce carbon emissions during flight.

American Airlines has set Science-based targets (SBTi) to reduce carbon emissions by 30% by 2025.

Etihad Airways has made significant achievements in eliminating single-use plastic, enhancing its eco-friendly travel experience and enhancing consumer identification with the brand.

Delta Airlines has significantly improved the environmental performance of flight through its sustainable flight demonstration program and new aircraft designs such as cantilever wings.

Through this analysis, it can be seen that different airlines have significant differences in the implementation and effect of sustainability strategies. This difference is not only reflected in specific environmental measures, but also in how they strengthen market competitiveness and build consumer trust through technological innovation and response to policy changes.

4 Research result

4.1 PEST analysis result

The influence of political factors

The political environment plays a key role in shaping an airline's sustainable strategy. Environmental regulations and international policies push airlines to take specific steps to reduce carbon emissions, including purchasing carbon emissions rights and using sustainable aviation fuels. For example, the EU's Emissions Trading System (ETS) not only requires airlines to purchase sufficient emission rights to cover the carbon dioxide emissions generated by their flight activities, but also promotes the aviation industry's transition to a more environmentally friendly operating model. Driven by this policy, companies such as Royal Dutch Airlines (KLM) have begun to introduce biofuels and synthetic fuels on a large scale to reduce carbon emissions during flights.

Influence of economic factors

Economic factors also play a decisive role in airlines' sustainable development strategies. Global economic fluctuations and changes in oil prices directly affect airlines' costs and revenues. During economic booms, demand for air travel increases, driving the aviation industry's growth; while during recessions, as seen in the 2008 global financial crisis, demand collapses, leading to significant declines in airline revenue. In addition, the volatility of oil prices increases the financial incentives for airlines to adopt sustainable fuels. For example, American Airlines has demonstrated positive change driven by economic factors by setting science-based emission reduction targets (SBTi) and committing to reducing carbon emissions by more than 30% by 2030.

Impact of social trends

Among social trends, the public's increasing concern for environmental protection has pushed airlines to pay attention to sustainable development strategies. Consumers are increasingly choosing airlines that implement sustainability measures, prompting airlines to invest more in environmentally friendly technologies and sustainable practices. Etihad Airways, for example, is improving its environmental profile and attracting environmentally conscious consumers by completely eliminating single-use plastics on its flights.

Impact of technological progress

Technological advances provide the means to reduce environmental impact, such as through increased flight efficiency and the implementation of new communications technologies. The development of electric and hybrid aircraft offers airlines significant potential to reduce greenhouse gas

emissions and operating costs. For example, Delta Air Lines has opened its first aviation innovation laboratory to accelerate research and development of new aircraft designs that can improve the environmental performance of flying.

4.2 SWOT analysis results

It can be seen from the SWOT analysis that although airlines have achieved positive results in responding to regulatory requirements and market expectations by adopting new technologies and improving operational efficiency, they also face the challenges of high initial investment and technical limitations. For example, although sustainable aviation fuel (SAF) offers significant environmental advantages, its high production costs and limited supply limit its widespread application.

In terms of opportunities, policy support and consumer preference for environmentally friendly aviation services are likely to drive industry growth. Changes in the market and policy environment provide airlines with opportunities to shift to greener operations. In addition, technological innovations such as electric aircraft and more efficient fuel technologies, while facing cost and technology maturity challenges, provide the aviation industry with effective ways to reduce its environmental footprint in the long term.

In terms of threats, economic instability and fierce market competition may hinder the implementation of environmental protection measures. Financial crises and market turmoil could undermine airlines' ability to invest in new technologies and green strategies. In addition, the high degree of fixed costs within the aviation industry and the sensitivity to external economic factors also bring uncertainty to the implementation of sustainable strategies for airlines.

These two analytical methods - PEST and SWOT - provide airlines with a framework for strategic development in the face of global sustainability challenges, helping them to remain competitive while achieving environmental responsibility.

