Technical and Digital Tools for Identifying and Assessing the Environmental Impacts of Airport Operations: A Case Study of Felipe Ángeles International Airport

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Keywords: Airport Environmental Impact, Geographic Information Systems, Air and Noise Pollution, Impact Assessment Tools, Aviation Sustainability

Abstract

The operational phase of an airport generates several environmental impacts, particularly related to air and noise pollution. These effects can extend several kilometers beyond the site, depending on meteorological conditions, topography, flight frequency, and the type of emission sources involved. These impacts are not easy to study with traditional Environmental Impact Assessments (EIA), because they are static and not flexible. This paper reviews digital tools used in airport environmental studies, such as Geographic Information Systems (GIS), the Aviation Environmental Design Tool (AEDT), and simple matrices like the Leopold Matrix. Their use, limits, and benefits are explained. A small case of Felipe Ángeles International Airport (AIFA) in Mexico is included only as an illustration of how these tools can be applied in practice. The review shows that mixing these tools with regulations helps to improve airport planning and management.

1. Introduction

Airports are complex infrastructures that play a key role in economic development, national security, and regional and global connectivity. They allow the fast movement of people, goods, and services, supporting tourism, trade, and investment. However, airport operations also causes significant environmental impacts that can be long-lasting and affect large areas. These impacts come from various sources, including aircraft engines, auxiliary power units (APUs), ground support equipment (GSE), shuttle buses, baggage tractors, and fixed installations such as boilers, power plants, HVAC systems, and fuel storage facilities.

The environmental effects of airport operations are often extensive and persistent over time. Major concerns include air pollution from nitrogen oxides (NO_x), carbon monoxide (CO), sulfur dioxide (SO_2), volatile organic compounds (VOCs), and particulate matter (PM_{10} and $PM_{2.5}$). These pollutants affect local air quality and public health and contribute to global issues like climate change and ecosystem damage. Noise pollution from takeoffs, landings, taxiing, and GSE operations also affects nearby communities and natural habitats, causing sleep problems, stress, and the displacement of wildlife.

To evaluate these impacts, Environmental Impact Assessments (EIAs) are essential. In Mexico, the Manifestación de Impacto Ambiental (MIA), managed by SEMARNAT, provides the legal and procedural framework for environmental assessment. The MIA identifies direct, indirect, cumulative, synergistic, and residual impacts and requires public participation. However, conventional EIAs are limited when dealing with the dynamic and complex impacts of airport operations, which change with technology, flight demand, weather, and regulations.

Modern studies use digital and technical tools to improve spatial and temporal analysis and make more accurate forecasts. These include the Aviation Environmental Design Tool (AEDT) for fuel consumption, noise, and emissions, and air quality impacts, and Geographic Information Systems (GIS) for spatial analysis and visualization. Scenario simulation models, such as KSIM and GSIM, also help plan under uncertainty by testing different operational and policy options. These tools ensure that airport environmental evaluations follow international standards, such as ICAO Annex 16 on aircraft noise and emissions.

Similar practices exist worldwide in countries like Canada, Germany, and the European Union, using tools like AERMOD (for dispersion modeling), INM and SoundPLAN (for noise modeling), and Life Cycle Assessment (LCA) techniques to support sustainable airport management.

This study focuses on Felipe Ángeles International Airport (AIFA), in Zumpango, State of Mexico (latitude 19.8340° N, longitude 99.0610° W), which started operations in 2022. AIFA is a useful case to show how combining technical tools, legal frameworks, and scenario-based planning can improve environmental assessment.

Figure 1 was created using ArcMap, a Geographic Information System (GIS) tool. It shows the geographic location of AIFA within the State of Mexico, highlighting its position relative to surrounding municipalities.

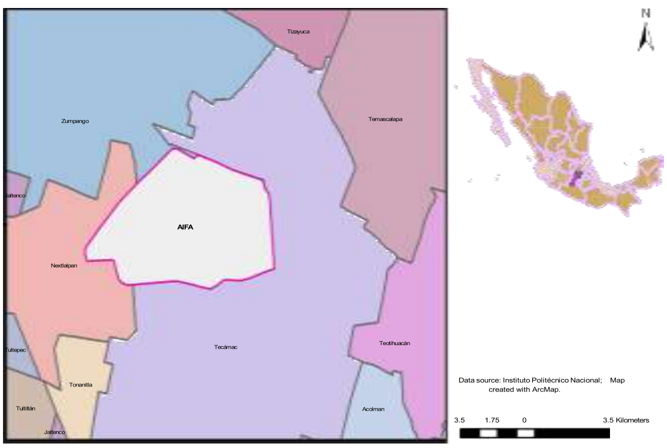

Figure 1. Location map of Felipe Ángeles International Airport (AIFA) with ArcMap a Geographic System Information.

