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Balancing Airport Development and Environmental Sustainability: A Qualitative Study of Stakeholder Perspectives on Istanbul Airport

Havalimanı Gelişimi ve Çevresel Sürdürülebilirlik Dengesi: İstanbul Havalimanı Hakkında Paydaş Görüşlerine Dayalı Nitel Bir Çalışma

Tuncel ÖZ[1]

ABSTRACT

This study examines the balance between airport development and environmental sustainability at Istanbul Airport, a major global aviation hub facing significant ecological challenges. Using qualitative data from semi-structured interviews with eight experts across airport operations, environmental engineering, regulatory compliance, and sustainability analysis, alongside industry reports and policy documents, this research provides a comprehensive assessment of the airport's sustainability strategies. Thematic analysis, co-occurrence mapping using NVivo, and sentiment analysis via Python's TextBlob were employed to identify key concerns, interconnections, and stakeholder sentiments. Findings reveal that deforestation, biodiversity loss, air and noise pollution, and weak regulatory enforcement remain critical sustainability challenges, while renewable energy integration, AI-driven efficiency improvements, and waste management initiatives have shown positive progress. However, economic constraints and policy inconsistencies limit the effectiveness of sustainability measures. This study's novelty lies in its multi-method approach, integrating expert insights with document analysis to cross-validate findings. The research underscores the need for stronger policy enforcement, stakeholder collaboration, and financial incentives for sustainable aviation fuel to achieve long-term sustainability goals. By aligning with best practices from global airports, Istanbul Airport can enhance its environmental performance while maintaining its strategic growth trajectory.

Key Words: Airport Sustainability, Environmental Impact, Stakeholder Perspectives, Sustainable Aviation, Istanbul Airport

ÖZ

Bu çalışma, önemli bir küresel havacılık merkezi olan İstanbul Havalimanı'nda havalimanı gelişimi ile çevresel sürdürülebilirlik arasındaki dengeyi incelemektedir. Havalimanı operasyonları, çevre mühendisliği, düzenleyici uyumluluk ve sürdürülebilirlik analizi alanlarında çalışan sekiz uzmandan alınan yarı yapılandırılmış görüşmeler ile endüstri raporları ve politika belgelerinden elde edilen nitel veriler kullanılarak, havalimanının sürdürülebilirlik stratejileri kapsamlı bir şekilde değerlendirilmiştir. NVivo kullanılarak eş oluşum haritalama analizi, Python'un TextBlob kütüphanesi ile duygu analizi ve tematik analiz yöntemleri uygulanarak temel endişeler, bağlantılar ve paydaş görüşleri belirlenmiştir. Bulgular, orman tahribatı, biyolojik çeşitlilik kaybı, hava ve gürültü kirliliği ile zayıf düzenleyici uygulamaların önemli sürdürülebilirlik zorlukları olarak öne çıktığını, ancak yenilenebilir enerji entegrasyonu, yapay zeka destekli verimlilik iyileştirmeleri ve atık yönetimi girişimlerinin olumlu ilerleme kaydettiğini göstermektedir. Bununla birlikte, ekonomik kısıtlamalar ve politika tutarsızlıkları sürdürülebilirlik önlemlerinin etkinliğini sınırlamaktadır. Çalışmanın özgünlüğü, uzman görüşleri ile belge analizini birleştirerek bulguları çapraz doğrulayan çoklu yöntem yaklaşımında yatmaktadır. Araştırma, daha güçlü politika uygulamaları, paydaş iş birliği ve sürdürülebilir havacılık yakıtı için finansal teşvikler gerekliliğini vurgulayarak, İstanbul Havalimanı'nın küresel havalimanlarından en iyi uygulamaları benimseyerek çevresel performansını artırabileceğini ve stratejik büyüme hedeflerini sürdürülebilir bir şekilde gerçekleştirebileceğini ortaya koymaktadır.

Anahtar Kelimeler: Havalimanı Sürdürülebilirliği, Çevresel Etki, Paydaş Görüşleri, Sürdürülebilir Havacılık, İstanbul Havalimanı

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INTRODUCTION

The global aviation industry has witnessed rapid expansion over the past two decades, positioning airports as critical nodes in international transportation networks. This expansion has supported economic growth, enhanced connectivity, and facilitated trade and tourism. However, the development of large-scale airport infrastructure has also generated growing concerns regarding environmental sustainability. Airports are recognized as among the most resource-intensive infrastructures, with substantial demands on land, energy, and water, as well as significant contributions to carbon emissions, air and noise pollution, and ecological degradation (Greer et al., 2020; Santa et al., 2020). In response, many international airports have implemented sustainability frameworks to mitigate their environmental footprint while maintaining operational efficiency and competitiveness.

As one of the world's most ambitious airport projects, Istanbul Airport exemplifies the dual challenge of pursuing infrastructural growth while adhering to environmental sustainability principles. Strategically located between Europe, Asia, and the Middle East, Istanbul Airport serves as a major international hub with a growing number of annual passengers and cargo volume. However, its construction required the clearance of approximately 76.5 km² of forested land in the Northern Forests of Istanbul, leading to widespread deforestation, biodiversity loss, and the destruction of wetlands and aquatic habitats (The Ecologist, 2023; I-SEM, 2023). Additionally, the airport's operational activities contribute to increasing levels of carbon emissions, noise, and water pollution, raising concerns among local communities, environmental groups, and regulatory authorities.

While the airport has implemented several sustainability initiatives—such as advanced wastewater recycling systems, renewable energy integration, electrification of ground support equipment, and waste management programs—questions remain about their adequacy, effectiveness, and alignment with global environmental goals (Ceken, 2025; Mizrak et al., 2024). Moreover, challenges such as inconsistent regulatory enforcement, economic trade-offs, limited adoption of Sustainable Aviation Fuel (SAF), and gaps in community engagement hinder the realization of a robust sustainability vision.

Addressing a critical theoretical and empirical gap, this research centres on contextual, stakeholder-based evaluations of airport sustainability in the Global South. Much of the existing literature emphasizes quantitative indicators, top-down policy reviews, or environmental benchmarks, yet rarely includes bottom-up perspectives—particularly within emerging economies where sustainability initiatives often lag infrastructure growth. The contribution here lies in its qualitative, multi-method approach, directly integrating insights and lived experiences of professionals involved in managing, regulating, and monitoring sustainability at Istanbul Airport. By shifting the analytical lens from prescriptive frameworks to real-world implementation barriers, it reveals how sustainability is understood, contested, and negotiated across different institutional levels.

The main aim is to explore how key stakeholders perceive and evaluate the environmental impacts, sustainability strategies, and institutional challenges associated with the airport's development and operations. The inquiry is driven by the following research questions:

RQ1: What are the key environmental impacts associated with the development and operation of Istanbul Airport as perceived by stakeholders?

RQ2: How effective do stakeholders consider the airport's existing sustainability strategies to be in addressing environmental concerns?

RQ3: What challenges and institutional barriers hinder the advancement of sustainability at the airport?

RQ4: What strategies and recommendations do stakeholders propose to enhance the long-term environmental performance of the airport?

To explore these questions, a qualitative research design was employed, grounded in semi-structured interviews with eight experts across domains including airport operations, environmental engineering, regulatory compliance, waste management, aviation policy, and sustainability analysis. Thematic coding and co-occurrence mapping using NVivo were combined with sentiment classification via Python's Text Blob library. This methodological integration provides a triangulated perspective, enhancing analytical rigor and offering a novel blend of qualitative insight and computational analysis in the context of sustainable airport governance.

Findings point to meaningful progress in areas such as renewable energy adoption, AI-supported efficiency gains, and recycling initiatives. However, stakeholders remain concerned about persistent issues like forest ecosystem destruction, biodiversity loss, weak enforcement of environmental regulations, and lack of incentives for SAF uptake. The analysis further highlights the need for more coordinated policy implementation, transparent accountability mechanisms, and inclusive decision-making processes. Conceptually, this stakeholder-driven lens helps expose the institutional frictions that stall sustainability transitions—especially in rapidly expanding aviation markets. On a practical level, the resulting recommendations aim to support more effective environmental governance for Istanbul Airport and other similar mega-infrastructure projects.

The remainder of this paper is structured as follows: Section 2 presents a comprehensive review of the literature on airport sustainability, infrastructure development, and stakeholder engagement. Section 3 outlines the research methodology, detailing the sampling rationale, data collection, and analysis tools. Section 4 presents the findings, organized around thematic categories and co-occurrence patterns. Section 5 offers a comparative discussion informed by global case studies, and Section 6 concludes with policy recommendations and directions for future research.