4.3 Analysis of overlay matrix method

The overlay matrix approach used in the study provides a systematic comparison and assessment of the sustainability strategies of different airlines. The overlay matrix provides a detailed analysis of the following four companies based on six research dimensions - sustainability strategy, environmental impact, economic performance, technological innovation, policy and regulatory impact, market competitiveness and consumer loyalty: Royal Netherlands Airlines (KLM), American Airlines, Etihad Airways and Delta Air Lines.

Sustainability strategy: Each airline has adopted a different sustainability strategy. For example, KLM has introduced biofuels and synthetic fuels, American Airlines has set science-based targets to reduce carbon emissions, and Etihad Airways has taken steps to reduce the use of single-use plastics.

Environmental impact: Companies' strategies vary in how they reduce their environmental impact. For example, Etihad Airways has achieved significant CO2 emissions reductions by reducing plastic use and using Boeing 787 Dreamliners as part of its green fleet.

Economic performance: Although the initial investment in sustainable strategies is large, in the long run, for example, American Airlines will help reduce operating costs and enhance market competitiveness by introducing new more environmentally friendly aircraft models and improving fuel efficiency.

Technological innovation: Companies also differ in technological innovation. KLM has made breakthroughs in biofuel and synthetic fuel technology, while Delta Air Lines has innovated in new aircraft designs such as suspension airfoil design.

Policy and regulatory impact: Policies and international standards have a significant impact on airlines' sustainability strategies. All companies are actively responding to international carbon emission standards and policies, especially participating in international carbon offset and emission reduction programs.

Market competitiveness and consumer loyalty: Companies that adopt sustainable measures can enhance their market competitiveness and consumer loyalty. For example, Etihad Airways' environmental initiatives have enhanced consumers' favorability and loyalty to its brand

The analysis results of the overlay matrix show that despite facing cost, technology and policy challenges, airlines have effectively promoted the realization of environmental protection goals by implementing diversified sustainability strategies, while also improving the company's market competitiveness. The successful implementation of these strategies demonstrates the aviation industry's active role and potential influence in global efforts to reduce carbon emissions.

5 Research summary

5.1 Reaffirm the importance and purpose of the research

In today's context of rapid globalization, the aviation industry, as one of the important pillars of modern society, has an increasingly significant impact on the global economy. The aviation industry not only greatly promotes international trade and personnel exchanges, but also greatly shortens the international distance and accelerates the flow of culture and information. However, as this article explores, the aviation industry is also a significant source of global greenhouse gas emissions. As the global community pays increasing attention to climate change, sustainable development has become a core issue in the future development of the aviation industry. Despite facing many challenges, including technical limitations, economic costs and policy constraints, many airlines around the world have begun to actively reduce their carbon footprint by improving energy efficiency, using sustainable aviation fuel, optimizing flight paths and other measures in response to global environmental protection requirements. voice.

This article systematically analyzes the current status, challenges and strategies of sustainable development in the aviation industry through literature review, case analysis, SWOT and PEST analysis, etc., aiming to provide practical and feasible sustainable development paths for airlines and provide policy makers with Provide decision-making reference to industry decision-makers. Through in-depth analysis of the specific practices of multiple airlines, this study reveals how the industry can effectively integrate environmental protection and social responsibility goals while pursuing economic benefits, and promote the aviation industry to develop in a greener and more sustainable direction. .

5.2 To summarize the main findings

The research findings of this article point out that although the development of the aviation industry has brought significant economic benefits, its environmental impact cannot be ignored. Research shows that the rapid expansion of the aviation industry, if not supported by effective sustainable management and technological innovation, may lead to a gradual increase in its environmental impact. To this end, many airlines around the world have begun to adopt a series of sustainable development strategies in an effort to balance the relationship between their economic development and environmental protection. These strategies include improving flight operation efficiency, enhancing aircraft fuel efficiency, and implementing aircraft waste recycling and regeneration.

