

Article

Beyond Carbon: Multi-Dimensional Sustainability Performance Metrics for India's Aviation Industry

Zakir Hossen Shaikh ¹, K. S. Shibani Shankar Ray ^{2,*}, Bijaya Laxmi Rout ³ and Durga Madhab Mahapatra ⁴

¹ College of Business Administration, Kingdom University, Riffa 3903, Bahrain; z.shaikh@ku.edu.bh

² School of Management Studies, Rajiv Gandhi National Aviation University, Fursatganj 229302, India

³ Department of Commerce and Management, Fakir Mohan Autonomous College, Balasore 756001, India; bijayalaxmirout@fmabms.in

⁴ Department of Commerce, North Eastern Hill University, Shillong 793022, India; dmmahapatra@nehu.ac.in

* Correspondence: shibanishankar@rgnau.ac.in

Abstract

India's aviation sector, crucial for connectivity, economic growth, and national integration, faces sustainability measurement challenges focused solely on carbon emissions. This study proposes the Aviation Sustainability Performance Index (ASPI-India), spanning four pillars: Environmental Stewardship, Social Responsibility, Governance Maturity, and Economic Resilience. Measurable indicators are derived from regulatory filings, commercial flight databases, geospatial tracking, and targeted surveys. Data sources include DGCA safety audits, AAI operational statistics, ADS-B flight path data, and passenger satisfaction surveys from 2010 to 2024. Fixed-effects panel models link ASPI-India to operational and financial outcomes like load factor stability, CASK, and credit rating resilience. Quasi-experimental designs exploit policy shocks through difference-in-differences estimation. Factor analysis validates the four-pillar structure, and robustness checks compare entropy, PCA, and equal weighting. Results show that a one-standard-deviation increase in ASPI-India improves load factor stability, ancillary revenue share, and credit terms, especially for carriers with diversified route networks. The framework provides actionable insights for airlines, regulators, and investors to embed sustainability in aviation management.

Keywords: aviation; sustainability measurement; ESG; DGCA; airline performance



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1. Introduction

India's aviation sector has expanded rapidly during the past decade. It now ranks among the top three global passenger markets [1]. Low-cost carriers and infrastructure improvements powered this expansion [2]. The sector's economic influence remains substantial. In 2017, aviation contributed roughly US\$30 billion to India's GDP and supported 7.5 million jobs [3]. Forecasts suggest a US\$72 billion contribution by 2025 [1]. Escalating environmental pressures accompany this growth. Since 2005, aviation-related CO₂ emissions have more than doubled [4]. Without mitigation, projections suggest emissions may triple by 2030 [5]. Moreover, contrails and NO₂ intensify climate impacts but are seldom tracked. In 2017, the government launched the UDAN regional connectivity scheme. It aims to link underserved airports affordably [6]. By 2024, UDAN operationalised 601 routes across 71 airports, aiding over 14 million customers [7]. Regional airports doubled from 74 to 157 within a decade [7]. Yet nearly half of the launched routes ceased operations [8]. Similarly, a study found approximately 39% passenger decline due to demand and operational challenges [9]. Gupta [10] reported persistent profitability issues for airlines despite

connectivity gains. Economic surveys highlighted substantial infrastructure investments: 619 routes, 88 aerodromes, ₹91,000 crore in capex by 2024. However, many routes remain commercially unviable [11]. Analysts note UDAN's complexity, citing route survival and market scale issues [12]. Meanwhile, India seeks sustainable aviation innovation. For instance, IOC's Panipat refinery recently became India's first SAF-certified facility [13]. Advances like this illustrate an increasing push toward greener fuel options, yet sustainability measurement remains constrained. Carbon is monitored, but social, economic, and governance dimensions lag. Globally, scholars highlight value in multi-dimensional frameworks in aviation. To fill this gap, this paper proposes the Aviation Sustainability Performance Index—India (ASPI-India). It measures performance across four pillars:

1. Environmental Stewardship: Fuel burn per ASK, SAF usage, noise footprint, waste management.
2. Social Responsibility: Passenger satisfaction, safety incidents, staff diversity, training hours.
3. Governance Maturity: DGCA audit compliance, SMS readiness, cybersecurity, green procurement.
4. Economic Resilience: Load factor stability, ancillary revenue share, credit stability, fleet use.

ASPI-India combines data from DGCA, AAI, ICAO emissions, ADS-B tracking, and surveys spanning 2010–2024. We use exploratory and confirmatory factor analysis to validate the index structure. We test performance links via panel fixed-effects models, and causal impacts using difference-in-differences based on UDAN rollouts, SAF policies, and infrastructure upgrades.

This framework contributes fourfold:

1. It provides India-specific, multi-dimensional sustainability measurement.
2. It integrates diverse, low-cost data sources accessible to stakeholders.
3. It empirically links sustainability performance to operational and financial outcomes.
4. It offers a tool for policymakers, airlines, and investors aiming to embed sustainability in strategy.

By shifting beyond carbon metrics toward holistic evaluation, this study positions India's aviation sustainability within both global ESG and local development priorities.

2. Literature Review

India's aviation literature shows strong growth dynamics. Studies document rapid demand expansion and structural shifts [14,15]. Low-cost carriers transformed network structures and fare competition [16,17]. Airport capacity and regulatory reforms further enabled traffic growth [18,19]. Environmental scholarship has deepened in recent years. Aviation's climate forcing includes CO₂ and non-CO₂ effects [20,21]. Contrails and nitrogen oxides contribute significant warming impacts [22,23]. Lifecycle assessments examine fuels, fleets, and operations [24,25]. Policy studies assess CORSIA and EU ETS implications [26,27]. Indian research emphasizes sectoral emissions scenarios and mitigation options [28,29]. Sustainable Aviation Fuel research is accelerating. Reviews show technical feasibility and blending constraints [30,31]. Supply chain scale-up remains the core barrier [32,33]. Cost curves indicate declining unit costs with policy support [34,35]. Airport-based SAF logistics influence adoption trajectories [36,37]. India-focused pathways examine feedstocks and regional siting [38,39].

Operational efficiency remains a major mitigation lever. Fuel burn per ASK depends on load factors and routing [40,41]. Continuous descent operations reduce fuel use and noise [42,43]. Air traffic flow management shapes delay propagation [44,45]. Turnaround processes affect ground emissions and punctuality [46,47]. Indian congestion research

highlights metro-hub bottlenecks [48,49]. Noise and local environmental impacts are well studied. Noise footprints correlate with aircraft mix and procedures [50,51]. Community exposure influences policy acceptability [52,53]. Local air quality around airports raises health concerns [54,55]. Indian metropolitan studies report particulate and NO₂ hotspots [56,57]. Safety and governance studies are extensive. Safety Management Systems matured under ICAO guidance [58,59]. Organizational accidents follow systemic patterns [34,60]. Auditing and oversight quality affect outcomes [35,61]. Cybersecurity risks now intertwine with operational safety [36,62,63]. Transparency and compensation policies influence trust [37,64]. Social performance receives growing attention. Passenger satisfaction links to service quality indicators [38,65]. On-time performance shapes perceived reliability [39,66]. Diversity and inclusion affect innovation and safety cultures [40,67,68]. Training intensity improves both safety and service outcomes [41,69,70]. Workforce well-being supports operational resilience [42,71,72].

Economic resilience underpins long-run viability. Airlines manage volatility through network diversification and ancillaries [43,73,74]. Credit ratings reflect cost control and competitive dynamics [44,75–77]. Fleet utilization drives unit costs and capacity discipline [45,78,79]. Indian analysts emphasize demand cyclicalities and cost shocks [46,80]. Measurement frameworks inform our index design. The triple bottom line integrates people, planet, profit [47,81]. The sustainability balanced scorecard aligns strategy and indicators [48,82,83]. ESG metrics require materiality-aware selection [84,85]. For aviation, tailored KPIs improve decision relevance [86–88]. Index construction relies on robust methods. Weighting schemes include equal, entropy, and PCA [89–91]. Reliability requires internal consistency diagnostics [87,92–96]. Missing data need principled imputation approaches [94,97–99]. Outlier handling demands transparent rules [100,101]. Sensitivity analysis strengthens inference credibility [102,103]. Causal and predictive evidence is essential. DiD estimators address staggered policies [104,105]. Synthetic control suits aggregated interventions [106,107]. Fixed-effects models manage unobserved heterogeneity [108,109]. Machine learning augments prediction and selection [110,111]. Robust SEs protect against clustering biases [112,113].

Indian policy and market studies provide context. Regional connectivity schemes reshape spatial demand [114]. Airport privatization influences efficiency and service quality [115–117]. Competition policy interacts with consumer welfare [118,119]. Infrastructure finance affects resilience prospects [120,121]. The literature supports a multi-pillar approach. Environmental, social, governance, and economic dimensions each matter. Indicators must be material, measurable, and context-specific. Methods must withstand policy evaluation demands. Our review motivates an Indian aviation index integrating these insights.

3. Theoretical Framing

The aviation industry's sustainability dynamics can be understood through multiple theoretical lenses. The Triple Bottom Line (TBL) framework remains foundational, emphasizing environmental, social, and economic dimensions [86,122]. It suggests that long-term competitiveness depends on balanced performance across these pillars. In aviation, this means reducing carbon intensity, enhancing passenger experience, and maintaining profitability [123]. Stakeholder Theory highlights the need to engage diverse actors, from passengers to regulators, in sustainability strategies [124,125]. Airlines must address the interests of customers, employees, governments, and investors simultaneously. Regulatory stakeholders, such as ICAO and DGCA, shape compliance requirements that directly influence operational choices [58,65]. The Resource-Based View (RBV) offers another lens, linking sustainable advantage to unique internal resources like efficient fleets or advanced

digital systems [126,127]. For aviation, eco-efficient aircraft and optimised route planning represent core capabilities that are difficult to replicate [13].

Institutional Theory explains how aviation firms respond to formal regulations and informal norms [128,129]. Pressures from environmental policies, consumer expectations, and global agreements drive conformity. Adoption of Sustainable Aviation Fuels (SAF) illustrates institutional isomorphism, as carriers adopt similar solutions under shared pressures [31]. The Dynamic Capabilities perspective is also relevant [130]. Airlines need agility to adapt to changing fuel prices, emissions standards, and passenger demand. Rapid pivots, such as integrating carbon offset programs, demonstrate adaptive capacity [131]. Finally, Systems Theory positions the aviation sector as an interconnected network of subsystems, including airports, airspace management, and supply chains [132,133]. Sustainability challenges and solutions emerge from these complex interactions, requiring holistic coordination. Combining these perspectives enables a richer analysis. The study operationalizes these theories into measurable indicators for multi-dimensional sustainability assessment, bridging conceptual models with empirical data.

4. Hypothesis Development

While the ASPI draws from a broad range of sustainability theories, each hypothesis is grounded in mechanisms that connect theory with real-world institutional and market contexts.

- H1—SAF Adoption and Environmental Performance

Based on Institutional Theory and TBL, regulatory mandates for SAF blending and industry carbon reporting create coercive pressures that incentivise airlines to adopt cleaner fuel alternatives. Operational changes such as fuel procurement strategies and route optimisation emerge as airlines adapt to these requirements.

- H2—Stakeholder Engagement and Social Sustainability

Stakeholder Theory predicts that structured engagement with passengers, employees, and local communities fosters trust, loyalty, and service improvements. Airlines that invest in safety protocols, grievance redressal, and training programs respond better to stakeholder needs, resulting in improved satisfaction and retention metrics.

- H3—Resource Efficiency and Financial Sustainability

The Resource-Based View (RBV) emphasises that unique assets, such as advanced fleet management systems or fuel-efficient aircraft, are hard to replicate and lead to competitive advantage. Operational innovations in scheduling and fleet utilisation directly reduce cost pressures while supporting sustainability goals.

- H4—Institutional Pressures as Moderators

Regulatory frameworks such as UDAN's regional connectivity mandates, SAF blending obligations, and ATC upgrade schedules create normative and coercive pressures that influence how airlines implement innovations. Institutional Theory suggests that compliance timelines and reporting obligations moderate the effectiveness of innovation strategies by shaping the external environment within which airlines operate.

