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Qualitative Impact Analysis of Sustainable Aviation Fuels on Aviation Sustainability

Sürdürülebilir Havacılık Yakıtlarının Havacılık Sürdürülebilirliği Üzerine Niteliksel Etki Analizi

ABSTRACT

Sustainable Aviation Fuels have become a defining aspect of the global industry's efforts towards achieving a more sustainable and aligned future with international environmental objectives. The purpose of this study is to conduct a qualitative impact analysis of SAF on aviation sustainability using several impact exploration instruments to understand the impact dialogue topics relevant to the theme of SAFs in the Turkish aviation sector. These methods include Word Clouds, Code Relationships Browser, Clustering Analysis, and Single Case Impact Model. Identifying and analyzing key topics and the relationship between them contribute to a better understanding of the chosen impact dialogue. This study highlights the environmental benefits of Sustainable Aviation Fuels (SAFs), but also identifies significant challenges in the economic, technological, and policy spheres that must be addressed strategically to achieve these goals. Therefore, the study recommends adopting these impact solutions to address the perceived feasibility issues and promote the implementation of Sustainable Aviation Fuels (SAFs).
Keywords: Aviation Management, Sustainability, Aviation Fuels.

ÖZET

Sürdürülebilir Havacılık Yakıtları, küresel endüstrinin uluslararası çevresel hedeflerle uyumlu, daha sürdürülebilir bir gelecek elde etme yönündeki çabalarında belirleyici bir unsura dönüşmüştür. Bu çalışmanın amacı, Sürdürülebilir Havacılık Yakıtlarının, havacılık sürdürülebilirliği üzerindeki niteliksel etkisini anlamak için çeşitli etki araştırma araçlarını kullanarak SAF'larin Türk havacılık sektöründeki etki diyaloğu konularına ilişkin bir niteliksel etki analizi yapmaktır. Bu yöntemler, Kelime Bulutları, Kod İlişkileri Tarayıcısı, Kümeleme Analizi ve Tek Vaka Etki Modeli'ni içermektedir. Önemli konuları ve aralarındaki ilişkileri tanımlamak, analiz etmek, seçilen etki diyaloğunu daha iyi anlamayı sağlamaktadır. Bu nedenle, çalışma, algılanan uygulanabilirlik sorunlarını ele almak ve Sürdürülebilir Havacılık Yakıtlarının (SAFs) uygulanmasını teşvik etmek için bu etki çözümlerinin benimsenmesini önermektedir.
Anahtar Kelimeler: Havacılık Yönetimi, Sürdürülebilirlik, Havacılık Yakıtları

1. INTRODUCTION

This places the aviation industry - one of the largest contributors to global greenhouse gases - on the brink of an incredibly important crossroad for the pathway to sustainability. It has a major share in CO2 worldwide, and one of the techniques in aviation is Sustainable Aviation Fuel (SAF) to cut down on environmental impact. Recent research suggests that SAF could make greenhouse gas emissions considerably lower and therefore be a cleaner alternative to traditional jet fuels (Grimme, 2023; Detsios et al., 2023).

The purpose of this study is to conduct a qualitative impact analysis of SAF on the sustainability of aviation in Turkey. This research will look to integrate the insights of industry experts and apply advanced qualitative analysis tools such as NVivo so that the research questions of the study are better answered in seeking to uncover more nuanced perspectives regarding the challenges, opportunities, and future directions for implementing SAF within the Turkish aviation sector.

In other words, to further clarify this, five stakeholders of the aviation industry from Turkey, including policy-makers, engineers, and sustainability officers, will be interviewed. These interviews will be focused and designed to bring out in-depth qualitative data that will be analyzed through NVIVO to find themes, trends, and patterns. As such, they should yield rich qualitative insights into the sector's transition to sustainable fuels.

The paper is structured in the following way: after the introduction, the paper will begin with a literature review on the environmental, economic, and operational impacts of SAF globally. The following sections introduce the methodology for expert interviews, and the following section introduces the methodology of data analysis. The sections following the findings will cover the local and global context of the presented qualitative analysis, and lastly, the discussion. The last section of this paper discusses the conclusions and proposed recommendations for policymakers, industry stakeholders, and researchers. In focusing on Turkey, a country with a fast development of the aviation market, a unique view of the challenges ahead of SAF adoption in the developing market will be achieved. This local context, dominated by knowledge from experts and qualitative analysis, represents valuable local knowledge within the larger global discourse on sustainable aviation and possibly guides similar initiatives in other emerging markets (Stafford et al., 2023).