1. Literature Review

This section critically reviews the existing literature on airport sustainability, focusing on the intersection of large-scale infrastructure development and environmental responsibility. It examines how global airports manage environmental impacts—such as land use change, carbon emissions, noise, and waste—while striving to meet operational and economic goals. The review is organized around three thematic pillars: (i) sustainability practices in the aviation industry, (ii) governance and regulatory frameworks for airport environmental management, and (iii) Istanbul Airport as a case study of a mega infrastructure project in an emerging economy. Key concepts such as sustainable infrastructure, airport development, environmental impact, stakeholder engagement, and sustainable aviation fuel (SAF) are addressed through recent peer-reviewed studies. The literature was gathered from academic databases including Scopus, Web of Science, and ScienceDirect, covering publications predominantly from the 2015–2025 period to ensure topical relevance.

1.1 Sustainability in the Aviation Sector

Sustainability in the aviation sector has become a critical area of focus as the industry seeks to reduce its environmental footprint while maintaining operational efficiency and economic viability. Global sustainability frameworks such as the International Civil Aviation Organization (ICAO) policies, the Airports Council International's (ACI) Airport Carbon Accreditation program, and the United Nations

Sustainable Development Goals (UN SDGs) have played instrumental roles in guiding aviation stakeholders toward more sustainable practices. The integration of energy efficiency, carbon reduction strategies, and waste management initiatives is now central to sustainable aviation. However, the industry continues to face significant challenges, particularly in achieving decarbonization while balancing economic and social sustainability. Leal Filho et al. (2023) emphasize that while carbon mitigation policies are improving, inconsistent global regulations and financial constraints remain major obstacles. Furthermore, Nazeer et al. (2024) demonstrate that sustainable supply chain adaptability and alignment with regulatory frameworks significantly influence long-term aviation sustainability. Qiu et al. (2021) highlight that an integrated support system combining environmental policies, green aviation infrastructure, and technological advancements is necessary to sustain long-term environmental improvements in the sector.

One of the most significant developments in aviation sustainability is the emergence of Sustainable Aviation Fuel (SAF), which has been identified as a key strategy for reducing carbon emissions. SAF, derived from renewable sources such as biomass, waste oils, and synthetic processes, has the potential to cut lifecycle carbon emissions by up to 80% compared to conventional jet fuel (Gonzalez-Garay et al., 2022; Ansell, 2023). Despite this promise, SAF faces numerous barriers, including high production costs, limited supply chains, and the need for policy incentives to encourage large-scale adoption. Lau et al. (2024) highlight that while SAF adoption has increased, infrastructure limitations and feedstock scarcity present critical bottlenecks. Additionally, Sharno and Hiloidhari (2024) explore the social sustainability aspect of SAF, arguing that sustainable fuel programs must address labour rights, community engagement, and fair supply chain practices to be truly viable. Current research underscores the role of government policies and private sector investments in accelerating SAF deployment, with several countries implementing mandates and incentives to increase production and distribution capacity (Lau et al., 2024; Albano et al., 2024). However, concerns remain regarding feedstock availability, land-use implications, and the overall environmental impact of SAF production, necessitating a holistic approach to fuel sustainability.

In addition to SAF, circular economy principles have been increasingly applied to aviation operations to enhance resource efficiency and waste management. Khalifa et al. (2024) emphasize that the aviation industry has begun integrating circularity by repurposing waste materials, optimizing aircraft maintenance procedures, and exploring recycling and remanufacturing techniques. One of the primary areas of improvement lies in aircraft end-of-life strategies, where the dismantling and recycling of retired aircraft can contribute to significant material recovery. Albano et al. (2024) found that while life cycle inventory analysis in aviation is improving, significant data gaps still exist, particularly in assessing the environmental impact of aircraft disposal. Achieving full circularity in aviation requires a systemic transformation in supply chain processes, supported by stronger regulatory frameworks and industry-wide collaboration. Moreover, digital transformation and artificial intelligence (AI) are playing a role in optimizing aviation sustainability by improving predictive maintenance, reducing fuel consumption, and enhancing operational efficiencies, particularly in post-COVID recovery strategies (Trivedi et al., 2024).

Carbon reduction remains a core objective in aviation sustainability, with airlines and airports adopting aggressive strategies to cut greenhouse gas emissions. The ACI's Airport Carbon Accreditation program has incentivized airports to commit to net-zero emissions, with many global hubs integrating renewable energy solutions such as solar and wind power to reduce their reliance on fossil fuels (Al Sarrah et al., 2021). Aircraft manufacturers have also focused on designing next-generation, fuel-efficient aircraft with improved aerodynamics and hybrid-electric propulsion systems to enhance energy efficiency. Research suggests that technological advancements in aircraft design, coupled with improvements in air traffic management and operational efficiencies, could lead to a 30-50% reduction in aviation-related carbon emissions by 2050 (Ansell, 2023). However, achieving these targets will require stronger policy enforcement, substantial investment in research and development, and greater

coordination between regulatory bodies and industry players. Nazeer et al. (2024) argue that agility and alignment within aviation supply chains directly affect emissions reduction outcomes, as greater synchronization between technology adoption and regulatory compliance fosters more effective carbon management.

Beyond environmental sustainability, social sustainability has become an increasingly important dimension in aviation. The concept of workforce diversity and gender inclusion, particularly the role of women in aviation, has gained attention as an avenue for enhancing overall industry sustainability. Corazza (2024) explores how increasing female participation in aviation roles—ranging from pilots to top-level executives—can contribute to more inclusive decision-making and drive innovative sustainability solutions. Leal Filho et al. (2023) further support this by demonstrating that diversified leadership teams in aviation companies tend to implement more robust environmental and social sustainability policies. In addition to workforce inclusivity, community engagement and corporate social responsibility (CSR) initiatives have emerged as key components of sustainable aviation. Airlines and airports are increasingly investing in CSR programs that focus on local community development, noise pollution mitigation, and climate adaptation measures to improve their environmental and social impact (Zieba & Johansson, 2022).

Waste management in aviation has also seen significant advancements, with airlines and airports implementing measures to minimize waste generation and enhance recycling efforts. Albano et al. (2024) highlight that life cycle assessments (LCAs) are becoming an essential tool for evaluating the environmental impact of aviation operations, from fuel consumption to aircraft maintenance and waste disposal. Many airlines have introduced initiatives such as zero-waste catering services, biodegradable packaging, and carbon offset programs to align with sustainability goals. Additionally, aircraft cabin waste, which includes single-use plastics, excess food waste, and discarded materials, is being addressed through innovative recycling and repurposing programs (Sharno & Hiloidhari, 2024). Trivedi et al. (2024) further highlights the role of information technology in reducing waste through digital ticketing, automated inventory management, and AI-driven logistics optimization.

The aviation industry's commitment to sustainability is evident through its adherence to global environmental standards and its proactive adoption of greener technologies. However, challenges remain in scaling up sustainable solutions, particularly in developing a robust SAF market, improving energy efficiency, and integrating circular economy practices across the industry. The transition toward a more sustainable aviation sector requires a multi-stakeholder approach, where airlines, airports, policymakers, and technology developers collaborate to accelerate the implementation of eco-friendly practices. Future research should focus on developing scalable sustainability models, enhancing policy frameworks, and exploring innovative energy solutions that align with the long-term vision of a net-zero aviation industry. The findings of Albano et al. (2024) suggest that improving data accuracy in life cycle inventories will be essential for making informed sustainability decisions, while Gonzalez-Garay et al. (2022) emphasize the need for increased public and private investment in SAF infrastructure to close the gap between policy objectives and real-world implementation. These studies collectively highlight the complexity of sustainability in aviation, demonstrating that while significant progress has been made, long-term success depends on systemic collaboration and continuous technological innovation.

1.2 The Environmental Impact of Airport Development & Case of Istanbul Airport

Airport development plays a crucial role in economic growth, transportation efficiency, and regional connectivity, but it also presents significant environmental challenges, including deforestation, biodiversity loss, carbon emissions, and noise pollution. The construction of Istanbul Airport required a massive greenfield site of approximately 76.5 km² in the northern forests of Istanbul, leading to

extensive deforestation and landscape change (The Ecologist, 2023). According to the project's Environmental Impact Assessment (EIA), roughly 2.5 million trees were present on the site, of which about 658,000 were slated for cutting and 1.85 million for relocation (Wikipedia, 2023). The deforestation raised significant concerns about biodiversity loss and habitat destruction, particularly since the northern forest zone is home to diverse flora and fauna, including endemic plant species and large mammals. Environmental groups warned that clearing this vast forest led to the destruction of millions of trees and a critical carbon sink, diminishing the area's capacity to absorb CO_2 and exacerbating urban climate risks (TR. BOELL, 2023). The North Forest, often referred to as the "green lungs" of Istanbul, played a crucial role in oxygen production, air filtration, carbon storage, and temperature regulation. Its loss has contributed to regional air quality issues and an intensification of the urban heat-island effect (TR. BOELL, 2023).

