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Innovative Green Aviation: Strategic Management and Technological Advancements in Airport Ecosystems

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Abstract

Adopting Sustainable Development Goals has driven significant changes in the aviation industry, and airport ecosystems are committed to minimizing their environmental impact. This article examines the sustainable strategies implemented within airport ecosystems and the associated technologies that support them. We develop a qualitative research approach anchored in documentary analysis and the theoretical framework of sustainable strategic management proposed by Stead and Stead (2004) that analyses sustainable strategies at a competitive and functional level. Strategies are defined from reports of airports certified with Level 5 of the Airport Carbon Accreditation program and official documents issued by non-governmental organizations and professional services firms such as KPMG, Deloitte, and McKinsey. The main strategies and technologies at a competitive level seek to reduce the carbon footprint by using renewable energy and electric vehicles, thus obtaining a cost advantage, and reducing resource depletion. Strategies and technologies that enable the exploitation of market opportunities are related to improving user experience and designing new routes using artificial intelligence. Total quality environmental management and environmental marketing strategies are relevant to primary activities, and the formation of infrastructure supporting long-term strategy stands out among the support activities. However, there is still a need for human resource management systems to have a sustainable vision. The aviation industry is known for its high level of complexity and the large number of actors involved in its operation, in this sense, using or developing technology and identifying its application in a concrete manner in the sustainable strategies of airports considered can favor the transition towards green aviation. Equally important is the formulation of public policies that encourage and support the transition towards decarbonization. However, it is the availability of financing the development of sustainable aircraft fuels, promoting research, technological developments, and the acquisition of machinery, equipment, and personnel training.

Keywords: Airport ecosystems, technological developments, sustainable practices, strategy

Introduction

Air transport is a vital catalyst for economic growth and development, fostering integration into the global economy and promoting connectivity at regional, national, and international levels. It significantly contributes to trade facilitation and the transfer of goods, while also playing a crucial role in enhancing tourism and job creation (Özdemir, 2024; Quadros, Barqueira and Abrantes, 2024, World Bank Group, 2022).

The world economy has yet to recover after the economic and health crises suffered during 2020 and 2021. Global GDP growth slowed, and oil prices and inflation increased. However, global connectivity has been restored; in 2022, it saw a substantial improvement, growing from 50% to 75%. North America and Latin America reached or exceeded 2019 levels, while Asia/Pacific remained below average. Air passenger traffic gained momentum on a global scale in 2022 and recovered substantially, rising from 41.7% of revenue passenger kilometers (RPKs) in 2019 to 68.5% in 2022. (World Bank Group, 2023).

Air transport is in a phase of constant recovery, representing an opportunity for many countries to improve their supervision, public policies, and infrastructure to make the sector more resilient and sustainable (World Bank Group; 2021, 2022; Özdemir, 2024).

At the same time, tackling climate change has become a priority for the aviation industry, as it is responsible for around 2.5% of global CO2 emissions. Emissions associated with aircraft taking off and landing account for the most significant part, i.e., 70% at large airports (ICAO, 2008). The industry is considered to affect the environment in many other ways. It can substantially impact critical environmental factors beyond emissions, such as air quality, noise, biodiversity, water, and waste, among others. (Gössling, Humpe and Sun; 2024).

The aviation industry's transition to a net-zero carbon industry by 2050 requires implementing significant changes with collaboration supported by government policies, adequate financing and investment, new technologies, operational innovation, and organization capacity building (ACI, 2024). In this context, airport ecosystems have a crucial role, given their position in the value chain and ability to connect airlines, passengers, and other stakeholders (ACI, 2023; Gössling, Humpe and Sun, 2024; Gössling and Humpe; 2024).

Airport ecosystems are an interconnected network of internal and external actors that depend on each other to serve the end customer, the passengers. Much of an airport's greenhouse gas (GHG) emissions are not directly due to its operations but are the product of the activities of other participants in the ecosystem, particularly air operators. Airport ecosystems will play a vital role in the sector's decarbonization efforts through the supply of low-carbon fuels. They are beginning to adopt decarbonization strategies to reduce their carbon footprints, starting with emissions directly under their control (ACI, 2024).

In summary, airports and their internal and external stakeholders generate significant carbon emissions from flight operations, ground vehicle use, and on-site energy consumption. They also consume large amounts of resources, such as water, and waste management is a significant challenge. Also, the governments are imposing regulations on environmental sustainability. However, if airports develop sustainable strategies will comply with these regulations avoid penalties, and contribute to a healthier environment. The question then is: What sustainable strategies are being implemented within airport ecosystems, and what related technologies could help drive the transition to “green aviation” while ensuring that these organizations remain competitive? Therefore, this research aims to identify the sustainable strategies implemented in airport ecosystems and the technological developments that could facilitate the transition to "green aviation."

Methodological design

We developed a qualitative research approach anchored in documentary analysis, drawing on the theoretical framework of sustainable strategic management (Stead and Stead, 2004), to analyze sustainable strategies at both competitive and functional levels. Competitive strategies include process (cost advantage and reduced resources depletion) and market opportunities (differentiation of products, services, or processes, and minimizing environmental risk). Functional strategies focus on internal capabilities and processes that enable the organization to operate sustainably.

