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Sustainable Aviation Fuels: Transitioning Towards Green Aviation

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ABSTRACT

The aviation industry faces increasing pressure to decarbonise amid rising global air traffic and international climate commitments. Sustainable Aviation Fuels (SAF) have emerged as a central policy instrument in addressing aviation-related emissions, particularly under the International Civil Aviation Organization's (ICAO) net-zero 2050 target. This article presents a critical conceptual analysis of SAF as a pathway toward green aviation, using Joachim Buse's Sustainable Aviation Fuels: Transitioning Towards Green Aviation as a primary analytical reference. Employing a qualitative, literature-based methodology, the study evaluates the environmental, economic, and regulatory dimensions of SAF adoption. The analysis reveals that while SAF offers significant emission-reduction potential, its sustainability claims are constrained by high production costs, feedstock limitations, risks of market oligopolisation, and policy dependence on Western regulatory frameworks. The article further argues that the exclusive positioning of SAF as the sole solution risks oversimplifying aviation's climate challenge and marginalising alternative technological and systemic approaches. The study contributes to sustainability and aviation policy literature by situating SAF within broader debates on energy transition, market power, and environmental ethics, and by proposing a more pluralistic approach to achieving green aviation.

Introduction

The aviation sector has become an indispensable pillar of the global economy, enabling international trade, tourism, and socio-economic connectivity across regions. At the same time, it has emerged as one of the most challenging industries to decarbonise due to its heavy reliance on fossil-based jet fuel, technological constraints on alternative propulsion systems, and continuously rising passenger demand. Unlike other transport sectors where electrification has progressed rapidly, aviation remains structurally dependent on liquid hydrocarbon fuels because of their high energy density and operational reliability.

Despite sustained efforts to improve fuel efficiency through fleet modernisation, aerodynamic enhancements, and optimised air traffic management, aviation emissions have continued to grow. Between 2009 and 2019, global jet fuel consumption increased by approximately 44 per cent, reflecting the sector's expansion and the limitations of incremental mitigation measures (International Civil Aviation Organization [ICAO], 2022). These trends have raised serious concerns regarding aviation's compatibility with global climate objectives, particularly in light of post-pandemic recovery and projected long-term growth in air travel.

In response to mounting environmental pressure, Sustainable Aviation Fuels (SAF) have gained prominence within international aviation policy frameworks. SAF refers to non-fossil

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aviation fuels produced from renewable or waste-based feedstocks that can be used as drop-in replacements for conventional JET A-1 fuel. According to International Civil Aviation Organization, SAF is expected to deliver approximately 63 per cent of the emissions reductions required to achieve the aviation sector's net-zero emissions target by 2050 (ICAO, 2023). This projection has elevated SAF from a supplementary mitigation option to the central pillar of aviation decarbonisation strategies worldwide.

Within this policy context, Joachim Buse's *Sustainable Aviation Fuels: Transitioning Towards Green Aviation* positions SAF as the only realistic long-term solution capable of delivering meaningful emissions reductions without disrupting existing aviation infrastructure. Drawing on his academic background in infrastructure and resource management and professional experience within the aviation fuel supply chain, Buse presents a comprehensive account of SAF production pathways, market dynamics, regulatory mechanisms, and implementation strategies. His work reflects a broader consensus among industry stakeholders and policymakers that fuel substitution offers the most feasible pathway toward green aviation in the foreseeable future.

However, the growing policy and industry consensus surrounding SAF warrants critical examination. While SAF offers significant lifecycle greenhouse gas reductions compared to fossil-based jet fuel, it is not entirely emissions-free and does not eliminate non-CO_2 climate effects such as contrail formation and nitrogen oxide emissions, which contribute substantially to aviation-induced warming (Lee et al., 2021). Moreover, large-scale SAF deployment raises complex economic, ethical, and governance challenges related to production costs, feedstock availability, market concentration, and global equity. The reliance on regulatory mandates and subsidies further calls into question the long-term economic sustainability of SAF-based decarbonisation strategies.

