Environmental reporting in airlines: An analysis of mandatory and voluntary KPIs in the EU

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ABSTRACT:

The decarbonisation of the aviation industry requires strict regulation to align with the EU Green Deal, which aims to make the EU the world's first climate-neutral region by 2050. EU regulations continuously evolve and impact the key performance indicators (KPIs) used to measure progress towards this ambitious objective. Supported by the Marie Skłodowska-Curie Actions (MSCA) programme, the AZERO project assesses airline reduction commitments to achieve net-zero carbon by 2050. It uses an interdisciplinary approach to map greenhouse gas (GHG) KPIs, evaluate actions taken, and simulate traffic scenarios to estimate feasibility using the System Dynamics method for the timeframes of 2030, 2040, and 2050. This advanced simulation method uses real airline emission data and environmental, social and governance (ESG) report commitments.

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Climate and Aviation

Global temperatures have already risen by about 1.2°C, and aviation could add another 0.05°C by 2050, a significant amount given the tight scientific limit to stay below the Paris Agreement's 1.5–2°C target. The Paris Agreement and the EU Green Deal both set ambitious goals for climate neutrality by 2050 and major emission reductions by 2030, putting strong pressure on the aviation sector to act.

While the air transport industry has pledged to align with these climate targets, researchers remain concerned about the sector's ability to deliver on net-zero promises. Ongoing issues with inconsistent reporting and non-standardized metrics, along with risks of greenwashing, continue to undermine the credibility and effectiveness of aviation's climate commitments.

Objectives

The objective is to systematically identify and categorize all mandatory and voluntary Greenhouse Gas (GHG) Key Performance Indicators (KPIs) reported by airlines. This involves mapping which GHG-related metrics are required by regulations and which are disclosed voluntarily, in order to provide a comprehensive overview of how the aviation sector measures and reports its climate impact.

Identify and assess both mandatory and voluntary GHG-related KPIs disclosed by major European airline groups, highlighting inconsistencies, gaps, and drivers of KPI selection in the context of evolving regulatory frameworks.

Literature Review I

Lack of Standardisation and Comparability in Airline Sustainability Reporting

The literature consistently identifies the lack of harmonization and standardization in how airlines define, measure, and report environmental sustainability metrics—especially greenhouse gas (GHG) emissions—as a major challenge. This issue, recognized for over two decades, leads to inconsistent and non-comparable reporting, which undermines transparency, regulatory oversight, and stakeholder trust. Airlines often select their own definitions, assessment methods, and KPIs, resulting in highly variable disclosures that complicate efforts to benchmark progress and ensure regulatory compliance.

Risks of Greenwashing and Greenhushing in Airline Environmental Communication

The review highlights two significant risks in the communication of airline sustainability practices:

Greenwashing: Airlines may overstate or misrepresent their environmental achievements, selectively reporting favorable data or using ambiguous claims to enhance their public image without demonstrating real progress in emissions reduction. This can mislead stakeholders and slow broader climate action.

Greenhushing: Conversely, some airlines may deliberately under-communicate or omit genuine sustainability achievements to avoid scrutiny or accusations of hypocrisy. Both practices threaten the credibility and effectiveness of sustainability reporting, making it increasingly difficult for stakeholders to assess true environmental performance.

Methodological and Practical Challenges in KPI Extraction and Reporting

The literature notes that extracting and analyzing environmental KPIs from airline sustainability reports is complicated by several factors:

- Reports are often lengthy, unstructured, and vary widely in format (PDF, HTML, iXBRL), making manual extraction labor-intensive, inconsistent, and prone to error.
- The growing complexity and volume of required disclosures, driven by evolving regulations, further challenge manual and even semi-automated approaches.
- Recent advances in Natural Language Processing (NLP) and Large Language Models (LLMs) offer potential for automating KPI extraction, but their effectiveness is highly dependent on prompt specificity and data source format. Standardization of data and clear, guided extraction strategies are essential for reliable, scalable KPI reporting and analysis.

Literature Review II

The mandatory KPIs defined by regulatory schemes: Non-Financial Reporting Directive (ESG Reporting), the EU emission trading system (ETS), Carbon Offset and Reduction Scheme for International Aviation (CORSIA), and ReFuelEU. These four schemes, together with emission intensity, KPI widely used in the industry, are introduced below in detail.

