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Assortment of Airports' Sustainability Strategy: A Comprehensiveness Analysis Framework

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Abstract: Global sustainability challenges are transforming 21st century business. Economic, social, and environmental sustainability impacts regulatory agencies and enterprises, particularly in the air transport industry, which facilitates access to productive services and market linkage. Stakeholders, shareholders, consumers, employees, and society are increasingly pressuring businesses to examine their socioeconomic consequences and manage them sustainably and resiliently. In this competitive and economically sensitive climate, good management is a primary responsibility for airport operators and authorities, as well as national and local economies. An assessment tool for airport strategic plans is developed in this research. Corporate activities can encourage responsible infrastructure development and company sustainability. The assessment methodology is based on a comparative analysis between airports and regulatory authorities' threshold. The role of sustainability in the air transport business ecosystem is depicted using a systemic approach, demonstrating that its relationship to business performance is a significant barrier to business resilience and competition for planners, managers, and decision makers. The numerical application considers a group of European, U.S, and Asian airports serving international flights. Conventional wisdom is to provide the evaluation analysis framework for planning and managing capital-intensive transport hubs such as airports.

Keywords: sustainable development; sustainability strategy; managing sustainability; environmental assessment; comprehensiveness evaluation; performance management

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1. Introduction

In today's business environment, where economic and social activities are geared toward transformation, the concept of sustainability is critical. Global sustainability issues are influencing 21st century business practices. Achieving economic, social, and environmental sustainability impacts regulatory agencies and businesses, particularly in the air transport sector, which promotes access to productive services and market connectivity. Shareholders, customers, employees, and society are increasingly pressuring businesses to assess their socioeconomic impacts and manage them sustainably and resiliently [1] because effective management is critical for airport operators, authorities, and national and local economies. The corporate eco-system and environmental consciousness are closely intertwined and harmonizing these two pillars can help a company run more efficiently. In this context, evaluating the environmental performance of vital infrastructure such as airports is critical for ensuring their long-term sustainability. Airport operations and development can cause pollution of air, water, soil, waste, and biodiversity. According to [2], airport environmental impacts could obstruct the uninterrupted operation of the airport infrastructure and facilities, especially when there is no strict regulatory framework which provides for corresponding fines when the levels of pollutants or sound exceed the permissible limits. In this context, airport operators should develop effective strategies in order to offset the economic and social benefits of operating the airport with its environmental impact [3]. The fact that the sustainability concept is extended to mainly

environment disturbance aspects and taking into consideration the inelasticity in airport operation, therefore, the mitigation measures focused on four primary categories of mitigation actions: emissions, energy, water, and waste. These four features appear to be critical for analyzing the influence of airports on environmental disturbance mitigation. When it comes to the concept of a comprehensive analysis of environmental strategy, it is worth noting that traditional environmental studies have almost always been divided into, and limited to, CO_2 mitigation calculations compared to the past and projections for the future, and evaluating carbon neutrality in terms of energy or resource consumption. While the study of effective mitigation strategies is excellent, it is true that not enough research has been done on the comprehensiveness of an airport's approach toward a balanced action plan that covers the entire chain of services. In this field, this paper explores and builds increments of analytical thoughts and methods explained, promoting a mix of evaluation schemes depicting the primary strategy comprehensiveness evaluation framework. The comprehensive environmental strategy analysis framework is developed in three axes, in which the primary axis deals with the mitigation actions delivered by airport operators (in the above-mentioned four features of environmental impact analysis) and adjusting performance in terms of the balanced distribution of phased measures in terms of impact effect zone and scale (evaluation subsystem axis). This paper discusses how corporate actions can promote responsible transport infrastructure strategy dealing with business and operational sustainability. The first part of the paper introduces the evaluation framework towards a sustainability comprehensive strategy for airports. The second part provides an application taking into consideration the airports' environmental plans of a group of twenty European, American, and Asian airports serving international flights. The real application results highlighting key messages to planners, managers, and decision makers are given, promoting best practices and addressing the issues for further research in this field. The conclusion section depicts the analysis concept and highlights key issues for further research. At the end are the key references used in the paper.

2. Literature Background

2.1. Contribution of Air Transport to Economic Development

The output, employment, and income of a country are all linked to transportation and related mobility. Transportation accounts for 6–12% of GDP in many developed countries. Transportation assets make for roughly half of an industrialized economy's GDP. Producer, consumer, and distribution expenses are all tied to transportation costs (the im-portance of transportation to specific sectors of the economy). As a result, the importance of specific modes of transportation and infrastructure in each sector can be appraised [4]. In 2016, transport accounted for 5% of the EU's gross value added and 5.2% of all jobs (approximately 11 million). It has a direct impact on the daily lives of all EU citizens and ensures the free movement of commodities between 11 million EU producers, manufacturers, and consumers [5]. As a result, effective transportation is essential for global integration. To complete and run the global market network, well-planned, sustainable, and integrated transportation networks are required. Building transportation infrastructure will cost a lot of money. Annual investment needs in this field are estimated to be over EUR 130 billion by the European Commission, with major maintenance investment required. Additionally, new developments such as automation, digitalization, and shared mobility have the potential to improve transportation efficiency. As a result, questions about new regulations, privacy protection, safety, liability, and data security have surfaced. Furthermore, by 2050, a change to sustainable mobility could save USD 70 trillion in car, fuel, operational, and congestion expenditures [6].

To optimize regional economic potential, effective air transportation services and infrastructure are required to maximize economic, territorial, and social cohesiveness. Because of its pivotal significance, air transportation is intricately related to environmental and digitalization policy. Additional investment and a rethinking of network and business model design will be required to build a new infrastructure for clean, alternative fuels.

Airports, without a doubt, play a critical role in economic development. Airports are frequently viewed as the economic engine of the communities they serve [7]. According to numerous studies, locations with airports and considerable air service appear to have increased productivity and lower unemployment [5]. Airports facilitate international commercial, cultural development, educational, and recreational tourism [8]. The total economic impact of an airport on a region is the sum of its direct, indirect, induced, and catalytic effects [9]. Even though airport expansion is a major developmental factor in some locations, it will have detrimental environmental and social consequences.

