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A framework for environmental performance evaluation in resource-constrained air navigation services: a Cuban case study

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Abstract
The aeronautical sector confronts unprecedented challenges to mitigate its environmental impact amid accelerated climate change and stringent regulations. This study's objective was to design and apply a methodology for evaluating environmental performance at the Cuban Air Navigation Company through a mixed-methods case study. Based on ISO 14001 and 14031 standards, the methodology's design integrated systematic literature review and documentary analysis and was validated using inductive-deductive and systemic approaches. The results, based on three premises and six key indicators, revealed high compliance in environmental objectives (92.3%) and waste management (102%). However, the evaluation also highlighted key areas for improvement, such as electromobility strategies (70% compliance) and the environmental training plan (83.6% compliance). The resulting framework not only enables monitoring environmental practices to ensure regulatory compliance but also serves as a strategic tool for advancing sustainability and driving continuous management improvement.

Keywords: climate change; environmental performance; methodology; environmental management; sustainability; environmental training.

Evaluación del desempeño ambiental en navegación aérea con recursos limitados: estudio de caso en Cuba

Resumen
El sector aeronáutico enfrenta desafíos inéditos para mitigar su impacto ambiental ante un cambio climático acelerado y regulaciones más estrictas. Este estudio diseñó y aplicó una metodología para evaluar el desempeño ambiental en la Empresa Cubana de Navegación Aérea mediante un estudio de caso mixto. La metodología, basada en las normas ISO 14001 y 14031, integró la revisión sistemática de literatura y el análisis documental, y fue validada mediante métodos inductivo-deductivos y sistémicos. Los resultados, a partir de tres premisas y seis indicadores clave, mostraron alto cumplimiento en objetivos ambientales (92,3%) y gestión de residuos (102%), pero también revelaron áreas de mejora como la electromovilidad (70%) y la formación ambiental (83,6%). El marco resultante facilita el monitoreo de prácticas ambientales, el cumplimiento normativo y sirve como herramienta estratégica para promover la sostenibilidad y la mejora continua de la gestión.

Palabras clave: cambio climático; desempeño ambiental; metodología; gestión ambiental; sostenibilidad; formación ambiental.

1 Introduction

In recent decades, the relationship between human activities and changes in the natural environment has become critically important. One of the most extensively studied phenomena is climate change, which involves significant and long-term variations in global and regional climate patterns, primarily driven by human activities such as the burning of fossil fuels, deforestation, and industrialization [1]. These activities contribute to the increase in greenhouse gas concentrations, such as carbon dioxide (CO_2) and methane, in the atmosphere, thus driving global warming [2].

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The aeronautical sector is responsible for approximately 2% to 3% of global CO_2 emissions due to the large quantities of fossil fuels consumed during flight operations. These operations significantly impact the environment through air pollution and other contributions to climate change [3,4]. In addition to CO_2 emissions, the sector also contributes to climate change through other environmental impacts such as noise pollution and the consumption of resources, including fuel and water, required to maintain operations [5, 6]. These factors underscore the urgent need to explore strategies for mitigating the environmental footprint of the sector.

1.1 Environmental management in the aeronautical sector

The International Organization for Standardization (ISO), through consensus among its member countries, establishes systems and methodological tools to address the environmental impacts of organizational management. The ISO 14000 family of standards, developed by the ISO/TC 207 Technical Committee on environmental management, provides a set of international benchmarks to guide organizations in minimizing their environmental impacts [7]. Within this series, the ISO 14050:2020 standard defines environmental management as "the coordinated set of activities within an organization related to its environmental aspects" [8] (p. 3).

Grounded in the principles of sustainable development, environmental management seeks to balance industrial growth with environmental preservation [9]. In the aviation industry, this balance is pursued through policies, procedures, and practices designed to mitigate the environmental effects of operations [10]. To this end, frameworks like the Cuban standard NC-ISO 14001:2015, Environmental Management Systems—Requirements with Guidance for Use, equip organizations with a formal system to control environmental impacts, continuously improve performance, and demonstrate a commitment to sustainability. The standard aims to ensure regulatory compliance and address risks and opportunities by promoting interrelated actions, such as setting clear objectives and implementing integrated processes [1].