Environmental, Social, and Governance (ESG)

ESG frameworks have become integral to how airlines are evaluated by investors and regulators, with ratings influencing access to capital and shaping corporate strategies. The EU has established a comprehensive regulatory framework (Regulation 2024/3005) for ESG rating activities, mandating transparency, requiring separate ratings for E, S, and G, and providing oversight by the European Securities and Markets Authority (ESMA) to enhance integrity and prevent greenwashing.

Environmental, Social, and Governance (ESG) reports serve as a primary and increasingly standardized data source for tracking airlines' environmental performance. For publicly traded European airlines, ESG and sustainability disclosures are mandated by regulations such as the Non-Financial Reporting Directive (NFRD) and the Corporate Sustainability Reporting Directive (CSRD), ensuring that key environmental metrics—particularly greenhouse gas (GHG) emissions—are reported consistently and transparently. These reports provide the foundational data for monitoring compliance with climate goals, benchmarking progress across airlines, and informing both regulatory oversight and investor decision-making.

EU Emissions Trading System (EU-ETS)

The EU-ETS is a mandatory cap-and-trade mechanism for aviation emissions, covering flights within the European Economic Area since 2012. The cap on emissions is being progressively reduced, with the annual reduction factor rising to 4.3% (2024–2027) and 4.4% (from 2028), with the goal of achieving a 62% reduction by 2030 compared to 2005 levels. Free allowances for airlines are being phased out, with all allowances set to be auctioned by 2026.

The EU-ETS now reserves 20 million allowances to support Sustainable Aviation Fuel (SAF) adoption and will require airlines to monitor and report non-CO_2 emissions (CO_2-equivalents) per flight starting in 2025, reflecting a broader approach to aviation's climate impact.

Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

CORSIA, established by ICAO, requires airlines to offset emissions growth above 85% of 2019 levels on international routes. The scheme is being implemented in phases: a pilot phase (2021–2023) and a first phase (2024–2026), both voluntary, followed by a mandatory phase for most ICAO member states from 2027. Airlines must acquire carbon credits to offset emissions, with the amount determined by ICAO's sectoral growth factors and individual operator emissions.

Airlines report emissions on a route basis to national authorities, with ICAO aggregating data and calculating offset requirements. The scheme's effectiveness depends on the quality and credibility of carbon offsets, and there is ongoing debate over the environmental integrity and sufficiency of offsetting as a primary mitigation tool.

RefuelEU

ReFuelEU requires a minimum share of SAF in aviation fuel supplied at EU airports—starting at 2% in 2025 and rising to 70% by 2050, with a separate sub-target for synthetic (e-fuel) blends. This regulation aims to accelerate the decarbonization of aviation fuel supply chains and is a key part of the EU's Fit for 55 package to reduce greenhouse gas emissions.

The regulation also includes the rollout of a Flight Emissions Label (FEL) by July 2025, providing passengers with standardized, comparable information on greenhouse gas emissions for each flight. This aims to increase transparency and support more informed, sustainable consumer choices.

Carbon Intensity (CO2 per Revenue Passenger Kilometer)

This metric is typically calculated by dividing the total CO_2 emissions of a flight (derived from fuel consumption and an emission factor) by the number of passengers onboard, and often further normalized

per passenger-kilometre to allow comparisons across routes and airlines. Key factors influencing this value include the passenger load factor (the percentage of occupied seats), flight distance, and cabin class, as premium seats occupy more space and weight, resulting in higher per-passenger emissions.

Industry-standard calculators, such as IATA's Passenger CO_2 Emission Calculator, use actual airline data, aircraft type, and cabin class weighting to provide more accurate and route-specific emissions estimates. Airlines may highlight improvements in emissions intensity (e.g., lower CO_2 per passenger-kilometre) due to higher load factors or more efficient aircraft, even as their total emissions rise with increased traffic. This can create a disconnect between reported performance and actual climate outcomes, as reductions in intensity do not necessarily equate to overall emissions reductions. Such selective reporting can contribute to greenwashing, where airlines frame their environmental performance favorably without fully addressing the sector's growing absolute emissions.

Methodology

Documentary Analysis of Regulatory Frameworks

The researchers conducted a comprehensive documentary analysis to identify all relevant regulations and reporting requirements affecting European airlines (ESG Reporting, EU-ETS, CORSIA, ReFuelEU). This established the set of mandatory environmental KPIs and their definitions.