2.2. Air Transport and Sustainable Development Linkage

People and communities globally are connected via transport, which creates markets and facilitates business [10]. Sustainable transport could also lead to sustainable development and prosperity. Moving people and commodities in a safe, economical, accessible, efficient, and resilient manner while lowering carbon emissions and other environmental consequences on present and future generations is what sustainable transportation entails [10]. However, not all goals can be met at the same time. The importance of industry priorities for sustainability cannot be overstated. For example, reducing emissions while meeting rising demand in the aviation sector must be balanced. The opportunities for visionary transportation decisions now and in the future, both in developed and developing countries, are enormous. Goals, objectives, and metrics will shape this path. Monitoring and evaluating progress is required to correct course. The 2030 Agenda for Sustainable Development outlines a path toward more general sustainable development, guided by the 17 SDGs (SDGs). Advancing sustainable transport is critical to the SDGs. Several SDGs have targets and indicators related to sustainable transport.

Assisting the public while addressing social, economic, and environmental concerns is an important component of effective transportation planning [3]. While balancing short and long-term needs is common sense in all planning, it is critical in transportation due to its complexity and resource-intensive nature. In particular, transport infrastructure, whose operation contributes significantly to economic growth and prosperity, is directly linked to objectives and goals such as the promotion of innovation, the use of renewable and clean energy, as well as the development of synergies with other sectors of the economy to enhance their sustainable transition. Moreover, competition drives private sector businesses and, as previously stated, local and national governments to become more sustainable, which benefits businesses, governments, and the world at large. Resilience planning ensures that passenger and freight transportation networks can also adapt well to climate change-related and other unexpected extreme events [11].

Ensuring the sustainability of mega infrastructure projects such as airports requires adequate infrastructure provisions from the start [12]. A resilient and sustainable business performance framework is presented in Figure 1. Business and environmental awareness are intrinsically linked, so balancing the two can help businesses' smooth operation. Achieving business resilience and sustainability requires us to assess the environmental performance of critical infrastructures such as airports. In this study, airports' environmental plans are reviewed to evaluate their environmental sustainability performance in terms of setting specific environmental targets, taking efficient measures regarding the consumption of natural resources and conducting effective long-term strategic plans with targeted policy tools, as highlighted in Figure 1.

2.3. Airports Environmental Performance Aspects

While aviation benefits the economy, it also impacts the environment globally and locally. Global climate change exemplifies regulators' challenges. While noise has been the main concern for the last two decades, there are also other critical factors, such as emissions, energy, and water management, related to the quality of life of the local communities [2]. In this context, environmental management at airports is primarily concerned with identifying, assessing, and controlling environmental impacts that could affect air

transport infrastructures' operation [9]. The main aspects related to environmental impacts at airports are summarized below.

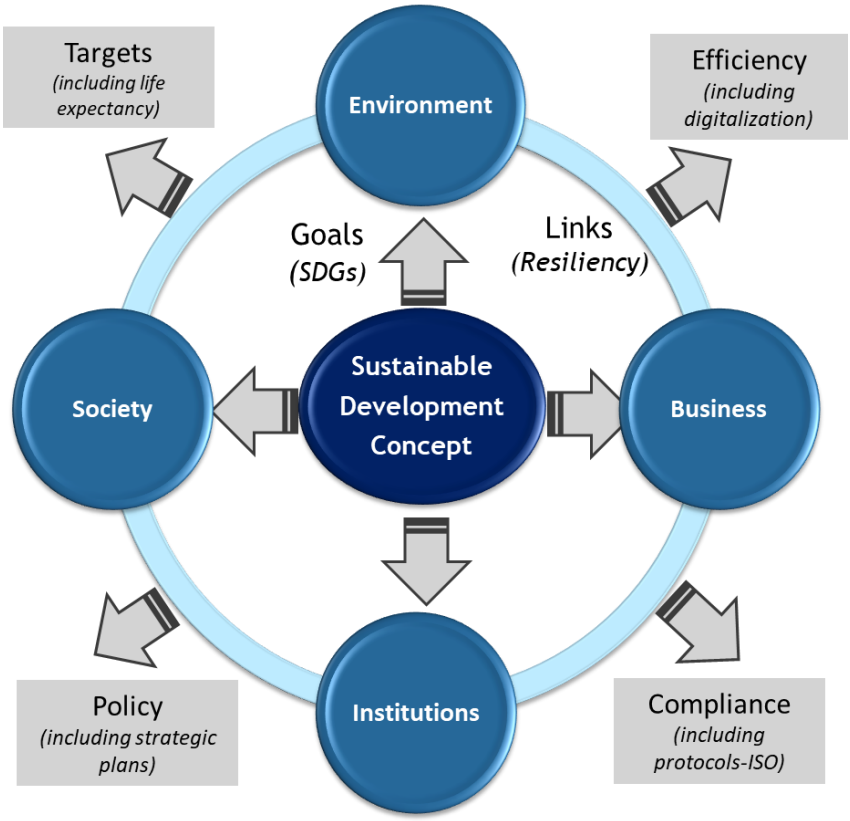

Figure 1. Depiction of business resilience and sustainability performance.

2.3.1. Emissions

According to the literature, among the biggest emitters at airports are aircrafts, ground transport, energy generation facilities, as well as fire training [13]. Reduced air travel has major worldwide environmental consequences, particularly in terms of climate change. All of these contaminants have an impact on the quality of the air [14]. Despite producing only 2% of all anthropogenic CO_2 emissions, aviation's CO_2 emissions are increasing as the industry's growth outpaces airframe and engine development [13]. There are many factors that influence air quality near airports, such as the air quality in the local area, emissions management strategy, and its compliance with the existing frameworks concerning pollutant levels. As a result, establishing efficient measures for monitoring and reducing emissions produced at the airport is a significant task for airport authorities in order to meet worldwide standards and reduce the carbon footprint of the infrastructure [15].