In particular, the efforts of companies such as KLM and American Airlines in introducing sustainable aviation fuels not only reduce carbon emissions during flights, but also demonstrate their active response to global environmental initiatives. In addition, Etihad Airways' practices in reducing the use of single-use plastics and promoting circular economy have strengthened the airline's ability to achieve environmental sustainability. These cases highlight the challenges and achievements faced by airlines on the road to sustainable development, and also reveal the progress the aviation industry has made in environmental protection and sustainability with the support of existing technologies and policies.

The research in this part not only reflects airlines' innovative measures to improve energy efficiency and reduce environmental impact, but also shows how these measures help airlines stay competitive in the global market. This shows that the sustainable development strategy of the aviation industry has shifted from a single economic driver to a diversified development model that comprehensively considers the environment, society and economy, emphasizing the importance of a comprehensive and long-term strategic perspective for the future of the industry.

5.3 Discuss implementation challenges and opportunities

We not only have a deep understanding of the specific measures taken by airlines to implement sustainable development strategies, but also have a comprehensive understanding of the challenges and opportunities arising from the implementation of these strategies. Airlines must face cost and technology challenges while pursuing reduced environmental impact. Although sustainable aviation fuel (SAF) offers an effective way to reduce carbon emissions, its high cost and limited supply pose major obstacles. In addition, inconsistent policies and regulations around the world create complexities for airlines’ sustainable practices.

However, these challenges also bring development opportunities. By adopting innovative technologies and improving operational processes, airlines not only help reduce environmental impact, but also improve service efficiency and customer satisfaction, and enhance the brand's market competitiveness. For example, by optimizing flight routes and improving fuel efficiency, airlines can not only reduce carbon emissions but also reduce operating costs. Additionally, as consumer demand for environmentally friendly products and services increases, airlines can attract more environmentally conscious customers by implementing sustainable strategies.

In the future, the sustainable development of the aviation industry will require cooperation and innovation in all aspects. Governments, industry organizations and airlines need to work together to ensure policy consistency and effective enforcement. Technological innovation will continue to be key to driving sustainable development in the aviation industry, while educational and cultural changes will also enable more stakeholders to engage in sustainable practices. Airlines should continue to explore and implement forward-looking strategies not only to respond to upcoming regulatory changes, but also to stay ahead of the curve in an increasingly competitive global market.

5.4 Recommendations and future research directions

To sum up, the sustainable development of the aviation industry is a multi-dimensional, cross-field challenge involving technological innovation, policy formulation, social responsibility and economic benefits. Faced with the pressure of global climate change, airlines have begun to adopt a variety of measures to reduce environmental impacts, including but not limited to the use of sustainable aviation fuels, improved energy efficiency, circular economy practices, and behavioral changes driven by policy and market mechanisms. . However, in order to achieve truly sustainable development, the following efforts are needed: Strengthen technological innovation and research and development: Continued investment in the research and development of more efficient aviation technologies, such as new propulsion systems and energy management technologies, is key to promoting the sustainability of the aviation industry. In addition, improving the application efficiency of existing technologies and exploring the use of new materials will further reduce the environmental impact of aviation activities.

Promote and enforce globally unified policies: International cooperation plays a vital role in the sustainable development of the aviation industry. Airlines and governments around the world should work together to develop and implement policies and standards that support sustainable development, such as international carbon emissions trading and sustainable fuel use standards.

Raising social awareness and engagement: Educating and raising public awareness of the importance of sustainability in aviation is another key factor driving change in the industry. Airlines should increase consumer awareness of and support for their sustainability efforts through transparent communications and community engagement activities.

Integration of economic strategies and environmental responsibilities: Airlines should integrate economic strategies and environmental responsibilities and achieve a win-win situation between

commercial interests and environmental protection through innovative business models. For example, by optimizing route design and improving load efficiency, not only can fuel consumption and carbon emissions be reduced, but operational efficiency can also be improved.