Identifying and quantifying the environmental impacts of an organization's activities is therefore essential for strategic decision-making. It allows for setting clear objectives, implementing preventive or corrective measures, and seizing opportunities to enhance environmental performance [11]. The NC-ISO 14001:2015 standard defines an environmental impact as any change to the environment, whether adverse or beneficial, resulting wholly or partially from an organization's environmental aspects [1]. An environmental aspect, in turn, is defined as any element of an organization's activities, products, or services that interacts or can interact with the environment.

Consequently, implementing an Environmental Management System in air service companies requires specific methods to evaluate environmental performance. This process entails measuring and analyzing operational impacts on the environment, local communities, and the economy. Furthermore, it involves designing sustainable strategies and fostering a culture of continuous improvement in environmental management [12].

1.2 Context, framework, and rationale for environmental performance evaluation

The Cuban context presents unique challenges that heighten the importance of this study. The national aeronautical sector operates under significant economic constraints that limit access to cutting-edge, fuel-efficient technologies and international capital for green infrastructure projects [13]. Furthermore, as an island nation, Cuba is particularly vulnerable to the impacts of climate change, such as rising sea levels and an increase in the frequency of extreme weather events, which directly affect airport operations and safety. These factors create a pressing need for innovative, low-cost, and highly adaptable environmental management methodologies that can be effectively implemented within the existing resource framework, making the Cuban case a relevant model for other developing nations facing similar circumstances.

In line with national policies to reduce the environmental impacts of aviation, the Instituto de Aeronáutica Civil de Cuba (IACC) is responsible for developing aeronautical standards and regulations. These are based on the international requirements of the International Civil Aviation Organization (ICAO), which promotes global cooperation in the sector [14]. Consequently, Cuban companies in the aeronautical sector are mandated to implement practices to conserve resources, improve and rehabilitate environmental conditions, and monitor impacts and risks. These control actions must involve both workers and managers and be conducted in accordance with relevant budgets, ensuring compliance with all national and international regulations [15-18].

The Empresa Cubana de Navegación Aérea (ECNA), the focus of this research, provides air navigation services within the Havana Flight Information Region (FIR), operating through a Central Level with seven directorates and eleven Base Business Units [19]. The company has implemented an Environmental Management System (EMS) based on NC-ISO 14001:2015, certified by national and international bodies. This system aligns its operations with ICAO policies and follows a process-based approach for predictable results [20,21]. For this research, the specific unit of study selected from ECNA's eleven Base Business Units was the Air Traffic Control Center (Centro de Control de Tránsito Aéreo - CCTA).

The selected unit, CCTA, is located in proximity to several potential sources of environmental interaction, including an electrical substation, a warehouse facility, and the hangars of the Cuban Aviation Company. The nearest residential area is a populated settlement approximately 2 km from the site, featuring well-developed infrastructure such as drainage and aqueduct systems and multi-story buildings. Although a portion of the CCTA workforce resides in this settlement, no environmental conflicts related to the unit's operations had been formally reported at the time of the study. This physical and social context is relevant for identifying baseline environmental conditions and potential community-related environmental aspects.

While an EMS provides a foundation, its effectiveness hinges on a robust process for environmental performance evaluation (EPE). The ISO 14031:2021 standard defines EPE as an internal process employing indicators to measure and promote continuous improvement, structured around the Plan-Do-Check-Act (PDCA) cycle. In the Plan stage, key indicators are selected, which fall into two main categories: Environmental Condition Indicators and Environmental Performance Indicators. The first category, Environmental Condition Indicators (ECIs), provides information on the environmental context affected by the organization. The second category, Environmental Performance Indicators, is further subdivided into two types: Management Performance Indicators (MPIs) and Operational Performance Indicators (OPIs). MPIs focus on management commitment and socio-economic benefits, while OPIs analyze the efficiency of organizational operations [22].

Following the cycle, the Do stage involves the systematic collection and analysis of reliable, high-quality data, which are transformed into actionable information to support environmental objectives (EO) and facilitate communication with stakeholders. During the Check and Act phases, results are compared against established objectives using statistical tools to identify progress or deficiencies. These findings are then communicated to senior management to support strategic decision-making and drive continuous improvements [22]. To ensure its utility and promote accountability, ISO 14031:2021 also stipulates that all EPE information must be relevant, comprehensive, transparent, consistent, and accurate.