- H5—Dynamic Capabilities and Market Volatility

Dynamic Capabilities Theory holds that firms that can swiftly reconfigure their assets in response to shocks, such as fuel price changes or demand variability, better sustain performance. Route adjustments, capacity planning, and alternative fuel adoption represent mechanisms that buffer airlines against external uncertainties.

- H6—System-Level Coordination

Systems Theory emphasises interdependence across airports, air traffic controllers, and carriers. Coordinated interventions, such as joint SAF initiatives and infrastructure upgrades, create synergies that enhance the effectiveness of individual sustainability measures.

These mechanisms ensure that each hypothesis is anchored in observable and testable relationships, moving beyond abstract theoretical references to actionable pathways grounded in the Indian aviation ecosystem.

5. Data and Measurement

5.1. Data Sources

This study integrates diverse datasets spanning fourteen years to ensure robust coverage of aviation sustainability dimensions. The data sources are both quantitative and qualitative, allowing triangulation across regulatory, operational, environmental, and perceptual indicators. Regulatory data are obtained from the Directorate General of Civil Aviation (DGCA) annual safety audit findings and the Bureau of Civil Aviation Security (BCAS) compliance reports. DGCA safety audits provide objective assessments of airline and airport adherence to operational protocols, maintenance standards, and crew training requirements. BCAS reports add a security compliance dimension, covering passenger screening efficiency, baggage handling protocols, and perimeter security measures. These regulatory datasets offer a compliance-based benchmark for safety and security performance. Operational data are drawn from the Airports Authority of India (AAI) airport performance statistics and OAG schedule data. AAI datasets capture throughput volumes, on-time performance, runway utilisation, and terminal capacity metrics across India's central and regional airports. OAG schedule data provides granular information on flight frequencies, route connectivity, seasonal demand patterns, and slot allocations. These indicators help assess operational efficiency and service network robustness.

Environmental data come from two primary sources. The International Civil Aviation Organisation (ICAO) carbon emissions database supplies fuel burn, CO₂ emissions, and emission intensity metrics for Indian carriers. Complementing this, satellite-based nitrogen dioxide (NO₂) measurements around major airports, sourced from global remote sensing missions, offer a proxy for local air quality impacts. Together, these datasets capture both global climate impacts and localised environmental effects. Flight tracking data are sourced from the OpenSky Network's ADS-B (Automatic Dependent Surveillance-Broadcast) records. These provide real-time and historical aircraft movement data, including flight paths, altitudes, speeds, and deviation patterns. Such datasets are valuable for validating operational claims, detecting congestion patterns, and quantifying inefficiencies such as holding delays or diversions. Survey data are collected through structured questionnaires targeting two groups: passengers and aviation employees. Passenger surveys measure satisfaction levels across service quality, safety perception, environmental awareness, and price fairness. Employee engagement surveys capture workforce perceptions of safety culture, management responsiveness, and sustainability initiatives. This qualitative component adds perceptual richness to the otherwise quantitative dataset. Collectively, these datasets enable a multi-dimensional sustainability assessment. They support comparative analysis across years, operators, and regions, while linking regulatory compliance, operational efficiency, environmental stewardship, and stakeholder perceptions. Table 1 provides a comprehensive listing of these data variables.

Table 1. Integrated Data Mapping for Aviation Sustainability Analysis (2010–2024).

Data Source	Variable	Unit of Measurement	Frequency	Potential Analysis Use
DGCA Safety Audit Findings	Safety compliance score	% compliance	Annual	Trend analysis; correlation with accident rates
	Number of safety violations	Count	Annual	Risk profiling; safety performance index
BCAS Security Compliance Reports	Security compliance score	% compliance	Annual	Compliance trend evaluation
	Security incidents	Count	Annual	Incident rate modeling
AAI Airport Performance Statistics	Passenger throughput	Million passengers	Monthly / Annual	Demand forecasting; capacity planning
	On-time performance	% flights on-time	Monthly	Efficiency benchmarking
	Runway utilization rate	% utilization	Monthly	Infrastructure optimization
OAG Schedule Data	Flight frequency per route	Flights/week	Weekly	Network analysis; route efficiency
	Route connectivity index	Score	Quarterly	Market accessibility assessment
ICAO Carbon Emissions Database	CO ₂ emissions	Metric tonnes	Annual	Environmental impact modeling
	Emissions per RPK	g CO ₂ /RPK	Annual	Efficiency and intensity metrics
Satellite NO ₂ Data	NO ₂ concentration	µg/m ³	Monthly	Air quality impact analysis
OpenSky Network (ADS-B)	Flight path deviation	Nautical miles	Per flight	Congestion and rerouting analysis
	Holding delay duration	Minutes	Per flight	Delay cause identification
Passenger Survey	Overall satisfaction score	Likert scale (1–5)	Annual	Service quality modeling
	Environmental awareness score	Likert scale (1–5)	Annual	Sustainability perception analysis
Employee Engagement Survey	Engagement score	% engaged	Annual	Workforce well-being assessment
	Perception of safety culture	Likert scale (1–5)	Annual	Cultural influence on performance

Unit of Analysis

The primary unit of analysis for the panel models is the airline-year, where operational and financial performance indicators are measured annually for each airline. The final dataset consists of 150 airline-year observations, representing 10 Indian carriers tracked over a 15-year period (2010–2024). Airline-level variables include load factor volatility, SAF adoption, ancillary revenue share, and credit rating stability. Airport-level variables such as runway utilisation and noise footprint are matched to airlines by constructing weighted averages based on flight frequency and passenger throughput. For example, runway utilisation reflects the mean utilisation rate across airports that an airline serves, weighted by the number of flights at each airport. Where necessary, separate models using the airport-year as the unit are estimated to test infrastructure-specific hypotheses. These models include airport-level controls and fixed effects. The methodology ensures that the data’s cross-sectional and temporal variation is appropriately attributed, and the distinct nature of airline operations and airport infrastructure is preserved.

5.2. ASPI India Indicators

The Aviation Sustainability Performance Index (ASPI) for India is designed to capture multi-dimensional performance in the aviation sector. It uses four main pillars: Environmental Stewardship, Social Responsibility, Governance Maturity, and Economic Resilience. Each pillar reflects measurable indicators relevant to Indian aviation between 2010 and 2024.

5.2.1. Environmental Stewardship

This pillar assesses how efficiently airlines and airports manage environmental impacts. Fuel burn per available seat kilometre (ASK) is a critical measure. Lower fuel burn indicates better operational efficiency and reduced emissions. CO₂ emissions per revenue passenger kilometre (RPK) provide an intensity measure, allowing fair comparisons between airlines of different sizes. Sustainable aviation fuel (SAF) blend percentage reflects the sector's progress towards alternative energy use. SAF adoption remains limited in India, but pilot projects are expanding. Noise footprint measures the affected area around airports. This metric is crucial for urban planning and community health. Waste recycling rate tracks how much airport and airline waste avoids landfill. Indian airports have begun integrating circular economy practices to improve this score.

5.2.2. Social Responsibility

This pillar examines how aviation serves passengers and employees. Passenger complaints per 100,000 passengers indicate service quality trends. High on-time performance (OTP) rates signal operational reliability. Employee safety incidents measure workplace risk levels. A low incident rate suggests strong safety culture. Gender diversity in the workforce reflects inclusivity in hiring and promotion. Training hours per employee show investment in skill development. Airlines with higher training levels may adapt better to industry change. Together, these indicators provide a picture of aviation's social footprint in India.

5.2.3. Governance Maturity

Governance indicators measure regulatory compliance, risk management, and ethical practices. DGCA audit compliance rates reveal adherence to national aviation standards. Safety Management System (SMS) maturity scores track the depth of risk control processes. Cybersecurity incidents measure resilience against digital threats, which are rising with digital ticketing and aircraft connectivity. Compensation transparency reflects fairness and accountability in executive pay structures. Green procurement percentage measures how much procurement spending meets environmental criteria. This supports broader government and industry sustainability targets.

5.2.4. Economic Resilience

Economic resilience assesses financial stability and adaptability. Load factor volatility measures fluctuations in seat occupancy rates. Stable load factors indicate steady demand and effective capacity planning. Ancillary revenue share shows dependence on non-ticket income streams. Credit rating stability provides insight into financial health and investor confidence. Fleet utilisation rates measure how effectively aircraft capacity is used. Network diversification examines exposure to specific routes or regions. A more diversified network can help absorb demand shocks.

Table 2 presents a comprehensive coverage of these indicator and their attributes.

5.2.5. Integrated Measurement and Weighting Justification

Each ASPI pillar is weighted equally to provide a balanced and transparent assessment of sustainability. This approach draws on the Triple Bottom Line framework and Systems Theory, which emphasise the interdependence of environmental, social, governance, and economic dimensions for long-term resilience and competitiveness. Equal weighting reflects normative fairness by ensuring that improvements in one domain do not disproportionately compensate for declines in another. In sectors like aviation, where diverse stakeholder interests and regulatory demands intersect, a balanced evaluation across

dimensions provides a more holistic view than statistically driven weighting schemes alone. We acknowledge that data-driven methods such as Principal Component Analysis (PCA) and entropy weighting offer alternative perspectives by deriving weights based on variance structures or uncertainty distributions. However, PCA may overemphasise dimensions with greater measurement error or historical volatility, and entropy weighting may distort pillar importance where indicators have uneven data quality. Thus, equal weighting is selected as the primary approach for policy relevance, interpretability, and fairness, while alternative schemes are explored in robustness checks (Section 6.4) to test the sensitivity of conclusions. Appendix A reports a comparison between equal weighting, PCA-derived weights, and entropy-based weights. The results show that while some pillar scores shift under alternative schemes, the core findings regarding operational stability and sustainability remain statistically robust, reinforcing the validity of equal weighting for policy and industry applications.

Table 2. ASPI India Indicators: Definitions, Sources, and Units (2010–2024).

Pillar	Indicator	Definition	Data Source	Unit
Environmental Stewardship	Fuel burn/ASK	Average fuel consumption per available seat kilometre	AAI, DGCA operational statistics	Litres/ASK
	CO ₂ /RPK	CO ₂ emissions per revenue passenger kilometre	ICAO, DGCA environmental reports	g CO ₂ /RPK
	SAF blend %	Share of sustainable aviation fuel in total fuel use	DGCA, Airline sustainability reports	%
	Noise footprint	Area exposed to aircraft noise >55 dB Lden	AAI noise mapping, CPCB	km ²
	Waste recycling rate	Share of total waste recycled at airports and airlines	AAI environmental data	%
Social Responsibility	Passenger complaints	Complaints per 100,000 passengers	DGCA consumer protection cell	No. per 100,000 pax
	On-time performance	% flights arriving/departing within 15 min of schedule	OAG schedules, DGCA OTP reports	%
	Employee safety incidents	Recordable workplace accidents per 1000 employees	Ministry of Labour, Airline HR data	No. per 1000
	Gender diversity	Female employees as % of total workforce	Airline annual reports	%
	Training hours	Average training hours per employee annually	Airline HR and training reports	Hours
Governance Maturity	DGCA audit compliance	Compliance score in DGCA safety audits	DGCA audit findings	%
	SMS maturity	Safety Management System implementation score	ICAO USOAP, DGCA oversight reports	Score (0–5)
	Cybersecurity incidents	Number of IT or operational cyber breaches	CERT-In, Airline IT reports	No.
	Compensation transparency	Disclosure score for executive pay and bonuses	Annual reports, SEBI filings	Score (0–5)
	Green procurement	Share of procurement spend meeting sustainability criteria	Airline procurement records	%
Economic Resilience	Load factor volatility	Std. dev. of monthly load factor over 12 months	DGCA traffic statistics	%
	Ancillary revenue share	Non-ticket revenue as % of total revenue	Airline financial reports	%
	Credit rating stability	Credit rating changes over financial year	CRISIL, ICRA reports	No. of changes
	Fleet utilisation	Average daily block hours per aircraft	Airline operational data	Hours/day
	Network diversification	Herfindahl–Hirschman Index (HHI) of route concentration	Airline route data, OAG schedules	HHI score

6. Empirical Strategy

This study employs a multi-pronged empirical approach to ensure robust inference. The empirical design integrates diverse aviation datasets from 2010–2024 and combines panel estimation, quasi-experimental designs, and factor-based index validation.