Conclusion

As the world continues to pursue sustainable development goals, the aviation industry, as an important driving force for international exchanges and economic development, has become increasingly important in its sustainable development strategy. Through the in-depth analysis of this study, we can see that although the aviation industry faces multiple challenges, including technological limitations, economic pressures, and policy and regulatory uncertainty, many airlines have taken proactive measures to reduce environmental influence and push the industry to develop in a more sustainable direction.

These efforts by the airline not only demonstrate its commitment to environmental protection, but also reflect far-reaching considerations for future business sustainability. By implementing innovative operating models, adopting efficient energy solutions, and actively participating in global environmental initiatives, the aviation industry is gradually building a greener, more efficient, and more responsible future.

Finally, this study highlights the need for continued innovation and international collaboration to address ongoing changes in global environmental challenges. In the future, with the advancement of technology and the further improvement of global environmental policies, the sustainable development path of the aviation industry will continue to evolve. Therefore, continued attention and research on the aviation industry will be a key factor in promoting its sustainable development.

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Appendix

Appendix1.SWOT table summary

S(Advantage)	W (disadvantage)	O (opportunity)	T (threat)
New technologies and operational efficiency improvements: Invest in new technologies, such as efficient aerodynamic design and lightweight materials, to reduce carbon emissions by up to 30%. Biofuel use: Using biojet fuel significantly reduces carbon emissions, is compatible with existing infrastructure, and reduces retrofit costs. Product Service System (PSS): Such as the Amadeus Altea system, which optimizes booking, ticketing and other processes and improves customer service quality. Shared consumption model: Optimize operating costs, improve service flexibility, and reduce environmental impact by sharing resources such as aircraft and crew.	Sustainable aviation fuel (SAF) costs and economic benefits are uncertain: high initial investment and uncertain economic returns. Electrified aircraft technology limitations: Current battery energy density and cost are major obstacles limiting the widespread application of electric aircraft. Inadequate infrastructure: Lack of adequate biofuel supplies and associated charging infrastructure. Increased prices: Increased environmental protection and consumer sensitivity to increased fares may affect acceptance of greener options	Environmental protection and market demand: Bio-jet fuel can help achieve carbon neutrality goals and attract environmentally conscious consumers. Technological innovation: New aviation technologies such as electric and hybrid aircraft reduce greenhouse gas emissions and provide the possibility to shift to environmentally friendly operations. Cross-border cooperation: Cooperation with other industries, such as the automotive and energy industries, to jointly promote the development of sustainable technologies.	Industry financial instability: high fixed costs and sensitivity to external economic factors. Rapid changes in technology: Rapid technological changes can result in huge capital expenditures. Technology Dependence and Cybersecurity Risks: As reliance on complex technologies increases, any technology failure or cybersecurity incident could lead to serious consequences Environmental challenges: Such as noise pollution and water resource management, measures need to be taken to reduce environmental impact.

Appendix2. PEST table summary

Political	Environmental regulations: For example, the European Union's Emissions Trading System (ETS) forces airlines to purchase emission rights. International agreements: such as ICAO's CORSIA plan, which aims to reduce global aviation carbon emissions. Government support: In times of economic or environmental crisis, the government provides financial support and subsidies.	**Social**	Public environmental awareness: Consumers prefer airlines that adopt environmentally friendly measures. Labor practices and CSR: Impact on airline brand image and consumer trust. Cultural differences: affecting service models and marketing strategies.
Economic	Global economic conditions: Aviation industry revenue is closely related to fluctuations in the global economy, with demand for tourism and business travel increasing during economic booms and decreasing demand during recessions Oil Price Volatility: Fuel price instability has a direct impact on airline operating costs and profitability Policy changes: Changes in economic policies such as collection policies and government subsidies will also reshape airlines' cost structures and market development opportunities.	**Technology**	Flight efficiency technologies: such as new route optimization and more efficient aircraft designs to reduce carbon emissions. Information and Communication Technology (ICT): Improve operational efficiency and cost structure. Sustainable aircraft design: Explore new technologies like Blended Wing Body to improve efficiency and reduce environmental impact.

Appendix3.Time series chart on technological development trends in the aviation industry