2. CONCEPTUAL FRAMEWORK

2.1. Technological Innovations and Adaptations in Sustainable Aviation Fuels (SAF)

Sustainable Aviation Fuels (SAF) are renewable and low-carbon energy sources produced from the aviation sector. There are other new developments in SAF technology, with a focus on further improvements in the processes to produce these fuels from bio-based and synthetic sources (Mizrak & Kizilcan, 2022). Such progress is to enable the resolution of the technical challenges and optimization of production pathways so that SAF can be made efficient, scalable, and economically viable (Mızrak & Cevher, 2023).

Bioconversion processes consist of the conversion of biomass or wastes into liquid fuels. The technological breakthroughs in this field are basically with an aim to improve the microbial and enzymatic methods that are applied to the conversion of plant oils, sugars, or fats to hydrocarbons that would hold the same properties as conventional jet fuels. These innovations span from the genetic modification of microorganisms to improve efficiency and productivity, to enzyme modification for more efficient processing of a wider variety of feedstocks and conditions (Detsios et al., 2023). Major technological stride brought in by SAF production is the integration of synthetic pathways—Fischer-Tropsch (FT) synthesis and the Alcohol-to-Jet (AtJ) pathway. In this process, FT synthesis is the process to convert synthesis gas into a mixture of hydrocarbons by catalytically reacting with carbon monoxide and hydrogen. The feedstocks used for the process range from gasified biomass to even carbon dioxide extracted from air, making the process pretty versatile for the production of SAF. The "AtJ pathway" implies the use of alcohols in the preparation of synthetic jet fuel. Moreover, the scientific and technological advancements in the mentioned pathways aim to bring out an increased performance for these conversions and reduce the energy input that is required for making these pathways commercially viable (Detsios et al., 2023).

It is still dimmed by several obstacles in technology. Finally, the outstanding issue, the scalability of these technologies. Although some successful research projects at laboratories and some pilot demonstration units have shown good results, scaling up is often considered to be technologically feasible but very expensive.

Further, the sustainability of the feedstocks themselves may be limited by the dependence on agricultural products or land-intensive crops. Dependence is an unintentional way of carrying out the environmental impacts (Mızrak et al., 2022). In this regard, the feasibility of such technological innovations will largely be a subject of local resource, infrastructural capability, and the regulatory environment. There are several critical factors that shall further determine feedstock availability—soils fit for agriculture, agricultural residues, as well as non-food biomass or synthetic gases. Besides, Turkey's strategic geography and the trends of the aviation industry to grow in Turkey make technological integration with SAF hold different opportunities and challenges. Understanding these technological aspects is the responsibility of all Turkish aviation stakeholders. They should be informed of providing the required information for making well-informed decisions in relation to investment decisions pertaining to SAF technologies and complexities in adoption.

2.2. Policy and Regulatory Environment on Sustainable Aviation Fuels (SAF)

Importantly, policy incentives and regulatory frameworks should underpin the uptake and scaling of Sustainable Aviation Fuels (SAF). This would help mitigate the risks associated with early-stage technologies and, at the same time, ensure the alignment of SAF initiatives with broadened environmental and economic goals. Another important case that Turkey could follow in its efforts to integrate some of the similar strategies is EU policies.

This means that blending mandates will require a certain percentage of the fuel composition to be made up of aviation sustainable alternatives. The European Commission sets extremely ambitious targets for the blending of SAF. The most obvious example is that of the EU under the European Green Deal with its initiative "ReFuelEU Aviation," according to which, starting from 2022, the required minimum share of SAF in the fuel mixture should be annually increased until 2030 to very high percentages (European Commission, 2022). This strategy could set a precedent for Turkey and, in a domino effect, it may assist in local production and use of SAF.

The emissions trading systems have therefore been key in the promotion of SAF by making it more attractive financially to reduce emissions. The EU ETS, for example, limits the emission of CO2 and allows firms, which limit the emission of CO2 below these limits, to trade their surplus allowances. This system will motivate the airlines to use SAF by which they can considerably reduce the carbon content and hence the related carbon costs (European Commission, 2022).

The policy environment will also need to take into consideration challenges such as the high costs of SAF production and advancements in technology. In this regard, incentives such as tax reductions, grants for research on SAF, and grants for installing biofuel production installations take prominence in the light of the domestic air transport industry (Grimme, 2023). Adoption of such policies by Turkey would require similar incentives that are suited to local policies adopted in the given economic and environmental framework to enable harnessing the national renewable energy resources. Such insights are more critical for a country like Turkey, which has greater potential to expand its aviation but, at the same time, is keen to do so by keeping the commitment of the Paris Agreement. Regulations that approach those of the EU will facilitate a smooth transition to SAF with governmental support of both kinds and supporting international collaborations.