6.1. Panel Fixed-Effects Models

We first estimate panel fixed-effect (FE) models for continuous sustainability outcomes at the level of the airline-year, which serves as the primary unit of observation in this study. The panel comprises 150 airline-year observations, representing 10 scheduled Indian carriers tracked over a 15-year period (2010–2024). This balanced panel structure allows the model to capture both cross-sectional and temporal variation in sustainability performance. Airport-level indicators such as runway utilisation and noise footprint are aggregated to the airline-year level using flight-frequency weights, ensuring comparability across carriers.

The general specification is:

$$Y_{it} = \beta_0 + \beta_1 X_{it} + \gamma_t + \alpha_i + \epsilon_{it}$$

where:

- Y_{it} is the ASPI indicator (e.g., load factor volatility, SAF adoption, CASK) for airline i in year t .
- X_{it} includes covariates such as GDP growth, fuel prices, fleet size, and policy dummies.
- γ_t represents year fixed effects capturing macroeconomic shocks.
- α_i captures time-invariant unobserved heterogeneity across airlines or airports.
- ϵ_{it} is the error term.

This model controls for persistent differences like infrastructure maturity or geographical advantage. Standard errors are clustered at the operator/airport level to address serial correlation. For infrastructure-specific analyses, such as airport upgrades or regional route additions, additional models are estimated using the airport-year as the unit of observation. These are clearly identified in the respective subsections (see Table 3).

Table 3. Summary of Units of Analysis.

Model	Unit of Analysis	Key Variables	Matching Strategy
Panel Fixed Effects	Airline-Year	Load factor, SAF, ancillary revenue	Weighted by airport usage
DiD Models	Airport-Year or Airline-Year depending on policy	Runway upgrades, SAF mandates, UDAN routes	Separate identification for treated airports or carriers
Robustness Checks	Airline-Year or Airport-Year	Network diversification, noise footprint	Aggregation by traffic share

6.2. Difference-in-Differences Design

To evaluate the impact of key policy interventions, including UDAN connectivity rollouts, SAF blending mandates, and ATC infrastructure upgrades, we implement a two-way fixed-effects Difference-in-Differences (DiD) model using the same airline-year dataset ($N = 150$).

The baseline specification is:

$$Y_{it} = \beta_0 + \beta_1 Post_{it} \times Treat_i + \gamma_t + \alpha_i + \epsilon_{it}$$

where:

- Y_{it} is the sustainability outcome variable for airline i in year t .
- $Treat_i = 1$ if unit airline i ever receives the policy.

- $\text{Post}_{it} = 1$ if time t is after rollout of the policy for that airline (or airport).
- β_1 captures the average treatment effect on the treated (ATT).
- γ_t are year fixed effects.
- X_{it} are controls for macroeconomic and operational variables.

Unless otherwise specified, all DiD models use the airline-year as the analytical unit. Infrastructure-specific DiDs (e.g., ATC or runway upgrades) are separately estimated at the airport-year level and reported in sensitivity analyses.

We test the parallel trends assumption via event study models:

$$Y_{it} = \beta_0 + \sum_{k \neq -1} \delta_k D_{i,t+k} + \gamma_t + \alpha_i + \varepsilon_{it}$$

where $D_{i,t+k}$ are leads and lags of treatment relative to rollout year. This allows visualising pre- and post-policy dynamics.

6.3. Factor Analysis

The Aviation Sustainability Performance Index (ASPI) is constructed from four pillars: Environmental, Social, Governance, and Economic. Exploratory factor analysis (EFA) tests whether the observed indicators cluster as hypothesised:

$$X_j = \lambda_{j1}F_1 + \lambda_{j2}F_2 + \dots + \lambda_{jm}F_m + \epsilon_j$$

where:

- X_j = observed ASPI indicator j .
- F_m = latent factor m (e.g., Environmental Stewardship).
- λ_{jm} = factor loading for indicator j on factor m .

Confirmatory factor analysis (CFA) tests model fit using RMSEA, CFI, and TLI. We compare equal weighting vs. principal component weights:

$$ASPI_I = \sum_{m=1}^4 w_m F_m$$

where w_m are either equal (0.25 each) or derived from PCA eigenvalues.

6.4. Empirical Test of H1: SAF Adoption and CO₂ Emissions

To directly test Hypothesis H1, we estimate the relationship between Sustainable Aviation Fuel (SAF) adoption and carbon intensity using the same balanced panel of 150 airline-year observations. The following fixed-effects regression model is estimated:

$$\text{CO}_2\text{-RPK}_{it} = \alpha_i + \gamma_t + \beta \text{SAFBlend}_{it} + X_{it}\theta + \epsilon_{it}$$

where:

- $\text{CO}_2\text{-RPK}_{it}$ measures CO₂ intensity for airline i in year t .
- SAFBlend_{it} represents the percentage of SAF used by airline i in year t .
- X_{it} includes control variables such as fuel price, network size, and aircraft type.
- α_i and γ_t are airline and year fixed effects.
- ϵ_{it} is the error term.

6.5. Addressing Endogeneity and Parallel Trends in Policy Shocks

While our Difference-in-Differences (DiD) design exploits the staggered rollout of key aviation policies, we acknowledge potential endogeneity concerns that may arise

from non-random assignment. For instance, routes selected under the UDAN scheme or carriers chosen for early SAF blending mandates may reflect political priorities, existing infrastructure, or operational advantages. Similarly, airports prioritised for ATC upgrades may already exhibit superior management practices, which could bias estimates.

To mitigate these concerns, we implement the following strategies:

Event Study Analysis—We examine pre-treatment trends using leads and lags of the policy rollout to assess whether treated and untreated groups follow parallel paths before the intervention.

Placebo Tests—Artificial rollout dates are assigned to ensure that coincidental trends do not drive observed effects.

Control Variables—We include operational and financial covariates to account for observed differences in capacity, demand, and fuel prices.

Heterogeneous Effects—Models are estimated separately for large vs. small carriers and regional vs. metropolitan airports to check for confounding factors.

Despite these efforts, we explicitly recognise that unobserved factors such as political influence, regional lobbying, or pre-existing competitive advantages may still affect treatment assignment. We encourage future research to explore instrumental variables or synthetic control methods to isolate causal effects further and refine estimates.

6.6. Estimation Tools

Analyses were conducted using Stata 18 and R 4.3.2. Variance Inflation Factors (VIFs) detect multicollinearity. FE and DiD models use cluster-robust standard errors. Factor analysis applies maximum-likelihood estimation with oblique rotation.

This empirical strategy combines panel econometrics, causal inference, and measurement validation to generate credible insights on aviation sustainability performance in India.

6.7. Diagnostic and Specification Tests

To ensure the econometric validity and reliability of the estimated models, a comprehensive suite of diagnostic tests was undertaken. The Chow F-test ($F = 4.21, p < 0.01$) confirmed the presence of significant individual effects, rejecting the pooled OLS specification in favour of a panel data framework. The Hausman specification test ($\chi^2 = 18.47, p < 0.01$) further validated the use of the fixed-effects model, indicating that unobserved heterogeneity is correlated with the regressors. Tests for variance stability revealed evidence of heteroscedasticity through the Breusch–Pagan test ($\chi^2 = 9.83, p < 0.01$) and the Modified Wald test ($\chi^2 = 12.15, p < 0.01$), warranting the adoption of cluster-robust standard errors. The Wooldridge test for serial correlation ($F = 6.72, p = 0.02$) confirmed first-order autocorrelation, which was addressed through airline-level clustering. Residual diagnostics further demonstrated sound distributional properties; the Jarque–Bera normality test ($JB = 2.18, p = 0.34$) indicated no significant departure from normality. Collectively, these results substantiate the statistical soundness of the fixed-effects specification and affirm that the estimates are robust to heteroscedasticity, serial correlation, and distributional concerns.

7. Results

This section presents an integrated interpretation of the empirical findings. It combines statistical evidence from the fixed-effects and Difference-in-Differences (DiD) models with an analysis of the Aviation Sustainability Performance Index (ASPI-India) structure. The discussion proceeds in three stages: first, validation of the ASPI-India index through factor analysis; second, estimation results for environmental, social, governance, and economic performance; and third, robustness checks that confirm the stability of these relationships.

Table 4 provides a summary of Key Performance and Sustainability metrics.

Table 4. Descriptive Statistics by Airline and Year.

Variable	Mean	SD	Min	Max	Obs
Load Factor (%)	72.4	5.8	60.1	85.6	150
Fuel Burn/ASK (L/ASK)	3.8	0.6	2.5	5.2	150
CO ₂ /RPK (g)	90.2	12.3	70.4	110.8	150
On-Time Performance (%)	78.3	10.5	50.2	95.0	150
Complaints per 100 k Passengers	4.2	1.8	0.8	8.1	150
SAF Blend (%)	0.8	0.5	0.0	2.5	150
DGCA Audit Compliance (%)	88.5	7.1	70.0	98.0	150

Table 5 confirms a clear four-factor structure—Environmental Stewardship, Social Responsibility, Governance Maturity, and Economic Resilience, accounting for 71.2 percent of total variance. All 25 indicators load strongly (≥ 0.40) on their expected factors, supporting the conceptual coherence of the index.

Table 5. Exploratory Factor Analysis: Loadings for 25 ASPI-India Indicators (Maximum-Likelihood Extraction; Promax Rotation; Primary Loading Threshold ≥ 0.40 ; $N = 150$ airline-year observations).

No.	Indicator	Env.	Soc.	Gov.	Econ.	Communality	Assigned Factor
1	Fuel burn/ASK	0.72	0.15	0.05	0.10	0.63	Environmental
2	CO ₂ /RPK	0.80	0.10	0.05	0.08	0.70	Environmental
3	SAF blend (%)	0.65	0.12	0.05	0.10	0.58	Environmental
4	Satellite NO ₂ concentration	0.68	0.18	0.09	0.11	0.60	Environmental
5	Noise footprint (km ² > 55 dB Lden)	0.71	0.20	0.07	0.05	0.64	Environmental
6	Waste recycling rate (%)	0.74	0.16	0.09	0.12	0.66	Environmental
7	Passenger complaints/100 k pax	0.08	0.68	0.10	0.08	0.56	Social
8	On-time performance (%)	0.10	0.75	0.12	0.05	0.61	Social
9	Passenger overall satisfaction	0.14	0.77	0.09	0.07	0.63	Social
10	Passenger environmental awareness	0.22	0.66	0.11	0.05	0.55	Social
11	Employee safety incidents	0.05	0.70	0.14	0.10	0.59	Social
12	Training hours per employee	0.09	0.73	0.18	0.06	0.62	Social
13	DGCA audit compliance (%)	0.08	0.15	0.70	0.10	0.60	Governance
14	Number of safety violations	0.05	0.10	0.74	0.12	0.63	Governance
15	SMS maturity score (0–5)	0.05	0.10	0.75	0.12	0.65	Governance
16	Cybersecurity incidents	0.07	0.09	0.72	0.14	0.61	Governance
17	Compensation transparency score (0–5)	0.12	0.10	0.69	0.15	0.59	Governance
18	Green procurement (%)	0.18	0.08	0.71	0.11	0.62	Governance
19	Load factor volatility	0.10	0.05	0.10	0.78	0.66	Economic
20	Ancillary revenue share (%)	0.05	0.08	0.12	0.70	0.58	Economic
21	Cost per ASK (CASK)	0.14	0.07	0.09	0.72	0.61	Economic
22	Credit rating stability	0.09	0.11	0.16	0.74	0.63	Economic
23	Fleet utilisation (hrs/day)	0.12	0.06	0.10	0.76	0.64	Economic
24	Network diversification (HHI)	0.08	0.09	0.07	0.70	0.57	Economic
25	Passenger throughput (weighted)	0.15	0.12	0.11	0.67	0.55	Economic

Note: All 25 indicators from Table 2 are included. Extraction Method: Maximum Likelihood. Rotation: Promax ($\kappa = 4$). KMO = 0.83; Bartlett's χ^2 (300) = 1985.4, $p < 0.001$; eigenvalues > 1: 4 factors retained; cumulative variance explained: 71.2%. Reliability: Env $\alpha = 0.84$ (CR = 0.86); Soc $\alpha = 0.82$ (CR = 0.84); Gov $\alpha = 0.81$ (CR = 0.83); Econ $\alpha = 0.85$ (CR = 0.87). All primary loadings ≥ 0.65 ; no cross-loadings > 0.30.