Strategies pertinent to primary activities are eco-design, total quality environmental management, and environmental marketing. Those related to support activities include total cost accounting, environmental auditing, environmental reporting, Environmental Management Information Systems, and Human Resources Management Systems.

We identify the sustainable strategies and the associated technologies analyzing the reports of airports certified with Level 5 of the *Airport Carbon Accreditation program,* specialized databases such as Scopus and Web of Science for the literature review, official documents issued by non-governmental organizations, and professional services firms offering specialized technology consulting such as KPMG, Deloitte, and McKinsey, The International Civil Aviation Organization (ICAO), the International Air Transport Association (IATA), the World Economic Forum (WEF), and the Airports Council International (ACI). The information gathered from these sources was basic to identify the strategies and technologies employed to achieve the transition to sustainable aviation. Then, we contrasted these results with the theoretical framework to identify competitive and functional strategies and associated technologies.

The Sustainability Index issued by the ACI was selected to ensure the relevance of the study subjects. We used this index to identify airports worldwide that have obtained certification at the highest level of sustainability, Level 5 of the Airport Carbon Accreditation program and to identify sustainable strategies and technologies.

This document is structured as follows: the first section presents the fundamental concepts of Sustainable Strategic Management. Subsequently, it explains how airport ecosystems work and identifies sustainable strategies, practices, and technological developments related to each member. Finally, it presents the results, discusses them, and provides the study's conclusions.

Sustainable Strategic Management and Business Ecosystems

In 1987, the United Nations Brundtland Commission defined sustainability as actions that allow "*meeting the needs of the present without compromising the ability of future generations to meet their own needs."* As sustainability has become more prominent in society, it has become a central concern in the business environment. Senge (2011) describes the growing awareness of sustainability in business as a "profound change in the strategic context" of organizations.

According to Stead and Stead (2004), "Sustainable Strategic Management includes strategic management processes that are economically competitive, socially responsible and in balance with the cycles of nature" (p.6). He presupposes a comprehensive vision of the term, including the survival and renewal of the company, as well as the economic and social systems. Hart (1995), Shrivastava (1996), and Stead and Stead (1995) are pioneers in the study of sustainability strategies and their relationship with competitive advantages. The competitive advantages emanating from the strategies proposed by Porter (1985) have been pointed out, including cost leadership and market differentiation leadership.

Sustainable strategies have been categorized at both the competitive and functional levels. At the competitive level, they are classified based on the nature of their competitive advantages: cost reduction or market opportunities. Hart (1995) subsequently proposed an evolution of these strategies, beginning with pollution prevention processes and progressing to market-driven and management-driven strategies (Stead and Stead, 2004).

a) Sustainability strategies are driven by cost reduction and pollution prevention. From an economic point of view, they seek to achieve cost advantages through environmental efficiency. From an ecological point of view, they seek to reduce resource depletion, material use, energy consumption, emissions, and effluents. Examples of these strategies are creating pollution and waste control systems, redesigning production processes, using recycled materials from the production process or external sources, and using renewable energy. (Stead and Stead, 2004)
b) Market-driven sustainability strategies and product management aim to differentiate products as organic to capture market share from an economic perspective. Ecologically, they advocate minimizing environmental risks and life cycle costs. Examples of these strategies include entering environmental markets, introducing, and redesigning environmentally oriented products, disseminating the environmental benefits of products, and redesigning and recycling product packaging (Stead and Stead, 2004).

Functional strategies can be related to Porter's (1985) value chain activities encompassing both primary activities (inbound logistics, operations, outbound logistics, marketing and sales, and service) as well as support activities (infrastructure, human resources, technology development, and purchasing). Functional-level strategies have focused on eco-efficiency and Life Cycle Assessment (LCA). Strategies pertinent to primary activities are eco-design, total quality environmental management, and environmental marketing. Those related to support activities include total cost accounting, environmental auditing, environmental reporting, Environmental Management Information Systems, and Human Resources Management Systems.

Business ecosystems

Volberda and Lewin (2003) argue that organizations must navigate a complex balancing act. They need to develop structures that generate profits, enhance social, human, and environmental capital, and satisfy customers' needs. This is a challenging task, particularly within the entrepreneurial ecosystem, where the industry is seen as a community of companies that evolve together around some form of innovation or shared vision (Stead and Stead, 2013).

A Business Ecosystem is "an economic community sustained by a base of organizations and individuals that interact. This economic community produces goods and services of value for customers, who are themselves members of the ecosystem. Member bodies include suppliers, leading producers, competitors, and other stakeholders. Over time, they co-evolve their capabilities and roles and tend to align with the directions set by one or more core companies. Companies with leadership roles may change over time. Still, the community values the ecosystem leader role because it allows members to move toward shared visions to align their investments and find mutually supportive roles (Moore, 1996).