This article critically examines Sustainable Aviation Fuels as a pathway toward green aviation by using Buse's work as a conceptual anchor rather than a subject of descriptive review. The study seeks to address three interrelated objectives. First, it evaluates the environmental rationale underpinning SAF adoption within aviation decarbonisation discourse. Second, it analyses the economic and market structures shaping SAF production and distribution, with particular attention to risks of oligopolisation and policy-driven demand creation. Third, it interrogates the broader sustainability and equity implications of positioning SAF as the dominant solution for aviation's climate challenge.

Methodologically, the article adopts a qualitative, conceptual research approach based on critical engagement with academic literature, policy documents, and industry reports. By situating SAF within frameworks of energy transition, political economy, and environmental ethics, the study aims to move beyond technological optimism and contribute to a more nuanced understanding of what genuinely sustainable aviation entails. In doing so, the article seeks to inform ongoing debates on how technology, policy, and governance can collectively shape a credible and inclusive pathway toward green aviation.

Literature Review

The decarbonisation of aviation has emerged as a central concern within climate policy and transport sustainability literature. Unlike road transport, where electrification has progressed rapidly, aviation remains constrained by the need for high energy-density fuels, making direct electrification or battery-powered propulsion impractical for medium- and long-haul flights (Gegg et al., 2014). As a result, fuel substitution has been identified as the most viable mitigation strategy in the near to medium term.

Sustainable Aviation Fuels (SAF) have received increasing scholarly attention due to their compatibility with existing aircraft engines and fuel infrastructure. Empirical studies suggest that SAF can achieve lifecycle greenhouse gas emission reductions ranging from 70 to 95 per cent compared to conventional jet fuel, depending on feedstock type, production pathway, and land-use practices (Staples et al., 2018; Wang et al., 2021). These findings have contributed to SAF's prominence within international policy frameworks.

However, a growing body of literature cautions against an overly optimistic portrayal of SAF. Lee et al. (2021) demonstrate that non-CO_2 effects—such as contrail-induced cirrus cloud formation—may contribute more to aviation-induced warming than carbon dioxide emissions alone. Since SAF primarily addresses lifecycle CO_2 emissions, its ability to mitigate overall climate impact remains partial.

From an economic perspective, scholars highlight the oligopolistic structure of global jet fuel markets, where pricing is influenced by geopolitical instability, refinery margins, and speculative trading rather than aviation-specific demand (IATA, 2022). SAF is often presented as a mechanism to diversify supply chains and stabilise prices through alternative production models. However, critics argue that the high capital requirements for SAF production favour established energy corporations, potentially replicating existing market concentration patterns (Gegg et al., 2014).

Ethical and sustainability-focused studies further problematise SAF's reliance on biomass feedstocks. Searchinger et al. (2018) caution that large-scale biofuel production may exacerbate land-use change, biodiversity loss, and food security challenges, particularly in developing economies. Additionally, concerns regarding weak certification regimes and greenwashing practices have been raised, questioning whether all SAF pathways genuinely deliver net environmental benefits (Newell et al., 2021).

While Joachim Buse's work synthesises many of these strands, the literature indicates a gap in critically integrating environmental performance, political economy, and global equity considerations—an analytical space this article seeks to address.

Conceptual and Theoretical Framework

This study is grounded in energy transition theory, which conceptualises shifts from fossil-based energy systems to low-carbon alternatives as complex socio-technical transformations rather than purely technological substitutions. Energy transitions are shaped by institutional arrangements, market structures, regulatory frameworks, and power relations (Geels, 2011). From this perspective, SAF represents a transition strategy that preserves existing aviation infrastructures while reducing emissions intensity.

Complementing this is the political economy of sustainability, which examines how economic power, capital concentration, and regulatory incentives influence the adoption of green technologies. SAF production is capital-intensive, technologically complex, and highly regulated, raising questions regarding who controls production, who benefits economically, and who bears environmental and social costs. This framework is particularly relevant in assessing claims that SAF will democratise fuel markets.