Regression results in Tables 6 and 7 show that both operational and governance variables exert economically meaningful effects.

Table 6. Panel FE Results for Load Factor Stability (Dependent: Load Factor Volatility).

Variable	Coefficient	SE	t-Stat	p-Value	95% CI
Fuel Burn/ASK	0.120	0.045	2.67	0.008	[0.032, 0.208]
SAF Blend (%)	−0.215	0.070	−3.07	0.002	[−0.353, −0.077]
On-Time Performance (%)	−0.185	0.055	−3.36	0.001	[−0.293, −0.077]
Constant	8.50	1.20	7.08	<0.001	[6.14, 10.86]

Table 7. CASK Regressions (Dependent: Cost per ASK, ₹/ASK).

Variable	Coefficient	SE	t-Stat	p-Value	95% CI
SAF Blend (%)	−0.013	0.004	−3.25	0.001	[−0.021, −0.005]
Fleet Utilisation (hrs/day)	−0.075	0.020	−3.75	<0.001	[−0.115, −0.035]
Network Diversification	−0.060	0.022	−2.73	0.007	[−0.103, −0.017]
Constant	0.85	0.15	5.67	<0.001	[0.55, 1.15]

A one-percentage-point increase in sustainable aviation fuel (SAF) blending is associated with a 0.27 percent reduction in CO₂ intensity ($p < 0.01$). In comparison, airlines linking executive pay to ESG metrics achieve 6.4 percent higher ASPI scores on average. These results suggest that environmental investments yield measurable efficiency gains, and governance integration magnifies those gains through stronger accountability mechanisms. Heterogeneity analyses indicate that full-service carriers benefit more from governance and innovation variables, whereas low-cost carriers respond primarily to fuel-efficiency and route-density factors. The DiD models further reveal that UDAN connectivity policies and ATC upgrades significantly improve regional carriers' sustainability outcomes after implementation, with effects persisting for two to three years.

Overall, the results point to a complementary relationship between operational decarbonization and institutional maturity. Economic and statistical significance align closely, reinforcing the interpretation that sustainability in Indian aviation is both a managerial and policy-driven capability.

7.1. Descriptive Statistics

Table 4 summarises key performance and sustainability metrics across airlines from the sample of 150 observations. The average load factor was 72.4% (SD = 5.8), with values ranging from 60.1% to 85.6%, indicating moderate variability in how efficiently airlines filled available seats. Fuel efficiency, measured by fuel burn per available seat kilometre (ASK), averaged 3.8 L/ASK (SD = 0.6), with a minimum of 2.5 and a maximum of 5.2 L/ASK, suggesting notable differences in operational performance.

Carbon intensity, shown as CO₂ per revenue passenger kilometre (RPK), averaged 90.2 g (SD = 12.3), with extremes ranging from 70.4 g to 110.8 g, highlighting environmental performance disparities. On-time performance averaged 78.3% (SD = 10.5), spanning 50.2% to 95.0%, pointing to reliability issues in some carriers. Customer complaints per 100,000 passengers were relatively low at 4.2 (SD = 1.8) but with outliers up to 8.1, indicating passenger service gaps.

SAF blending remained limited, with an average of 0.8% (SD = 0.5) and a maximum of 2.5%, showing slow adoption. DGCA audit compliance stood at a high average of 88.5% (SD = 7.1), ranging from 70.0% to 98.0%, reflecting good governance practices overall.

7.2. Factor Loadings and Reliability

Table 5 presents the complete exploratory factor analysis (EFA) loadings for the 25 manifest indicators used to construct ASPI-India. EFA was performed using maximum-likelihood extraction with oblique (Promax) rotation, and indicators were assigned to latent factors based on a primary loading threshold of ≥ 0.40 . Items exhibiting substantive cross-loadings were adjudicated according to theoretical relevance and subsequently verified via confirmatory factor analysis (CFA). Communalities for each indicator are reported alongside factor loadings. Summary diagnostics, the Kaiser–Meyer–Olkin measure of sampling adequacy, Bartlett’s test of sphericity, extracted eigenvalues, and cumulative variance explained together with CFA fit statistics (RMSEA, CFI, TLI), composite reliability (CR) and average variance extracted (AVE) for each factor, are reported in Appendix B. The full reporting of loadings and diagnostics ensures transparency and justifies the ASPI’s four-pillar structure.

Table 4 now reports the complete exploratory factor analysis (EFA) results for all 25 manifest indicators underlying the ASPI-India index. Each indicator’s factor loading, communality, and assigned latent factor (Environmental, Social, Governance, or Economic) are presented in full, confirming the validity of the four-pillar structure.

7.3. Load Factor Stability

Table 6 reports panel fixed-effects results where load factor volatility is the dependent variable. Fuel burn per ASK significantly increased volatility by 0.120 (SE = 0.045, $t = 2.67$, $p = 0.008$). In contrast, SAF blending reduced volatility by -0.215 (SE = 0.070, $t = -3.07$, $p = 0.002$), while on-time performance also contributed to stability, reducing volatility by -0.185 (SE = 0.055, $t = -3.36$, $p = 0.001$). These results show that environmental improvements and operational efficiency both play key roles in stabilising load factors.

7.4. Cost per ASK (CASK)

Table 7 analyzes the determinants of cost per ASK (₹/ASK). SAF blending lowered costs by -0.013 (SE = 0.004, $t = -3.25$, $p = 0.001$), suggesting economic benefits from sustainable practices. Fleet utilisation had a more substantial impact, reducing costs by -0.075 (SE = 0.020, $t = -3.75$, $p < 0.001$). Similarly, network diversification contributed to cost savings of -0.060 (SE = 0.022, $t = -2.73$, $p = 0.007$). The constant term was 0.85 (SE = 0.15, $t = 5.67$, $p < 0.001$).

7.5. Policy Impact Analysis: Difference-in-Differences (DiD)

Table 8 reports how policy shocks influenced key metrics. The UDAN scheme reduced dependent variables by -0.040 (SE = 0.018, $t = -2.22$, $p = 0.027$). The SAF mandate had a larger effect, reducing the metric by -0.055 (SE = 0.020, $t = -2.75$, $p = 0.006$). Air traffic control upgrades also contributed, lowering the measure by -0.032 (SE = 0.015, $t = -2.13$, $p = 0.033$). These results confirm that policy interventions targeting sustainability and efficiency can drive measurable improvements.

Table 8. DiD Results for Policy Shocks.

Policy Interaction Term	Coefficient	SE	t-Stat	p-Value	95% CI
UDAN (Post $\times$ Treated)	-0.040	0.018	-2.22	0.027	$[-0.076, -0.004]$
SAF Mandate (Post $\times$ Treated)	-0.055	0.020	-2.75	0.006	$[-0.095, -0.015]$
ATC Upgrade (Post $\times$ Treated)	-0.032	0.015	-2.13	0.033	$[-0.061, -0.003]$

Negative coefficients indicate reductions in dependent variables like load factor volatility or CASK, depending on the specification.

7.6. SAF Adoption and CO₂ Emissions

Table 9 focuses on how SAF adoption impacts CO₂ emissions per RPK. A higher SAF blend led to a significant reduction of -5.20 ($SE = 1.75$, $t = -2.97$, $p = 0.003$). Fuel prices were positively associated with emissions, increasing them by 0.15 ($SE = 0.06$, $t = 2.50$, $p = 0.014$). A larger network size correlated with lower emissions, with a coefficient of -0.08 ($SE = 0.03$, $t = -2.67$, $p = 0.008$). The constant term was 96.50 ($SE = 4.20$, $t = 22.98$, $p < 0.001$).

Table 9. SAF Adoption and CO₂ Emissions per RPK.

Variable	Coefficient	SE	t-Stat	p-Value	95% CI
SAF Blend (%)	-5.20	1.75	-2.97	0.003	$[-8.62, -1.78]$
Fuel Price (INR/l)	0.15	0.06	2.50	0.014	$[0.03, 0.27]$
Network Size	-0.08	0.03	-2.67	0.008	$[-0.14, -0.02]$
Constant	96.50	4.20	22.98	<0.001	$[88.25, 104.75]$

7.7. Heterogeneity by Route Type and Carrier Size

Table 10 examines variation by carrier size and route. For large domestic carriers, the effect was -0.060 ($SE = 0.020$, $t = -3.00$, $p = 0.003$), while small domestic carriers showed a smaller but significant effect of -0.045 ($SE = 0.018$, $t = -2.50$, $p = 0.013$). International large carriers exhibited the most substantial effect with -0.070 ($SE = 0.022$, $t = -3.18$, $p = 0.002$). These results suggest that larger and more globally connected airlines benefit more from sustainability interventions.

Table 10. Heterogeneity by Route Type and Carrier Size.

Subsample	Coefficient	SE	t-Stat	p-Value	95% CI
Domestic-Large Carriers	-0.060	0.020	-3.00	0.003	$[-0.100, -0.020]$
Domestic-Small Carriers	-0.045	0.018	-2.50	0.013	$[-0.080, -0.010]$
International-Large Carriers	-0.070	0.022	-3.18	0.002	$[-0.110, -0.030]$

7.8. Robustness Checks

To evaluate the stability and generalisability of the empirical findings, multiple robustness assessments were conducted. First, alternative index weighting schemes, namely Principal Component Analysis (PCA) and entropy weighting, were employed in constructing the ASPI. Results exhibited strong convergence with the baseline equal-weighted index (average inter-method correlation > 0.90), underscoring structural consistency across weighting approaches. Second, re-estimation using random-effects and pooled OLS models produced comparable coefficient signs, though with diminished explanatory power (within $R^2 = 0.61$ versus 0.74 for fixed effects), reinforcing the appropriateness of the fixed-effects specification. Third, sub-sample analyses by carrier size demonstrated that the relationships between SAF adoption, load factor stability, and cost efficiency remained statistically significant ($p < 0.05$) across both large and small airline groups, confirming the robustness across heterogeneous market segments. Finally, placebo policy simulations, employing randomly assigned UDAN rollout years, yielded statistically insignificant effects ($p > 0.10$), indicating that the documented policy impacts are not artefactual. Together, these diagnostic and robustness tests affirm the empirical integrity and credibility of the study's core conclusions.

Taken together, the empirical results highlight that sustainability in the Indian aviation sector is not merely a regulatory compliance exercise but a strategic capability shaped

by operational efficiency, governance quality, and institutional support. The consistent significance of SAF adoption, ESG-linked incentives, and infrastructure modernisation points to a reinforcing cycle: airlines that institutionalise sustainability at the governance level also tend to perform better environmentally and economically. These findings underscore the interdependence of policy frameworks and managerial choices, where public incentives and private innovation jointly accelerate the transition to low-carbon aviation. The regional differences observed across carriers further suggest that the benefits of sustainability investments depend on absorptive capacity and strategic alignment. Airlines embedded in stronger governance ecosystems, those with transparent disclosure and data-driven oversight, convert sustainability measures into tangible efficiency gains more effectively. Conversely, where governance structures remain weak, even well-designed environmental initiatives yield limited improvements. By integrating econometric evidence with institutional interpretation, this section provides a holistic understanding of what drives sustainability performance in a developing-country aviation market. The next section builds on these insights to discuss the theoretical and policy implications, particularly how governance reform, technology adoption, and market-based instruments can together advance the long-term decarbonization and resilience of India's aviation industry.

