

TRPRO\_14th International Conference on Air Transport – INAIR 2025: Fly High, Learn Far  
**Aviation Decarbonisation: A Bibliometric Analysis of Productivity,  
Research Trends, and Gaps**

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**Abstract**

Decarbonising aviation is a growing priority in global climate mitigation, yet research in this domain remains fragmented across disciplines and themes. This study offers the first comprehensive bibliometric analysis of aviation decarbonisation research over the past 25 years, using the Bibliometrix R-package and Scopus data. Beyond mapping publication trends, authorship networks, geographical distribution, and keyword evolution, the study reveals how the field has shifted from emissions quantification and biofuels to system-level innovations such as sustainable aviation fuels (SAFs), hydrogen, and electric propulsion. Our analysis uncovers three dominant intellectual clusters—technological innovation, policy and market instruments, and operational strategies—while highlighting persistent blind spots, including demand-side measures, behavioural change, and equity considerations. A key contribution of this research lies in exposing the technology-centric and Global North–dominated orientation of the field, thereby identifying overlooked perspectives crucial for achieving a just transition. By providing a structured overview of knowledge trajectories and emergent themes, this study establishes a research agenda that integrates technical, policy, and societal dimensions, supporting more coherent and interdisciplinary approaches to aviation decarbonisation.

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**1. Introduction**

The aviation sector stands as both a critical enabler of global economic development and a significant contributor to anthropogenic climate change (Martin-Domingo et al., 2025). In 2019, commercial aviation was responsible for approximately 915 million tonnes of carbon dioxide (CO<sub>2</sub>), representing 2–3% of total global emissions and a

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substantially higher share of emissions from the transport sector. However, aviation's overall climate impact is considerably more severe due to non-CO<sub>2</sub> effects, including nitrogen oxides (NO<sub>x</sub>), water vapour, and contrail formation at high altitudes, which collectively double or triple its radiative forcing compared to CO<sub>2</sub> alone (Lee et al., 2021).

Amid growing urgency to limit global temperature rise to well below 2°C as stipulated in the Paris Agreement, attention has increasingly turned to the decarbonisation of aviation. Achieving net-zero emissions by mid-century is especially challenging for aviation due to several structural constraints: the long lifecycle of aircraft fleets, the slow pace of technological turnover, and the high energy density requirements that render batteries and hydrogen less viable in the short to medium term for long-haul flights. Consequently, the pathway to net-zero aviation is expected to rely on a multifaceted strategy, encompassing the deployment of sustainable aviation fuels (SAFs), improvements in operational efficiency, market-based measures such as emissions trading schemes, and potentially disruptive innovations in aircraft propulsion technologies.

Despite the proliferation of research on aviation and climate change, the academic landscape remains fragmented across multiple disciplines, including aerospace engineering, environmental science, policy studies, and energy economics. While isolated reviews have examined decarbonisation pathways—such as SAF production technologies or carbon offsetting mechanisms—there remains a paucity of integrative analyses that map the evolution of academic discourse on aviation decarbonisation over time. Furthermore, the recent acceleration in climate-related policy initiatives by international bodies (e.g., EU Emissions Trading Scheme, International Civil Aviation Organisation Carbon Offsetting Scheme for International Aviation) has generated a surge in publications, highlighting the need for a systematic synthesis of existing knowledge.

This study aims to address this gap by conducting a comprehensive bibliometric analysis of the global research landscape on aviation decarbonisation. By systematically examining patterns in scholarly publications, collaboration networks, keyword trends, and citation dynamics, the study seeks to identify intellectual turning points, dominant thematic clusters, and emerging areas of inquiry. In doing so, it provides researchers, policymakers, and industry stakeholders with a structured overview of current knowledge trajectories and potential research frontiers in the field of aviation climate mitigation.