2. Methodology

This research is based on a comprehensive literature review complemented with consultations with subject-matter experts. The aim was to identify, analyze, and synthesize technical and digital tools employed in environmental assessments of airports, with a focus on emission sources and their mitigation. The Felipe Ángeles International Airport (AIFA) in Mexico is included as an illustrative case to demonstrate the practical application of these tools, rather than as a full empirical study.

2.1 Literature Search

This literature review followed a systematic approach:

Databases and Platforms Consulted: Web of Science, Scopus, ScienceDirect, Google Scholar, and institutional repositories from ICAO, FAA, and SEMARNAT.

Keywords Used: "airport emissions," "environmental impact assessment," "AEDT," "GIS in aviation," "Leopold Matrix," "scenario modelling airports," "air dispersion modelling," "LCA airports," "EMS airports," "remote sensing environmental monitoring."

Publication Years Considered: 2000–2025, prioritizing recent studies (2015–2025) for contemporary relevance.

Inclusion Criteria: Peer-reviewed articles, official reports, technical guidelines, and case studies directly related to airport environmental management and assessment tools.

A total of 82 documents were included in the review: 46 peer-reviewed articles, 21 institutional reports, and 15 technical guidelines or case studies.

2.2 Data Extraction and Analysis

From each document, information was extracted regarding:

Type of environmental impact assessed (air quality, noise, land use, water quality, biodiversity).

Technical and digital tools employed (AEDT, GIS, Leopold Matrix, KSIM, GSIM, SIRRIA, LCA, EMS, AERMOD, CALPUFF, remote sensing).

Geographic and operational context of the airport studied.

Temporal coverage (historical, current, and projected scenarios).

Data were then synthesized qualitatively to identify patterns, best practices, tool effectiveness, and gaps in knowledge.

2.3 Expert Consultation

Subject-matter experts from the Instituto Politécnico Nacional (IPN) and relevant airport authorities provided insights on:

1. Applicability of tools in the Mexican context, specifically Felipe Ángeles International Airport (AIFA).
2. Limitations and challenges in operational data availability.

2.4 Scenario-Based Framework

The study integrates six environmental scenarios to structure the assessment:

Historical Scenario: Pre-AIFA (Santa Lucía Air Base) with limited infrastructure and low population density.

Contextual Scenario: Current operational and environmental conditions, considering urban expansion, habitat fragmentation, and pollution.

Tendential Scenario: Projected outcomes if existing management practices are unchanged.

Ideal Scenario: Optimized operations with minimal emissions and noise.

Prospective Scenario: Long-term impacts considering climate change and evolving regulations.

These scenarios provide a structured framework for demonstrating the practical use of digital and technical tools without implying full empirical data collection at AIFA.

3. Application of Technical and Digital Tools

The identification and assessment of airport environmental impacts rely on multiple technical and digital tools. Each tool was reviewed in the literature for its strengths, limitations, and practical relevance.

3.1 Direct Emission Sources

Direct emissions occur within airport boundaries, including:

1. Aircraft operations: taxiing, waiting, takeoff, landing, reverse thrust, engine tests, and engines running at gates.
2. Auxiliary Power Units (APU): aircraft parked with engines off.
3. Ground support vehicles and equipment: baggage transport, fuel trucks, catering, maintenance vehicles, emergency vehicles.
4. Fixed installations: generators, lighting towers, HVAC, fuel storage, water systems, hangars.
5. Airport infrastructure: runways, taxiways, parking platforms, service roads, and access roads.

3.2 Indirect Emission Sources

Indirect emissions are generated outside immediate airport operations, including:

1. Passenger and personnel transport: private vehicles, transport vans, public transportation.
2. Cargo and freight logistics: trucks and delivery vehicles.
3. External roadways: roads and highways that provide airport access.

3.3 Identification Methods

Emissions are identified using:

- Operational data review: flight logs, vehicle fleets, fuel consumption, infrastructure inventories.
- Emission inventories: linking sources to emission factors.
- Field monitoring: sensors measuring pollutant concentrations.
- Modeling and spatial analysis: tools like AEDT and GIS.
- Stakeholder engagement: consultations with airport authorities, regulatory bodies, and local communities.