Because Sustainable Strategic Management requires the participation of multiple interdependent actors, Business Ecosystems are networks of actors that can collaborate in a transition toward sustainability. In this transition, innovation is necessary to develop products and processes that do not harm the environment, and innovation can arise from collaboration between agents in the ecosystem. Because the ecosystem is more resilient to crises, as members support each other by sharing knowledge and resources, the aim is to ensure the adaptability and long-term viability of the company.

Cooperation between ecosystem organizations goes beyond direct suppliers and buyers and includes all participants in the value-creation community, including stakeholders. They are interdependent in the sense that they co-evolve with each other, leading to a shared destiny (Moore, 1993) or a *"strategic community of destiny"* (Gueguen, Pellegrin-Boucher, & Torres, 2006, cited by Stead and Stead, 2013).

In addition, business ecosystems set standards and encourage accountability, enabling the efficient functioning of the ecosystem.

The airport ecosystem, a complex network where internal and external agents are interconnected (See Figure 1), is a testament to the unity and teamwork within the system. While carrying out distinct activities, these agents collaborate and depend on each other to provide services to the end customer, resulting in various emissions and pollutants. (WEF, 2023).

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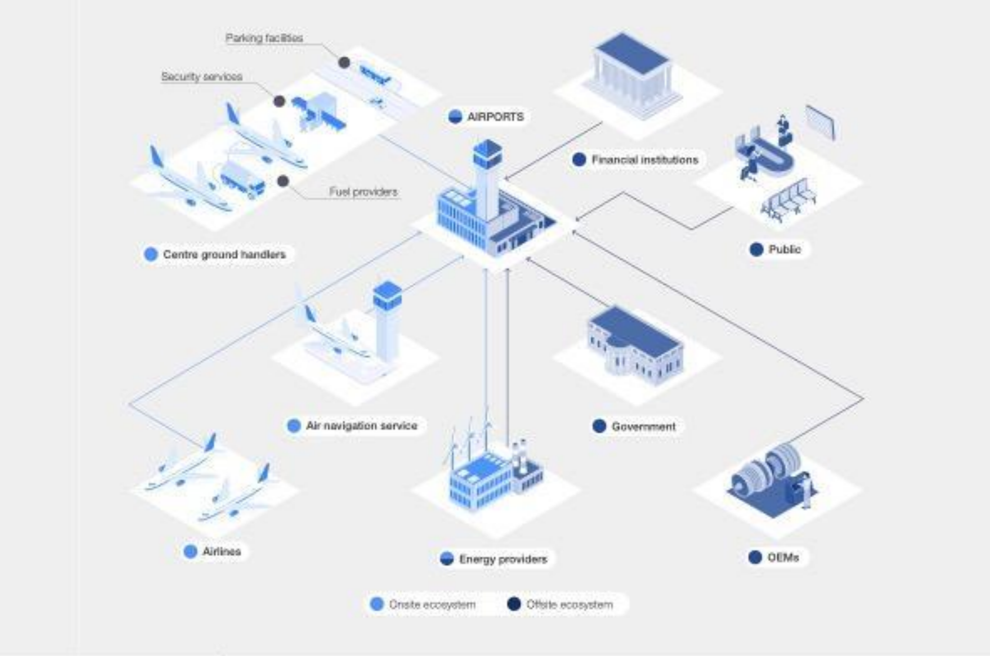
Figure 1: Airport Ecosystems



Source: WEF (2023)

As Figure 1 shows, the airport ecosystem is divided into two main categories: internal and External.

1. *The internal airport ecosystem, which* includes the airport, its retailers and concessionaires, airlines, fuel suppliers, and ground handling service providers, is the backbone of airport operations. Their collective efforts ensure the safety, efficiency, and effectiveness of airport operations, all with the shared goal of serving airport customers (ACI, 2024).
2. *External airport ecosystem:* This includes governments and policymakers who regulate and help finance airport operations. In almost all cases, they are the driving forces of decarbonization efforts. Other important participants include financial institutions and investors financing airport initiatives and institutional investors in airport operations. Finally, local economies play a vital role in this external ecosystem by influencing government policy and providing a market that supports airport operations (ACI, 2024).

The actors described above generate waste and greenhouse gas emissions that must be considered when implementing a decarbonization plan. Specifically, the pollutants generated at airports can be classified into three large categories, which are summarized in Table 1. The emissions generated by end consumers and suppliers are responsible for 97% of pollutants.

Table 1: Pollutants generated at airports

Types of waste	Direct emissions from own or controlled resources	Energy purchased and consumed by the company	Upstream and downstream emissions
Description	It includes emissions from company-owned or company-managed facilities, such as stores, warehouses, and distribution centers, in addition to emissions from company vehicles.	It includes emissions from electricity used in stores, distribution centers, and other facilities.	Covers supplier and consumer emissions

Source: Authors' elaboration with information obtained from WEF (2023)

To reduce the waste generated at airports, international organizations such as the World Economic Forum (World Economic Forum; 2023) have recommended that short-, medium- and long-term strategies be established (See Figure 2), which should consider aspects such as the size of the airport, type of airport (national, international, cargo or tourist) as well as create a collaboration plan with universities and research centers.