The execution of such a detailed process requires a structured methodology. Fernández Sotelo [23] describes a methodology as a sequence of methods, procedures, and techniques that integrate actions, resources, and tools to achieve defined objectives. Furthermore, de Armas Ramírez et al. [24] emphasize that an effective methodology must be built upon clear premises and include specific objectives, stages, and implementation recommendations to ensure its applicability.

Considering the above, and despite its certified EMS, ECNA's management identified a critical gap. There was a recognized need to set more specific environmental goals to prevent pollution, eliminate hazards, and reduce risks. Concurrently, it was observed that there was insufficient information to identify strategic opportunities, track trends in environmental performance, and establish clear objectives against which performance could be measured. This lack of a systematic process for understanding its environmental impact was identified as the core research problem. Consequently, the objective of this research was to design and apply a methodology for evaluating environmental performance within ECNA, enabling the organization to address these gaps and achieve its sustainability goals.

2 Method

2.1 Research design and approach

This study employed a mixed-method research design, combining qualitative analysis with practical application. The qualitative phase involved systematic literature and documentary reviews to establish a theoretical foundation. The practical phase consisted of the pilot-testing of the resulting methodology within a specific organizational context. This integrated approach allowed for a comprehensive examination of the intervention's effectiveness. The research was structured as a single-case study of the Air Traffic Control Center, a Base Business Unit within the Empresa Cubana de Navegación Aérea.

2.2 Study participants and collaborators

The design and validation of the methodology were conducted in collaboration with an expert panel. This panel consisted of three researchers specializing in environmental management, with affiliations to ECNA, the University of Havana, and the Pontifical Catholic University of Ecuador, ensuring a blend of internal and external academic perspectives.

The pilot implementation of the methodology was carried out at the CCTA. The study population comprised all 166 employees of the unit. Their participation was defined as follows: direct participation involved key personnel, such as managers and department heads, who actively engaged in providing data and feedback during the evaluation process. Indirect participation included the remainder of the workforce, whose departmental activities, resource consumption data, and waste generation figures were essential for the overall environmental performance analysis. All organizational data were anonymized and handled with strict confidentiality to protect the privacy of the company and its employees.

2.3 Methodology development and application

The development of the methodology began with a systematic review of scientific and technical literature to establish a theoretical foundation. This review utilized databases such as Scopus, Web of Science, and Google Scholar, with key search terms including “environmental management,” “environmental performance,” “service companies,” and “aviation.”

Simultaneously, a comprehensive documentary analysis was conducted on the following key standards, regulations, and internal procedures relevant to the aeronautical sector:

- NC-ISO 9001:2015 Quality Management Systems - Requirements.
- NC-ISO 14001:2015 Environmental management systems - Requirements with guidance for use.
- ISO 14031:2021 Environmental management - Environmental performance evaluation - Guidelines.
- Aeronautical Regulation No. 16. Environmental Protection - Part 1. Environmental Management [15].
- Procedure P.01-15. Environmental Aspects. Internal procedure to identify, evaluate, and control environmental aspects at CCTA [25].

To facilitate a comprehensive diagnostic of ECNA’s environmental performance, a checklist was developed, grounded in the elements provided by standards NC-ISO 14001:2015 and ISO 14031:2021. This tool comprised 29 criteria, whose relevance was validated through unanimous approval by ECNA's senior management, ensuring alignment with the organization's operational and strategic needs.

Using this diagnostic checklist in conjunction with other documentary analysis techniques, including systematic comparison, critical analysis, and comparison matrices, a gap analysis was performed. This involved comparing the principles and requirements from the literature and official documentation against ECNA's existing practices to identify key deficiencies and areas for improvement.

Based on the results of the gap analysis, relevant environmental performance indicators were selected and subsequently adapted to the specific processes and activities of ECNA. This step ensured that all proposed indicators were directly applicable to the organization's operational context.

The proposed methodology and its adapted indicators then underwent a rigorous validation by an expert panel. This validation was conducted through a structured consensus workshop where each indicator was systematically assessed against SMART criteria (Specific, Measurable, Achievable, Relevant, and Time-bound). Indicators were collectively discussed, revised, and formally adopted upon reaching expert consensus on their practical applicability, robustness, and strategic alignment with ECNA's goals.