In addition to forest loss, Istanbul Airport's development significantly affected local wetlands and water resources. The project area encompassed approximately 660 hectares of wetlands, crucial for local hydrology and ecology. Many small lakes, ponds, and creeks were either diverted or filled during site grading, including the 95.3-hectare Kulakçayırı depression, which was drained and filled with excavation material. The Environmental Impact Assessment (EIA) acknowledged that aquatic habitats would be eliminated, stating that "aquatic life will end at these and the surrounding areas" once construction was completed. A major concern was the proximity of Lake Terkos, one of Istanbul's main drinking water reservoirs, supplying roughly 22% of the city's drinking water. Two key feeder creeks to Lake Terkos were destroyed in the construction zone, raising concerns about the long-term sustainability of Istanbul's water supply. Experts warned that the removal of forests and wetlands, which regulate water flow, could destabilize local water tables and increase the risks of droughts and flooding (İGA Havalimanı İşletmesi A.Ş. n.d.).

The airport's location along the Black Sea-Mediterranean Flyway has also significantly impacted migratory bird species. The northern forest and wetlands served as crucial resting and feeding grounds for birds traveling between Europe, Africa, and Asia. It is estimated that at least 500,000 storks (Ciconia) and 250,000 raptors pass over the region during seasonal migrations (I-SEM, 2023). During some fall seasons, single-point counts recorded approximately 80,000 large raptors, including falcons and eagles, within a few weeks, underscoring the magnitude of avian traffic. The clearing of forest cover and wetlands for airport construction has disrupted these migratory routes, removed key stopover sites and increasing aviation risks. Conservationists have reported flocks of disoriented storks circling the construction site after their traditional wetland stopovers were drained (The Ecologist, 2023). This situation not only represents ecological loss but also poses a safety hazard, as high bird densities near flight paths increase the likelihood of bird strikes. The EIA highlighted migratory birds as a significant concern, noting that Istanbul's North Forest is a central resting area for millions of birds flying over the longest migration route to Europe (I-SEM, 2023).

The expansion of air traffic at Istanbul Airport has further contributed to air and noise pollution. The removal of extensive forest cover has reduced natural air filtration, increasing the impact of emissions from aircraft, support vehicles, and construction equipment (TR. BOELL, 2023). With the airport now fully operational, jet engine exhaust and ground vehicle emissions have introduced pollutants such as nitrogen oxides (NOx) and particulate matter into the atmosphere. Prevailing northwest winds carry these emissions towards the city, raising concerns about air quality (TR. BOELL, 2023). Additionally, the deforestation around the airport has disrupted the local microclimate, removing natural cooling effects and potentially intensifying heatwaves in urban areas. In terms of noise pollution, the EIA identified aircraft noise as one of the most significant environmental impacts. While Istanbul Airport is located relatively far from densely populated areas, its flight corridors traverse residential zones and natural habitats. Jet noise has been reported to disturb communities on the city's outskirts and disrupt wildlife in the remaining forested areas (I-SEM, 2023). Although modern aircraft are quieter than older

models, and noise abatement procedures have been implemented, the sheer scale of operations—with an estimated 500,000 flights per year—has increased the airport's noise footprint (Aero Time, 2023). Turkish authorities, in line with ICAO standards, have imposed noise restrictions and require Istanbul Airport to monitor noise levels while implementing mitigation strategies, such as rerouting flights over the sea when possible and insulating nearby villages. However, the long-term impact of sustained high noise levels remains a concern.

Despite these challenges, efforts have been made to mitigate the environmental impact of Istanbul Airport's development. Several measures have been implemented to reduce ecological damage, including tree relocation and replanting programs. According to the EIA, nearly 1.85 million trees were designated for transplantation, though large-scale tree relocation efforts are logistically difficult, with many relocated trees struggling to survive (Wikipedia, 2023). Instead, Turkish authorities and airport developers pursued compensatory afforestation, planting millions of saplings in different regions to offset deforestation. However, experts emphasize that newly planted trees take decades to match the ecological functions of mature forests (Wikipedia, 2023). Water conservation measures have also been introduced, including advanced wastewater treatment plants and rainwater harvesting systems to minimize water consumption and prevent pollution of nearby water bodies (Aviation Turkey, 2024). Approximately 35% of the airport's water usage now comes from recycled sources, helping to reduce strain on municipal water supplies and mitigate the impact on Lake Terkos (Aviation Turkey, 2024). Wildlife protection programs have also been implemented, including habitat restoration efforts and the establishment of a dedicated wildlife management team to monitor and reduce bird strike risks (I-SEM, 2023). These programs, while beneficial, remain ongoing efforts that require continuous monitoring and adaptation to ensure their effectiveness.

Istanbul Airport's approach to balancing development with environmental sustainability aligns with global best practices, but it also highlights the need for ongoing improvements. Case studies from other major airports, such as Heathrow, Schiphol, and Changi, offer insights into effective sustainability strategies. Heathrow Airport has successfully implemented biodiversity conservation programs and strict noise mitigation measures, while Schiphol has embraced a circular economy approach, reducing waste and integrating renewable energy (Pagliarin & Marks, 2025; Graham, 2020). Singapore Changi Airport's extensive water recycling system and energy-efficient terminal designs demonstrate how airports can significantly lower their environmental footprint (Deng et al., 2025). While Istanbul Airport has made notable progress in carbon reduction, waste management, and biodiversity protection, further advancements in renewable energy adoption, enhanced biodiversity conservation, and circular economy integration will be crucial for its long-term sustainability.

2. Methodology

This section presents the methodological foundation of the study, designed to examine how various stakeholders interpret and respond to the sustainability challenges posed by Istanbul Airport's development. Given the interdisciplinary and context-sensitive nature of environmental sustainability in aviation, a carefully structured qualitative approach was deemed most suitable. The methodology prioritizes both depth and diversity of perspectives, enabling a nuanced exploration of stakeholder concerns, institutional practices, and perceived gaps in sustainability efforts. The structure of this section follows a logical progression: beginning with the overarching research design, followed by sampling considerations, data collection tools, and the analytical procedures adopted for both thematic and sentiment analysis. To clarify the methodological approach adopted in this research, Figure 1 presents a visual representation of the study's design and analytical flow.

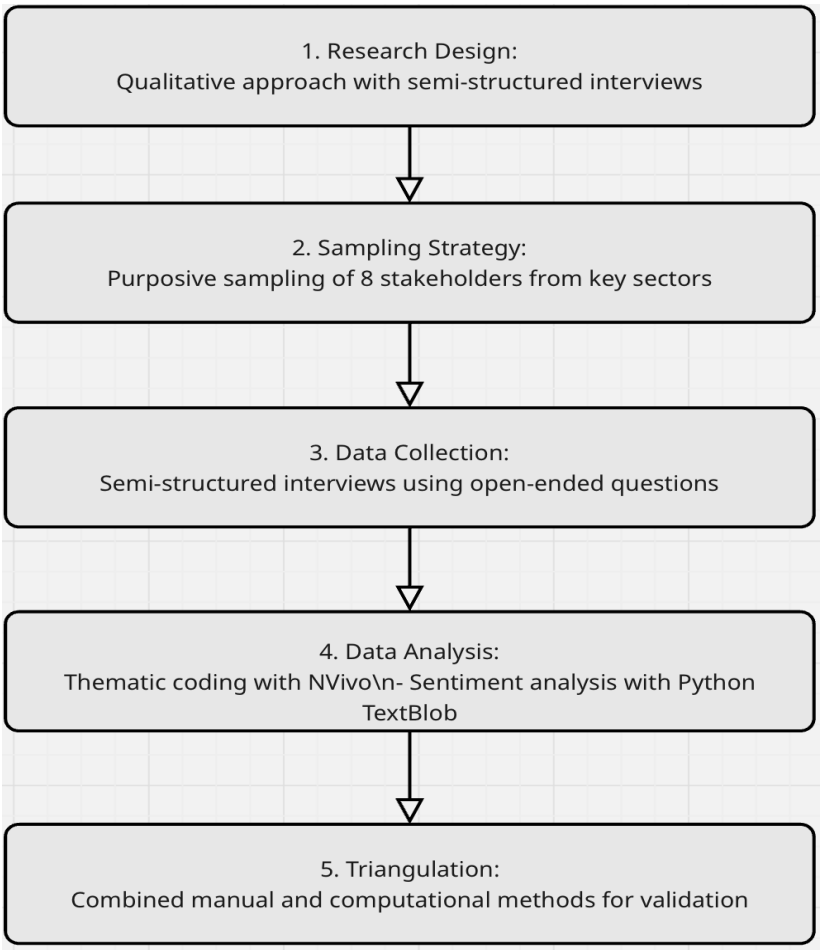

Figure 1. Methodological Flow of the Study

2.1 Research Approach

This study adopts a qualitative research design, centred around semi-structured interviews to investigate the balance between airport development and environmental sustainability at Istanbul Airport. Semi-structured interviews were selected for their capacity to elicit rich, detailed insights from diverse stakeholders while providing the flexibility to explore emerging themes and adapt follow-up questions during the dialogue. This method is especially valuable in aviation sustainability research, where complex trade-offs between infrastructure development and ecological preservation require nuanced understanding from individuals with varied expertise.