Figure 2: Airport strategies for the decarbonization process

Short-term strategies	**Medium-term strategies**	**Long-term strategies**
Establish baseline emissions. Defining the transition plan towards decarbonization.	Implement actions to distribute environmentally friendly fuels (SAF fuels).	Invest in infrastructure for the distribution of new fuels (hydrogen, electricity).

Source: Authors' elaboration with information obtained from WEF (2024)

The Airport Carbon Accreditation is a globally recognized carbon management certification, the only institutionally endorsed global carbon management certification program for airports. It assesses and recognizes airports' efforts to manage and reduce their carbon emissions through 7 levels of certification:

level 1 Mapping, level 2 Reduction, level 3 Optimization, level 3-plus Neutrality, level 4 Transformation, level 4-plus Transition, and Level 5 which is the highest in the Airport Carbon Accreditation program.

> “Setting high standards for airports to significantly reduce their absolute carbon emissions. In addition, airports at this level must

collaborate with their entire ecosystem, including employees, suppliers, business partners, airlines, and other companies and third parties active on the airport site, to significantly contribute to emissions reduction, aligning with the broader Net Zero commitments of the sector. Regular monitoring and assessment are essential to measure progress and ensure transparency (Airport Carbon Accreditation,2024).[1]

Table 3: Sustainable strategies and practices applied in global airports accredited at Airport Carbon Accreditation level 5

Airport	**Sustainable practices Found**	**Technologies used**	**Expected results**
Amsterdam Airport Schiphol in the Netherlands	Introduction of a long-duration energy storage system (LDES). Make the platform's vehicles more sustainable. Produce sustainable jet fuel on a large scale and improve the circular use of materials. Passenger journeys and cargo will also be investigated, as well as the capture of ultrafine particles produced by aircraft on takeoff. Recycling waste to produce energy. Construction of a building for circular economy practices.	Iron flow battery system developed by the company ESS. Use of electric vehicles Construction of a high-voltage substation	It will allow ground operations to be decarbonized. GHG reduction Reduction and eventual elimination of solid waste.
Beja, Madeira and Ponta Delgada airports in Portugal	A few operational improvements have been made to the boarding and disembarking areas and taxiways of the aircraft parking aprons, ensuring smooth operations. Improvements were made on the landside, including the redesign of parking spaces and road access roads. In the airside, a new channel for domestic arrivals (Schengen) was established, with the possibility of a passenger transfer circuit.	Use of Biometric Data Artificial intelligence	Implementation of biometrics to speed up access to the plane's last waiting and boarding rooms. Artificial intelligence is used to collect and process real-time data on the cleanliness of facilities, frequency of use of toilets and waste management. Robotics is also used through a humanoid who provides information to passengers, to send them to the correct baggage carousel after identifying their flight, etc.

[1]https://www.airportcarbonaccreditation.org/about/7-levels-of-accreditation/level-5/

Airport	Sustainable practices Found	Technologies used	Expected results
Toulon – Hyères airport in France	Implementation of an energy-saving policy (presence detectors, temperature set points, etc.). Replacement of terminal lighting and aircraft parking with LEDs; Replacement of an oil boiler with heat pumps. The use of electric or biofuel-powered ramp vehicles; and The signing of a guaranteed renewable electricity contract.	Artificial intelligence Renewable energy sources for aircraft and airport facilities Electric Vehicles	Supply of sustainable aviation biofuels (SAF), Implementation of an eco-modulation of landing fees linked to CO2 emissions from aircraft to encourage airlines to equip themselves with lower-emission aircraft. The supply of decarbonized electricity to aircraft and the installation of electric vehicle charging stations for passengers.
Christchurch Airport in New Zealand	The dismantling of our latest oil and LPG boilers. The conversion of our entire fleet of corporate vehicles to electric vehicles. Implementation of ground power units (GPUs) at all our jet aircraft bases. Autonomous vehicle programs and car-sharing systems such as Electric Day Pass and Zilch.	Artificial intelligence Renewable energy sources for aircraft and airport facilities Electric Vehicles SAF Fuels	By minimizing energy consumption, you can reduce your carbon footprint, business costs, and demand on the national grid.
Göteborg Landvetter and Malmö airports in Switzerland	Implementation of curved approaches (new routes)	Artificial intelligence	An important measure to reduce aviation noise and air emissions is the continuous work to develop the possibility of making curved approaches. The use of the new flight path system and curved approaches offers more opportunities to avoid flying over densely populated areas.

Source: Own elaboration with information obtained from Airport Council International (2024); Schipol Airport (2024); Aeroportos de Portugal (2022); Toulon Hyères airport (2024); Christchurch Airport (2024); Göteborg Landvetter Airport (2023).

As seen in Table 3, airports with level 5 certification went from implementing action plans to reduce the emission of pollutants to establishing practices using technological advances. These practices range from investments in infrastructure to improve airport conditions, waste recycling, use of electric or shared vehicles to investing in creating SAF fuels and making the necessary changes to store and distribute such fuels.