Following the validation, the application phase of the study was conducted. Data corresponding to the selected environmental performance indicators (energy consumption, emissions, waste generation) were collected from existing operational records within CCTA. The collected data were then processed and analyzed using descriptive statistical techniques. Furthermore, comparative analyses were performed to identify areas with the greatest potential for improvement and those with outstanding performance, providing the quantitative basis for the evaluation. All data processing and analysis were conducted using Microsoft Excel.

3 Results

3.1 Framework of the proposed methodology

The methodology was developed based on three fundamental premises:

1. The ECNA operates within an environmentally sensitive sector, necessitating robust environmental management to address the challenges posed by climate change.
2. The methodology aims to ensure compliance with both national and international regulations related to sustainability and environmental management.
3. The organization's success is contingent upon its ability to adapt operations to climate and environmental challenges, aiming to reduce negative impacts while enhancing operational efficiency.

Based on these premises, the objective of the methodology was to establish a structured framework for systematically evaluating ECNA's environmental performance and providing reliable data to support strategic decision-making. The resulting framework, depicted in Figure 1, is structured around the PDCA cycle and is designed to transform a series of key inputs into tangible outputs through four distinct stages.

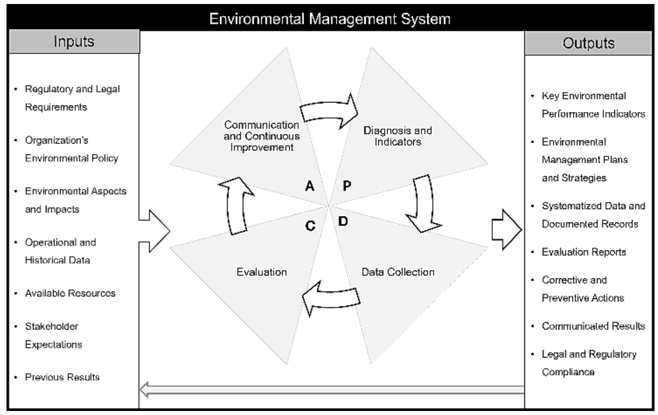

Figure 1. Framework of the Methodology for EPE based on the PDCA Cycle
Source: Own elaboration.

The proposed methodology requires a set of essential inputs to ensure its alignment with the principles of an ISO 14001-based Environmental Management System and its effective implementation within the organization. These inputs are:

- The mandatory reference framework established by local, national, and international regulations applicable to the aeronautical sector.
- The organization's environmental policy, serving as a strategic guide that reflects senior management's commitment to improving environmental performance and preventing pollution.
- A thorough identification and prioritization of environmental aspects and impacts related to the organization's activities, products, and services (e.g., emissions, waste generation, and the consumption of natural resources).
- Operational and historical data, including records of energy consumption, emissions, water use, and waste generation, which form the basis for analysis and planning.
- All available resources for implementation and monitoring, including equipment, measurement systems, trained personnel, and financial assets (allocated budgets).
- The expectations and concerns of relevant stakeholders, such as communities, regulators, and customers, which are taken into account to influence strategic decision-making.
- The findings from previous audits, initial assessments, or past evaluations, which are integrated within the operational framework of the PDCA cycle to ensure a systematic approach to continuous improvement.

The methodology systematically processes the inputs through the four stages shown in Figure 1, which correspond to the PDCA cycle. Table 1 provides a detailed summary of the key actions performed within each of these stages, from the initial diagnosis and planning to the final communication and implementation of improvements.

Table 1.
Summary of Methodology Stages, Actions, and PDCA Cycle Mapping

PDCA Phase	Methodology Stage	Key Corresponding Actions
Plan	Diagnosis and Indicators	• Identify and prioritize significant environmental aspects. • Select and design SMART performance indicators (MPIs, OPIs). • Align indicators with strategic objectives and regulations.
Do	Data Collection	• Develop standardized protocols for data gathering. • Collect reliable, verifiable, and traceable data for each indicator. • Organize information in a centralized database.
Check	Evaluation	• Analyze data and compare performance against established targets. • Identify deviations, non-conformities, and opportunities for improvement. • Generate structured reports for senior management.
Act	Communication and Continuous Improvement	• Formulate and implement corrective and preventive action plans. • Communicate performance results to all relevant stakeholders. • Periodically review and adjust indicators and processes.

Source: Own elaboration.