Identification of the 16 European Airline Groups

Researchers systematically identified the 16 major European airline groups by screening all IATA member airlines in Europe, verifying corporate structures via investor relations pages and the Pitchbook database, and excluding cargo-only operators. They also cross-checked the top 40 airlines by flight volume (Eurocontrol data) to ensure all major passenger carriers, including non-IATA members, were included.

Manual Expert Extraction and Classification of Environmental KPIs

Two sustainability experts systematically reviewed the emissions sections of annual and sustainability reports from 16 major European airline groups. They independently extracted the full metric name, unit, and value for each emission-related KPI, then resolved any discrepancies through joint review to ensure data accuracy. After extraction, each KPI was classified as either mandatory or non-mandatory according to relevant regulatory definitions. The validated and categorized KPIs were then compiled into a standardized table for comprehensive comparison and analysis across airlines.

Automated Extraction Using Large Language Models (LLMs)

The study automated the extraction of airline environmental KPIs from ESG reports by employing three advanced Large Language Models (LLMs)—GPT-4.0, o3-mini, and Deepseek R1—using the Perplexity platform1. Two extraction strategies were tested: unguided extraction, where the LLMs were simply prompted to extract all environmental KPIs from the uploaded reports without further direction, and guided extraction, where the models were provided with explicit KPI terms or a master list to target specific data points1. The outputs from both approaches were systematically compared to manual expert extraction, with particular attention paid to how prompt specificity and the format of the source document (PDF versus HTML) affected the accuracy and consistency of KPI extraction.

Results

LLMs can streamline ESG data collection with proper guidance
When prompt engineering and data standardization are prioritized, LLMs can substantially automate and improve the efficiency of extracting environmental KPIs from complex, unstructured sustainability reports. This points to the potential for integrating LLMs into ESG analysis workflows, though challenges remain for unstructured or poorly formatted data.

LLM accuracy depends on prompt specificity and data sorce
The study found that the accuracy of Large Language Model (LLM) extraction of airline emission KPIs from sustainability reports is highly dependent on how specific and guided the prompts are. Unguided extraction attempts (where LLMs were simply told to extract all environmental KPIs) yielded low accuracy (below 30%), while providing explicit KPI terms in prompts increased extraction accuracy to above 70% for models like GPT-4.0.

Extraction performance was significantly better when reports were in HTML format compared to PDF. For example, extraction from Icelandair's HTML report achieved much higher accuracy than from its PDF version, demonstrating that structured, machine-readable formats facilitate more reliable automated extraction.

Progress in reporting core KPIs, but not others

Most European airline groups now routinely disclose core mandatory KPIs such as Total CO_2 (Scope 1) emissions and Emissions Intensity, reflecting growing regulatory alignment. However, reporting rates for other mandatory KPIs—like Scope 2 and 3 GHG emissions, energy consumption, GHG removals, and metrics related to Sustainable Aviation Fuel (SAF) and non-CO_2 effects—remain low, indicating significant gaps and inconsistencies.

Lack of standardization and comparability
The analysis revealed ongoing inconsistencies in how airlines define, measure, and report both mandatory and voluntary KPIs. This lack of harmonization undermines transparency and comparability, making it difficult for stakeholders to benchmark performance or assess genuine progress toward climate goals.

Risks of greenwashing and greenhushing

The study highlighted that airlines may selectively report favorable data (greenwashing) or under-communicate substantive achievements (greenhushing), both of which threaten the credibility and effectiveness of sustainability reporting in the sector.

Conclusions

Advanced LLMs such as GPT-4.0, o3-mini, and Deepseek R1 can significantly streamline the extraction of environmental KPIs from airline sustainability reports, especially when guided by explicit prompts and used with structured data formats. However, unguided extraction from unstructured documents yields poor results, highlighting the need for prompt engineering and data standardization to maximize the effectiveness and reliability of automated ESG data extraction.

Despite regulatory progress, European airlines show significant variability and inconsistency in reporting key environmental KPIs. While most airlines disclose core metrics like total CO_2 emissions and emissions intensity, reporting on other mandatory indicators (e.g., Scope 2 and 3 emissions, energy consumption, SAF, and non-CO_2 effects) remains limited and uneven. The lack of standardization in definitions and reporting structures undermines transparency, comparability, and stakeholder trust.

Airlines face ongoing risks of greenwashing—where favorable data is selectively reported or exaggerated—and greenhushing, where genuine achievements are under-communicated to avoid scrutiny. These practices threaten the credibility and effectiveness of sustainability disclosures, making it difficult for stakeholders to assess real progress toward climate goals.