It also underscores the pivotal role of artificial intelligence in capturing and processing large amounts of data. This technological advancement not only allows for the creation of new routes but also contributes to the industry's commitment to reducing noise pollution. The use of *bots* and biometrics as common practices in airport facilities not only increases security but also enhances the passenger experience, demonstrating the industry's dedication to environmental sustainability and customer satisfaction.

According to the Airport *Carbon Accreditation* report (2022-2023), 498 airports worldwide are accredited as "sustainable airports," which have implemented specific actions aimed at achieving "green aviation." However, it is impossible to meet the objective of decarbonization in air transport if the strategies do not consider both public and private actors that are part of airport ecosystems. Therefore, the following section identified and detailed some implemented sustainable practices and adopted or suggested technologies.

Internal and external actors in the airport ecosystem

In the previous section, we explored the practices of some of the members of the airport ecosystems. One of the key commitments of air transport is to achieve 'green aviation' by 2050 through the decarbonization of the industry. The strategies we describe have the potential to significantly impact the industry, from the design, production, and manufacturing processes to the operation of aircraft and the provision of services to airline users, offering a hopeful vision for the future.

Tables 4 and 5 summarize the strategies and associated technologies found when reviewing specialized databases, official documents issued by non-governmental organizations, and specialized technology consultancies such as KPMG, Deloitte, and McKinsey.

Table 4: Sustainable Strategies and Practices in the Domestic Airport Ecosystem: Airlines and Ground Services

Organization	Short-term strategies	Medium-term strategies	Applicable technologies	Description
Airlines	Establish emission reduction commitments. Increase operational efficiency (e.g., improve flight routes).	Execute emission reduction projects. Investment in the development of new technologies	SAF Fuels[2] Acquiring lighter aircraft Artificial intelligence	A large part of the pollutants generated originate in the operation of aircraft; therefore, it is suggested to acquire lighter aircraft whose fuel is considered sustainable (electricity, hydrogen, through processing waste). Regarding the improvement of operational efficiency, it is suggested to adopt technologies associated with artificial intelligence, which can be used to process large amounts of data and implement changes in organizations based on the information collected.
Ground Services	Establish emission reduction commitments.	Implement emission reduction projects: electrification of vehicles, reduction of emissions from employee transport; recycling waste.	Electric Vehicles Infrastructure to store and supply SAF fuels	Using electric vehicles to provide passenger, employee, and baggage transfer services at airport facilities can reduce the carbon footprint generated in some basic operations.

Source: Authors' elaboration with information obtained from WEF (2023)

[2] SAF or "Sustainable Aviation Fuel" are fuels used in aircraft to reduce the impact of aviation on the atmosphere. To be considered SAF, a fuel must reduce its greenhouse gas emissions by 50 to 60% and its raw material must be from land and techniques that do not affect diversity.

Within the airport ecosystem, the starting point is to establish commitments and action plans to reduce emissions. It is suggested that the adoption of technologies already available on the market, such as electric vehicles, will improve the decarbonization of air transport. However, the participation of actors outside the airport ecosystem, such as aircraft manufacturers or the government, is still needed in the formulation of public policies or in providing the necessary financing to implement the actions (See Table 5).

Table 5: Sustainable strategies and practices in the external airport ecosystem

Organization	Short-term strategies	Medium-term strategies	Applicable technologies	Description
Financial institutions	Establish commitments to finance the transition to decarbonization. Publish a sustainable financing framework.	Offer conventional debt financing (e.g., A-term loans, bond issuance)/refinancing. Offer and commit to increasing the supply of green/sustainable bond investments. Require clients to establish and implement science-based transition plans.	Artificial Intelligence to Analyze the Market	Making a change towards sustainability requires a large investment, as an alternative for organizations to commit to this purpose is to have financial institutions that support the development or acquisition of sustainable technologies, or the implementation of practices aimed at reducing pollutants.
Government-public policy makers	Establish "green" or "green" laws and standards. Set a carbon tax/carbon tariff. Offer loan guarantees.	Offer investment aid. Tax and capital incentives for carbon reduction projects.	Artificial intelligence to analyze and control companies and the results of their public policies.	As a starting point, the implementation of fiscal incentives that support the implementation of sustainable practices in organizations is useful. Promoting the development of laws and regulations associated with the adoption of sustainable practices, as is the case of the Circular Economy Law, is an important part of the transition to sustainability.

Organization	Short-term strategies	Medium-term strategies	Applicable technologies	Description
Aircraft assemblers (OEMs)	Establish research projects in new SAF materials and fuels.	Generate prototypes for new aircraft designs.	Additive Manufacturing Artificial intelligence Swapping internal combustion engines for electric or hydrogen engines.	In the search to reduce the generation of greenhouse gases during the operation of aircraft, assemblers are looking for new designs, as well as the implementation of lighter materials and new fuels. Due to the structure of the industry itself, these changes will have repercussions throughout the global value chain by requiring suppliers to adhere to the new requirements of OEMs.