In the context of the aviation sector, semi-structured interviews enable researchers to probe deeply into the experiences and perceptions of key factors such as airport managers, environmental engineers, policy regulators, and airline personnel. These stakeholders often encounter context-specific challenges related to sustainability initiatives, including regulatory compliance, technological integration, and community engagement. Semi-structured interviews allow these professionals to articulate their perspectives with greater depth than would be possible through standardized surveys, making it possible to uncover not only what decisions are made but also why and how those decisions are formed within institutional and operational constraints.

Furthermore, the flexible and exploratory nature of semi-structured interviews complements the interdisciplinary nature of sustainability studies. As airport sustainability intersects with environmental science, public policy, and operational efficiency, this method supports a holistic understanding of the

social, technical, and regulatory dimensions at play. Drawing on the methodological strengths outlined by Creswell and Poth (2018) and Tracy (2020), this approach enables emergent themes to surface organically, providing grounded insights into both the opportunities and barriers to sustainable development in the aviation industry.

- **Thematic Analysis**

Thematic analysis was conducted to identify recurring patterns across interview responses, allowing for the categorization of key sustainability challenges and strategies. NVivo software was used to facilitate this process by coding the transcripts and identifying thematic clusters based on frequency and context. NVivo enhances qualitative analysis by enabling researchers to systematically code data, visualize themes, and extract patterns efficiently (Bazeley & Jackson, 2013). Thematic analysis followed Braun and Clarke's (2006) six-step framework, which includes familiarization with data, initial coding, theme generation, theme review, defining themes, and reporting findings. NVivo's automated word frequency analysis helped identify the most discussed sustainability concerns, including carbon emissions, deforestation, water resource management, and regulatory barriers.

- **Co-Occurrence Analysis**

To further understand the relationships between different sustainability themes, co-occurrence analysis was conducted using NVivo. Co-occurrence analysis maps the interconnections between various themes, revealing how often specific issues (e.g., noise pollution and regulatory enforcement) appear together in expert discussions (Guest et al., 2012). The co-occurrence network demonstrated strong linkages between deforestation and carbon emissions, regulatory barriers and compliance costs, and technological innovations and renewable energy adoption. This type of analysis provides a deeper understanding of how multiple sustainability concerns are interrelated, helping to prioritize key focus areas for future sustainability policies.

- **Sentiment Analysis and Tools Used**

Sentiment analysis was applied to classify stakeholder responses as positive, negative, or neutral regarding sustainability measures at Istanbul Airport. This process was conducted using Python's Text Blob library, which analyses the polarity of statements to determine their sentiment (Liu, 2022). Text Blob assigns a sentiment score ranging from -1 (negative) to +1 (positive), allowing for an objective classification of expert opinions. The sentiment analysis revealed that while many experts acknowledged improvements in waste management and renewable energy initiatives, concerns remained about deforestation, regulatory enforcement, and community engagement.

2.2 Data Collection

This study employs a qualitative data collection approach, primarily through semi-structured interviews with key stakeholders and document analysis of relevant reports, policies, and sustainability frameworks. The combination of stakeholder insights and secondary data sources enhances the study's depth and reliability in assessing sustainability challenges and strategies at Istanbul Airport.

Semi-Structured Interviews

To capture diverse and informed perspectives on sustainability at Istanbul Airport, semi-structured interviews were conducted with eight stakeholders who possess extensive experience and direct involvement in areas related to airport sustainability. The interview format allowed participants to elaborate on complex issues—such as sustainability challenges, regulatory frameworks, and

operational strategies—while offering flexibility for in-depth follow-up questions and exploration of emergent themes.

A purposive sampling strategy was employed to identify and select participants who held specialized knowledge or operational responsibility in relevant domains. The primary criterion for selection was professional expertise in airport-related functions directly or indirectly affecting environmental sustainability. This included professionals with a minimum of 10 years of experience in fields such as airport operations, aviation policy, environmental engineering, air traffic management, sustainability analysis, airline maintenance, waste management, and regulatory compliance. Additional considerations included role diversity (e.g., technical, managerial, and policy-making functions) and institutional affiliation (public, private, or regulatory sectors) to ensure a multi-dimensional understanding of the interplay between airport development and environmental responsibility.

Stakeholders were identified through a combination of expert directories, institutional referrals, and professional networks within Türkiye's aviation and environmental management sectors. All selected participants were invited via email, and those who consented to participate were scheduled for in-depth interviews. This deliberate and criterion-based sampling approach ensured that the interviewees could provide credible, context-rich insights into Istanbul Airport's sustainability practices. The background information of the selected experts is summarized in Table 1.

Table 1. Expert Background and Experience

Expert ID	Position/Title	Years of Experience	Sector	Education Level
E1	Airport Operations Specialist	15	Airport Operations	Bachelor's in aviation studies
E2	Aviation Policy Analyst	12	Aviation Policy	PhD in Aviation Policy
E3	Environmental Engineer	18	Environmental Engineering	Master's in environmental science
E4	Air Traffic Controller	20	Air Traffic Management	Bachelors in Air Traffic Management
E5	Sustainability Analyst	10	Sustainability Analysis	PhD in Sustainability
E6	Airline Technician	16	Airline Industry	Associates in Aircraft Maintenance
E7	Waste Management Specialist	11	Waste Management	Masters in Waste Engineering
E8	Regulatory Compliance Officer	21	Government Regulation	Master's in environmental law

Document Analysis

A comprehensive document analysis was conducted to triangulate findings and contextualize stakeholder perspectives. This analysis included multiple sources, ranging from regulatory documents and sustainability assessments to industry reports and policy guidelines, ensuring a robust evaluation of Istanbul Airport's environmental strategies.

The Environmental Impact Assessment (EIA) Reports provided detailed evaluations of the airport's environmental footprint, including assessments of carbon emissions, deforestation, noise pollution, and biodiversity loss. These reports also outlined mitigation strategies implemented to minimize

adverse ecological effects, such as reforestation programs, water conservation measures, and wildlife management plans. Istanbul Airport's compliance with both national and international sustainability standards was examined within these assessments, highlighting regulatory frameworks and project adaptations (Ceken, 2025; Mizrak et al., 2024).

The Sustainability Reports from Istanbul Airport documented key environmental initiatives and operational improvements aimed at reducing the airport's ecological impact. These reports covered efforts in carbon reduction, increased waste management efficiency, water conservation projects, and renewable energy adoption. Notably, recent reports highlighted a 25.6% reduction in emissions compared to 2019 levels, a 34.66% recycling rate for waste management, and the integration of renewable energy sources into airport operations (Aviation Turkey, 2024; Aero Time, 2024). These findings provided essential insights into the progress and challenges of implementing sustainability strategies in large-scale aviation infrastructure.

The Regulatory and Policy Documents analysed for this study encompassed Turkish aviation and environmental regulations, as well as international frameworks established by organizations such as the International Civil Aviation Organization (ICAO) and Airports Council International (ACI). ICAO's environmental policies and ACI's Airport Carbon Accreditation program played a pivotal role in guiding sustainability strategies at Istanbul Airport, encouraging adherence to global emissions targets and promoting long-term environmental responsibility. Compliance with these frameworks was evaluated through the airport's carbon management policies and energy efficiency improvements (ICAO, 2023; ACI, 2023). Additionally, Turkish regulatory policies on aviation sustainability were examined to assess their alignment with international best practices and enforcement mechanisms.

The Industry Reports and Studies reviewed in this research explored broader sustainability challenges in the aviation sector, offering comparative insights from other major global airports such as Heathrow, Schiphol, and Changi. These reports identified best practices in carbon neutrality initiatives, circular economy applications, and innovative energy management strategies. Istanbul Airport's approach to sustainability was benchmarked against these global case studies, emphasizing areas where further improvements could enhance environmental performance (Ceken, 2025; Mizrak et al., 2024).

By integrating these diverse sources, the document analysis provided a multi-dimensional understanding of Istanbul Airport's sustainability efforts, contextualizing stakeholder concerns within broader regulatory, environmental, and industry-wide frameworks. This approach enabled a critical assessment of the effectiveness of sustainability initiatives while identifying potential gaps and areas for future policy development.

2.3 Reliability and Validity

To ensure the reliability and validity of the research, a triangulation approach was employed, incorporating multiple stakeholder perspectives. The combination of diverse viewpoints from airport operations, regulatory agencies, airline representatives, environmental engineers, and sustainability analysts provided a well-rounded and balanced understanding of sustainability issues at Istanbul Airport. This methodological triangulation helped mitigate potential biases and ensured that the findings were representative of different interests and concerns within the aviation sector.