Applying the methodology yields a series of concrete outputs that enhance the organization's environmental performance and reinforce its alignment with the EMS objectives. The principal outputs are:

- A tailored set of environmental performance indicators to monitor critical areas such as emissions reduction, resource efficiency, and waste minimization.
- The creation of environmental management plans and strategies, which are supported by the indicators and include targeted programs to mitigate significant impacts, optimize processes, and meet established goals.
- Systematized data and documented records, encompassing monitoring results, measurements, and findings from internal and external audits, which provide verifiable evidence of the organization's environmental performance.
- Periodic evaluation reports that detail compliance with indicators and objectives, identify areas for improvement or non-conformities, and propose corresponding corrective and preventive actions.
- The promotion of a continuous improvement cycle, reflected in updates to procedures, processes, or technology, ensuring the ongoing optimization of environmental performance.
- The effective communication of performance results to all relevant stakeholders, fostering transparency and reinforcing confidence in the organization's environmental commitment.
- Periodic updates to the environmental policy based on achieved results, consolidating long-term sustainability and ensuring lasting environmental, social, and economic benefits.

Table 2.
Design and measurement criteria for MPI

Indicator	Method of measurement	Reference point	Score breakdown	
MPI 1	$CEO=\frac{\text{TEO (actual)}}{\text{TEO (plan)}}*100$	A = CEO ≥ 90 % = 1	A + B = 2	2
			A + B = 1	1
	$CEA = \frac{\text{TC}}{\text{TP}} * 100$	B = CEA ≥ 90 % = 1	A + B = 0	0
MPI 2	$\text{CETP} = \frac{\text{ETA (real)}}{\text{ETA (plan)}} * 100$	CETP ≥95%	CETP≥95%	1
			CETP<95%	0
MPI 3	Score from worker environ- menttal perception survey	E. P ≥ 4	E. P ≥ 4	1
			E. P < 4	0
	Complaints received	C = 0	C = 0	1
			C ≠ 0	0

Note. The formulas use the following abbreviations: TEO = Tasks contributing to compliance with EO; TC = Tasks Completed; TP = Tasks Planned; ETA = Environmental Training Actions.
Source: Own elaboration.

3.2 *Design of performance indicators*

To assess environmental performance in accordance with the integrity principle outlined in ISO 14031:2021 (ISO, 2021), three management performance indicators (MPI) and three operational performance indicators (OPI) were defined. The design and measurement criteria for the MPI are detailed in Table 2, while the criteria for the OPI are presented in Table 3. The design and measurement of environmental condition indicators were entrusted to external specialized entities, which conducted evaluations under service contracts for agreed-upon environmental categories.

Designed Management Performance Indicators:

1. MPI 1: Compliance with Environmental Objectives and Actions (CEO and CEA).
- Objective: Determine the extent to which ECNA achieves its environmental improvement goals.
- Information Sources: Environmental strategic plan, monitoring reports, environmental committee meeting minutes, internal compliance audits.

2. MPI 2: Compliance with the Environmental Training Plan (CETP).
- Objective: Assess how well the organization promotes environmental awareness among its employees.
- Information Sources: Training records, attendance logs, post-training satisfaction surveys, environmental competency evaluations, training session minutes.

3. MPI 3: Stakeholder Satisfaction Level.
- Objective: Evaluate whether ECNA's environmental management meets the expectations of its stakeholders.
- Information Sources: Stakeholder surveys and interviews, complaint and suggestion records.

Designed Operational Performance Indicators:

1. OPI 1: Compliance with the Route Realignment Plan (CRRP).
- Objective: Assess progress in redesigning airspace to

achieve more direct and efficient routes, optimizing flight times and fuel consumption.
- Information Sources: Flight plans, airspace redesign reports, route time and fuel consumption statistics, air traffic monitoring software reports.

2. OPI 2: Compliance with the Emissions Reduction Program (CERP).
- Objective: Measure the degree to which ECNA meets its commitments to adopt more efficient technologies.
- Information Sources: Flight emission records, electric technology migration project (ETMP), energy efficiency audits.

3. OPI 3: Compliance with the Recyclable Waste Delivery Plan (CRWDP)
- Objective: To verify how the organization ensures the fulfillment of commitments made for the sustainable management of its waste.
- Sources of Information: Records of recyclable waste delivery and reception, agreements with recycling companies, waste management audits, environmental compliance reports.