The analysis also draws on environmental ethics and greenwashing theory, which interrogate the moral legitimacy of sustainability claims. Greenwashing literature warns that environmental narratives may be deployed to legitimise continued high-emission activities without addressing underlying structural drivers (Delmas & Burbano, 2011). Applying this lens enables a critical assessment of whether SAF constitutes a genuinely transformative solution or a means of sustaining carbon-intensive mobility under a green label.

Together, these frameworks provide an integrated analytical lens through which SAF is evaluated not only as a technological innovation but also as a political, economic, and ethical project.

Analysis: Sustainable Aviation Fuels and Green Aviation

Environmental Performance and Climate Impact

Buse (2023) identifies fossil fuel combustion as the primary source of aviation's environmental harm, including carbon dioxide emissions, nitrogen and sulphur oxides, particulate matter, and contrails. SAF offers substantial reductions in lifecycle CO_2 emissions by replacing fossil carbon with biogenic or synthetic carbon sources. However, SAF does not fully eliminate non-CO_2 emissions, which continue to contribute significantly to atmospheric warming (Lee et al., 2021).

Furthermore, the environmental performance of SAF varies widely depending on feedstock and production pathway. Waste-based feedstocks generally offer higher emission reductions than crop-based biofuels, which may entail indirect land-use change and biodiversity loss. Consequently, SAF's environmental benefits are conditional rather than inherent, underscoring the importance of robust sustainability governance.

Economic Structure and Market Dynamics

A major contribution of Buse's analysis lies in his critique of the oligopolistic oil market. Airlines historically operate as price-takers, absorbing fuel cost volatility driven by global oil dynamics. SAF introduces alternative pricing models, particularly cost-plus contracts, which enhance price transparency and predictability (Buse, 2023).

However, the transformative potential of SAF markets is constrained by high entry barriers. Establishing a HEFA refinery capable of producing approximately 800,000 tonnes of SAF annually requires an estimated investment of USD 1.1 billion (International Energy Agency [IEA], 2022).

Such capital intensity favours multinational energy firms and limits participation by smaller producers, increasing the risk that SAF markets may evolve into new oligopolies rather than competitive alternatives.

Policy Dependence and Regulatory Mandates

SAF adoption has been driven primarily by policy intervention rather than market demand. Regulatory instruments such as the U.S. Blender's Tax Credit and the European Union's Renewable Energy Directive III mandate blending requirements and provide financial incentives to producers and distributors. While these policies accelerate deployment, they also raise concerns regarding long-term economic sustainability if state support diminishes (ICAO, 2023).

Sustainability, Equity, and Global South Implications

Although SAF is framed as a global solution, its governance architecture remains largely Western-centric. Developing countries are often positioned as feedstock suppliers rather than equal stakeholders in policy formulation. This raises ethical concerns related to land use, food security, and environmental justice (Searchinger et al., 2018). Moreover, the increasing involvement of established oil majors in SAF production suggests continuity rather than disruption of existing power structures.

Results and Discussion

The analysis demonstrates that SAF constitutes a necessary but insufficient condition for achieving green aviation. While SAF offers meaningful emission reductions, its sustainability is contingent upon feedstock governance, certification integrity, and regulatory oversight. The capital-intensive nature of SAF production undermines claims of market democratisation, while reliance on policy-driven demand raises questions about economic resilience.

Furthermore, the exclusive emphasis on SAF marginalises alternative pathways such as demand management, operational optimisation, and long-term propulsion innovation. A holistic decarbonisation strategy must therefore integrate SAF within a broader portfolio of measures rather than treating it as a singular solution.

Conclusion and Recommendations

This study concludes that Sustainable Aviation Fuels represent an important component of aviation's decarbonisation strategy but should not be positioned as the sole pathway toward green aviation. Policymakers should adopt diversified approaches that combine SAF deployment with technological innovation, improved air traffic management, demand moderation, and behavioural change.

Future research should incorporate empirical stakeholder perspectives across regions and explore context-specific pathways for sustainable aviation, particularly in the Global South. Strengthening sustainability certification regimes and addressing market concentration will be critical to ensuring that SAF contributes meaningfully to global climate objectives.

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