Source: Authors' elaboration with information obtained from WEF (2023)

Effective coordination of the actors in the airport ecosystem is a key step towards sustainable air transport. Equally important is the formulation of public policies that encourage and support the transition towards decarbonization. However, it is the availability of financing that fuels progress, promoting research, technological developments, and the acquisition of machinery, equipment, and personnel training.

Technology can drive sustainability across the aviation ecosystem in many ways (ACI, 2023). For example, artificial intelligence can help collect and interpret data to understand the impact of operations on both the ground and in the air. In terms of aircraft production, it can be supported by identifying supply chain issues and developing simulations using "digital twins." There is also great potential in the adoption of renewable energies, the use of electric vehicles and the adaptation of infrastructures, which will reduce energy consumption in buildings, minimize waste in terminals, optimize the use of fuel by aircraft and vehicles, improve air quality in operations and, in general, to improve airport operations and the passenger experience sustainably. (ACI, 2023)

Results and discussion

Among the findings is that in the airports analyzed, functional strategies have focused on eco-efficiency and life cycle assessment (LCA). Strategies related to primary activities are eco-design, total quality environmental management and environmental marketing. Those related to supporting activities are full cost accounting, environmental auditing, environmental reporting, environmental management information systems and human resource management systems.

Table 6 presents the ranking of the sustainable strategies of five airports at the competitive level as proposed by Stead and Stead (2004). Most of the airports with "level 5" certification have implemented strategies associated with the carbon footprint reduction by using technologies related to the generation and use of renewable energies and the use of waste, such as food, for fuel generation. In this sense, minimize energy consumption can reduce the carbon footprint of the national grid, business costs and demand, thus gaining a cost advantage and reducing resource depletion.

In the same picture, to achieve market opportunities, "level 5" certified airports have implemented strategies that improve the user experience by using artificial intelligence and the design of new routes. Environmental risks are minimized by implementing activities for proper waste management (recycle, reuse, transform) also CO2 emissions have been reduced through better management of aircraft landings reducing noise pollution.

Table 6: Classification of sustainable strategies of five airports.
Competitive level according to the proposal of Stead and Stead (2004)

	Processes		**Market opportunities**	
Airports certification 5	**Cost Advantage**	**Reduce resource depletion**	**Differentiate product**	**Minimizing environmental risks**
Amsterdam Airport Schiphol in the Netherlands	Reduction of costs associated with energy consumption.	Search for new ways to obtain fuels by replacing jet fuel, which is a petroleum derivative.		Reduction and eventual elimination of solid waste. Decarbonize ground operations.
Beja, Madeira and Ponta Delgada airports in Portugal	Cost reduction by optimizing ground operations.	Improvements in the use and treatment of water.	Real-time monitoring of facility cleanliness, improving the user experience.	Improvements in waste management.
Toulon – Hyères airport in France	Reduction in costs through the implementation of energy-saving policies.	Use of electric vehicles	Installation of charging centres for electric vehicles in areas used for passengers.	Reduction of CO2 emissions in aircraft operation through landing management.
Christchurch Airport in New Zealand	Cost reduction through the use of	The last diesel and LPG boilers		

	shared and electric vehicles.	were dismantled.		
Göteborg Landvetter and Malmö airports in Switzerland			Implementation of new routes.	Reduction of noise pollution.

Fountain. Prepared from tables 2, 3, 4 and 5 of this document; and with information obtained from Airport Council International (2024); Schipol Airport (2024); Aeroportos de Portugal (2022); Toulon Hyères airport (2024); Christchurch Airport (2024); Göteborg Landvetter Airport (2023)

It is concluded that the strategies aim to achieve cost advantages through enhanced environmental efficiency and by mitigating resource depletion and energy consumption. However, there is a need to report comprehensive pollution and waste control systems or redesigned production processes. Observations indicate the presence of market-driven sustainability strategies and product management practices, particularly new routes that conserve energy and avoid overflying urban areas to minimize noise. These strategies are designed to differentiate the service as environmentally friendly to capture specific market segments.

Table 7 presents the classification of sustainable strategies in five airports at the functional level according to the proposal of Stead and Stead (2004). Functional and Service strategies are explained in Porter's value chain (1985) activities. Functional strategies include inbound logistics, operations, outbound logistics, marketing, and sales, and service strategies include infrastructure, human resources, technology development, and purchasing.

Table 7: Classification of sustainable strategies in five airports at the functional level according to the proposal of Stead and Stead (2004)

	Functional level and value chain	
Airports certification 5	Sustainable strategies related to primary activities	Sustainable strategies related to enabling activities
Amsterdam Airport Schiphol in the Netherlands	Marketing: Creation of new flight routes for passengers and cargo. Operations: producing and using sustainable aircraft fuel on a large scale and improving the circular use of materials.	Infrastructure: Construction of infrastructure to obtain renewable energy and reuse waste. Electric Vehicle Purchases
Beja, Madeira and Ponta Delgada airports in Portugal	Services: Use of biometrics in the identification of	Infrastructure: to streamline ground operations.