## 2. Literature Review

The imperative to mitigate aviation's contribution to anthropogenic climate change has catalysed a multidisciplinary research agenda spanning engineering, environmental science, policy, and economics. The sector's unique operational profile—marked by high-altitude emissions, long investment cycles, and dependence on liquid hydrocarbon fuels—renders it particularly resistant to conventional decarbonisation strategies. Despite its relatively modest share of global CO<sub>2</sub> emissions, aviation's non-CO<sub>2</sub> effects—particularly contrails and nitrogen oxide (NO<sub>x</sub>) emissions at high altitudes—exacerbate its radiative forcing, amplifying its climate impact well beyond carbon dioxide alone (Lee et al., 2021). In this context, academic research has focused on a variety of decarbonisation levers, encompassing both supply-side and demand-side strategies. As such, the academic discourse on aviation climate mitigation has evolved through several interlinked research streams.

### 2.1. Technological Advancements in Aircraft Design and Propulsion

A substantial body of research has explored technological improvements in aircraft design and propulsion systems as pathways to reduce fuel burn and emissions (Farokhi, 2021). Aerodynamic innovations, such as laminar flow control and blended wing body configurations offer efficiency gains, but face manufacturing and certification constraints (Schäfer et al., 2019). Lightweight composite materials, notably carbon-fiber-reinforced polymers, also improve energy efficiency (Kundu, 2010), though most advances remain incremental and constrained by safety regulation. Propulsion research highlights geared turbofans and open-rotor designs, with hybrid-electric and all-electric systems under development for regional use (Aguida et al., 2024; Sziroczak et al., 2020). Hydrogen aircraft could achieve near-zero emissions, but challenges in storage, energy density, and infrastructure make large-scale deployment unlikely before 2040. While essential long-term, these technologies are costly, infrastructure-intensive, and rarely assessed through full lifecycle analyses, which may overstate their climate benefits.

## 2.2. Operational and Infrastructure Improvements

Operational efficiencies have been widely examined for their potential to deliver short-term emissions reductions. Enhanced air traffic management (ATM), including continuous descent operations (CDO), performance-based navigation (PBN), and collaborative decision-making (CDM), can reduce fuel burn by 5–10% under optimal conditions (Efthymiou and Papatheodorou, 2018). Airport-level actions such as optimized taxiway routing, gate assignment algorithms, and single-engine taxiing have been shown to marginally improve fuel efficiency (Avogadro and Redondi, 2024; Mankowska et al., 2023). However, these “low-hanging fruit,” are constrained by airspace sovereignty, fragmented regulation, and limited digital infrastructure (Efthymiou and Papatheodorou, 2019). Their cumulative effect is insufficient to offset projected traffic growth, and thus they serve more as stabilizing measures than transformative ones. Infrastructure investments, such as runway redesign or the development of hydrogen refuelling facilities, remain largely conceptual and rarely assessed empirically, with debates often centred on technical feasibility rather than funding, governance, or equity.

## 2.3. Sustainable Aviation Fuels (SAFs)

Among the most intensively studied mitigation options, SAFs have received considerable attention for their potential to enable near-term decarbonisation within existing aircraft fleets (Efthymiou and Ryley, 2022). Multiple studies have demonstrated that SAFs can deliver lifecycle emissions reductions of 50–80%, depending on feedstock, conversion pathway, and energy source inputs. Regulatory frameworks such as ASTM D7566 have approved several pathways—including HEFA, FT-SPK, and ATJ—allowing drop-in blending with conventional jet fuel. However, the literature is increasingly critical of the scalability of SAFs. Studies highlight significant feedstock constraints, competition with food production, and indirect land use change (ILUC) risks associated with first-generation biofuels (Breen et al., 2025). Techno-economic analyses consistently point to production costs at least double those of fossil kerosene, rendering SAFs economically uncompetitive without policy support (Kumar et al., 2025). Additionally, infrastructure for large-scale SAF logistics and blending is underdeveloped, and harmonized global standards remain nascent. Despite their theoretical appeal, the SAF literature often suffers from techno-optimism, underestimating market inertia, regulatory gaps, and political resistance. There is also a dearth of studies addressing regional disparities in SAF availability and production capacity, particularly in the Global South.