2.3. Economic Vision of Sustainable Aviation Fuels (SAF)

Economic sustainability can be realized with SAF through technical investigations, as long as it overrides the significant cost gap between SAF and conventional jet fuels. Current literature identifies a range of ongoing challenges and seeks to propose potential strategies that would make SAF a viable alternative within the aviation industry. Koščáková et al. (2022) discuss SAF market dynamics, quoting the costs of its production as one of the greatest barriers in switching from fossil fuels. The remaining work evaluated different alternative fuels for the reduction of their economic and environmental impacts; among them, SAF can reduce these impacts but are currently less competitive compared to fossil kerosene (Barke et al., 2022). Further, a study regarding the production of biojet fuel from woody biomass suggests that, although it has the potential to reduce greenhouse gas emissions, the cost of production is very high compared to conventional fuels and therefore could, in turn, be a roadblock toward its economic feasibility (2023).

Eswaran et al. (2021) go ahead to carry out a detailed techno-economic analysis of the catalytic hydrothermolysis pathway for SAF production and propose that the cost of SAF remained higher than petroleum-based jet fuel without appropriate financial incentives. The forecasted Sustainable Aviation Fuel (SAF) costs over the next decade are around $1.80 to $2.50 and greatly depend on technological innovation, economies of scale in production, and regional economic fundamentals. Bettenhausen (2022) explains that the enormous endeavor continues in such a way that Air Products and World Energy are repurposing around $2 billion of the ancient factory for the production of commercial-scale SAF. This probably helps further explain the sheer amounts of capital involved in a large setting.

This facility targets annual production of SAF to reach 1.3 billion liters, signaling an economic scale. Tullo (2022) reports another project by World Energy targeting a SAF plant in Houston with a capacity of about 950 million liters a year by 2025. This would signal a trend toward significant expansion in SAF production capacity, reflecting expected per-unit costs declines as technologies mature and operations scale up (Tullo, 2022).

2.4. Environmental Impact of Sustainable Aviation Fuels (SAF)

The transformation into Sustainable Aviation Fuels (SAF) indeed targets to reduce, to a great extent, the adverse environmental effects of the aviation industry, especially carbon emissions. Recent studies underline the complexities and the benefits that accrue from the SAF through life cycle assessments (LCA). The International Renewable Energy Agency (IRENA) explains that in recent studies, SAF has improved the quality of air with mitigation of the climatic issues, ensuring sustainable energy diversification.

Ugbeh-Johnson and Carpenter, (2023), further explain that in 2023, the Journal of the Royal Aeronautical Society had a study that discussed how SAF may influence the icing of an aircraft's fuel line and how they operate pumps that are critical for operational safety of aircraft operating with such types of fuel. Another interesting point is the effect on non-CO2 emissions. For example, SAF cases on local pollutants, such as nitrogen oxides (NOx), among other substances responsible for climate change. Teoh et al. (2022) have recently demonstrated in Environmental Science & Technology that, although SAF indeed has the potential to minimize CO2 emissions at a high degree, its effect on other pollutants, such as NOx, depends on its composition and the combustion conditions.

However, a concern is that the land use and clean energy resources that would be needed for the production of SAF are vast and pose a potential conflict with other global environmental objectives (Becken et al., 2023). On a general scale, though SAF offers a way toward decarbonizing air transport, comprehensive environmental effects, and also the effect on biodiversity, land use, water resources, among others, need to be managed with due care, so as to assure the achieved sustainability.

2.5. Stakeholder Perspectives and Challenges to Adoption of Sustainable Aviation Fuel

The deployment of Sustainable Aviation Fuels (SAF) comes with multifaceted challenges and quite a number of considerations to be taken into account from the perspective of various stakeholders involved in the aviation industry. For example, Hooda and Yadav (2023) offer an insight into the explicit role which green finance can play in realizing sustainable aviation since, as observed, indeed, financial support and stakeholder involvement have been critical enablers in many industries for the upscaling of SAF production.

Moreover, Grimme (2023) adds that both regulatory and economic hurdles are connected to the adoption of SAF in Europe. He discloses that in such a situation, challenges and opportunities could be in the form of possible future mandatory quotas for the use of SAF. Ahmad and Xu (2021) consider the perspective of stakeholders across the SAF supply chain by use of a cognitive mapping approach to determine the barriers and strategic levers necessary for accelerating SAF development.