2.3.2. Noise

The primary local impact on airport communities appears to be noise [16]. In addition to negatively impacting people's health and quality of life, noise can detract from destination appeal and elicit strong feelings from locals. Airport operations and development are often hampered by aircraft noise nuisance [11]. The rapid expansion of air travel has slowed technological advancements somewhat. Air noise measurements have forced most major airports to reduce operational capacity. It is estimated that by 2020, 80% of airports will be affected by noise restrictions or have their operations hampered by noise [17]. A balanced approach to noise management should consider reducing noise at source, adopting land-use planning and management regulations, and regulating airplane noise [18,19]. Technological advancements allow airports to design an effective noise action plan and monitoring system to fulfill local community needs.

Land-use planning, along with airplane noise mitigation, is crucial to lowering noise exposure. Aeronautical noise-insensitive infrastructure such as storage areas and industrial buildings could be designed and built by airport operators in collaboration with local authorities [20]. Moreover, registering noise complaints could help monitor the airport's influence on the neighboring population and improve noise management [21].

2.3.3. Energy Management

Airports consume a significant amount of energy to power their infrastructure and their facilities needs for heating, air conditioning and lighting [22,23]. Renewable energy supply at airports has many advantages, according to the International Civil Aviation Organization [24], including lower emissions than fossil fuels during their life cycle, lower operating costs, less environmental impact, and funding and revenue opportunities.

A recent IRENA research [25] found that the average cost of wind and solar energy has fallen considerably in recent years and is anticipated to fall by 59% by 2025. This cost savings often inspire airport operators to invest in renewable energy sources. Green energy choices for airports focus on improving energy efficiency and demonstrating renewable energy technology as viable alternatives [26]. Solar PV, wind, hydropower, geothermal heat pumps, and biomass are the energy-producing technologies best capable of providing the airport's energy needs [22,27,28]. According to [29], solar thermal collectors can be installed on existing airport buildings to supply heating and cooling for interior operations, while microgrid technology can ensure the airport's independence from the local grid.

2.3.4. Water Management

Water resources are crucial for the uninterrupted and efficient operation of the airport, especially in water-scarce areas. Many airports, especially those in the Mediterranean, are already devoid of water. Even still, even airports not located in drought-prone areas, water availability was viewed as a long-term limitation [30]. Among the principal pollutants detected in wastewater are 'surface water discharges, de-icing and anti-icing fluids, chemicals, fuel spillages, and, of course, sewage water from buildings' [31]. Water availability in the region is critical to the airport's operation and water needs [30]. Moreover, responsible water use rules set by the airport community could greatly reduce water demand in the wider area, especially in drought-prone areas, helping to improve inhabitants' quality of life [32]. The airport operator can implement several water management measures and rules outlined in the literature. These include water use, wastewater treatment, water quality, and water recycling and reuse [30]. Sustainable water management involves all airport stakeholders, including airlines, handlers, and any other operator whose activities notably impact water consumption. By lowering freshwater demand, eliminating pollutants associated with deicing operations, performing water conservation programs, and giving financial incentives to airport partner industries that conserve water [31,33]. Climate change also affects water levels, especially in coastal and hot locations [32]. Desperately needed measures to protect coastal airports from water shortages, floods, and climatic threats are urgently needed.

2.3.5. Waste Management

The waste generated by airport operations is significant, and it must be managed according to the 'polluter pays' principle. The amount of waste generated is determined by the number of passenger and aircrafts operating at the airport. In most cases, waste generated primarily consists of solid urban waste, non-hazardous waste, and special hazardous waste generated at terminals or by airlines and other entities operating at the airport. While airlines are responsible for the majority of waste, airport operators are usually in charge of its disposal [34,35]. Separation of solid and liquid waste, hazardous and non-hazardous waste, waste reduction methods for created trash and strategies to increase reuse, recycling, and reprocessing are all part of a successful waste management process [28,36,37].

2.3.6. Ecosystems

The development and construction of mega infrastructure such as airports requires the expropriation of large areas of land and intervention in the natural environment. For this purpose, during airport development, large expanses of land must be replaced by infrastructures and buildings [17]. This usually impacts local ecosystems, potentially affecting their functions and leading to a loss of biodiversity.

According to [9], environmental concerns differ by airport, based on public criticism of aviation and other social issues. Environmental considerations will be determined by current operations and the demand for additional infrastructure, affecting global and local airport expansion. Effective airport planning and management can reduce the possibility of environmental issues becoming capacity restrictions, allowing for growth [38].

3. Evaluation Methodology Framework

Several significant airports have already released sustainability reports laying out their environmental protection goals, carbon-neutral efforts, and investment objectives. Another alternative is to just propose an environmental strategy without specifying any environmental performance goals, which is adopted mostly by regional airports. Moreover, it is widely understood that all environmental issues associated with airport operations must be identified. Many airports, however, continue to rely on outdated traffic, operational, and financial indicators [11]. Rather than limiting current operations, many airports' policies appear to be focused on attracting new flights and increasing demand for new destinations. Few airports, on the other hand, have a comprehensive environmental policy in place to lessen their total impact on the environment.

Generally, the selection of the most appropriate methodological framework for evaluating airports' environmental management performance and assessing their environmental strategies, is crucial for the proper comparison of results and the production of conclusions useful for the air transport business ecosystem. In this framework, benchmarking provides substantial benefits in terms of illustrating results and comparing similar industry units on the same business [34,39]. Performance benchmarking is a vital part of improving an organization's efficiency. From an airport's standpoint, it could improve the link between specific goals and consumer, stakeholder, and airport demands. Achieving the standard or target level of performance is based on the individual and collective performance of numerous stakeholders [40]. Benchmarking could be a beneficial tool for both airport operators and regulatory bodies in measuring the sector's success in reducing environmental impacts.

The evaluation methodology framework is analyzed in the following sub-sections, and its key features are depicted in the flow chart below (Figure 2).