## 2.4. Policy Instruments and Market-Based Measures

Policy design and regulatory frameworks have emerged as a critical area of scholarly focus, especially in evaluating the effectiveness and legitimacy of multilateral mechanisms such as CORSIA and the EU Emissions Trading Scheme (EU ETS). While CORSIA was intended to provide a global baseline for carbon-neutral growth post-2020, multiple studies have critiqued its reliance on low-quality offsets, lack of enforcement mechanisms, and voluntary nature (Mai, 2021; Zhang et al., 2021). Market-based measures (MBMs), including carbon pricing, fuel taxes, and SAF blending mandates, have been explored through various modelling approaches. Moreover, regional disparities in policy ambition—most notably between the EU and other ICAO members—undermine global coherence (Dominioni and Efthymiou, 2024; Efthymiou and Papatheodorou, 2019). The policy literature, while rich in normative prescriptions, often lacks empirical validation through real-world case studies. Furthermore, the role of path dependency, lobbying by industry actors, and institutional inertia are under-theorized, limiting the field’s explanatory power regarding policy adoption and effectiveness.

## 2.5. Demand Management and Societal Perspectives

Demand-side strategies represent a relatively underdeveloped but increasingly important area of research. Studies have examined behavioural change mechanisms, such as flight shame (flygskam), voluntary carbon offsets, and modal shifts to rail, particularly in the European context (Doran et al., 2022; De Mello, 2024; Morgan et al., 2025). Scenario-based modelling suggests that significant emissions reductions are possible through reduced business travel and increased virtual communication (Borggren et al., 2013). Nevertheless, these strategies face cultural, economic, and

political barriers. The literature acknowledges the resistance of high-frequency flyers to behavioural interventions and the absence of policies that explicitly seek to constrain demand. Governments are often reluctant to regulate leisure or business air travel, particularly in the context of economic recovery post-COVID-19, a period during which airlines were heavily subsidized (Martín-Domingo & Martín, 2022). This reluctance limits the practical applicability of demand-side measures at scale. Critically, while demand reduction could offer high-leverage climate benefits, it remains marginalized in most national and international aviation strategies—a gap that reflects deeper political-economic dynamics which deserve greater scholarly attention.

### 2.6. Research Gaps and the Need for Synthesis

Despite the breadth of existing research, significant gaps persist in integrating these various decarbonisation pathways into a coherent and actionable framework. Much of the literature remains siloed by discipline—engineering, economics, policy studies—with limited interdisciplinary synthesis. Few studies incorporate systems thinking to assess interactions, trade-offs, or cumulative impacts across technological, operational, and behavioural domains. Moreover, there is limited attention to geographic disparities in research focus and capacity. Most empirical and theoretical studies are concentrated in Europe and North America, with underrepresentation of perspectives from low- and middle-income countries, despite their growing share in future air traffic. Bibliometric analysis offers a valuable methodological approach to addressing these gaps (Donthu et al., 2021). By systematically mapping the intellectual structure, thematic clusters, and citation dynamics of the field, this study seeks to provide an integrative overview of aviation decarbonisation research, identify intellectual turning points, and highlight emergent areas requiring further inquiry.

## 3. Methodology

This study employs a bibliometric approach to systematically examine the intellectual structure and thematic evolution of research related to aviation emissions, climate change, and decarbonisation strategies. Bibliometric analysis provides a replicable and quantitative means to evaluate scientific output, knowledge networks, and conceptual development across disciplines (Ellegaard and Wallin, 2015). The methodology encompasses four main phases: data retrieval, preprocessing, analysis, and visualization (Donthu et al., 2021).