8. Discussions

The results provide a comprehensive and nuanced view of sustainability in Indian aviation, confirming several theory-driven expectations while highlighting operational heterogeneity across carriers and routes. Descriptive statistics reveal substantial variation in environmental, social, governance, and economic performance, both across airlines and over time. Some carriers consistently demonstrate high sustainability scores, while others show fluctuations tied to fuel price shocks, regulatory interventions, or operational constraints. This pattern aligns with prior evidence on variability in emerging markets, suggesting that external shocks and policy environments play a critical role in shaping airline performance [65,77,134].

H1—Sustainable Aviation Fuel (SAF) and Environmental Performance

The results confirm that SAF adoption significantly reduces CO₂ emissions intensity. A one percentage point increase in SAF blend is associated with a reduction of 5.2 g of CO₂ per RPK, holding other factors constant. This aligns with TBL and Institutional Theory predictions that regulatory and societal pressures, operationalised through SAF mandates, effectively drive greener aviation practices, supporting the argument that institutional mechanisms, such as policy mandates and industry standards, are instrumental in achieving environmental sustainability [31,84,129]. Moreover, the correlation between SAF adoption and operational performance highlights potential synergies where environmental investments may also stabilise operational efficiency.

H2—Stakeholder Engagement and Social Sustainability

High ASPI-social scores are associated with more robust community programs, higher employee retention, and improved passenger service quality. This confirms the predictions of Stakeholder Theory, emphasizing that proactive engagement with passengers, employees, and local communities fosters goodwill, trust, and enhanced social outcomes [68,85,135]. Airlines with structured stakeholder initiatives not only achieve superior social sustainability scores but also benefit from reputational and operational resilience. This reinforces the idea that social sustainability can generate both intangible and tangible value [118–120], including improved brand perception and employee loyalty, which are crucial in highly competitive and service-intensive sectors like aviation.

H3—Resource Efficiency and Financial Sustainability

Carriers demonstrating superior resource efficiency, through optimised fleet utilisation, effective scheduling, and fuel management, achieve better financial sustainability, consistent with the Resource-Based View (RBV) [80,121,122]. Empirical results show lower CASK and more stable load factors for these carriers, indicating that operational and environmental efficiency can translate directly into financial benefits. This challenges the conventional notion that sustainability necessarily entails cost trade-offs, suggesting instead that well-managed resource efficiency can be a source of competitive advantage. The findings also highlight that operational capabilities, when integrated with environmental initiatives, can reinforce overall firm performance.

H4—Institutional Pressures as Moderators

The relationship between operational innovations (e.g., SAF adoption, route adjustments) and sustainability outcomes is moderated by institutional pressures. Regulatory interventions, such as the UDAN regional connectivity scheme and ATC upgrades, amplify the effectiveness of these innovations, reflecting the moderating role predicted by Institutional Theory [6,123,124]. This finding emphasises that the institutional context shapes not only whether innovations are adopted but also how effectively they translate into improved environmental, social, and financial performance. Airlines that align their strategic initiatives with regulatory and policy frameworks are better positioned to extract the full benefits of sustainability-oriented practices.

H5—Dynamic Capabilities and Market Volatility

Dynamic capabilities, including rapid route restructuring, fleet adjustments, and SAF procurement strategies, mediate the impact of market volatility on sustainability outcomes. Larger carriers that leverage these capabilities maintain operational stability and sustain performance during fuel price shocks and other external disturbances [5,125,126]. This underscores the importance of adaptability and real-time responsiveness in buffering external shocks. The results also suggest that developing such dynamic capabilities is not merely operational but strategic, as it allows airlines to maintain sustainability performance while navigating complex and unpredictable market environments.

H6—System-Level Coordination

System-level coordination across airlines, airports, and regulators enhances overall sustainability outcomes, in line with Systems Theory [75,127,128]. Coordinated ATC improvements, SAF mandates, and regional connectivity programs generate measurable gains across environmental, social, and economic ASPI pillars. These findings suggest that holistic, cross-stakeholder planning can produce synergistic effects that exceed the benefits of isolated initiatives. Effective coordination enables the entire aviation ecosystem to optimize resource allocation, improve operational reliability, and enhance overall sustainability performance.

Table 11 presents the comprehensive Summary of Hypotheses, Empirical Evidence, and Theoretical Bases.

Implications and Integration

Collectively, the findings highlight that sustainability in aviation is inherently multi-dimensional. Environmental, social, governance, and economic performance are interdependent, and strategic alignment across these dimensions can produce mutually reinforcing benefits. The validated ASPI framework offers a robust tool for policymakers, regulators, airline managers, and investors to monitor, benchmark, and strategically improve sustainability performance. Moreover, sustainability emerges as a source of operational resilience and competitive advantage rather than a mere compliance requirement, supporting theoretical perspectives from TBL, RBV, Stakeholder, Institutional, Dynamic Capabilities, and Systems Theory.

Table 11. Summary of Hypotheses, Empirical Evidence, and Theoretical Bases.

Hypothesis	Expected Relationship	Empirical Evidence	Effect Direction	Theoretical Basis
H1—Higher adoption of sustainable aviation fuels (SAF) positively impacts environmental performance	Positive	SAF mandates decreased CO ₂ per RPK; stronger effects for large carriers; short-term cost increased due to SAF price premium	(↑) Environmental performance; (↑) Short-term CASK	Triple Bottom Line (TBL), Institutional Theory
H2—Strong stakeholder engagement leads to higher social sustainability scores	Positive	High ASPI- social scores linked to community programs, employee retention, and service quality	(↑) Social sustainability	Stakeholder Theory
H3—Superior resource efficiency improves financial sustainability	Positive	High ASPI economic scores associated with lower CASK, stable load factors, and better asset use	(↑) Financial performance	Resource-Based View (RBV)
H4—Institutional pressures moderate the innovation-sustainability link	Moderated positive	SAF and operational innovations had stronger effects under UDAN and ATC policy environments	(↑) Innovation pay off under regulation	Institutional Theory
H5—Dynamic capabilities mediate the market volatility- sustainability link	Mediated buffering	Larger carriers adapted routes, capacity, and SAF procurement under fuel shocks, maintaining sustainability scores	(↓) Volatility impact; (↑) Performance resilience	Dynamic Capabilities Theory
H6—System-level coordination improves overall sustainability	Positive	Joint ATC upgrades, SAF mandates, and UDAN route coordination increased ASPI scores across pillars	(↑) System efficiency& resilience	Systems Theory

Future Research Directions

Future studies should examine long-term SAF cost trajectories and integrate climate transition scenarios to assess risks and investment needs. Incorporating passenger sentiment and reputational metrics alongside operational performance could provide richer insights into social and market drivers of sustainability adoption. Additionally, longitudinal studies tracking post-policy implementation may uncover persistent or diminishing effects, helping to refine regulatory strategies and industry best practices.

9. Policy and Managerial Implications

The Aviation Sustainability Performance Index (ASPI India) offers a practical framework. It measures environmental, social, governance, and economic performance consistently. This integrated approach can inform regulatory policy and industry strategy. The following sections outline implications for regulators, airlines, and investors.

9.1. Implications for Regulators

Regulators can embed ASPI India within compliance scoring systems. Existing systems often assess safety and security separately. ASPI India allows a unified sustainability assessment across pillars. This helps regulators monitor industry trends in near-real time. By adopting ASPI India, DGCA can enhance audit precision. It can track governance maturity beyond basic regulatory compliance. Indicators such as SMS maturity show readiness for future challenges. Cybersecurity performance metrics help prepare against digital threats. BCAS can integrate ASPI environmental indicators in security compliance checks. Security operations also consume energy and generate emissions. Tracking fuel burn and carbon intensity supports green security operations. AAI can use ASPI data for airport-level sustainability oversight. Load factor stability and network diversification reveal operational resilience. Noise footprints and recycling rates reflect environmental stewardship near airports. Regulators can use ASPI to benchmark domestic and foreign carriers. This helps ensure fair competition under uniform sustainability criteria. It also allows monitoring of foreign carriers in Indian airspace. ASPI results can guide incentive

design for sustainable aviation. For example, high SAF adoption scores can trigger tax credits. Airlines with low noise footprints may get preferential slot allocation. ASPI data can improve public transparency of airline performance. Publishing annual rankings may create reputational incentives for carriers. Transparency also supports passenger choice based on sustainability performance. Integration into policy allows regulators to detect early warning signs. Declining economic resilience scores may precede route withdrawals. Falling governance maturity may predict safety or compliance lapses. In the long run, regulators can tie ASPI to certification. High ASPI scores may accelerate approval for fleet expansion. Low scores could trigger additional audits or corrective plans.

9.2. Implications for Airlines

Airlines can embed ASPI into strategic decision-making processes. It provides a structured view of strengths and weaknesses. Environmental indicators help track progress towards emission reduction targets. Fuel burn per ASK informs fleet efficiency strategies. Social indicators support human capital and passenger experience management. Low complaint rates can be used in marketing narratives. High employee safety performance reduces accident-related costs and downtime. Governance maturity metrics help identify procedural and compliance gaps. Strength in SMS maturity can reduce insurance premiums. Strong green procurement scores may attract eco-conscious corporate clients. Economic resilience measures support revenue stability planning. Monitoring load factor volatility helps anticipate seasonal capacity adjustments. Ancillary revenue share informs diversification of income streams. ASPI can also guide route planning and network development. Carriers can prioritise routes with higher sustainability profitability potential. Low-carbon intensity routes may align with environmental branding strategies.

Fleet investment decisions can be aligned with ASPI performance gaps. Poor fuel efficiency scores may justify upgrading to newer aircraft. High SAF availability on certain routes can shape deployment choices. Airlines can use ASPI for competitive benchmarking within India. Tracking rivals' environmental and social scores informs marketing positioning. Weak governance scores in competitors may signal market capture opportunities. Operational teams can integrate ASPI indicators into daily monitoring dashboards. This ensures sustainability remains a live operational priority. It moves performance management from annual review to continuous improvement. Linking ASPI scores to staff incentives may boost engagement. Cabin crew may be rewarded for improving passenger satisfaction. Ground staff may be recognised for reducing waste footprints.

ASPI can support communication with external stakeholders. Clear metrics make sustainability reports more credible and comparable. This can strengthen trust with passengers, regulators, and investors alike.

9.3. Implications for Investors

Investors can integrate ASPI scores into aviation credit assessments. Traditional credit ratings often neglect sustainability-related risks. ASPI adds non-financial indicators that predict long-term viability. Environmental performance can signal exposure to carbon pricing risks. Poor fuel efficiency may lead to higher operational costs. Low SAF adoption may attract regulatory penalties in the future. Social metrics indicate labour stability and service quality. High employee safety incidents may lead to operational disruptions. Poor passenger satisfaction may reduce brand loyalty and market share. Governance maturity reflects management discipline and compliance readiness. Low cybersecurity scores could signal exposure to costly breaches. Weak SMS maturity may increase insurance and financing costs. Economic resilience captures adaptability to market shocks. Stable load factors reduce revenue volatility during downturns. Diversified networks may lower

exposure to regional disruptions. For equity investors, ASPI enables sustainability-adjusted valuation models. Airlines with improving ASPI scores may merit higher price multiples. Those with declining scores may face long-term value erosion. Fixed-income investors can use ASPI to assess bond risk. Airlines with low environmental scores may face refinancing challenges. Weak governance scores could increase default probability over time. Private equity can leverage ASPI in post-acquisition value creation. Sustainability performance improvements can increase exit valuation. It also aligns with global ESG investment mandates. ASPI-based rankings can influence investor relations strategies. High-scoring airlines can market themselves as sustainability leaders. This may improve access to green finance and lower borrowing costs.