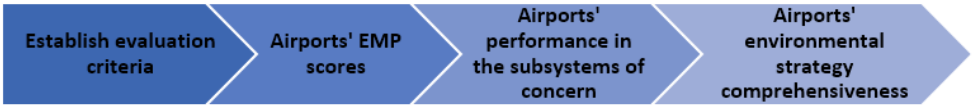

Figure 2. Methodology framework flow chart.

3.1. Evaluation Concept

An integrated, comprehensive, and complete analysis of airports' environmental sustainability can be conceived along three, at least, axes of action [41], as depicted in Figure 3. One of these axes is related to the phased actions taken by the airport operator regarding the environmental management categories mentioned above. A second axis can be formed representing the equilibrium between impacts related to climate change and air quality (E, N) and other environmental impacts such as degradation of water resources, waste management, and ecosystem management (W, WE). The third axis would be the one that expresses the airport's impact footprint, representing the equilibrium between emissions with a global impact (E) and impacts which affect mostly the local environment and community (N, W, WE). In the second axis, the evaluation is mostly focused on environmental aspects related to high taxation and the establishment of specific targets,

while in the third, it is focused on the equilibrium between aspects with impact to industry and to the local community. The actual treatment of the triple goals of this study begins with the development of a comprehensive framework regarding airports' environmental sustainability performance, within which the balance between these three main elements (axes) is providing evidence of a sustainable environmental strategy.

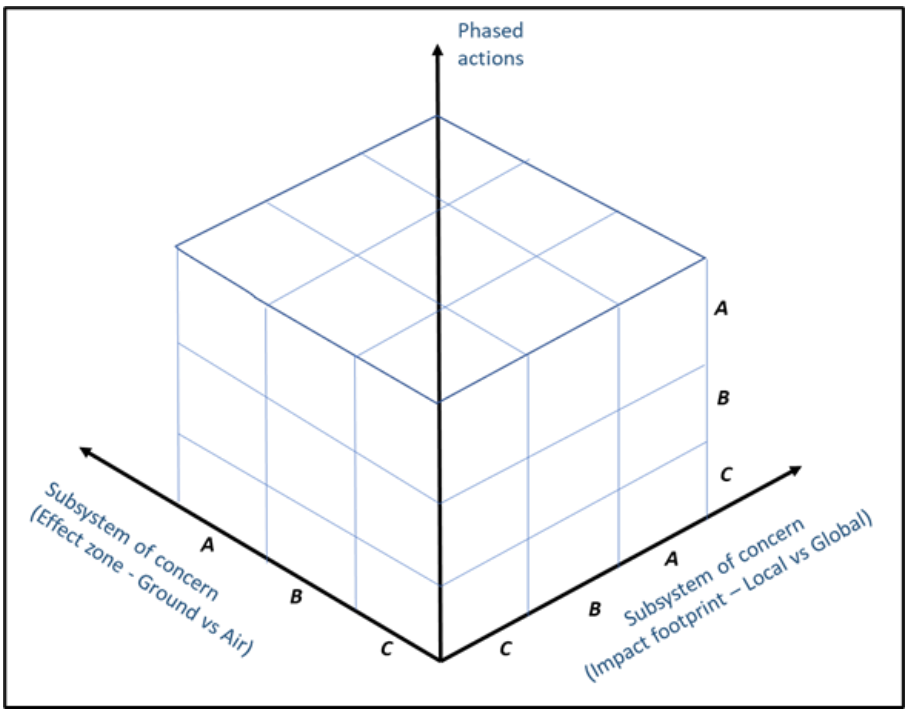

Figure 3. Elements of evaluation of sustainability comprehensiveness; Category A: 4.00 < EMP $\leq$ 5.00, Category B: 2.00 < EMP $\leq$ 4.00, Category C: EMP $\leq$ 2.00.

3.2. Assessment Modeling

The assessment modeling is based on multi-objective method in terms of identifying the evaluation criteria. Moreover, an analytical hierarchy process (AHP) (multicriteria) was followed for quantifying the weights of the evaluation criteria (importance multipliers). Regarding the phased actions taken by the airport operator in terms of its environmental management, the main categories are emissions, noise, water, and waste-ecosystems (evaluation criteria) are emerging [14]. In addition to emissions and noise monitoring, the evaluation sub-criteria include resource conservation, anti-noise infrastructure, and waste (solid and liquid) management. GHG reduction targets, recycling, waste pricing policy incentives are among the other approaches (Table 1). The statistical software SPSS Statistics was used to perform the analysis and visualize the results of the evaluation framework.

The environmental management performance score (EMP) for the airport sample is given by the following equation:

$$EMP = aE + bN + cW + dWE \quad (1)$$

where:

E = number of sub-criteria succeeded in environmental plans in category of emissions
N = number of sub-criteria succeeded in environmental plans in category of noise
W = number of sub-criteria succeeded in environmental plans in category of water
WE = number of sub-criteria succeeded in environmental plans in category of waste ecosystems
a,b,c,d = importance multipliers

Table 1. Environmental performance evaluation criteria.

Emissions (E)	**Noise (N)**
Emissions monitoring	Noise monitoring
GHG emissions reduction target	Landside noise management
Carbon accreditation	Noise action plan
Energy-efficient infrastructure	Anti-noise infrastructure
Renewable electric power	Registration of noise complaints
Water (W)	**Waste–Ecosystems (WE)**
Water conservation system	Recycling
Water quality monitoring	Hazardous waste management
Water runoffs management	Waste minimization measures
Water consumption monitoring	Waste pricing policy
Wastewater treatment	Protection of biodiversity

Many studies have looked at how airports affect the environment, but few of them have examined the relative importance of this category. The weighting of the selected criteria is determined by the relative importance of each category to aviation growth. Climate change is the most essential concern for long-term aviation industry development, according to the literature [5,12,14,42,43], and the most important issue for airport sustainable development. Concerns regarding air quality and noise management at airports have been raised by the local communities. Moreover, concerns about water, waste, and ecosystem management differ based on the cultural and educational background, as well as the environmental sensitivity of the local communities. As a result, according to [14], the following importance multipliers (Table 2) have been established to indicate the relevance of each criterion in the review process, depending on the evaluation criteria impact on airports.