The dataset was derived from the Scopus database, selected for its comprehensive coverage of peer-reviewed scientific publications across engineering, environmental science, economics, and policy domains. Its integration with the Bibliometrix R-package also ensures reproducibility and compatibility of analyses. While combining Scopus with the Web of Science (WoS) could in principle enhance completeness, such integration risks duplicate records and inconsistent metadata, potentially affecting quality. Moreover, WoS's more selective journal coverage may omit relevant applied research. Although reliance on Scopus may introduce a bias towards English-language and Global North outputs, its breadth and practical advantages make it sufficient for the study's objectives. The database was queried in August 2025 using a targeted Boolean search strategy to ensure relevance and coverage of multiple decarbonisation pathways.

Using similar approach as Martín-Domingo et al. (2024), the search command Boolean string was: TITLE ("aviation" OR "airline" OR "airport" OR "air traffic control" OR "aeronautics") AND TITLE-ABS-KEY("climate change mitigation" OR "carbon reduction" OR "decarbonization" OR "emissions reduction" OR "sustainable aviation fuel" OR "SAF" OR "biofuel" OR "market-based measures" OR "carbon offset" OR "emissions trading" OR "carbon pricing" OR "air traffic efficiency" OR "hydrogen aircraft" OR "electric aircraft") AND PUBYEAR > 1999 AND PUBYEAR < 2026

The query was restricted to journal articles and reviews written in English and spanned the period from 1999 to 2025 to capture both the historical progression and recent acceleration in aviation decarbonisation research. Excluded from the dataset were editorials, conference proceedings, and non-peer-reviewed materials, to maintain analytical consistency and quality. The initial search returned 2,943 documents. Following a screening to remove irrelevant, incomplete or duplicate records, the final dataset comprised 1,843 publications. These records were exported in CSV format with full bibliographic metadata, including titles, abstracts, authors, institutional affiliations, keywords, publication year, citation counts, and reference lists.

Two principal software tools were utilized to conduct the bibliometric analysis: Bibliometrix and VOSviewer. The Bibliometrix R package provided a robust statistical and graphical environment for evaluating scientific productivity, author and institution performance, citation dynamics, and collaboration networks (Aria and Cuccurullo, 2017; Rodriguez-Soler et al., 2020). Using its biblioshiny() graphical interface, the dataset was subjected to descriptive and network analyses, including annual publication trends, most prolific and most cited authors, institutional contributions, and country-level collaboration patterns. In addition, the conceptual structure of the field was explored through keyword co-occurrence analysis, thematic mapping, and trend topic identification.

VOSviewer (version 1.6.x) was employed to construct and visualize bibliometric networks. This included keyword co-occurrence maps to identify thematic clusters, author co-authorship networks to reveal collaborative structures, and reference co-citation analyses to trace intellectual lineage and foundational works. VOSviewer's layout and clustering algorithms, based on association strength, were used to spatially organize nodes and detect thematic communities within the literature. Threshold values were applied to exclude infrequent terms and enhance interpretability of the resulting visualizations.

To ensure the reliability of the dataset and the robustness of the analysis, multiple validation steps were undertaken. First, the search strategy was iteratively refined using a combination of relevant keywords, Boolean operators, and domain-specific filters to minimize both false positives and omissions. Second, the dataset was manually screened for relevance by reviewing titles and abstracts of a random sample of 30 articles to ensure thematic alignment with aviation decarbonisation. Third, key bibliometric indicators (e.g., annual publication trends, top-cited documents) were cross-verified with results obtained from VOSviewer to confirm consistency. Finally, sensitivity checks were performed by adjusting the keyword set and time windows to assess the stability of thematic clusters.

The analytical focus of the study was structured around three dimensions: descriptive analysis of publication trends and academic output; social structure analysis of collaborations among authors, institutions, and countries; and conceptual structure analysis of thematic evolution and research frontiers. To ensure the robustness of the thematic classifications, co-occurrence clusters were interpreted in conjunction with manual review of representative articles within each group. Together, these methodological steps enabled a comprehensive and empirically grounded overview of the scholarly landscape on aviation decarbonisation, offering insights into how the field has evolved, where research is concentrated, and which areas warrant further investigation.