	Functional level and value chain	
Airports certification 5	Sustainable strategies related to primary activities	Sustainable strategies related to enabling activities
	personnel and access to the last waiting rooms. Services: Use of artificial intelligence to provide information to passengers. Services: speed up the arrival and transit of passengers.	Use of artificial intelligence to collect and process real-time data on the cleanliness of facilities, frequency of use of toilets and waste management.
Toulon – Hyères airport in France	Operations: Use of renewable energy sources for aircraft and airport facilities. Operations: implementation of the use of SAF fuels Operations: Use of electric vehicles	Shopping: Electric vehicles Incentives for airlines to acquire fewer polluting aircraft.
Christchurch Airport in New Zealand	Operations: Use of autonomous vehicles. Services: car-sharing systems. Operations: Implementation of the use of SAF fuels.	Infrastructure: Investment in infrastructure to obtain renewable energy.
Göteborg Landvetter and Malmö airports in Switzerland	Marketing. Using artificial intelligence to create new flight paths.	

Fountain. Prepared from tables 2, 3, 4 and 5 of this document; and with information obtained from Airport Council International (2024); Schipol Airport (2024); Aeroportos de Portugal (2022); Toulon Hyères airport (2024); Christchurch Airport (2024); Göteborg Landvetter Airport (2023)

It is found that strategies within the value chain focus on primary activities: operations, services, and marketing. It includes the use of SAF fuel, marketing with new routes, and services using biometric data that speed up the operation and make it safer. The acquisition and use of electric vehicles (for passengers, personnel, and transportation of goods and baggage) is essential and can be considered within operations and as a supporting activity. In the support activities, the construction of infrastructure and purchases stand out. Investments in infrastructure will allow the generation and supply of renewable energies such as electricity or biofuels in the medium and long term.

Conclusion

The aim of this research was to identify the sustainable strategies implemented in airport ecosystems, as well as the technological developments that could facilitate the transition to "green aviation".

Strategies associated with primary activities encompass total quality environmental management and environmental marketing. Regarding support activities, we found strategies involved the development of infrastructure that benefits the ecosystem. However, the reports identified no Environmental Management Information Systems or Human Resources Management Systems with sustainable tendencies. At the functional level, strategies aim for eco-efficiency, yet Life Cycle Analysis (LCA) still needs to be reported.

Among the technological developments used to facilitate the transition to a sustainable airport ecosystem that contributes to achieving green aviation are built plants for the storage of sunlight energy, the adoption of electric vehicles, and the implementation of artificial intelligence to collect and process information in real-time, humanoid robots in the provision of information services to passengers, use of biometrics to improve and speed up the user experience, as well as reduce the use of paper.

Achieving the goal of obtaining "green aviation" is not easy. It requires the participation of the different actors in the airport ecosystem, which must integrate specific actions into their strategies to achieve this goal gradually.

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References:

1. ACI. (2023). The twin transition playbook. Aviation version. Publications Department ACI World
2. ACI. (2024). Guidance on Airport Decarbonization. Publications Department ACI World
3. ACI. (2024b). Airport Carbon Footprint Accreditation Program. https://aci-lac.aero/acreditacion-de-carbono-del-aeropuerto/

4. Airports of Portugal. (2023). Sustanability Report 2022. https://www.ana.pt/sites/default/files/2023-09/ANA_RS_ING03_25.09.2023.pdf
5. Airport Council International (ACI). (2024). Airport Carbon Accreditation: Annual Report 2022 – 2023. https://www.acieurope.org/downloads/resources/AIRPORT%20CARBON%20ACCREDITATION%20ANNUAL%20REPORT%202022-2023.pdf
6. Carlucci, F.; Coccorese, P.; Cirà, A. (2018). Measuring and explaining airport efficiency and sustainability: Evidence from Italy. *Sustainability*, *10*, 400.
7. Christchurch Airport. (2024). Focus on climate. https://www.christchurchairport.co.nz/about-us/sustainability/climate/
8. David, F.R. (2013). *Strategic management: concepts and cases*. London: Pearson Higher Education. SBN 978-0-13-612098-8.
9. Flier, B., Van Den Bosch, F. A. J., & Volberda, H. W. (2003). Co-evolution in strategic renewal behaviour of British, Dutch and French financial incumbents: Institutional effects and managerial intentionality. *Journal of Management Studies*, *40,* 2163-2187.
10. Gössling, S. , Humpe, A. , Sun, Y.-Y. (2024). Are emissions from global air transport significantly underestimated? Current Issues in Tourism. DOI 10.1080/13683500.2024.2337281
11. Gössling, S. and Humpe, A. (2024). Net-zero aviation: Transition barriers and radical climate policy design implications. Science of the Total Environment. Volume 912. DOI 10.1016/j.scitotenv.2023.169107
12. Göteborg Landvetter Airport. (2023). Environment. https://www.swedavia.com/landvetter/miljo/
13. ICAO. (2008). La aviación y el medio ambiente. Revista de la OACI. 63 (4). https://www.icao.int/publications/journalsreports/2008/6304_es.pdf
14. Iansiti, M., & Levien, R. (2004a). Strategy as ecology. *Harvard Business Review, 82*(3), 68-78.
15. Iansiti, M., & Levien, R. (2004b). *The keystone advantage*. Boston, MA: Harvard Business School Press.
16. Lampel, J., & Shamsie, J. (2003). Capabilities in motion: New organizational forms and the reshaping of the Hollywood movie industry. *Journal of Management Studies*, *40*, 2190-2210.
17. Lewin, A. Y., & Volberda, H. W. (1999). Prolegomena on coevolution: A framework for research on strat- egy and new organizational forms. *Organization Science*, *10*, 519-534.