9.4. Cross-Sector Benefits

Integration of ASPI into policy and strategy creates synergies. Regulators benefit from more precise and comparable sustainability data. Airlines gain a clear roadmap for operational improvement. Investors reduce risk through sustainability-adjusted decision-making. Collaborative use of ASPI can accelerate industry-wide decarbonisation. It creates a common language between stakeholders. Shared benchmarks encourage innovation and performance improvement. In the Indian context, ASPI supports national climate commitments. It aligns with India's net-zero ambitions by 2070. It also fits within evolving global aviation sustainability frameworks.

10. Conclusions

This study developed and empirically validated the Aviation Sustainability Performance Index (ASPI-India) as a multidimensional measure of airline sustainability, combining environmental, social, governance, and economic dimensions. Using a balanced panel of ten Indian airlines from 2010 to 2024, the analysis revealed that sustainability outcomes are driven by a dynamic interaction between operational innovation, governance maturity, and policy context. The findings confirm that sustainability in aviation is not an isolated environmental initiative but a composite capability, anchored in both managerial intent and institutional design. The econometric results demonstrate that SAF adoption, ESG-linked executive incentives, and airport infrastructure upgrades are the most consistent predictors of improved sustainability performance. Their economic significance is nontrivial: even modest increases in SAF blending or governance-linked pay yield measurable reductions in carbon intensity and higher ASPI scores. These findings provide actionable insights for both corporate strategy and policy design, showing that operational decarbonization gains traction when supported by transparent governance and targeted regulatory interventions. From a *policy perspective*, the results reinforce the importance of coordinated public–private mechanisms to scale low-carbon transitions in aviation. Government initiatives such as the UDAN scheme and ATC modernisation generate sustained performance improvements when aligned with firm-level governance reforms. This suggests that sustainability policy should move beyond compliance toward incentive-based frameworks that reward innovation, data disclosure, and fuel diversification. *Theoretically*, the study extends the resource-based and institutional views by positioning sustainability as a *capability of co-ordination*, where governance quality amplifies the value of environmental investments. This conceptual integration advances our understanding of how developing-country firms internalise sustainability within resource constraints and evolving regulatory environments.

Future research should test the ASPI-India model across other emerging markets and expand the index to include carbon-offset strategies and digital efficiency measures. Cross-country comparative studies could also examine how institutional maturity mediates the relationship between technology adoption and sustainability outcomes. In essence, the

study shows that the path to decarbonising aviation in emerging economies lies not only in technology or policy, but in the governance architecture that connects them. Sustainable performance emerges where operational, strategic, and institutional systems move in concert toward long-term resilience.

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Appendix A. Comparison of Weighting Schemes for the Aviation Sustainability Performance Index (ASPI-India)

This appendix presents the comparative results of three weighting methodologies: Equal Weighting, Principal Component Analysis (PCA), and Entropy Weighting, used to construct the Aviation Sustainability Performance Index (ASPI-India). The objective is to evaluate whether the study's primary results remain robust across alternative schemes.

Appendix A.1. Methodological Overview

Equal Weighting: Each of the four ASPI pillars—Environmental Stewardship, Social Responsibility, Governance Maturity, and Economic Resilience—receives an equal weight of 0.25. This approach emphasises normative fairness and interpretability.

Principal Component Analysis (PCA): PCA weights are derived from the variance explained by each principal component within each pillar. Indicators contributing more to within-pillar variance receive proportionally higher weights. This captures latent data structure and inter-indicator correlations.

Entropy Weighting: Entropy weights are calculated based on the dispersion of each indicator. Higher variability across airlines or years yields higher information content and thus higher weight. This method reflects information richness rather than normative importance.

Table A1. Comparative Results.

Pillar	Equal Weight	PCA Weight	Entropy Weight
Environmental Stewardship	0.25	0.27	0.24
Social Responsibility	0.25	0.24	0.26
Governance Maturity	0.25	0.25	0.25
Economic Resilience	0.25	0.24	0.25

The PCA-based and entropy-based schemes show minimal deviation ($<\pm 0.03$) from the equal-weighted baseline, indicating structural stability. Pairwise correlation coefficients between the three ASPI variants exceed 0.90 ($p < 0.001$), confirming consistency in overall rankings and inter-pillar relationships.

Appendix A.2. Sensitivity Analysis

Regression models using the PCA-weighted and entropy-weighted ASPI scores yielded coefficients similar in magnitude and direction to the baseline equal-weighted model. Key findings, such as the significant impact of SAF adoption on CO₂ intensity and governance-linked pay on overall sustainability performance, remained statistically robust ($p < 0.05$). R² values varied within ± 0.02 of the baseline specification, underscoring the model's reliability under alternative weighting structures.

Appendix A.3. Conclusions

The comparative analysis demonstrates that equal weighting provides a fair, interpretable, and empirically valid structure for ASPI-India. While data-driven approaches like PCA and entropy weighting offer complementary perspectives, they do not materially alter the study's conclusions. Therefore, the equal-weighted index is retained as the main analytical specification for policy and managerial interpretation.

Appendix B. Robustness and Measurement Validation

Table A2. Sampling Adequacy and Sphericity Tests.

Test	Statistic	Value	Significance	Interpretation
Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy	KMO	0.83	-	Sampling adequacy is meritorious (≥ 0.80).
Bartlett's Test of Sphericity	χ^2 (300)	1985.4	$p < 0.001$	Correlation matrix suitable for factor analysis.

Note: The KMO statistic exceeds the recommended threshold of 0.70, and Bartlett's test rejects the null hypothesis of an identity matrix, confirming factorability of the dataset.

Table A3. Eigenvalues and Variance Explained (EFA).

Factor	Eigenvalue	% Variance Explained	Cumulative %
Environmental Stewardship	7.85	31.4%	31.4%
Social Responsibility	4.02	16.1%	47.5%
Governance Maturity	3.00	12.0%	59.5%
Economic Resilience	2.93	11.7%	71.2%

Extraction Method: Maximum Likelihood. Rotation: Promax ($\kappa = 4$). Retention Criteria: Eigenvalues > 1.0 and interpretability of factor structure.

Table A4. Reliability and Convergent Validity (Post-EFA Retained Model).

Pillar	Cronbach's α	Composite Reliability (CR)	Average Variance Extracted (AVE)	Indicators Retained	Notes
Environmental Stewardship	0.84	0.86	0.61	6	All loadings ≥ 0.65
Social Responsibility	0.82	0.84	0.58	6	All loadings ≥ 0.66
Governance Maturity	0.81	0.83	0.56	6	All loadings ≥ 0.69
Economic Resilience	0.85	0.87	0.63	7	All loadings ≥ 0.67

Interpretation: Cronbach's $\alpha > 0.80$ and CR > 0.70 indicate internal consistency; AVE > 0.50 confirms convergent validity.

Table A5. Confirmatory Factor Analysis (CFA) Model Fit.

Fit Index	Abbreviation	Value	Recommended Threshold	Interpretation
Root Mean Square Error of Approximation	RMSEA	0.046	<0.06	Good fit
RMSEA 90% Confidence Interval	-	(0.039, 0.054)	-	-
Comparative Fit Index	CFI	0.958	>0.95	Excellent fit
Tucker–Lewis Index	TLI	0.949	>0.90	Good fit
Standardised Root Mean Square Residual	SRMR	0.041	<0.08	Good fit
χ^2/df Ratio	-	1.87	<3.00	Acceptable parsimony

Model estimation method: Maximum Likelihood (robust). All factor loadings are significant at $p < 0.001$.

Table A6. Discriminant Validity.

Pillar Pair	$\sqrt{\text{AVE}}$ (Diagonal)	Inter-Factor Correlation	Discriminant Validity
Env—Soc	0.78/0.76	0.54	Satisfied
Env—Gov	0.78/0.75	0.51	Satisfied
Env—Econ	0.78/0.79	0.49	Satisfied
Soc—Gov	0.76/0.75	0.53	Satisfied
Soc—Econ	0.76/0.79	0.56	Satisfied
Gov—Econ	0.75/0.79	0.52	Satisfied

Fornell–Larcker criterion met: $\sqrt{\text{AVE}}$ exceeds all inter-construct correlations.

Table A7. Pre- and Post-Item Screening Summary.

Stage	Total Indicators	Items Dropped	Retained Items	Rationale for Deletion
Pre-EFA (Initial Model)	26	1	25	One redundant indicator (duplicate passenger satisfaction metric) removed due to cross-loading > 0.35 and communality < 0.30 .
Post-EFA (Final Model)	25	0	25	All retained items met loading and communality criteria.

Summary Interpretation

The measurement diagnostics confirm that the ASPI-India model exhibits strong construct validity, internal consistency, and model fit. Sampling adequacy (KMO = 0.83), high reliability coefficients ($\alpha = 0.81$ – 0.85), satisfactory AVE values (>0.50), and robust CFA indices (CFI = 0.958; RMSEA = 0.046; SRMR = 0.041) collectively affirm the soundness of the four-pillar structure. The final model, comprising 25 indicators, is thus empirically validated for subsequent inferential analysis.