#### 4. Results

The present bibliometric analysis offers a structured overview of the scholarly discourse on aviation emissions and decarbonisation, revealing both the trajectory of research outputs and the evolving thematic contours of the field. The integration of co-authorship patterns, keyword clustering, and citation networks enables a nuanced examination of intellectual development, disciplinary convergence, and emerging research frontiers.

The annual growth in publications (Fig. 1) shows a steady rise from the early 2000s, followed by a sharp acceleration after 2015. This inflection coincides with international climate policy milestones, most notably the Paris Agreement (2015), ICAO's adoption of CORSIA (2016), and the EU Green Deal (2019), which collectively elevated aviation within global climate agendas. The surge reflects both heightened awareness and the broadening of academic engagement across engineering, environmental policy, and economics. Thematic evolution supports this trend: the increasing prominence of keywords such as "sustainable aviation fuel," "carbon offset," and "emissions trading" signals a paradigm shift from narrow technological fixes to more systemic mitigation strategies. The bibliometric indicators further underline the maturity of the field, with an average of 16.09 citations per article and contributions from 5,363 authors, including 202 single-author papers. Together, these patterns suggest that aviation decarbonisation has become a recognised, multidisciplinary research domain shaped by external policy drivers and expanding scholarly networks.



The keyword word cloud (Fig. 2) provides an initial qualitative overview of dominant terms in the aviation decarbonisation literature. The size of each word indicates how often it appears in the literature: larger words occur more frequently. The prominence of “aviation fuel” and “sustainable aviation fuel” reflects the central role of fuel substitution in the research agenda, while related terms such as “biofuels,” “emission control,” and “climate change” highlight a dual emphasis on technological mitigation and environmental outcomes. Other recurrent keywords, including “air transportation” and “carbon dioxide,” show the sectoral and pollutant-specific framing through which much of the scholarship has developed. At the same time, the presence of overlapping or semantically related variants (e.g., “GHGs” vs. “greenhouse gases”) reveals terminological fragmentation, which required harmonisation in the subsequent co-occurrence analysis. Notably, the absence of terms linked to demand-side measures, equity, or the Global South points to a technology-oriented and Global North-centred research focus. As such, the word cloud not only visualises dominant themes but also highlights critical gaps in how aviation decarbonisation is conceptualised.