Table 2. Evaluation criteria importance multipliers.

Evaluation Criteria	**Importance Multipliers**	
	Code	**Value**
Emissions (E)	a	0.35
Noise (N)	b	0.30
Water (W)	c	0.20
Waste–Ecosystems (WE)	d	0.15
Sum		1.00

3.3. Strategy Comprehensiveness Depiction

The overall depiction of comprehensiveness is based on the adjustment of the environmental performance scores (EMP) as well as the performance in the subsystems of concern, in a category range from 'A' to 'C'.

Based on its EMP score, each airport is ranked into the following categories:

- Category A: $4.00 < \text{EMP} \leq 5.00$.

Airports in this category present the 'best' performance, by setting and achieving specific targets related to all evaluation categories.

- Category B: $2.00 < \text{EMP} \leq 4.00$.

Airports in this category present a 'moderate' performance and a partial development of activities related to their environmental performance. Targeted actions and measures are required to improve their environmental strategy and strengthen their sustainable transition.

- Category C: $\text{EMP} \leq 2.00$.

Airports in this category are characterized as 'unsustainable'. Thus, their environmental management strategy should immediately be redefined to enhance their sustainable transition.

Moreover, to determine the balance between emissions-noise (E-N) and water-waste-ecosystems (W-WE) on the one hand, and emissions (E) and noise-water-waste-ecosystems (N-W-WE) on the other hand, the environmental performance of airports in terms of managing these elements was considered. Therefore, each airport is ranked into the following categories, based on its performance in each of the above objectives:

- Category A: includes airports that present a cumulative score on both examined objectives of greater than 7.5 and less than 10.0. Airports in this category must have achieved at least the maximum score in one of the examined objectives and 50% of the maximum score in the other.
- Category B: includes airports that present a cumulative score on both examined objectives greater than 5.0 and less than 7.5. Airports in this category must have achieved at least the maximum score on one of the examined objectives.
- Category C: includes airports that present a cumulative score in both examined categories of less than 5.0.

Based on its ranking in each one the above critical elements (axes) of environmental sustainability evaluation, each airport takes a score which represents its environmental strategy comprehensiveness, providing evidence of its environmental management performance. More specifically, airports with a triple 'A' score follow a robust strategy in managing their environmental impact. These airports present a coherent approach, by implementing actions and taking measures towards all the examined environmental categories and evaluating all different environmental aspects for improving decision-making process. Moreover, airports with a 'A' score regarding their phased actions and a 'B' score in one of the subsystems of concern, although they present a great score in terms of the number of taken phased actions for mitigating their environmental impact, they appear to follow a sided strategy towards a specific subsystem of concern. On the other hand, airports with a 'B' score regarding their phased actions and a 'A' score in at least one of the subsystems of concern, follow an unbalanced strategy in terms of the mitigation of their overall environmental impact, both regarding the implementation of actions and measures towards all the examined environmental categories and the evaluation all different environmental aspects. These airports should focus on an environmental strategic approach for maintaining balance in dealing with the two main subsystems of concern. Finally, airports with a triple 'B' score follow a restrictive strategy, by implementing more generic and basic actions in mitigating their environmental impact and, focused on specific environmental categories unilaterally. These airports should invest both in the implementation of more effective actions and in maintaining balance in dealing with the two main sub-systems of concern.

4. Application

Identification of the various factors that contribute to an effective environmental management system is widely acknowledged by the air transport industry. While the Global Reporting Initiative (GRI) [44–46] provides a framework for airport sustainability reporting, not all airport operators follow these guidelines. Moreover, while sustainability reporting has been a key part of businesses' environmental strategy in recent years, most reports combine several metric frameworks, resulting in imprecise measurements and the omission of numerous sector-specific themes. Part of this study's literature review on airports' performances [1,3,11,14] reveals the difficulty of linking broader understandable and quantified aspects such as financial performance to less quantified aspects such as environmental management performance processes. Many different targets, business plans, and strategies exist, making it difficult to demonstrate accurate measurements that reflect a direct comparison system when it comes to airports' environmental management performance evaluation [2,10,14,17]. Generally, the need to measure industry performance is linked to supply chain decision-making processes. Performance evaluation assesses efficiency, analyzes outcomes, develops goals and strategies, and provides information to stakeholders and decision-makers [16,24].

Financial, economic and technical metrics and characteristics are commonly used to compare airport performance, according to the literature [2,14,47–49]. Fewer studies have reviewed how airports operate in terms of the environment and how they use sustainable business strategies [11]. Owing to their massive social and economic impact on local and global levels, airports as mega infrastructure projects impact the environment in numerous ways. Environmental consequences of airport activities may limit operational capacity or expansion potential. Thus, efficient environmental management for airports is a critical issue for airport authorities aiming to maximize future expansion potential while minimizing environmental impacts. In this framework, this study proposes a comprehensive way to analyzing airport operators' environmental management measures. The evaluation methodology includes airports that serve international flights with yearly passenger flow of 20 to 35 million passengers. The traffic volume was chosen so that comparable conclusions could be easily drawn between U.S, Asian and European airports. Moreover, only airports who employ worldwide Environmental Management Systems (EMS); thus, they are consistent with global standards, are taken into consideration in this study. Table 3 summarizes the airport sample.

Table 3. Airports sample key facts.