References

1. India Brand Equity Foundation (IBEF). *Indian Aviation Industry Report*; IBEF: New Delhi, India, 2025. Available online: <https://ibef.org/industry/indian-aviation> (accessed on 8 June 2025).
2. Iyer, K.; Thomas, J. Low-Cost Carr. Growth India: Policy Mark. Implications. *J. Air Transp. Manag.* **2020**, *87*, 101859.
3. Informaconnect. *Indian Aviation: Market Size and Economic Contribution*; Informaconnect: Burlington, MA, USA, 2018.
4. GHG Platform India. *National Greenhouse Gas Inventory: Aviation Sector Emissions*; GHG Platform: Noida, India, 2022. Available online: https://www.ghgplatform-india.org/wp-content/uploads/2022/09/GHGPI-PhaseIV-Briefing-Paper-on-Indias-Future-in-Sustainable-Aviation_CSTEP-Sep22.pdf (accessed on 22 June 2025).
5. Winchester, N.; McConnachie, D.; Wollersheim, C.; Waitz, I.A. Economic and Emissions Impacts of Renewable Fuel Adoption in Aviation. *Transp. Res. Part D Transp. Environ.* **2021**, *90*, 102642.
6. Das, A.K.; Bardhan, A.K.; Fageda, X. New Regional Aviation Policy in India: Early Indicators and Lessons Learnt. *J. Air Transp. Manag.* **2020**, *88*, 101870. [CrossRef]
7. Iyer, K.C.; Thomas, N. A Critical Review on Regional Connectivity Scheme of India. *Transp. Res. Procedia* **2020**, *48*, 47–59. [CrossRef]
8. Comptroller and Auditor General (CAG) of India. *Audit Report on Civil Aviation*; CAG: New Delhi, India, 2023. Available online: <https://www.slideshare.net/slideshow/report-no22-of-2023-union-government-ministry-of-civil-aviation-compliance-audit-on-regional-connectivity-scheme-udan-ude-desh-ka-aam-naagrik/261442020> (accessed on 24 June 2025).
9. Pokhriyal, R.; Pokhriyal, V. Demand Dynamics in India's UDAN Program. *Transp. Policy* **2025**, *127*, 45–56.
10. Gupta, R. Profitability Challenges in India's Regional Aviation Market. *J. Air Transp. Manag.* **2025**, *117*, 102295.
11. Legacy IAS. *UDAN Scheme and Infrastructure Investments: Policy Review*; Legacy IAS: Bengaluru, India, 2023. Available online: <https://www.legacyias.com/the-unstoppable-udaan-of-indias-civil-aviation/> (accessed on 24 May 2025).
12. Phuyal, M. Reviewing Airport Privatization: An Experience of India, SSRN 2024. Available online: <https://ssrn.com/abstract=4746651> (accessed on 8 June 2025). [CrossRef]
13. Indian Oil Corporation (IOC). *Panipat Refinery Certified for Sustainable Aviation Fuel Production*; IOC Press Release: New Delhi, India, 2024. Available online: <https://iocl.com/NewsDetails/59413> (accessed on 18 August 2025).
14. Rigas, D. *Flying Off Course: Airline Economics and Marketing*, 5th ed.; Routledge: London, UK, 2019.
15. Wensveen, J. *Air Transportation: A Management Perspective*, 8th ed.; Routledge: London, UK, 2019.
16. Belobaba, P.; Odoni, A.; Barnhart, C. *The Global Airline Industry*, 2nd ed.; Wiley: Chichester, UK, 2015.
17. O'Connell, J.F.; Williams, G. *Air Transport in the 21st Century: Key Strategic Developments*; Routledge: London, UK, 2011.
18. Graham, A. *Managing Airports: An International Perspective*, 4th ed.; Routledge: London, UK, 2013.
19. Button, K. *Transport Economics*, 4th ed.; Edward Elgar: Cheltenham, UK, 2017.
20. Lee, D.S.; Fahey, D.W.; Skowron, A.; Allen, M.R.; Burkhardt, U.; Chen, Q.; Doherty, S.J.; Freeman, S.; Forster, P.M.; Fuglestedt, J.; et al. The Contribution of Global Aviation to Anthropogenic Climate Forcing for 2000–2018. *Atmos. Environ.* **2021**, *244*, 117834. [CrossRef]
21. Poom, A.; Orru, K.; Ahas, R. The carbon footprint of business travel in the knowledge-intensive service sector. *Transp. Res. Part D Transp. Environ.* **2017**, *40*, 292–304. [CrossRef]
22. Schumann, U.; Heymsfield, A.J. On the Lifecycle of Individual Contrails and Contrail Cirrus. *Meteorol. Monogr.* **2017**, *58*, 3.1–3.24. [CrossRef]
23. Matthes, S.; Grewe, V.; Dahlmann, K.; Frömming, C. Aviation Climate Impacts: The Role of Nitrogen Oxides and Contrails. *Atmos. Chem. Phys.* **2021**, *21*, 12421–12445. Available online: <http://goldfinger.utias.utoronto.ca/IWACC5/IWACC7/Grewe.pdf> (accessed on 8 July 2025).
24. Peuckert, J.; Hansen, T.; Hellsmark, H. Assessing the Climate Impact of Aviation: LCA Perspectives. *J. Clean. Prod.* **2022**, *366*, 132933.
25. Schäfer, A.W.; Evans, A.D.; Reynolds, T.G.; Dray, L.M. Costs of Mitigating CO₂ Emissions from Passenger Aircraft. *Nat. Clim. Change* **2016**, *6*, 412–417. [CrossRef]
26. Brooks, N.; van Exel, J. Regulatory Policy for Aviation Emissions: CORSIA and the EU ETS. *Environ. Sci. Policy* **2020**, *106*, 186–197. Available online: <https://redshawadvisors.com/corsia-and-the-inclusion-of-aviation-in-the-eu-ets/> (accessed on 26 June 2025).
27. Larsson, J.; Kamb, A.; Nässén, J.; Åkerman, J. Measuring Greenhouse Gas Emissions From International Air Travel of a Country's Residents Methodological Development and Application for Sweden. *Environ. Impact Assess. Rev.* **2018**, *72*, 137–144. [CrossRef]
28. Ramya, M.A.; Chakrabarty, S. *Pathways to Decarbonize India's Transport Sector: Scenario Analysis Using the Energy Policy Simulator*; Working Paper; WRI India: New Delhi, India, 2024. [CrossRef]
29. de Jong, S.; Antonissen, K.; Hoefnagels, R.; Faaij, A.; Slade, R.; Mawhood, R.; Junginger, M. The Feasibility of Sustainable Aviation Fuels. *Renew. Sustain. Energy Rev.* **2017**, *79*, 1153–1173.
30. Jiang, C.; Liu, Y. The Role of Sustainable Aviation Fuel in CORSIA: An Economic Analysis. *Energy Econ.* **2025**, *143*, 108238. [CrossRef]

31. Sgouridis, S.; Bonnefoy, P.A.; Hansman, R.J. Air transportation in a carbon constrained world: Long-term dynamics of policies and strategies for mitigating the carbon footprint of commercial aviation. *Transp. Res. Part A Policy Pract.* **2011**, *45*, 1077–1091. [CrossRef]
32. Pavlenko, N.; Searle, S. A Comparison of Advanced Biofuel Production Pathways for Aviation. *Energy Policy* **2020**, *138*, 111271.
33. Bann, S.J.; Malina, R.; Staples, M.D.; Suresh, P.; Pearlson, M.; Tyner, W.E.; Hileman, J.I.; Barrett, S. The Costs of Production of Alternative Jet Fuel: A Harmonized Stochastic Assessment. *Bioresour. Technol.* **2016**, *227*, 179–187. [CrossRef]
34. Malins, C. Availability and Cost of Low-Carbon Jet Fuel in Europe. Cerulogy Report. 2017. Available online: https://www.cerulogy.com/wp-content/uploads/2022/10/Cerulogy_What-role-electrofuels_November2017_v1_3.pdf (accessed on 12 August 2025).
35. Kousoulidou, M.; Lonza, L. Biofuels in Aviation: Fuel Demand and CO₂ Emissions Evolution in Europe Toward 2030. *Transp. Res. Part D Transp. Environ.* **2016**, *46*, 166–181. [CrossRef]
36. European Union Aviation Safety Agency (EASA). *Sustainable Aviation Fuels: Guidance and Recommendations*; EASA Report; EASA: Cologne, Germany, 2019.
37. Ghosh, S.; Datta, S. Feedstock Options for Sustainable Aviation Fuel in India. *Renew. Energy Focus.* **2022**, *43*, 101–113.
38. Balasubramanian, K.; Krishnan, S.; Nair, A. Regional SAF Supply Chains for Indian Aviation. *Energy Policy* **2023**, *173*, 113345.
39. Cook, A.; Tanner, G.; Anderson, S. Reducing Airline Fuel Burn: Operational Strategies. *J. Air Transp. Manag.* **2009**, *15*, 148–155.
40. Reynolds, T.G.; Schäfer, A.; Dray, L. Fuel Efficiency and Route Optimization in Aviation. *Transp. Res. Part C* **2007**, *15*, 353–367.
41. Clarke, J.-P.B.; Ho, N.T.; Ren, L.; Brown, J.A.; Elmer, K.R.; Tong, K.-O.; Wat, J.K. Continuous Descent Operations: Environmental and Operational Benefits. *J. Aircr.* **2013**, *50*, 337–347.
42. Simaiakis, I.; Balakrishnan, H.; Reynolds, T.G. Fuel Burn Reduction via Air Traffic Flow Management. *Transp. Res. Part C* **2014**, *44*, 231–243.
43. Ball, M.O.; Barnhart, C.; Nemhauser, G.L.; Odoni, A.R. Air Transportation Systems Analysis and Design. *Oper. Res.* **2010**, *58*, 1–10.
44. Barnhart, C.; Belobaba, P.; Odoni, A. Applications of Operations Research in Air Transportation. *Transp. Sci.* **2012**, *46*, 1–9.
45. Wu, C.; Caves, R. Aircraft Turnaround Efficiency and Delay Management. *J. Air Transp. Manag.* **2000**, *6*, 201–208. [CrossRef]
46. Kusterer, J.; Scholz, D.; Hornung, M. Ground Operations and Emissions at Airports. *Aerosp. Sci. Technol.* **2017**, *66*, 1–10.
47. Sarkar, P.K.; Maitra, B. Congestion at Indian Airports: Capacity and Demand Issues. *Curr. Sci.* **2012**, *103*, 771–778.
48. Chandra, S.; Jain, A. Airport Capacity Constraints and Airspace Congestion. *Transp. Policy* **2015**, *37*, 123–132.
49. Zaporozhets, O.; Tokarev, V.; Attenborough, K. *Aircraft Noise: Assessment, Prediction and Control*; CRC Press: Boca Raton, FL, USA, 2011.
50. Hume, K.; Morley, D.; Terranova, D. Community Noise Exposure and Policy Responses. *J. Sound Vib.* **2012**, *331*, 3729–3743.
51. Fidell, S.; Pearsons, K. Community Annoyance and Aircraft Noise. *J. Acoust. Soc. Am.* **2003**, *114*, 718–725.
52. Hansell, A.L.; Blangiardo, M.; Fortunato, L.; Floud, S.; de Hoogh, K.; Fecht, D.; Ghosh, R.E.; Laszlo, H.E.; Pearson, C.; Beale, L.; et al. Aircraft Noise and Cardiovascular Disease Near Heathrow Airport in London: Small Area Study. *BMJ* **2013**, *347*, f5432. [CrossRef]
53. Stettler, M.E.; Eastham, S.; Barrett, S.R.H. Air Quality and Public Health Impacts of UK Airports. *Atmos. Environ.* **2011**, *45*, 5415–5424. [CrossRef]
54. Yim, S.H.L.; Stettler, M.E.J.; Barrett, S.R.H. Air Quality and Public Health Impacts of UK Airports: Part II-Impacts and Policy Assessment. *Atmos. Environ.* **2015**, *116*, 184–194. [CrossRef]
55. Sahu, S.K.; Beig, G.; Parkhi, N.S. Emissions Inventory of Anthropogenic PM_{2.5} and PM₁₀ in Delhi During the Commonwealth Games 2010. *Atmos. Environ.* **2011**, *45*, 6180–6190. [CrossRef]
56. Guttikunda, S.K.; Calori, G. Air Pollution Hotspots in Indian Cities. *Atmos. Environ.* **2013**, *71*, 239–251.
57. ICAO. *Safety Management Manual*, 4th ed.; International Civil Aviation Organisation: Montreal, QC, Canada, 2018.
58. Stolzer, A.; Halford, C.; Goglia, J. *Safety Management Systems in Aviation*, 2nd ed.; Ashgate: Farnham, UK, 2017.
59. Reason, J. *Managing the Risks of Organisational Accidents*; Ashgate: Surrey, UK, 1997.
60. Dekker, S. *The Field Guide to Understanding Human Error*, 3rd ed.; CRC Press: Boca Raton, FL, USA, 2017.
61. Amalberti, R. The Paradoxes of Almost Perfect Safety. *Saf. Sci.* **2001**, *37*, 109–126. [CrossRef]
62. Le Coze, J.C. Learning from Incidents: Organizational Accidents and Systemic Thinking. *Saf. Sci.* **2013**, *51*, 204–218.
63. Kovacevic, A.; Vukadinovic, K. Cybersecurity in Air Traffic Systems. *J. Air Transp. Manag.* **2017**, *65*, 31–39.
64. ICAO. *Aviation Cybersecurity Strategy*; International Civil Aviation Organisation: Montreal, QC, Canada, 2020.
65. Borenstein, S.; Rose, N. Competition and Price Dispersion in the Airline Industry. *J. Political Econ.* **2014**, *122*, 271–307.
66. Wittman, M.D.; Swelbar, W.S. Capacity Discipline and the Consolidation of U.S. Airlines. *Rev. Econ. Stat.* **2013**, *95*, 923–935.
67. Park, J.W.; Robertson, R.; Wu, C. Service Quality and Passenger Satisfaction in Air Transport. *J. Air Transp. Manag.* **2006**, *12*, 166–172.
68. Gilbert, D.; Wong, R.K.C. Passenger Expectations and Airline Services: A Hong Kong Perspective. *Tour. Manag.* **2003**, *24*, 519–532. [CrossRef]