4. Technical and Digital Tools Reviewed

Aviation Environmental Design Tool (AEDT)

AEDT is a comprehensive modeling platform developed by the FAA and USAF to simulate aircraft emissions and noise throughout the Landing and Take-Off (LTO) cycle. It calculates pollutants including CO_2, NO_x, PM2.5, PM10, and VOCs, as well as sound exposure levels.

Strengths: Provides highly detailed and scenario-specific outputs; supports temporal (hourly, daily, annual) and operational variations; integrates projected traffic growth for forward-looking analyses.

Limitations: Requires detailed operational input data; complex interface may necessitate trained personnel.

Application: Helps airports forecast environmental impacts under different operational scenarios, design mitigation strategies, and comply with ICAO Annex 16 noise and emissions standards.

Geographic Information Systems (GIS)

GIS allows for spatial visualization and analysis of multiple data layers, including land use, population density, vegetation cover, hydrology, and infrastructure.

Strengths: Excellent for mapping exposure zones, identifying vulnerable populations, assessing cumulative impacts, and supporting land-use planning.

Limitations: Accuracy depends on the quality and resolution of input data; requires GIS expertise.

Application: For airports, GIS enables the integration of emissions data with social and ecological contexts, supporting zoning decisions and environmental risk assessments.

Leopold Matrix

The Leopold Matrix is a semi-quantitative tool that systematically evaluates interactions between specific airport activities and environmental components. Each interaction is rated for magnitude and significance.

Strengths: Transparent fosters interdisciplinary discussion, suitable when empirical data are limited, integrates qualitative judgments with quantitative assessments.

Limitations: Subjective elements can influence ratings; best used in combination with quantitative data.

Application: Identifies high-impact activities, supports prioritization of mitigation measures, and complements other modeling tools in early-stage assessments.

SIRRIA and Hybrid Methods

SIRRIA combines risk, impact, and vulnerability assessments, integrating both qualitative and quantitative data. Hybrid approaches contextualize technical simulations with community concerns and regulatory priorities.

Strengths: Incorporates environmental justice perspectives; highlights who bears the burden of impacts; supports policy and decision-making.

Limitations: Data-intensive

Application: Ideal for complex airports where social, environmental, and health dimensions interact, providing a holistic view of potential impacts.

Environmental Management Systems (EMS)

EMS frameworks, particularly those aligned with ISO 14001, provide a systematic approach to environmental performance improvement.

Strengths: Supports continuous monitoring, legal compliance, and stakeholder engagement; facilitates certifications like Airport Carbon Accreditation (ACA).

Limitations: Implementation requires organizational commitment and ongoing monitoring.

Application: Airports can use EMS to track emissions, resource consumption, and environmental risks systematically, ensuring long-term sustainability.

Life Cycle Assessment (LCA)

LCA evaluates the environmental impacts of airport operations and infrastructure from construction to decommissioning.

Strengths: Identifies emission “hotspots” and resource-intensive processes; supports long-term planning and sustainable design decisions.

Limitations: Data collection can be extensive; assumptions may affect accuracy.

Application: Helps airports optimize design, operations, and maintenance strategies to reduce carbon footprint and environmental impacts.

Remote Sensing and Satellite Imagery

Remote sensing monitors land-use changes, vegetation loss, habitat fragmentation, and urban heat island effects at large spatial scales.

Strengths: Provides wide-area coverage; integrates with GIS for dynamic, temporal analysis.

Limitations: Resolution may limit detection of small-scale changes; requires image processing expertise.

Application: For airports, it helps monitor the surrounding environment, detect changes due to expansion, and support spatial planning decisions.

Air Dispersion Models: AERMOD and CALPUFF

Air dispersion models simulate how pollutants disperse in the atmosphere.

AERMOD: Suitable for local-scale dispersion in flat terrain; widely used for regulatory compliance.

CALPUFF: Models complex terrain and long-range transport; useful for regional impact assessments.

Strengths: Provide quantitative predictions of pollutant concentrations downwind; support permitting and mitigation planning.

Limitations: Accuracy depends on meteorological and emission data; model selection depends on terrain and scale.

Application: Evaluate aircraft, vehicle, and stationary source emissions around airports.

Noise Simulation Platforms

Noise simulation tools, like INM and SoundPLAN, model sound propagation to generate noise contour maps.

Strengths: Supports compliance with noise regulations; helps with urban planning and mitigation strategies; can combine multiple sources for cumulative noise analysis.

Limitations: Requires accurate operational and topographical data; specialized expertise needed.

Application: Identify high-noise exposure zones, guide land-use decisions, and design noise mitigation measures.

Environmental Data Management Systems (EDMS)

EDMS are digital platforms designed to collect, store, manage, and report environmental data generated by airports. These systems centralize information from air quality monitors, noise sensors, water quality stations, fuel usage logs, and other operational sources.