Region	Airport *	IATA Code	Operator	Pax 2019 (million)
Europe	Helsinki Airport	HEL	Finavia	21.86
United States	Daniel K. Inouye International Airport	HNL	U.S. Department of Transportation	21.87
United States	Tampa International Airport	TPA	Hillsborough County Aviation Authority	22.50
Asia	Haikou Meilan International Airport	HAK	HNA Infrastructure	24.12
United States	Dulles International Airport	IAD	Metropolitan Washington Airports Authority	24.82
United States	San Diego International Airport	SAN	San Diego County Regional Airport Authority	25.22
Europe	Düsseldorf Airport	DUS	Flughafen Düsseldorf GmbH	25.51
Europe	Athens International Airport	ATH	Athens Int. Airport S.A.	25.57
Europe	Stockholm Arlanda Airport	ARN	Swedavia	25.64
Asia	Jeju International Airport	CJU	Korea Airports Corporation	26.29
Europe	Brussels Airport	BRU	Brussels Airport Company	26.36
Europe	London Stansted Airport	STN	Stansted Airport Limited	28.12
Europe	Oslo Airport	OSL	Avinor	28.59
Asia	Antalya Airport	AYT	Fraport TAV Antalya Airport Terminal A.S.	28.63
Asia	Kansai International Airport	KIX	Kansai Airports	28.66
Europe	Malpensa Airport	MXP	SEA Aeroporti di Milano	28.85
Europe	Palma de Malliorca Airport	PMI	Aena	29.72
Europe	Copenhagen Airport	CPH	Copenhagen Airports	30.26
Asia	Hamad International Airport	DOH	Qatar Airways	35.40
United States	Fort Lauderdale–Hollywood International Airport	FLL	Broward County Aviation Department	36.75

Source: Airports operators' official websites (Accessed: December 2021). * Sorted by 2019 pax volume.

Some issues were addressed differently, and quantitative information was frequently omitted. To continuously improve their environmental performance, most airports have an EN-ISO 14001 Environmental Management System, which 'certifies that they have identified environmental risks and implemented measures to control and monitor activities that may have an environmental impact' [14]. Airports also report in a variety of timeframes and use a variety of measurement units. Thus, evaluating airport environmental management required a qualitative approach.

5. Evaluation Results and Discussion

This section provides the study's evaluation results based on the methodology framework approach and their discussion in terms of airports' comprehensiveness strategy ranking.

Based on the data identified in airports' environmental plans, the EMP scores for the airport sample are given in Table 4. According to Table 4, even though airports recognize that their business activities and operations have environmental consequences, not all of them have applied effective mitigating measures. As a result, none of the selected airports meets all the evaluation criteria. Overall, Tampa International Airport (TPA) in Florida, U.S., and London Stansted Airport (STN) seem to have the highest performance, while Jeju International Airport (CJU) presents the lowest performance in the sample. Most airports have applied a specific environmental plan to meet specific targets in most of the environmental management categories. Additionally, environment protection is one of the top priority actions related to future development of the business. Depiction of airports' performance based on each evaluation criterion is presented in Figure 4.

Table 4. Airports' environmental management performance scores.

Airport *	Evaluation Criteria				EMP Score
	E	N	W	WE	
TPA	1.75	1.50	0.80	0.60	4.65
STN	1.75	1.50	0.80	0.60	4.65
SAN	1.75	1.20	1.00	0.60	4.55
KIX	1.75	1.20	1.00	0.60	4.55
ATH	1.75	1.20	0.80	0.75	4.50
PMI	1.75	0.90	0.60	0.75	4.05
HNL	1.75	1.20	0.60	0.45	4.05
HEL	1.75	0.90	0.80	0.60	4.05
HAK	1.75	1.20	0.60	0.45	4.05
AYT	1.70	1.20	0.60	0.55	4.05
DOH	1.40	0.90	1.00	0.45	3.75
CPH	1.75	0.90	0.80	0.30	3.75
OSL	1.75	0.90	0.60	0.45	3.70
MXP	1.75	0.90	0.60	0.45	3.70
BRU	1.40	1.20	0.40	0.60	3.60
ARN	1.75	0.90	0.60	0.30	3.55
IAD	1.40	0.90	0.60	0.60	3.50
FLL	1.05	1.20	0.80	0.45	3.50
DUS	1.75	0.60	0.40	0.30	3.05
CJU	1.05	0.60	1.00	0.30	2.95

Source: Airports' environmental plans/reports (2019). * Sorted by EMP score.

Over 70% of the European airports in the sample score above average, and the vast majority of the sample scores the highest in the category of emissions. As a result, emissions appear to be the main concern, with most airports including 5 out of 5 noise-related sub-criteria in their environmental strategy. Water management, on the other hand, is deemed the least important issue, incorporating 3 out of 5 related sub-criteria. The U.S. airports in the sample have the best performance in the category of emissions, with most incorporating 5 out of 5 emissions-related sub-criteria. Moreover, 80% of airports perform well in the category of noise, meeting 4 out of 5 sub-criteria. However, waste-ecosystems seem to be the least important issue, incorporating 3 out of 5 related sub-criteria. Finally, in terms of Asian airports, water management appears to be the most critical issue, with 60% of the sample scoring the highest in this category, while noise and waste-ecosystems score the lowest, with 3 out of 5 related sub-criteria for meeting specific goals.

Notably, most of the airports in the sample, particularly those that play a major regional role, implement measures to mitigate their environmental impacts. Moreover, the sector acknowledges climate change as a significant constraint and is adapting environmental management strategies, trying to incorporate measures and actions focused not only on

carbon managements, but also to ensuring long-term sustainability. Average EMP scores were 4.04 out of 5.00 for US airports, 3.86 for European, and 3.76 for Asian airports.

Furthermore, the environmental strategy employed by the airport sample appears to be location dependent. Airports in tourist areas seem to place a higher priority on noise control than on reducing GHG emissions. As a major European tourist destination, Athens International Airport (ATH) appears to have set innovative goals for all evaluation sub criteria. Finally, water management strategies such as water consumption and quality monitoring, water conservation measures and water recycling and reuse tend to be prioritized by airports in water-stressed areas.