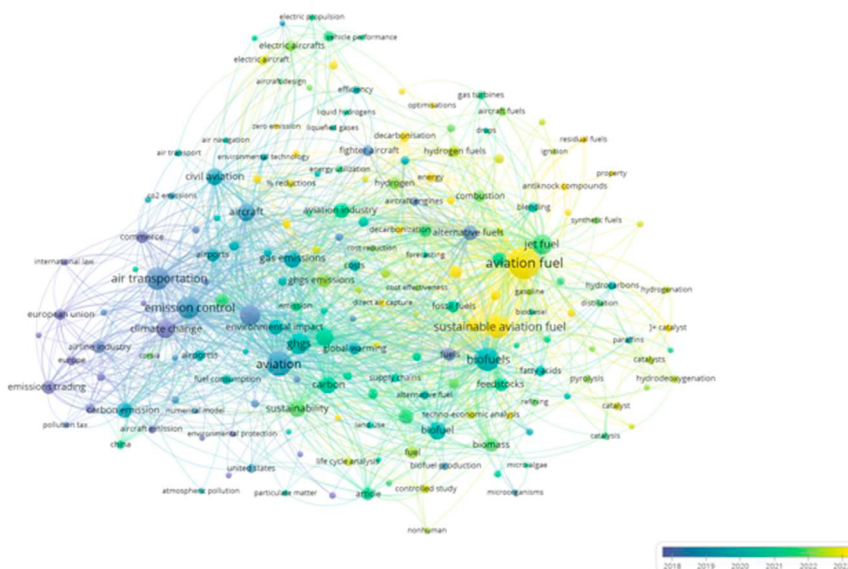


Fig. 3. Keyword Co-occurrence Network

A co-occurrence analysis (Fig. 3) was conducted using VOSviewer with fractional counting and a minimum threshold of 20 keyword occurrences illustrates how keywords appear together in publications. Of the 10,369 distinct author keywords extracted, 188 met the inclusion criterion. Larger circles represent more frequent terms, while connecting lines show their co-occurrence strength. The colour gradient reflects time, with darker tones marking older terms and lighter tones newer ones. The resulting network reveals a complex but interpretable thematic structure, organised into interconnected clusters. Core nodes such as “sustainable aviation fuel,” “life cycle assessment,” “carbon emissions,” and “hydrogen” highlight both established and emerging areas of technological development. The colour gradient reflects average publication year, illustrating a temporal shift in research priorities. Earlier clusters are dominated by foundational terms like “biofuels” and “CO2 emissions,” while newer nodes including “electric aircraft,” “green hydrogen,” and “power-to-liquid” represent the growing orientation towards long-term, disruptive decarbonisation options. The clustering pattern also exposes the fragmented nature of the field: technological themes dominate and are tightly linked, whereas connections to demand management, governance, or equity-related keywords are weak or absent. This suggests that while aviation decarbonisation research is advancing in technical sophistication, it remains insufficiently integrated with policy and societal perspectives.

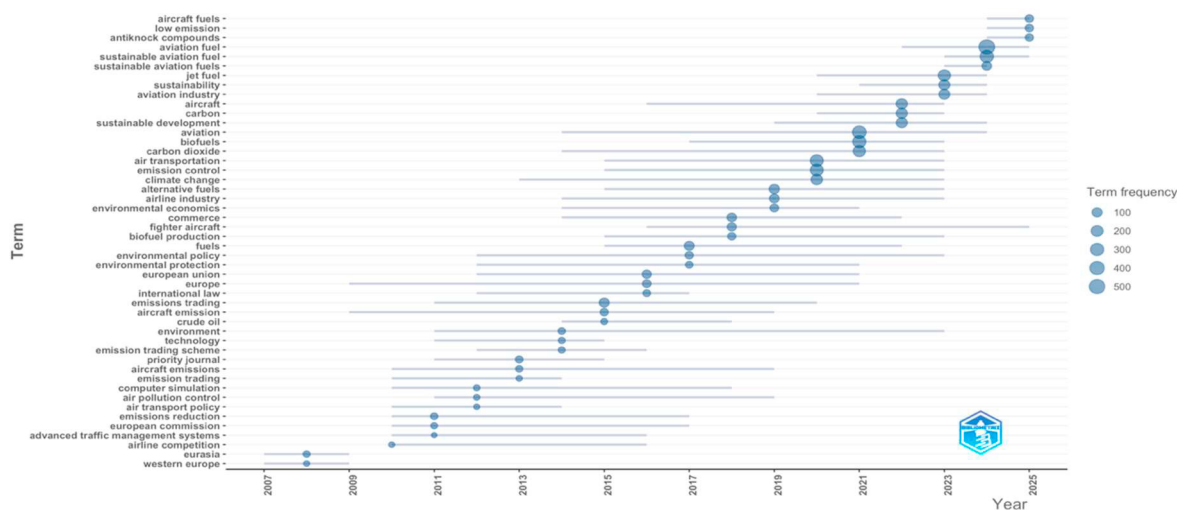


Fig. 4. Trend Topics: Thematic shifts over time

To further explore longitudinal dynamics, a trend topic analysis was conducted (Fig. 4). Each line represents the period during which a keyword was widely used, and the size of the bubble shows how frequently it appeared. The figure illustrates three distinct phases. In the early 2000s through the mid-2010s, research was dominated by broad environmental concerns and legacy technologies. Terms such as “emission,” “climate change,” “air transportation,” and “biofuels” were widely used but have since lost momentum. This reflects an initial focus on measuring impacts and trialling early mitigation approaches.