Certificate of Attendance

Figure 2: Certificate of Attendance to the Transport Research Symposium (TRS) 25-28 May 2025, Rotterdam, The Netherlands.

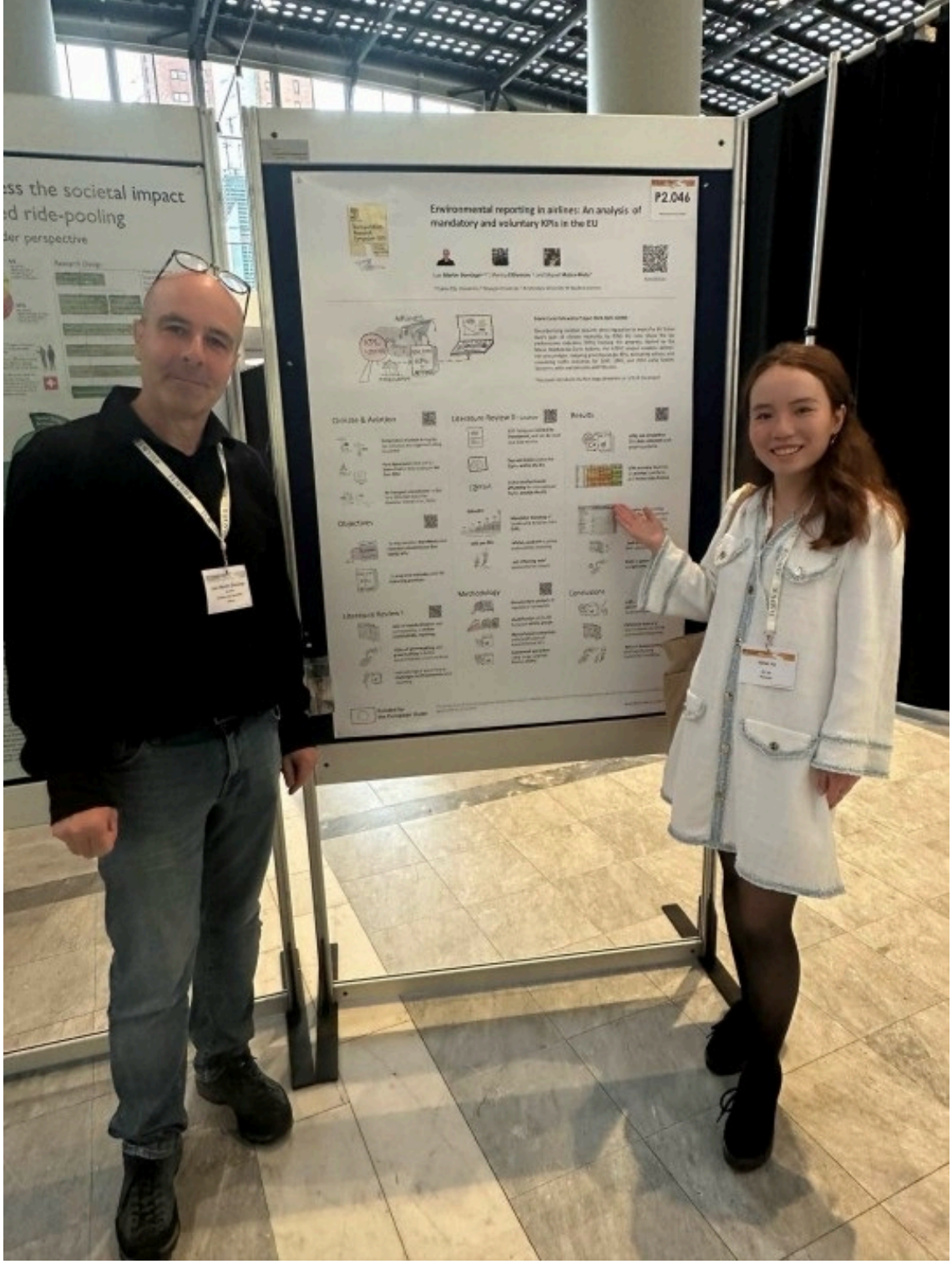

Figure 3: MSCA Postdoc Fellow Luis MARTIN-DOMIGO introducing the poster to PhD candidate Jia XIBEI at TRS Rotterdam 27 May 2023.