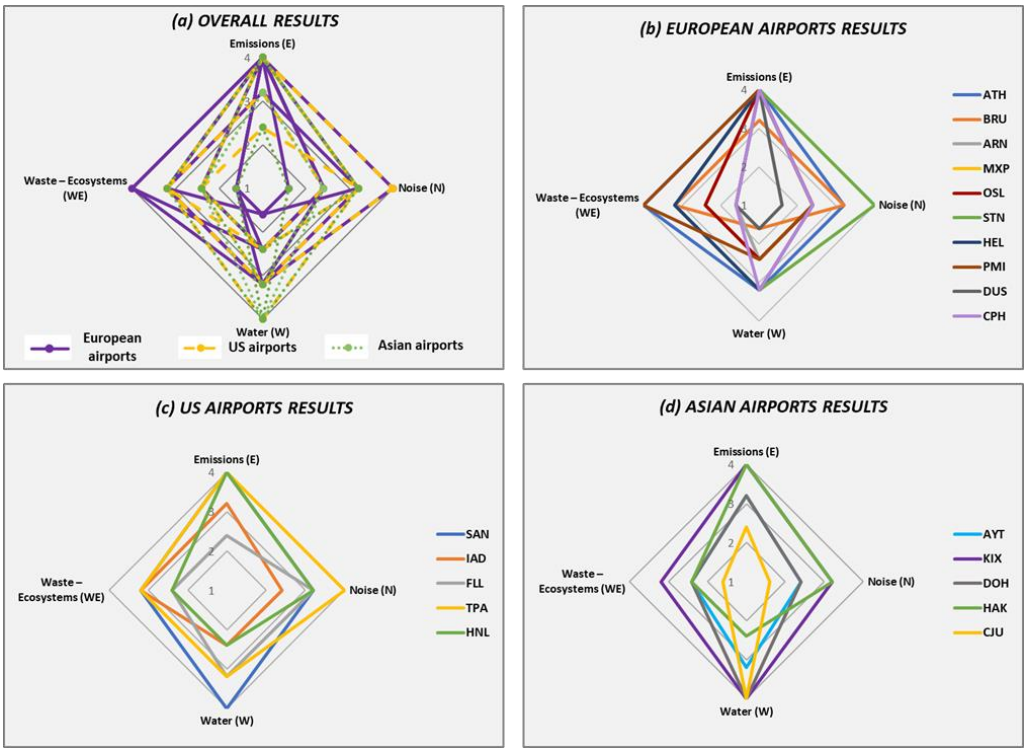

Figure 4. Depiction of airports' environmental management performance by region.

5.1. Airports' Performance in the Subsystems of Concern

The airports' sample scores in each subsystem of concern ('effect zone' and 'impact footprint') and their categorization are depicted in Figure 5 below.

Almost half of the sample airports appear to use a balanced development model to manage the two main evaluation categories (Figure 5a). More specifically, US airports perform the best across all evaluation criteria, with Tampa International Airport (TPA) and San Diego International Airport (SAN) present the highest performance. Moreover, 60% of the European airports in the sample seem to have a partial development of environmental performance activities (Category B). More specifically, Stockholm Arlanda (ARN) and Düsseldorf (DUS) appear to have adopted an Emissions (E) and Noise (N)-focused strategy, with little attention paid to water, waste, and biodiversity. AYT and KIX International Airports in Asia have the most balanced performance, whereas Jeju International Airport (CJU) appears to be focusing on water and waste-ecosystems (W&WE) targets while ignoring emission reduction and noise control. The selected airports are also not in category "C", which means they prioritize environmental sustainability and promote sustainable transition strategies.

A balanced development model appears to be used by nearly 80% of the sample airports (Figure 5b), owing to their excellent performance in the emissions category. The best performing European airports are Athens International Airport (ATH) and London Stansted Airport (STN). However, Düsseldorf Airport (DUS) appears to have a strategy

focused on Emissions (E) targets, with little focus on noise mitigation, water and waste management, or biodiversity protection. The sample's best-performing US airports are Tampa International Airport (TPA) and San Diego International Airport (SAN), while Fort Lauderdale–Hollywood International Airport (FLL) appears to focus on noise (N), water (W), and waste-ecosystems (WE). Finally, among Asian airports, only Jeju International Airport (CJU) appears to have a partial development of environmental performance activities (Category B).

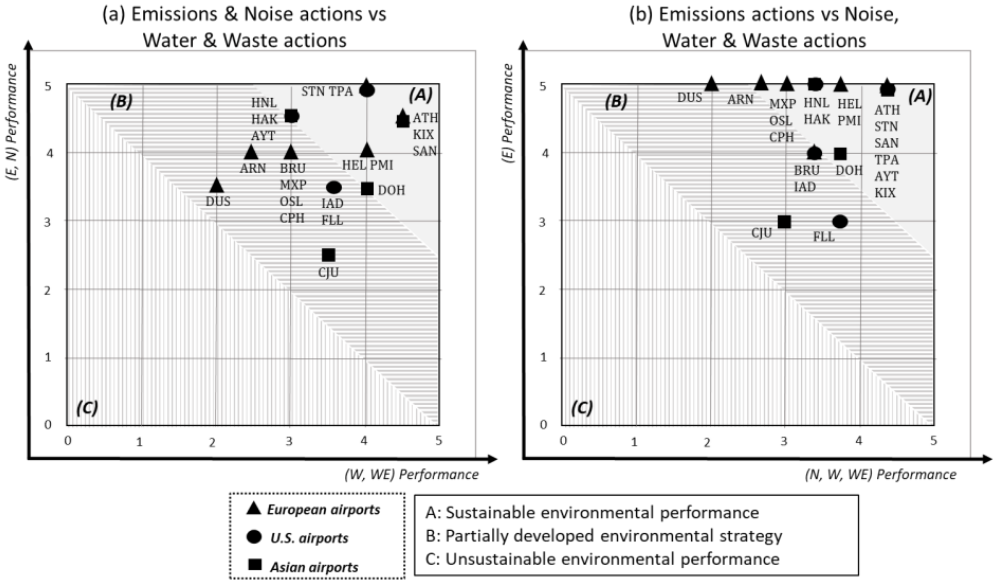

Figure 5. Depiction of airports' performance in the subsystems of concern.