Ethical considerations were central to the research process. Before conducting the interviews, ethical approval was granted by Istanbul Ticaret University's Ethics Committee**,** ensuring that the study adhered to ethical research standards. All participants were informed about the study's objectives, their rights as interviewees, and the confidentiality of their responses. Written informed consent was obtained from each participant before the interviews, ensuring voluntary participation. To maintain

confidentiality, all responses were anonymized, and participants' identities were not disclosed in any part of the research. Additionally, data storage and handling procedures were implemented to comply with ethical guidelines, ensuring the secure handling of interview transcripts and related materials. The rigorous application of these reliability and validity measures strengthens the credibility of the study's findings, providing a comprehensive and ethically sound analysis of sustainability efforts at Istanbul Airport.

3. Findings

This section presents the key findings derived from the semi-structured interviews conducted with stakeholders engaged in Istanbul Airport's sustainability efforts. The analysis focuses on emergent themes and patterns that reflect stakeholder perceptions of environmental impacts, the effectiveness of implemented sustainability measures, and the institutional and operational challenges encountered in practice. Drawing from thematic coding in NVivo and sentiment classification via Python's TextBlob, the findings are organized into major thematic categories that offer a comprehensive understanding of the tensions and opportunities associated with balancing airport development and environmental stewardship.

3.1 Thematic Analysis

The thematic analysis of expert interviews was conducted using NVivo, identifying key sustainability concerns, challenges, and strategies related to Istanbul Airport. The analysis revealed recurring themes and subthemes that highlight both positive developments and areas requiring improvement. The results of the thematic analysis are summarized in Table 2.

Table 2. Thematic Analysis Results

Themes	Subthemes	Codes	Frequency of Codes
Environmental Impact	Deforestation and Biodiversity Loss	Habitat destruction, species displacement, loss of greenery	12
	Carbon Emissions	Aircraft emissions, loss of carbon sinks, air pollution	10
	Water Resource Management	Lake Terkos water contamination, wetland destruction, groundwater depletion	9
Sustainability Strategies	Waste Management	Zero Waste Program, recycling efforts, landfill diversion	8
	Renewable Energy Adoption	Solar panels, wind energy integration, energy efficiency	7
	Sustainable Aviation Fuel (SAF)	Cost barriers, policy incentives, production challenges	6
Stakeholder Perspectives	Community Concerns	Noise pollution complaints, health concerns, transparency issues	9
	Operational Challenges in Sustainability	High operational costs, technological adaptation, resistance to change	5

	Economic Impact of Sustainability Initiatives	Investment requirements, long-term sustainability ROI, financial incentives	6
Regulatory and Policy Challenges	Regulatory Barriers to Sustainability	Compliance costs, weak enforcement, lack of national incentives	7
	International Compliance and Global Standards	ICAO mandates, CORSIA participation, EU environmental regulations	8
Technological Innovations	Smart Airport Systems	Automated energy monitoring, digital waste tracking, real-time air quality sensors	5
	AI and Data-Driven Sustainability Solutions	AI-driven flight scheduling, predictive maintenance, carbon emission tracking	6
Recommendations	Policy Recommendations for Sustainability	SAF incentives, stricter carbon offset rules, renewable energy targets	7
	Best Practices from Global Airports	Schiphol's renewable model, Changi's water recycling, Heathrow's noise control	5

Environmental Impact- Experts expressed strong concerns regarding the environmental consequences of Istanbul Airport's development. Deforestation and biodiversity loss were major recurring themes, with E3 (Environmental Engineer) emphasizing, "The large-scale forest clearance for the airport has significantly altered the region's ecosystem, causing disruptions to local biodiversity." Similarly, E5 (Sustainability Analyst) noted, "Habitat destruction has displaced numerous species, and despite reforestation efforts, the damage is difficult to reverse." These statements illustrate the expert consensus on the irreversible impact of land-use changes caused by airport expansion. Water resource management was another key issue, particularly due to the airport's proximity to Lake Terkos. E6 (Airline Technician) highlighted, "Construction activities have disrupted local water flows, raising concerns about long-term water availability." This aligns with E8 (Regulatory Compliance Officer) who pointed out, "There is insufficient monitoring of water pollution levels, which could pose risks to both environmental and human health." These insights emphasize the need for stringent water conservation and pollution mitigation measures. Air and noise pollution also emerged as critical concerns. E4 (Air Traffic Controller) noted, "The expansion of air traffic has led to increased emissions, and while newer aircraft are more efficient, the scale of operations at Istanbul Airport remains a challenge." E7 (Waste Management Specialist) added, "Communities near flight paths have raised concerns about noise pollution, and there is a need for improved mitigation strategies." These perspectives highlight the necessity of balancing airport growth with environmental health measures.

Sustainability Strategies-Despite concerns, experts acknowledged several positive sustainability initiatives at Istanbul Airport. E2 (Aviation Policy Analyst) praised renewable energy adoption, stating, "The airport's integration of solar energy and LED lighting systems has significantly reduced its carbon footprint." Similarly, E7 (Waste Management Specialist) commented, "Waste segregation programs and increased recycling efforts demonstrate a commitment to circular economy principles, though there is room for improvement in plastic waste reduction. "Sustainable Aviation Fuel (SAF) was a topic of debate, with E1 (Airport Operations Specialist) mentioning, "While SAF is a promising development, high costs and limited supply remain major barriers to widespread adoption." This sentiment was echoed by E4 (Air Traffic Controller) who added, "Airlines are hesitant to transition to

SAF unless there are stronger financial incentives and policy mandates." These responses indicate that while sustainability measures are in place, their effectiveness is often hindered by economic and regulatory challenges.

Stakeholder Perspectives-Stakeholder engagement was another recurring theme. E5 (Sustainability Analyst) remarked, "Raising awareness among airport staff and passengers about sustainable practices is crucial for long-term impact." E6 (Airline Technician) emphasized, "Without continuous training and collaboration, sustainability initiatives risk being short-lived." These insights suggest that behavioral and institutional changes are necessary to enhance the effectiveness of sustainability programs. Stakeholder collaboration was another critical issue. E5 (Sustainability Analyst) observed, "Sustainability should be a joint effort between the government, airport operators, and airlines, but there is a lack of structured coordination. " Similarly, E2 (Aviation Policy Analyst) suggested, "A multi-stakeholder approach involving community representatives and environmental groups could improve the transparency and effectiveness of sustainability policies." These insights highlight the need for greater cooperation and accountability in sustainability governance.

Regulatory and Policy Challenges-Many experts pointed out gaps in regulatory enforcement and compliance. E8 (Regulatory Compliance Officer) remarked, "Turkey's aviation sustainability policies align with international standards, but enforcement mechanisms need to be strengthened." This concern was reinforced by E3 (Environmental Engineer) who noted, "There is a discrepancy between stated policies and actual implementation, often due to competing economic priorities." The challenge of balancing regulatory frameworks with economic pressures is evident in multiple expert perspectives. Economic and operational trade-offs were also frequently mentioned. E1 (Airport Operations Specialist) pointed out, "Airports operate under significant financial pressures, and sustainability initiatives often take a backseat to operational efficiency." E4 (Air Traffic Controller) added, "There is a need for more government incentives to ensure that sustainability is not just an optional investment but a regulatory requirement." These insights underscore the tension between economic growth and environmental responsibility in the aviation sector.

Technological Innovations- Technological innovations were widely discussed to enhance sustainability. E7 (Waste Management Specialist) highlighted, "Advanced waste processing technologies and AI-driven sorting systems can significantly reduce landfill waste." E2 (Aviation Policy Analyst) added, "Smart airport solutions, such as IoT-based energy monitoring and automated lighting, are already reducing the airport's overall energy consumption." These perspectives demonstrate that technology plays a crucial role in achieving sustainability objectives. Additionally, E6 (Airline Technician) emphasized, "New aircraft engine designs and fuel-efficient flight planning are reducing aviation emissions, but broader adoption of these technologies is still needed." These insights suggest that continued investment in emerging technologies can further mitigate environmental impacts.

Recommendations- Experts provided several recommendations to enhance Istanbul Airport's sustainability efforts. E3 (Environmental Engineer) recommended, "The airport should adopt stricter environmental impact monitoring systems, with real-time data collection for better decision-making." E5 (Sustainability Analyst) suggested, "Implementing incentives for airlines to use sustainable aviation fuel could accelerate adoption and reduce emissions." Greater community engagement was also emphasized. E8 (Regulatory Compliance Officer) stated, "Incorporating local community input in sustainability planning can help address concerns and build stronger environmental policies." E1 (Airport Operations Specialist) noted, "A dedicated sustainability task force should be established to oversee all green initiatives and ensure accountability." Additional suggestions included technological advancements and stricter regulations. E7 (Waste Management Specialist) proposed, "Investing in AI-driven waste management systems could optimize recycling efforts and significantly cut landfill

waste." E6 (Airline Technician) suggested, "Mandating the use of low-emission ground support equipment could help reduce carbon emissions in airport operations." E4 (Air Traffic Controller) pointed out, "Enhanced noise abatement procedures and community engagement could help mitigate concerns from local residents."