From around 2015 onward, new themes emerged that were more directly linked to policy and implementation. Keywords like “sustainable aviation fuel” and “life cycle assessment” gained traction, reflecting the alignment of research with international climate agreements and regulatory debates. The period after 2018 shows a decisive shift toward future-oriented technologies and net-zero goals. The appearance of terms such as “aviation net zero,” “electric aircraft,” “green hydrogen,” and “power-to-liquid” signals a reorientation towards long-term, scalable solutions. These bubbles are larger and more recent, indicating both growing intensity and policy relevance.

This progression reflects a broader maturation of the field, whereby early diagnostic and exploratory inquiries are giving way to targeted studies aimed at operationalizing low-carbon aviation futures. At the same time, the relatively sharp decline in the frequency of broad terms such as “emissions” and “biofuels” points to a narrowing of focus and a crystallization of research around specific mitigation strategies. The observed trend signals an increasingly policy-relevant and solution-oriented research agenda, albeit one that may risk under-examining behavioural, institutional, and demand-side dimensions.

## 5. Conclusions

Taken together, the bibliometric findings point to a research field that has expanded rapidly in scope, complexity, and interdisciplinary reach. Yet, despite this growth, the underlying epistemic structure of aviation decarbonisation research remains uneven and selectively constructed. A clear technology-centric bias permeates the literature, particularly around sustainable aviation fuels (SAFs). While this reflects their strategic relevance and immediate policy traction, it also reveals a risk of technological determinism, where the search for scalable fuel solutions overshadows broader systemic questions, such as how to reshape air transport demand or reconfigure governance regimes. The over-representation of SAF-related keywords and clusters, alongside the high PageRank of fuel- and emissions-focused nodes, signals this imbalance. By contrast, behavioural, institutional, and justice-related dimensions remain peripheral, both conceptually and methodologically.

Moreover, the geopolitical skew in publication patterns—with Anglophone and European institutions dominating high-impact outputs—suggests that the research agenda is being driven by a narrow subset of global actors. This raises

critical questions about whose knowledge counts, and whether the dominant research trajectories adequately reflect the needs and constraints of the Global South, where aviation is poised to expand most rapidly. From a methodological standpoint, the predominance of keyword co-occurrence and co-authorship mapping provides valuable insights into the field's structure but also inherits the limitations of these techniques. Citation-based indicators may reinforce established paradigms and undervalue emerging or critical voices. Similarly, clustering algorithms often obscure inter-thematic linkages, flattening nuance in complex debates.

In short, while the field has matured in terms of volume, thematic richness, and policy alignment, it still exhibits blind spots that constrain its ability to contribute meaningfully to a truly just and systemic aviation transition. Addressing these gaps will require a deliberate rebalancing of the research agenda—one that integrates demand-side strategies, institutional analysis, equity considerations, and multi-scalar systems thinking into the core of aviation decarbonisation scholarship. From a policy perspective, the analysis affirms the necessity of a differentiated strategy across temporal scales. In the near term, incentives and mandates are critical for SAF uptake. Over the medium term, operational efficiencies and carbon pricing mechanisms will be essential. Long-term strategies require significant public investment in transformative propulsion technologies, with attention to geopolitical asymmetries in resource access and technological readiness.

While this study highlights the dominance of technology-focused research, it also shows that demand-side measures, equity concerns, and Global South perspectives remain comparatively neglected. Looking ahead, future research would benefit from a more holistic systems approach, integrating techno-economic assessments with socio-political and environmental justice considerations. Comparative lifecycle analyses, stakeholder-informed policy simulations, and transdisciplinary frameworks will be instrumental in guiding effective and equitable climate mitigation in aviation. Beyond academic value, our findings provide practical guidance for stakeholders. Policymakers can use the identified gaps to rebalance funding and support research in neglected areas such as demand-side and equity-focused strategies, while industry actors can benchmark sustainability priorities against emerging research trends in SAFs, hydrogen, and electrification. By mapping collaboration and thematic clusters, this study also helps academia, industry, and regulators to identify new partnerships and align research with policy and operational needs.

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