5.2. Airports' Environmental Strategy Comprehensiveness

Table 5 presents the airport sample's environmental strategy ranking results, based both on their overall environmental performance (EMP scores) and their performance in maintaining the balance in the two examined subsystems of concern (E vs. N, W, WE and E, N vs. W, WE).

Airports with the highest rating, getting a triple 'A' score seem to follow a robust strategy in managing their environmental impact. These airports present a coherent strategy, by implementing actions and taking measures towards all the examined environmental categories and evaluating all different environmental aspects for improving decision-making process. Airports with a 'A' score regarding their phased actions and a 'B' score in one of the subsystems of concern, present a great score in terms of the number of taken phased actions for mitigating their environmental impact, but appear to follow a sided strategy towards a specific subsystem of concern. These airports should invest in the development of a more holistic environmental management plan, with a balanced approach in dealing with the two main subsystems of concern. On the other hand, airports with 'B' score regarding their phased actions and a 'A' score in at least one of the subsystems of concern, seem to follow an unbalanced strategy regarding the actions taken for mitigate their overall environmental impact. These airports should focus on an environmental strategic approach for maintaining balance in dealing with the two main sub-systems of concern. Finally, airports with a triple 'B' score seem to follow a restrictive strategy, by implementing more generic and basic actions in mitigating their environmental impact and, focused on specific environmental categories unilaterally. These airports should invest both in the implementation of more effective actions and in maintaining balance in dealing with the two main subsystems of concern.

Table 5. Airports' comprehensiveness strategy ranking.

Airport Code *	Strategy Orientation	Comprehensiveness Rating		
		Phased Actions (EMP Score)	Subsystem of Concern (E) vs. (N, W, WE)	Subsystem of Concern (E, N) vs. (W, WE)
ATH	**Robust**	A	A	A
HEL		A	A	A
KIX		A	A	A
PMI		A	A	A
SAN		A	A	A
STN		A	A	A
TPA		A	A	A
HNL	**Sided**	A	A	B
HAK		A	A	B
AYT		A	A	B
ARN	**Unbalanced**	B	A	B
CPH		B	A	B
DOH		B	A	B
MXP		B	A	B
OSL		B	A	B
BRU	**Restrictive**	B	B	B
CJU		B	B	B
DUS		B	B	B
FLL		B	B	B
IAD		B	B	B

* Alphabetically sorted, In case of 'C': Unsustainable strategy.

It is noteworthy that none of the airports in the sample get a 'C' score, meaning none are categorized in the unsustainable strategy zone. In terms of the geographical distribution of the selected airports, the majority of European and U.S. airports seem to follow a more robust environmental strategy, by implementing actions and taking measures for mitigating their environmental impact, while most Asian airports appear to follow an environmental strategy directed to a specific environmental category.

Different environmental management systems and strategies tend to be used by airports in different regions, resulting in different environmental performance evaluation categories. Since they are subject to global regulatory frameworks, their environmental management strategies should include specific actions and targets. In terms of European airports, further investments in water footprint reduction and water reuse are needed to address emerging threats such as extremely high temperatures and droughts. This condition applies even more to airports located in Southern Europe and the Mediterranean region, as they already face the effects of the climate crisis. Moreover, environmental management strategies in U.S. airports should focus on effective recycling systems, waste prevention and protection of biodiversity.

Finally, Asian airports should improve their noise action plan, by taking measures related to the reduction of the nuisance caused by aircraft and applying a more effective waste management plan focused on waste reduction and recycling.

6. Concluding Remarks

The necessary condition of ensuring economic, social, and environmental impact mitigation also affects the functioning of regulatory authorities and businesses, particularly in the air transport sector, which, by facilitating access to productive services and connectivity to markets, is a critical contributor to the economy [1,3]. Businesses are increasingly being pressed by decision makers (e.g., stakeholders, shareholders, customers, employees, and society) to assess their socioeconomic impacts and manage their actions sustainably and resiliently. The evaluation of the strategy's effectiveness toward environmental impact mitigation and the efficiency of the accompanying mitigation actions delivered or permitted

by air carriers and airports is the cornerstone of the effective sustainability planning process in the aviation industry [14,17,38].

The primary objective of this paper is to introduce an evaluation framework of comprehensiveness of an environmental mitigation strategy implemented by the airport operators upon sustainable development concept. The analysis review takes into consideration the airport operators environmental or strategic plans, promoting a three-level environmental strategy assessment tool.

The numerical application reviewed 20 city airports across the world, providing continental and inter-continental attitudes of different approaches. While most airports are aware of their environmental impact, not all have taken the same steps, much alone implemented mitigating measures. Airport operators acknowledge climate change as a significant limitation and adjust their environmental strategies to incorporate not only measures focused on carbon management, but also on driving change towards the sector's sustainable transition. In terms of the geographical distribution of the selected airports, the majority of European and U.S. airports seem to follow a more robust environmental strategy [50], by implementing actions and taking measures for mitigating their environmental impact, while most Asian airports appear to follow an environmental strategy directed to a specific environmental category. Additionally, the airport sample's environmental strategy appears to be location dependent [51]. A potential limitation of this study could be the size of the sample. A larger sample size could lead to safer and more representative comparative conclusions regarding the environmental management of airports in each region.

The findings highlight critical issues regarding the impact of effective air transportation performance on business resilience and sustainable development, which is a significant challenge for planners, managers, and decision makers. Further research could focus on a quantitative analysis of airports' environmental sustainability performance, considering measurable outputs of airport distinguished operational zones (apron, terminal, and landside) for each evaluation criteria category correlating environment disturbance mitigation with operational performance (aircraft and passenger traffic, etc.) on the one hand and airport corporate performance on the other (e.g., revenue passengers, commercial revenues, etc.). In particular, for corporate performance towards sustainability, the formation and the structure of airport business should be reviewed considering the continuous tendency towards outsourcing many services [52].

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