18. Lewin, A. Y., & Volberda, H. W. (2003a). Beyond adaptation and selection research: Organizing self-renewal in co-evolving environments. *Journal of Management Studies*, *40*, 2109-2110.
19. Lewin, A. Y., & Volberda, H. W. (2003b). The future of organization studies: Beyond the selection-adaptation debate. In H. Tsoukas & C. Knudsen (Eds.), *The Oxford handbook of organization theory* (pp. 568-595). New York, NY: Oxford University Press.
20. Lewin, A. Y., Long, C. P., & Carroll, T. N. (1999). Coevolution of new organizational forms. *Organization Science*, *10*, 535-553.
21. Lytvynenko, S., Petrenko, O., Luchnikova, T., Vysochylo, O., & Kutsenko, M. (2023). Transformation of strategic management principles of air transport and logistics enterprises in conditions of instability. Operation and Economics in Transport
22. Moore, James (1996). The Death of Competition: Leadership and Strategy in the Age of Business Ecosystems / J.F. Moore. Harper Business, p.134. https://www.researchgate.net/publication/31744644_The_Death_of_Competition_Leadership_and_Strategy_in_the_Age_of_Business_Ecosystems_JF_Moore
23. Moore, J. F. (1993). Predators and prey: A new ecology of competition. *Harvard Business Review*, *71*(3), 75-86.
24. Moore, J. F. (1996). *The death of competition: Leadership and strategy in the age of business ecosystems*. New York, NY: Harper Business.
25. Moore, J. F. (2006). Business ecosystems and the view from the firm. *Antitrust Bulletin*, *51*, 31-75.
26. Omalaja, M. A., Eruola, O. A. (2011). Strategic management theory: concepts, analysis in relation to corporate competitive advantage from the resource based *Philosophy*. *Economic Analysis* [online] 44(1-2), p. 59-77. ISSN 1821-2573, eISSN 2560-3949. Available from: https://www.library.ien.bg.ac.rs/index.php/ea/article/ view/194/190
27. Özdemir, M.H. (2024). Productivity and strategy: A study on airports. Smart and Sustainable Operations Management in the Aviation Industry: A Supply Chain 4.0 Perspective, pp. 15–28. DOI 10.1201/9781003389187-2
28. UN. (2020). Sustainability. https://www.un.org/es/impacto-académico/sostenibilidad
29. Porter, M. E. (1985). The Competitive Advantage: Creating and Sustaining Superior Performance. NY: Free Press
30. Quadros, R.C., Barqueira, A. and Abrantes, J. (2024). COVID-19 disruption on tourism-aviation in Madeira. Strategic Management and Policy in the Global Aviation Industry, pp. 71–92. DOI 10.4018/979-8-3693-0908-7.ch005

31. Schipol Airport. (2024). Moving towards sustainable aviation. https://www.schiphol.nl/en/schiphol-group/page/a-sustainable-future/
32. Senge, P. M. (2011). *Educating leaders for a sustainable future*. Paper presented at the AACSB Sustainability Conference, Charlotte, NC.
33. Stead, J. and Stead, E. (2013). The Coevolution of Sustainable Strategic Management in the Global Marketplace. Organization & Environment 26(2) 162–183
34. Stead, W.E. and Stead, J.G. (1995) 'An empirical investigation of sustainability strategy implementation in industrial organizations', in D. Collins and M. Starik (Eds). Research in Corporate Social Performance and Policy, Supplement 1, Greenwich, CT: JAI Press, pp.43–66.
35. Stead, W.E. and Stead, J.G. (2004) Sustainable Strategic Management, Armonk, NY: M.E. Sharpe.
36. Toulon Hyères Airport. (2024). Sustainable development Toulon Hyeres airport's commitments. https://www.toulon-hyeres.aeroport.fr/en/sustainable-development
37. Volberda, W., & Lewin, A. Y. (2003). Coevolutionary dynamics within and between firms: From evolution to coevolution. *Journal of Management Studies*, *40*, 2111-2136.
38. World Bank Group. (2022). Air Transport. https://www.worldbank.org/en/topic/transport/brief/airtransport#:~:text=Air%20transport%20is%20an%20important,tourism%2C%20and%20create%20employment%20opportunities.
39. World Bank Group. (2023). Air Transportation. Annual Report 2022. Transport Global Practices. https://documents1.worldbank.org/curated/en/099614406122338723/pdf/IDU07cdd3e27044ec0491f089250038d36dc0460.pdf
40. World Economic Forum (2023). Financing The Airports Of Tomorrow: A Green Transition Toolkit.