69. Budd, L.; Ison, S. Airline Operations and On-Time Performance. *J. Air Transp. Manag.* **2017**, *63*, 15–25.
70. Klopheus, R.; Conrad, R.; Fichert, F. Reliability in Airline Scheduling. *Transp. Policy* **2012**, *24*, 14–21.
71. Roberson, Q.M. Disentangling the Meanings of Diversity and Inclusion in Organisations. *Group Organ. Manag.* **2006**, *31*, 212–232. [\[CrossRef\]](#)
72. Ely, R.J.; Thomas, D.A. Cultural Diversity at Work: The Effects on Team Innovation. *Adm. Sci. Q.* **2001**, *46*, 229–273. [\[CrossRef\]](#)
73. Salas, E.; Tannenbaum, S.I.; Kraiger, K.; Smith-Jentsch, K.A. The Science of Training and Development in Organisations: What Matters in Practice. *Psychol. Sci. Public Interest* **2012**, *13*, 74–101. [\[CrossRef\]](#)
74. Chen, G.; Kirkman, B.L.; Kanfer, R.; Allen, D.; Rosen, B. Motivation and Training Transfer in Aviation Teams. *J. Appl. Psychol.* **2018**, *103*, 367–387.
75. Hobfoll, S.E.; Halbesleben, J.; Neveu, J.P.; Westman, M. Conservation of Resources in Organizational Contexts. *Annu. Rev. Organ. Psychol. Organ. Behav.* **2018**, *5*, 103–128. [\[CrossRef\]](#)
76. Cooper, C.L.; Quick, J.C. *The Handbook of Stress and Health*; Wiley-Blackwell: Oxford, UK, 2017.
77. Mumbower, S.; Garrow, L.A.; Higgins, M.J. Airline Revenue Diversification and Economic Resilience. *J. Air Transp. Manag.* **2014**, *34*, 78–86.
78. Wittmer, A.; Bieger, T.; Müller, R. *Aviation Systems: Management of the Integrated Aviation Value Chain*; Springer: Berlin/Heidelberg, Germany, 2011.
79. Gittell, J.H. *The Southwest Airlines Way: Using the Power of Relationships to Achieve High Performance*; McGraw-Hill: New York, NY, USA, 2003.
80. Alderighi, M.; Cento, A.; Nijkamp, P.; Rietveld, P. Network Competition in Aviation. *J. Air Transp. Manag.* **2005**, *11*, 343–355.
81. Bazargan, M. *Airline Operations and Scheduling*, 3rd ed.; Routledge: New York, NY, USA, 2016.
82. Sriraman, S. Volatility in Indian Aviation: Demand and Cost Shocks. *Indian J. Transp. Econ.* **2017**, *45*, 27–46.
83. Sengupta, D.; Sen, S. Cost Volatility and Market Cycles in Indian Airlines. *Econ. Model.* **2020**, *89*, 110–122.
84. Elkington, J. *Cannibals with Forks: The Triple Bottom Line of 21st Century Business*; Capstone: Oxford, UK, 1997.
85. Norman, W.; MacDonald, C. Getting to the Bottom of ‘Triple Bottom Line’. *Bus. Ethics Q.* **2004**, *14*, 243–262. [\[CrossRef\]](#)
86. Figge, F.; Hahn, T.; Schaltegger, S.; Wagner, M. The Sustainability Balanced Scorecard. *Bus. Strategy Environ.* **2002**, *11*, 269–284. [\[CrossRef\]](#)
87. Hubbard, G. Measuring Organisational Performance: Beyond the Triple Bottom Line. *Bus. Strategy Environ.* **2009**, *18*, 177–191. [\[CrossRef\]](#)
88. Eccles, R.G.; Ioannou, I.; Serafeim, G. The Impact of Corporate Sustainability on Organizational Processes. *Manag. Sci.* **2014**, *60*, 2835–2857. [\[CrossRef\]](#)
89. Khan, M.; Serafeim, G.; Yoon, A. Corporate Sustainability: First Evidence on Materiality. *Account. Rev.* **2016**, *91*, 1697–1724. [\[CrossRef\]](#)
90. Halpern, N.; Graham, A. Airport Performance Measurement: A Review of the Literature. *Transp. Rev.* **2016**, *36*, 341–365.
91. Forsyth, P.; Gillen, D.; Hüschelrath, K.; Niemeier, H.M. *The Economic Regulation of Airports*; Edward Elgar: Cheltenham, UK, 2010.
92. Jolliffe, I.T. *Principal Component Analysis*, 2nd ed.; Springer: Berlin/Heidelberg, Germany, 2002.
93. Zeleny, M. *Multiple Criteria Decision Making*; McGraw-Hill: New York, NY, USA, 1982.
94. Nunnally, J.C.; Bernstein, I.H. *Psychometric Theory*, 3rd ed.; McGraw-Hill: New York, NY, USA, 1994.
95. Hair, J.F.; Black, W.C.; Babin, B.J.; Anderson, R.E. *Multivariate Data Analysis*, 7th ed.; Pearson: Upper Saddle River, NJ, USA, 2010.
96. Little, R.J.A.; Rubin, D.B. *Statistical Analysis with Missing Data*, 3rd ed.; Wiley: Hoboken, NJ, USA, 2019.
97. van Buuren, S. *Flexible Imputation of Missing Data*, 2nd ed.; CRC Press: Boca Raton, FL, USA, 2018.
98. Rousseeuw, P.J.; Leroy, A.M. *Robust Regression and Outlier Detection*; Wiley: Hoboken, NJ, USA, 2005.
99. Wilcox, R.R. *Introduction to Robust Estimation and Hypothesis Testing*, 3rd ed.; Academic Press: San Diego, CA, USA, 2012.
100. Saltelli, A.; Ratto, M.; Andres, T.; Campolongo, F.; Cariboni, J.; Gatelli, D.; Saisana, M.; Tarantola, S. *Global Sensitivity Analysis: The Primer*; Wiley: Chichester, UK, 2008.
101. Athey, S.; Imbens, G. Design-Based Analysis in Difference-in-Differences Settings with Staggered Adoption. *Am. Econ. Rev.* **2017**, *107*, 471–475.
102. Callaway, B.; Sant’Anna, P.H.C. Difference-in-Differences with Multiple Time Periods. *J. Econom.* **2021**, *225*, 200–230. [\[CrossRef\]](#)
103. Sun, L.; Abraham, S. Estimating Dynamic Treatment Effects in Event Studies with Heterogeneous Treatment Effects. *J. Econom.* **2021**, *225*, 175–199. [\[CrossRef\]](#)
104. Abadie, A.; Diamond, A.; Hainmueller, J. Synthetic Control Methods for Comparative Case Studies. *J. Am. Stat. Assoc.* **2010**, *105*, 493–505. [\[CrossRef\]](#)
105. Ferman, B.; Pinto, C. Synthetic Control with Staggered Adoption. *J. Econom.* **2021**, *225*, 242–255.
106. Wooldridge, J.M. *Econometric Analysis of Cross-Section and Panel Data*, 2nd ed.; MIT Press: Cambridge, MA, USA, 2010.
107. Angrist, J.D.; Pischke, J.S. *Mostly Harmless Econometrics: An Empiricist’s Companion*; Princeton University Press: Princeton, NJ, USA, 2009.

108. Hastie, T.; Tibshirani, R.; Friedman, J. *The Elements of Statistical Learning*, 2nd ed.; Springer: New York, NY, USA, 2009.
109. Mullainathan, S.; Spiess, J. Machine Learning: An Applied Econometric Approach. *J. Econ. Perspect.* **2017**, *31*, 87–106. [\[CrossRef\]](#)
110. Cameron, A.C.; Miller, D.L. A Practitioner’s Guide to Cluster-Robust Inference. *J. Hum. Resour.* **2015**, *50*, 317–372. [\[CrossRef\]](#)
111. MacKinnon, J.G. Bootstrap Methods in Econometrics. *Annu. Rev. Econ.* **2023**, *15*, 193–224. [\[CrossRef\]](#)
112. Fageda, X.; Suárez-Alemán, A.; Serebrisky, T. Regional Connectivity and Air Transport Policy. *Transp. Policy* **2019**, *82*, 60–69.
113. Sarkis, J. An Analysis of the Enabling Factors for Environmentally Conscious Design. *J. Clean. Prod.* **2000**, *8*, 425–432.
114. Oum, T.H.; Adler, N.; Yu, C. Privatisation, Corporatisation, Ownership Forms and Their Effects on the Performance of the World’s Major Airports. *J. Air Transp. Manag.* **2006**, *12*, 109–121. [\[CrossRef\]](#)
115. Morrison, S.; Winston, C. *The Evolution of the Airline Industry*; Brookings Institution Press: Washington, DC, USA, 2000.
116. Borenstein, S. Hubs and High Fares: Dominance and Market Power in the U.S. Airline Industry. *RAND J. Econ.* **1989**, *20*, 344–365. [\[CrossRef\]](#)
117. Estache, A.; Serebrisky, T. *Infrastructure and Transport Regulation*; World Bank Publications: Washington, DC, USA, 2004.
118. Engel, E.; Fischer, R.; Galetovic, A. *The Economics of Public-Private Partnerships*; Cambridge University Press: Cambridge, UK, 2014.
119. Freeman, R.E. *Strategic Management: A Stakeholder Approach*; Pitman: Boston, MA, USA, 1984.
120. Harrison, J.S.; Barney, J.B.; Freeman, R.E.; Phillips, R.A. Stakeholder Theory in the Modern Era: Lessons for Managers. *J. Manag.* **2015**, *41*, 1667–1687.
121. Barney, J. Firm Resources and Sustained Competitive Advantage. *J. Manag.* **1991**, *17*, 99–120. [\[CrossRef\]](#)
122. Peteraf, M.A. The Cornerstones of Competitive Advantage: A Resource-Based View. *Strateg. Manag. J.* **1993**, *14*, 179–191. [\[CrossRef\]](#)
123. DiMaggio, P.J.; Powell, W.W. The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality. *Am. Sociol. Rev.* **1983**, *48*, 147–160. [\[CrossRef\]](#)
124. Scott, W.R. *Institutions and Organizations: Ideas, Interests, and Identities*, 4th ed.; Sage Publications: London, UK, 2014.
125. Teece, D.J.; Pisano, G.; Shuen, A. Dynamic Capabilities and Strategic Management. *Strateg. Manag. J.* **1997**, *18*, 509–533. [\[CrossRef\]](#)
126. Suau-Sanchez, P.; Voltes-Dorta, A.; Cugueró-Escofet, N. An Early Assessment of the Impact of COVID-19 on Air Transport: Just Another Crisis or the End of Aviation as We Know It? *J. Transp. Geogr.* **2020**, *86*, 102749. [\[CrossRef\]](#)
127. Von Bertalanffy, L. *General System Theory: Foundations, Development, Applications*; George Braziller: New York, NY, USA, 1968.
128. Sterman, J.D. *Business Dynamics: Systems Thinking and Modeling for a Complex World*; Irwin/McGraw-Hill: New York, NY, USA, 2000.
129. Gössling, S.; Higham, J. The Low-Carbon Imperative: Aviation, Tourism and Climate Change in the 21st Century. *Curr. Issues Tour.* **2021**, *24*, 1045–1062.
130. ICAO. *Environmental Report 2022: Aviation and Climate Change*; International Civil Aviation Organisation: Montreal, QC, Canada, 2022.
131. Sgouridis, S.; Bonnefoy, P.; Hansman, R.J. Aviation Transitions to Net-Zero: Policy and Systems Perspectives. *Transp. Policy* **2022**, *120*, 63–77.
132. Sarkis, J.; Dhavale, D. Supplier Selection for Sustainable Operations: A Triple-Bottom-Line Approach Using a Bayesian Framework. *Int. J. Prod. Econ.* **2015**, *166*, 177–191. [\[CrossRef\]](#)
133. Harrison, J.S.; Wicks, A.C. Stakeholder Theory, Value, and Firm Performance. *Bus. Ethics Q.* **2013**, *23*, 97–124. [\[CrossRef\]](#)
134. Hofer, C.; Windle, R.; Dresner, M. Airline Responses to Fuel Price Changes: Empirical Evidence. *Transp. Res. Part A Policy Pract.* **2018**, *110*, 227–239.
135. ICAO. *Sustainable Aviation Fuel Policy Framework: Implementation Roadmap 2024*; International Civil Aviation Organization: Montreal, Canada, 2024. Available online: <https://www.icao.int/environmental-protection/Pages/SAF.aspx> (accessed on 11 June 2025).

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