Through the integration of these indicators, ECNA ensures a structured and evidence-based approach to monitoring and improving environmental performance, while aligning its strategic objectives and regulatory requirements.

3.3 Performance evaluation results

The application of the designed indicators yielded the results summarized in Figure 2, which compares the achieved performance against the established targets for each key indicator.

Table 3
Design and measurement criteria for OPI

Indicator	Method of measurement	Reference point	Score breakdown	
OPI 1	CRRP $= \frac{\text{R (actual)}}{\text{R (plan)}} * 100$	CRRP = 100 %	CRRP = 100 %	2
			CRRP < 100 %	0
OPI 2	$ETMP = \frac{\text{TA (real)}}{\text{TA (plan)}} * 100$	A: ETMP ≥ 85 % = 1	A + B = 2	2
			A + B = 1	1
	RCE $= \frac{\text{ER (real)}}{\text{ER (plan)}} * 100$	B: RCE ≥ 100 % = 1	A + B = 0	0
OPI 3	$CRWDP = \frac{\text{DQ (real)}}{\text{PR (plan)}} * 100$	CRWDP ≥ 100 %	CRWDP ≥ 100 %	1
			CRWDP < 100 %	0

Note. The formulas use the following abbreviations: R = Realignment of routes; TA = Total actions; ER = Climate equipment replaced; DQ = Delivered quantities; PR = Potential material to be recycled. The score for OPI 2 is a composite of two components: component A (Compliance with the technological migration program) and component B (Replacement of climate equipment with ecological refrigerant).
Source: Own elaboration.

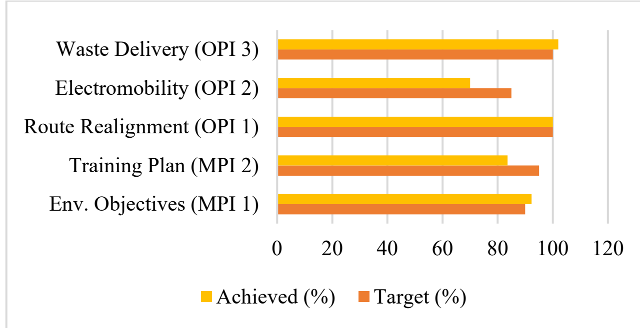

Figure 2. Target vs. achieved compliance for key performance indicators
Source: Own elaboration.

The evaluation shows full compliance (100%) was achieved in the Route Realignment Plan (OPI 1). The target for Recyclable Waste Delivery (OPI 3) was exceeded, reaching 102%, while the overall Environmental Objectives (MPI 1) achieved a 92.3% compliance. In contrast, the performance for the electromobility component of the Emissions Reduction Program (OPI 2) was 70%, and the Environmental Training Plan (MPI 2) reached an 83.6% completion rate.

4 Discussion

4.1 Interpretation of key findings

The evaluation of ECNA's environmental performance reveals a profile of strong compliance in established operational and administrative areas, contrasted with significant challenges in technology-intensive domains. Full compliance in the Route Realignment Plan (OPI 1) and high achievement in Environmental Objectives (MPI 1) suggest that the organization excels at optimizing existing processes and administrative controls. However, the most telling findings are the nuanced results. The overachievement in Waste Delivery (OPI 3 at 102%), for instance, was not a simple success in disposal, but rather an indicator of a successful, underlying digitalization strategy that reduced paper consumption. This highlights a key strength of the methodology: its ability to uncover causal relationships between seemingly unrelated initiatives.

Conversely, the shortfalls in the Environmental Training Plan (MPI 2 at 83.6%) and the electromobility strategy (OPI 2 at 70%) point to systemic issues. The link between inadequate training completion and lower employee satisfaction ratings on environmental education programs suggests that investment in human capital is a critical prerequisite for performance. The primary challenge, however, remains the implementation of capital-intensive technologies like electromobility, where progress is clearly hindered by the broader economic and logistical constraints faced by the organization.

4.2 Contribution and novelty of the methodological framework

The primary contribution of this research is the development of a valid and effective tool for EPE within an Environmental Management System. The methodology's practical applicability was demonstrated by its successful adaptation to the specific operational characteristics of an air navigation service provider. The findings confirm that its implementation enables the systematic identification of significant environmental aspects and the formulation of targeted improvement actions, thereby aligning with the core requirements of the ISO 14031 standard.