Strengths: Integrates large volumes of heterogeneous data in real time, facilitates regulatory reporting and compliance tracking, supports trend analysis, KPI monitoring, and operational optimization, enhances decision-making by linking environmental metrics with operational performance.

Limitations: Data quality depends on sensor accuracy and consistent input.

Application: monitor emissions, noise, water usage, and waste management, provide inputs for other tools like GIS, AEDT, LCA, and EMS, creating a unified environmental management framework, help ensure transparency with stakeholders and supports certification programs like Airport Carbon Accreditation (ACA).

5. Conclusions

This study conducted a comprehensive literature review to examine the use of digital and technical tools in assessing the environmental impacts of airports. A total of 82 documents were reviewed.

Key Findings from the Literature Review:

1. AEDT and GIS are consistently the most widely adopted tools. AEDT allows detailed modeling of aircraft emissions (CO_2, NOx, PM10, VOCs) and noise across Landing and Take-Off (LTO) cycles, while GIS provides spatial visualization and mapping of population exposure, sensitive ecosystems, and emission dispersion patterns.
2. Semi-quantitative and participatory tools, such as the Leopold Matrix and SIRRIA, complement technical models by integrating qualitative judgment, social vulnerability, and

environmental justice perspectives. These tools enable the identification of direct and indirect impacts, magnitude, significance, reversibility, and temporal characteristics.

3. EDMS, EMS, and LCA provide frameworks for systematic environmental monitoring, performance evaluation, and compliance tracking, enhancing long-term sustainability planning.
4. Conceptual scenarios (historical, contextual, tendential, ideal, and prospective) allow flexible assessment of environmental impacts under varying operational conditions.
5. These scenarios provide a structured framework to anticipate future challenges, support decision-making, and guide mitigation strategies, demonstrating the practical value of integrating multiple tools.
6. In the AIFA example, scenario-based modeling illustrates how combined technical and participatory approaches can predict the potential effects of emissions, noise, and land-use changes, even in rapidly urbanizing areas.
7. Tools such as SIRRIA help identify populations disproportionately affected by airport operations. Integrating social vulnerability data ensures that decision-making is equitable, highlighting areas where mitigation should be prioritized.
8. The literature shows that airports benefit from combining technical modeling with stakeholder engagement, fostering transparency and enhancing social acceptance of environmental management strategies.
9. Alignment with ICAO Annex 16 and Mexican NOM standards (e.g., NOM-085, NOM-081, NOM-025, NOM-156) guides the selection and application of tools, ensuring legal compliance and credibility in environmental assessments.
10. The integration of digital tools, scenario planning, and regulatory frameworks allows airports to design proactive mitigation measures, optimize operations, and achieve sustainability certifications such as Airport Carbon Accreditation (ACA).
11. Combining quantitative, qualitative, and participatory methods provides a robust, multi-layered framework for environmental management. Tools are complementary: technical models quantify impacts, GIS and remote sensing map spatial patterns, and participatory approaches address social dimensions.

The literature demonstrates that digital and technical tools, when applied in combination, provide flexible, predictive, and comprehensive frameworks for managing the environmental impacts of airport operations. Scenario-based approaches, supported by participatory methods and regulatory alignment, allow decision-makers to anticipate challenges, design mitigation strategies, and promote sustainable airport operations. Illustrative applications, such as the conceptual framework for AIFA, highlight the value of integrated methodologies in real-world contexts, showing that airports can achieve environmental management, regulatory compliance, and social responsibility simultaneously.

Acknowledgements

Gonzalez Vega
This research was supported by SEPI-Ticoman and CIIEMAD and benefited from technical input from national environmental authorities and ICAO documentation. I would like to sincerely thank the Instituto Politécnico Nacional (IPN), Mexico, for providing the essential institutional framework, resources, and academic environment that made this work possible.
Special gratitude is extended to my advisors, Dr. José Carlos Jiménez Escalona and Dr. Rodrigo Florencio da Silva, whose expert guidance, insightful feedback, and continuous support greatly contributed to the development and refinement of this study. Their dedication to academic excellence and commitment to mentoring have been invaluable throughout this research process.

I also deeply appreciate the encouragement and collaboration of the entire academic community at IPN, whose interdisciplinary perspectives enriched this project and fostered a stimulating environment for learning and innovation.

Finally, I wish to express my heartfelt thanks to my family, friends, and loved ones for their unwavering support, patience, and encouragement. Their constant belief in my work has been a source of strength and motivation during every phase of this research.

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