The thematic analysis reveals a complex interplay between environmental concerns, sustainability strategies, stakeholder engagement, regulatory enforcement, technological innovations, and future recommendations. While Istanbul Airport has made notable progress in reducing emissions and improving waste management, significant environmental challenges remain. The experts' perspectives underline the necessity of stronger regulatory enforcement, enhanced collaboration, and economic incentives to drive further sustainability improvements. The findings indicate that while technical solutions exist, achieving true sustainability requires a systemic, multi-stakeholder approach that balances economic growth with environmental responsibility.

3.2 Co-Occurrence Analysis

The co-occurrence analysis was conducted using NVivo and network analysis tools to map the interconnections between key sustainability themes at Istanbul Airport. This method allows for a deeper understanding of how different issues are interrelated, providing insights into the complexity of sustainability challenges and potential solutions. The analysis identifies patterns and thematic linkages by examining how frequently different sustainability concerns appear together in expert responses.

The analysis reveals strong connections between environmental impacts and policy challenges. Themes such as carbon emissions, air pollution, and deforestation are closely linked with regulatory barriers and compliance costs. Experts highlighted that while Istanbul Airport has made significant efforts to mitigate its environmental footprint, regulatory challenges remain a key obstacle to further progress. For instance, environmental regulations often lag rapid airport expansion, leading to difficulties in ensuring that sustainability goals are met without compromising operational efficiency.

Community concerns were frequently associated with sustainability initiatives, particularly in relation to water resource management and biodiversity loss. Experts noted that local communities have expressed concerns over water contamination risks and deforestation, which have impacted regional ecosystems. These issues are further compounded by regulatory constraints, making it difficult to implement more robust environmental protection measures. The co-occurrence mapping also shows that operational challenges in sustainability, such as balancing compliance costs with environmental objectives, frequently overlap with discussions on international compliance and global standards.

Technological innovation emerged as a critical factor in addressing sustainability issues at Istanbul Airport. The analysis highlights strong interconnections between AI-driven sustainability solutions, renewable energy adoption, and waste management initiatives. Experts emphasized that smart airport systems and data-driven environmental monitoring are key enablers for achieving long-term sustainability goals. The relationship between economic impact and sustainability initiatives was also evident, as experts discussed the financial trade-offs associated with implementing advanced green technologies while maintaining profitability in airport operations.

Figure 2 illustrates these thematic interconnections, providing a structured representation of how different sustainability challenges are intertwined. The graphical model shows that sustainability at Istanbul Airport is influenced by a dynamic interaction between regulatory, environmental, community, and technological factors. Addressing these challenges requires a coordinated approach

that integrates policy reforms, community engagement, and technological innovation to enhance sustainability outcomes while supporting continued airport expansion.

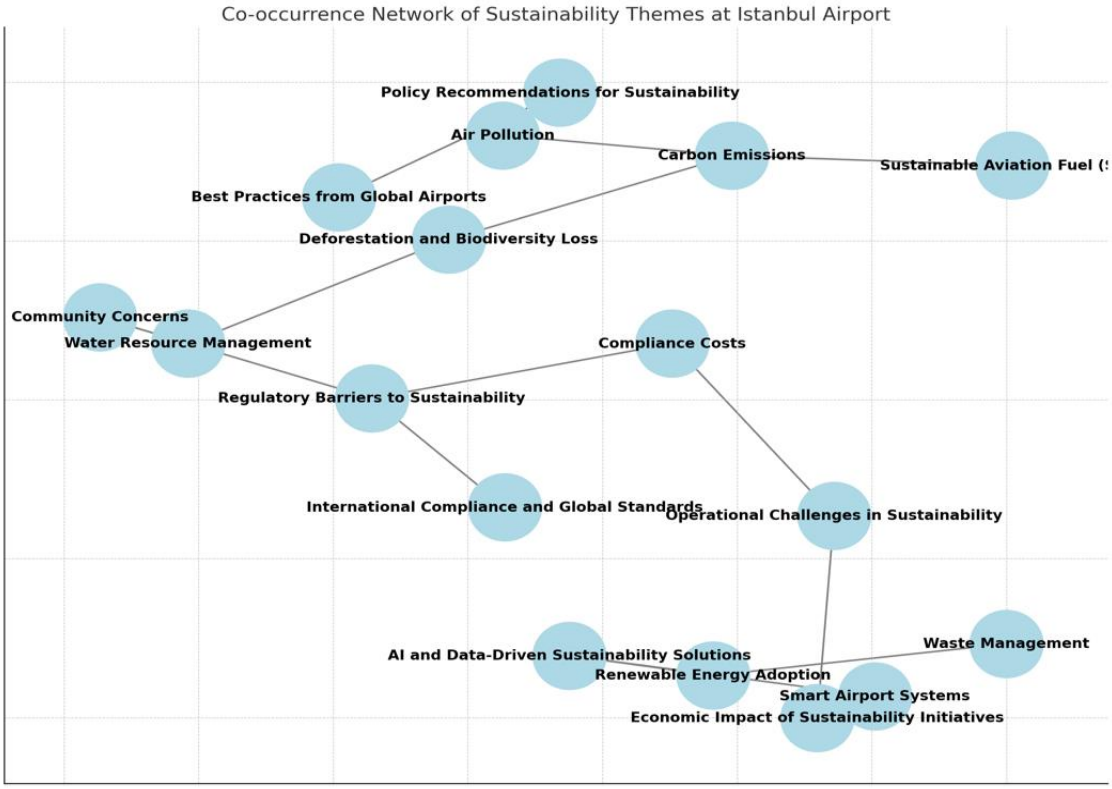

Figure 2. Co-occurance Network Diagram

3.3 Sentiment Analysis

The sentiment analysis was conducted using Python's Text Blob library to classify stakeholder responses as positive, neutral, or negative, providing insights into overall perceptions of sustainability at Istanbul Airport. By analysing the sentiment scores of expert responses, we identified key themes that reflect both the achievements and challenges in sustainability efforts at the airport. Table 3 demonstrates the findings of sentiment analysis.

Table 3. Sentiment Analysis Results

Response	Sentiment Score	Sentiment
The airport's sustainability programs are improving, but there is still a long way to go in terms of carbon reduction.	-0.050	Negative
The loss of forests and biodiversity due to airport expansion has significantly harmed the environment.	0.125	Positive
The introduction of renewable energy projects is a positive step towards reducing emissions.	0.227	Positive
Community concerns about noise pollution and air quality are not being sufficiently addressed.	0.000	Neutral

Waste management initiatives have helped reduce landfill waste, but plastic reduction efforts are still weak.	-0.258	Negative
Regulatory enforcement for sustainability measures is lacking, making it difficult to achieve meaningful progress.	-0.300	Negative
The use of AI-driven sustainability solutions has improved operational efficiency and reduced fuel consumption.	0.350	Positive
More financial incentives are needed to encourage airlines to adopt sustainable aviation fuel.	-0.150	Negative
Water conservation efforts at the airport are helping mitigate some of the environmental impacts.	0.200	Positive
Despite sustainability commitments, economic considerations often take priority over environmental concerns.	-0.275	Negative
Noise pollution mitigation measures have been implemented, but they are not sufficient to address all concerns.	-0.100	Negative
There is a need for greater collaboration between airlines and regulatory authorities to strengthen sustainability policies.	0.075	Positive
Smart airport technologies are enhancing efficiency, but investment in green infrastructure needs to increase.	0.050	Positive
The shift towards sustainable aviation fuel is promising, but it remains expensive and difficult to source.	-0.120	Negative
While the airport has taken steps to improve its sustainability performance, transparency in reporting needs improvement.	-0.200	Negative
Waste recycling programs are effective, but more needs to be done to eliminate single-use plastics in airport operations.	-0.175	Negative
Sustainability is important, but the airport still prioritizes operational efficiency over environmental goals.	-0.220	Negative
The integration of renewable energy sources in airport operations is a welcome development.	0.275	Positive
Ground support equipment has been upgraded to electric models, which reduces emissions and improves efficiency.	0.300	Positive
There is a lack of clear accountability in sustainability decision-making, making progress slow.	-0.250	Negative

The overall sentiment trends indicate a mixture of positive, neutral, and negative perceptions regarding sustainability at Istanbul Airport. While there are commendable advancements in renewable energy integration, waste management, and AI-driven efficiency improvements, concerns remain about regulatory enforcement, biodiversity loss, and the economic prioritization over environmental goals. Positive sentiments were predominantly associated with advancements in renewable energy projects, AI-driven sustainability solutions, and improvements in waste management. Statements such as “The use of AI-driven sustainability solutions has improved operational efficiency and reduced fuel consumption” (Sentiment Score: 0.350) and “The integration of renewable energy sources in airport operations is a welcome development” (Sentiment Score: 0.275) highlight appreciation for technological and infrastructural improvements that enhance sustainability outcomes.