When contextualized within existing international frameworks, the specific contribution of this methodology becomes evident. While the ICAO (2019) provides extensive environmental guidance, its tools are often structured for large-scale airport operators with significant resource availability. The framework developed in this study distinguishes itself by being specifically tailored for an entity operating under resource constraints. Its novelty derives not from proposing new theoretical constructs, but from the systematic integration of established ISO standards with national regulations and specific operational realities. This results in a pragmatic and adaptable framework, offering a valuable alternative to more prescriptive, universal models.

4.3 Implications for practice and replicability

The model's potential for replicability in other developing nations is a significant implication of this study. The operational challenges identified at ECNA—such as limited capital for green technologies and heightened vulnerability to climate impacts—are prevalent in many countries, particularly in small island developing states. Consequently, the proposed methodology, with its emphasis on leveraging internal data and expertise within the recognized ISO structure, offers a robust and transferable framework. Other organizations can adopt the core PDCA architecture while customizing the performance indicators to align with their specific environmental priorities, such as water stewardship in arid regions or biodiversity conservation near sensitive ecosystems.

From a management perspective, the results underscore that achieving environmental goals requires a dual focus: optimizing internal processes and securing strategic resources for technological upgrades. The mechanisms for communicating results, defined via a formal procedure involving periodic reports and feedback meetings, proved effective in refining strategies and ensuring stakeholder alignment.

4.4 Limitations and future research

Despite the successful application, this study has limitations. The evaluation relied primarily on existing historical data, which in some areas was incomplete, and the single-case study design limits the generalizability of the specific quantitative results. Based on these findings, it is recommended that the organization accelerate the implementation of advanced technological strategies and develop a more comprehensive training plan to address the identified shortfalls.

Future research should therefore focus on applying this methodology in other air navigation service providers to further validate its adaptability. Additionally, developing cost-effective, in-house methods for monitoring key Environmental Condition Indicators could enhance the autonomy and comprehensiveness of the evaluation.

5 Conclusions

This research successfully designed and applied a tailored methodology for environmental performance evaluation at ECNA. The study confirms that a systematic, evidence-based approach structured around the PDCA cycle is highly effective for identifying critical performance areas, even under significant resource constraints. The resulting framework not only provides a valid tool for ECNA's continuous improvement but also offers a replicable model for other organizations facing similar environmental and economic challenges, contributing a practical and relevant tool to the field of sustainable aviation management.

The key outcomes that substantiate this contribution are:

- The designed framework proved to be an effective and replicable tool for monitoring and improving environmental practices within a resource-constrained aeronautical entity.
- The evaluation successfully identified areas of strong performance, such as route realignment, while pinpointing critical weaknesses in the environmental training plan and the electromobility strategy.
- A new risk related to regulatory non-compliance due to deficiencies in worker environmental training was uncovered, alongside a strategic opportunity to quantify emissions reductions from route optimization.

These findings carry significant policy implications for the Cuban aviation sector. The validated methodology provides the Cuban Institute of Civil Aeronautics (IACC) with a proven model that can be promoted as a best practice for other national aeronautical entities. It demonstrates that robust, data-driven environmental oversight is achievable and can serve as a foundation for developing and refining future national environmental standards, ensuring that Cuba's aviation industry aligns with international sustainability goals and national climate policies.

Based on the results and challenges identified, the following strategic recommendations are proposed for ECNA and similar organizations:

1. Immediately enhance environmental training programs to address the identified performance gap and mitigate the associated risk of non-compliance.
2. Urgently review pending measures in the emissions reduction program, assessing the feasibility of alternative or phased approaches to the electromobility strategy given the existing constraints.
3. Secure the necessary inputs to formally quantify and report the aircraft emissions reduction index resulting from the use of optimized RNAV routes.
4. For future cycles, reinforce the methodology's effectiveness by integrating participatory workshops for stakeholder engagement and utilizing digital dashboards for real-time performance monitoring.
5. Initiate medium- and long-term impact studies to quantitatively evaluate how these environmental actions contribute to broader frameworks, such as the UN's Sustainable Development Goals.

In essence, by systematically integrating established standards with operational realities, the methodology provides a pragmatic pathway for similar organizations to transition from reactive compliance to proactive environmental stewardship.

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