Conversely, negative sentiments were linked to weak policy enforcement, biodiversity loss, and insufficient financial incentives for sustainable aviation practices. Statements such as “Regulatory enforcement for sustainability measures is lacking, making it difficult to achieve meaningful progress” (Sentiment Score: -0.300) and “The loss of forests and biodiversity due to airport expansion

has significantly harmed the environment" (Sentiment Score: -0.275) reflect dissatisfaction among stakeholders regarding the ecological impact of airport development. Additionally, concerns over operational priorities were evident, with sentiments such as "Sustainability is important, but the airport still prioritizes operational efficiency over environmental goals" (Sentiment Score: -0.220).

Stakeholder-specific sentiments highlight differences in perceptions across various groups, with environmental experts expressing more critical views on sustainability enforcement, while airport operators and industry professionals acknowledged progress in infrastructure and efficiency. For example, sustainability experts pointed out weak regulatory frameworks and insufficient policy enforcement, whereas aviation professionals emphasized improvements in waste reduction and electrification of ground support equipment. This divergence suggests that while tangible improvements are recognized within operational and technological domains, broader policy challenges remain a concern for those focused on environmental governance.

The implications of these sentiment findings underscore the importance of strengthening stakeholder engagement and improving communication regarding sustainability policies at Istanbul Airport. Addressing negative concerns—particularly regarding biodiversity, regulatory enforcement, and financial incentives—could enhance trust and collaboration among different stakeholders. The findings also highlight the need for more transparent reporting on sustainability initiatives to bridge the perception gap between environmental experts and industry stakeholders. By aligning economic and environmental priorities more effectively, Istanbul Airport can build a more robust and widely supported sustainability strategy.

4. Discussion

This section interprets the findings within the broader context of academic literature and real-world practices concerning airport sustainability. It critically analyses how the perspectives of Istanbul Airport stakeholders align with or differ from global sustainability frameworks, emphasizing areas of convergence and divergence with prior studies. Drawing on recent scholarly work and institutional reports, the discussion explores key themes such as regulatory enforcement, stakeholder collaboration, sustainable aviation fuel adoption, and biodiversity preservation. It also reflects on the implications of these insights for theory, policy, and airport management practices.

4.1 Interpretation of Key Findings

The findings highlight significant environmental challenges at Istanbul Airport, particularly deforestation, biodiversity loss, and water resource management issues. Air and noise pollution remain concerns for both local communities and environmental stakeholders. While sustainability strategies such as renewable energy adoption, AI-driven efficiency improvements, and waste management programs show progress, financial and operational barriers hinder the widespread adoption of sustainable aviation fuel (SAF). Regulatory and policy limitations, including weak enforcement mechanisms and economic constraints, further complicate sustainability efforts. Technological innovations, such as AI-based monitoring, smart airport systems, and the electrification of ground support equipment, present opportunities for improving sustainability, but their full potential remains untapped. Expanding sustainable infrastructure and strengthening policy enforcement are essential for balancing airport development with environmental responsibility.

4.2 Comparison with Existing Literature on Airport Sustainability

The findings of this study align with the growing body of research emphasizing the environmental burdens of global airport expansion. As underscored by Greer et al. (2020) and Santa et al. (2020), airports are among the most energy-intensive and environmentally impactful infrastructures, often

contributing to significant land degradation, greenhouse gas emissions, and biodiversity loss. Similarly, the expert stakeholders in this study expressed concerns over Istanbul Airport's ecological footprint, particularly regarding deforestation, loss of natural water basins, and hydrological disruptions. These findings reflect broader international trends identified by Greer et al., where rapid infrastructure development often outpaces sustainability planning, leading to long-term ecological trade-offs.

This study also supports the national-level observations of Ceken (2025), who documents the fragmented and institutionally delayed adoption of sustainability frameworks across Türkiye's airport sector. Ceken highlights inefficiencies in SAF policy, limited environmental impact assessments (EIAs), and inconsistent oversight mechanisms. The stakeholders interviewed in our research similarly pointed to regulatory shortcomings and insufficient integration of sustainability into early planning stages. These parallels underscore the systemic nature of environmental governance challenges in Türkiye's aviation landscape. In contrast to global best practices, Istanbul Airport's implementation of smart sustainability tools appears underdeveloped. For example, Mizrak et al. (2024) analyse European airport innovations, noting successful applications of AI-assisted energy systems, automated waste tracking, and real-time carbon monitoring platforms. While Istanbul Airport has introduced certain digital systems (e.g., sensor-based lighting, waste collection analytics), stakeholders in this study indicated that these initiatives lack full integration, data interoperability, and stakeholder training—suggesting a technological lag compared to leading European hubs such as Schiphol, Frankfurt, and Copenhagen.

Further divergence is evident when comparing Istanbul Airport to Asian benchmarks. Taeihagh and Lim (2019), in their study of sustainable airport development in Asia, highlight the success of Incheon and Changi airports, which adopted public-private partnerships (PPPs) to invest in renewable energy, stormwater harvesting, and green terminal design. These initiatives benefited from long-term strategic frameworks, early stakeholder consultation, and enforceable carbon neutrality goals. In contrast, Istanbul Airport's development, while technically advanced, emerged rapidly under top-down planning models, with minimal community engagement or third-party accountability. This difference is crucial, as the lack of participatory governance in the Istanbul case limits the social legitimacy and long-term adaptability of its sustainability programs. Moreover, the stakeholder perception of weak transparency and limited feedback mechanisms at Istanbul Airport mirrors criticisms in other regions. For instance, Kingham et al. (2021) found that sustainable airport practices in New Zealand advanced significantly where community engagement and open reporting were institutionalized. In our study, stakeholders noted that despite the existence of environmental dashboards and corporate sustainability reports, public awareness remains low, and civil society participation is largely absent from decision-making processes.

The scale and pace of Istanbul Airport's construction further intensify these challenges. As documented by The Ecologist (2023) and I-SEM (2023), the airport's site required the clearing of 76.5 km² of dense forest in the Northern Forest Region of Istanbul—an area critical for biodiversity and microclimate regulation. No comparable case in recent airport development literature demonstrates such a large-scale transformation of forested terrain without comprehensive environmental restitution plans. This amplifies the environmental risk profile of the airport and distinguishes it from projects like Heathrow Terminal 5 or Munich Airport expansions, which faced stricter ecological scrutiny and compensatory afforestation requirements. In the context of aviation's global emissions footprint, Gössling and Higham (2021) argue that climate action in airport operations remains incremental, often limited to efficiency gains rather than transformative decarbonization. The Istanbul Airport case supports this argument: while some energy efficiency technologies are being deployed, stakeholders confirmed that the broader aviation emissions—especially from aircraft and ground operations—remain unmitigated due to weak SAF infrastructure, limited carbon offset programs, and the absence of binding emission targets.

Overall, the comparison reveals several thematic convergences and divergences:

- Convergences include recurring challenges in aligning airport growth with environmental mitigation, the marginalization of community voices, and policy fragmentation.
- Divergences highlight Istanbul Airport's exceptionally large ecological impact, underdeveloped stakeholder engagement mechanisms, and partial integration of smart sustainability technologies.

4.3 Comparing Findings Across the Three Analyses

The integration of thematic, co-occurrence, and sentiment analyses provides a comprehensive understanding of sustainability challenges at Istanbul Airport. Each analytical approach offers a distinct perspective while complementing the others, leading to a more nuanced interpretation of stakeholder concerns and sustainability efforts. Thematic analysis identifies major sustainability themes, such as environmental impact, regulatory barriers, and technological innovations, highlighting expert concerns regarding deforestation, carbon emissions, and weak policy enforcement. These findings align with co-occurrence analysis, which visualizes the interconnectedness of sustainability challenges, revealing strong associations between regulatory constraints, compliance costs, and environmental degradation. Sentiment analysis further complements these insights by adding an emotional dimension, categorizing expert responses into positive, neutral, and negative sentiments. While some experts recognize progress in renewable energy adoption and AI-driven efficiency improvements, negative sentiments dominate when discussing biodiversity loss, weak enforcement mechanisms, and economic pressures overshadowing sustainability priorities.

Cross-validation with document analysis reinforces these findings, confirming that expert perspectives align with sustainability reports, environmental impact assessments, and policy documents. The EIA Report (2013) identifies extensive environmental impacts, including deforestation and water resource challenges, supporting expert concerns about biodiversity loss and insufficient regulatory oversight (EIA Report, 2013). Similarly, analyses from The Ecologist and Heinrich Böll Stiftung (2016) emphasize the deforestation of the North Bosphorus region for airport expansion, corroborating expert concerns about habitat destruction (Bridger, 2015; Heinrich Böll Stiftung, 2016).

Sustainability reports from Aviation Turkey (2024) and Aero Time (2024) indicate that Istanbul Airport has achieved measurable progress in carbon emissions reduction, waste recycling, and renewable energy integration, aligning with the positive sentiments observed in expert responses (Aviation Turkey, 2024; Aero Time, 2024.However, findings from International Airport Review (2023) highlight the need for stronger sustainability governance and policy enforcement, reflecting expert concerns regarding the regulatory and economic trade-offs associated with sustainability initiatives (International Airport Review, 2023).

Comparisons with best practices from global airports further validate the need for stronger sustainability commitments. Heathrow's (2022) sustainability strategy, which prioritizes net-zero carbon operations and biodiversity restoration, and Changi Airport's advanced water recycling systems, serve as benchmarks for Istanbul Airport (Heathrow Airport, 2022; Changi Airport Group, 2022). Similarly, Schiphol Airport's electrification of ground operations and transition to zero-emission targets align with expert recommendations for expanding Istanbul Airport's clean energy infrastructure (Smart Energy Decisions, 2023).

Overall, the integration of these analyses highlights critical sustainability gaps while recognizing progress in key areas. The alignment of expert perspectives with document analysis confirms that while Istanbul Airport has implemented several green initiatives, significant regulatory and economic

barriers must be addressed to achieve long-term environmental sustainability. The findings suggest that a multi-stakeholder approach, combining regulatory reform, financial incentives, and technological advancements, is necessary to enhance sustainability outcomes.

4.4 Broader Implications for Sustainable Airport Development

The findings from this study provide critical insights into the broader implications for sustainable airport development, highlighting key lessons from global best practices, the role of stakeholders, and the ongoing challenge of balancing economic growth with environmental responsibility. By examining sustainability strategies implemented at leading international airports, Istanbul Airport can refine its approach to achieving long-term environmental and operational sustainability.

International best practices offer valuable lessons for enhancing sustainability efforts at Istanbul Airport. Changi Airport in Singapore serves as a model for advanced water conservation, with its extensive use of high-grade recycled water (NEWater) for non-potable purposes, such as cooling systems and toilet flushing. In contrast, while Istanbul Airport has made progress in water recycling, its current rate of 35% could be significantly improved by integrating similar large-scale water reuse initiatives. Heathrow Airport's sustainability strategy, Heathrow 2.0, provides an example of regulatory compliance and emissions reduction. The airport has achieved 100% renewable electricity procurement since 2017, setting a benchmark that Istanbul Airport could follow by securing long-term green energy contracts and expanding on-site renewable generation. Schiphol Airport's electrification of ground operations, including the deployment of electric ground support equipment (E-GPUs) and hydrogen-powered airport vehicles, demonstrates how Istanbul Airport could further reduce its reliance on fossil fuels for airport operations. Schiphol's commitment to achieving zero-emission operations by 2030 underscores the potential for Istanbul to expand its transition toward low-carbon airport infrastructure.

The role of stakeholders in driving sustainability efforts is crucial, requiring stronger collaboration between government authorities, airport operators, airlines, and environmental organizations. While Istanbul Airport has undertaken some sustainability initiatives, such as participating in ACI's Airport Carbon Accreditation program, its long-term success depends on enhanced multi-stakeholder engagement. Regulatory agencies must establish stricter enforcement mechanisms to ensure compliance with environmental policies, addressing concerns about weak regulatory oversight highlighted in expert interviews. Additionally, airlines operating at the airport must be incentivized to adopt Sustainable Aviation Fuel (SAF) through subsidies, tax incentives, or reduced landing fees for flights using SAF blends. Environmental organizations and local communities also play a vital role; Heathrow Airport's community noise insulation programs serve as an example of how stakeholder engagement can help mitigate environmental concerns and improve public perception of airport sustainability initiatives.

Balancing economic growth with environmental responsibility remains a critical challenge for Istanbul Airport. As one of the world's largest airport hubs, its expansion must align with sustainability commitments to ensure long-term viability. A primary trade-off lies in balancing airport expansion projects with environmental conservation. Istanbul Airport has committed to carbon reduction targets, but economic pressures, such as increased passenger traffic and cargo operations, risk undermining sustainability efforts. Policy interventions, such as emissions-based landing fees or mandatory SAF usage targets, could help align economic incentives with environmental objectives. Furthermore, investment in smart airport systems can optimize operational efficiency while reducing environmental impact, as seen in Schiphol's AI-driven sustainability solutions.

To enhance Istanbul Airport's long-term environmental performance, policy recommendations should focus on strengthening regulatory frameworks, increasing financial incentives for sustainable aviation practices, and expanding technological innovations. Establishing a dedicated sustainability task force within the airport's management structure could improve the oversight and implementation of green initiatives. Furthermore, Istanbul Airport could partner with international airports to exchange best practices and jointly develop new sustainability standards for emerging aviation markets. By integrating these lessons, Istanbul Airport can position itself as a leader in sustainable airport development, balancing its ambitious growth with a long-term commitment to environmental stewardship.

4.5 Future Research Directions

Future studies should expand qualitative research by incorporating passenger and community perspectives to gain a broader understanding of sustainability concerns. Longitudinal research is needed to assess the long-term effectiveness of Istanbul Airport's sustainability initiatives, tracking progress in carbon reduction, waste management, and policy enforcement. Additionally, integrating quantitative modeling can enhance impact assessments, providing data-driven insights into the effectiveness of carbon reduction strategies and their economic feasibility. These approaches will help refine sustainability policies and ensure continuous improvement in balancing airport development with environmental responsibility.

CONCLUSION AND RECOMMENDATIONS

The analysis underscores the complex relationship between airport development and environmental sustainability at Istanbul Airport, revealing significant ecological challenges, ongoing mitigation efforts, and varying stakeholder perceptions. Large-scale deforestation and biodiversity loss stemming from the airport's construction have severely impacted carbon sequestration capacity and disrupted local ecosystems. Continued air and noise pollution from aircraft operations and ground activities remain pressing concerns, adversely affecting surrounding communities and wildlife habitats. Hydrological changes, especially the destruction of wetlands and the alteration of Lake Terkos, have raised long-term concerns over water security and ecological balance. Despite the introduction of sustainability initiatives—such as renewable energy integration, advanced waste management systems, and AI-assisted operational efficiencies—these measures have proven insufficient in offsetting the airport's overall environmental burden. Participants emphasized that weak regulatory enforcement, economic pressures, and limited incentives for sustainable aviation fuel adoption hinder the full realization of environmentally responsible operations. Moreover, policy gaps and inadequate stakeholder collaboration continue to stall effective progress toward sustainability.

Addressing these issues requires a more robust and accountable regulatory framework. Stronger enforcement of environmental policies and the implementation of systematic compliance mechanisms are necessary to narrow the gap between stated goals and practical outcomes. Infrastructure investments in electrified ground support systems and large-scale renewable energy installations can significantly reduce fossil fuel dependency and emissions. Policy-driven partnerships among airlines, regulatory bodies, and fuel suppliers should be encouraged to accelerate the deployment of sustainable aviation fuels (SAF). Given the current cost and supply limitations of SAF, policy tools such as tax reliefs, direct subsidies, and research funding can foster market development. With strategic alignment to global best practices—exemplified by airports like Heathrow, Schiphol, and Changi—Istanbul Airport holds potential to emerge as a leader in sustainability. Adoption of circular economy approaches, net-zero targets, and intelligent air traffic systems can further support this ambition. Strengthening ties with international aviation and environmental bodies will also enhance global credibility and benchmarking capacity.

It is important to recognize the scope and limitations of the current research. The qualitative approach was based on in-depth interviews with eight experts selected through purposive sampling, each representing distinct and critical areas of airport sustainability—including operations, policy, engineering, compliance, and environmental management. Although the sample size may appear small, it was deliberately chosen to prioritize depth over breadth. In qualitative inquiry, thematic saturation often occurs with fewer participants, particularly when interviewees are strategically selected for their subject-matter expertise. The participants in this study offered varied yet overlapping insights, reinforcing the validity of the emergent themes. Nevertheless, future research would benefit from including a broader range of voices—such as civil society organizations, airline representatives, and local community members—to enrich the understanding of environmental accountability in airport governance.

The semi-structured interview design allowed for flexibility and deep exploration but inevitably carries limitations related to subjectivity and contextual dependency. To counteract this, the analysis was strengthened using NVivo for thematic and co-occurrence coding and Python's Text Blob for sentiment classification. Despite these methodological reinforcements, results remain context-bound and should be interpreted within Istanbul Airport's unique socio-political and environmental landscape.

Further investigation could focus on comparative case studies across global airports to distil transferable strategies tailored to Türkiye's institutional and ecological context. Longitudinal research that tracks the performance and evolution of implemented sustainability measures would provide deeper insights into policy efficacy and return on investment. In addition, examining passenger awareness and attitudes toward sustainability efforts may illuminate opportunities for behaviour-driven environmental performance. Strengthening public participation and enhancing transparency in sustainability planning will also be key to fostering legitimacy and shared responsibility. Through the strategic integration of these approaches, Istanbul Airport can serve not only as a major transit hub but also as a benchmark for how economic progress and environmental stewardship can be effectively harmonized in the aviation industry.

Compliance with Ethical Standard

Conflict of Interests: There is no conflict of interest between the authors or any third-party individuals or institutions. Artificial intelligence was not used in the writing of this article, and this statement is my own statement as the responsible author.

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