Santos and Delina (2021) further noted that with the positioning aim squarely at fulfilling broader sustainability goals, robust multi-stakeholder partnerships and government support for promotion remain the key enablers of SAF uptake during and post-pandemic. These studies therefore converge to underline that SAF adoption is a multifaceted dimension: not only the economic, regulatory, and financial but it is also the one of collaboration to be mastered in order to diffuse their penetration widely.

The following sequence of interviews with local aviation experts in Turkey is likely to bring more in-depth insight into national challenges and opportunities. These can relate to the regulatory frameworks in place, the potential to access local feedstocks, and preparedness of Turkish airlines and airports to conversion into the use of SAF. Understanding such localized perspectives is vital to devising strategies that may meet the test of being globally informed but locally applicable.

3. LITERATURE REVIEW ON THE IMPACT OF SUSTAINABLE AVIATION FUELS (SAF) ON AVIATION SUSTAINABILITY (2010-2024)

This paper will review the evolving changes that are taking place in the Sustainable Aviation Fuels (SAF) landscape and their contribution to aviation sustainability from 2010 to 2024. In the process of this search, consideration was given to a number of major databases which included Google Scholar, ScienceDirect, and JSTOR. The search used terms such as "sustainable aviation fuels," "aviation sustainability," "greenhouse gas emissions," and "techno-economic assessments." These will be developed into the themes that would address the reduction in greenhouse gas emissions, economic impacts and viability of SAFs, challenges in the production of SAFs, and market scalability of SAFs. These would then be refined to themes addressing environmental and economic sustainability of the technological breakthroughs in the production of SAF. This structured investigation will assist in understanding the impact of SAFs on environmental footprints mitigation in an integrated manner, as per the socio-economic challenges and opportunities coming in conjunction with transitioning to sustainable fuels.

SAFs are now considered key to bringing down the carbon footprint of the aviation sector, providing a viable alternative fuel for the traditional one made of fossil fuels. Recent studies by Marszałek et al. (2022) and Koščáková et al. (2022) add to the view that SAFs are able to replace traditional jet fuels and contribute to great reductions in greenhouse emissions, which help fulfill the environmental sustainability goals.

The integration of carbon credits with SAF presents environmental benefits and, indeed, huge economic incentives. Sharma et al. (2023) estimated from the benefits analysis that with the integration, the emission could be reduced to about 65% and acquire benefits ranging between 12 and 51 million US dollars every year.

However, this benefit comes with large-scale barriers in production of SAFs. According to Male et al. (2021), it is argued that in 2019, the US only produced SAF that represented a fraction of the amount required, thus indicating the scale-up challenge for meeting an annual demand of 26 billion gallons. On the other hand, Barke et al. (2022) evidence that Europe is still struggling in the battle against all odds to make SAF economically competitive with fossil kerosene, despite the potential of greatly reducing the carbon emissions produced by aviation.

Rojas-Michaga et al. (2023) focused on the PtL systems, which seem to be promising in strengthening the sustainability of aviation due to high carbon conversion efficiency and competitive fuel price. Further evidence supporting its efficiency are those of Kroyan et al. (2022), who demonstrated that SAFs in jet engines reduce the fuel consumption and carbon dioxide emissions, thus supporting the conclusion that they help in sustaining aviation.

Building upon this earlier work, Koščáková et al. (2022) bring to light the feasibility that SAF could open up departures from the current aviation fuel market, allowing for an eventual departure from fossil fuel dependence. In a study case by Sharma et al. (2023), it outlines how inclusion by airlines to purchase carbon credits with SAF usage could make a huge reduction in emissions by around 65%.

In light of the immediate positive impacts of SAFs, Detsios et al. (2023) say that IATA has endorsed the use of sustainable drop-in liquid fuels as a strategic short-term measure of reducing environmental impacts by aviation. Zhou et al. (2022) purport supporting these markets by expanding international carbon markets and sustainability certifications to help support broader biofuel use in aviation.

Reflecting on a prior scholarly piece of work, Brown (2011) discovered that the R&D of alternative fuels has the potential to bring about economic, environmental, and energy security benefits that will allow for the establishment and further advancement of future technology SAF.

4. METHODOLOGY

The approach for the study is predicated on a critical exploration of the divergent views of key stakeholders in the aviation industry regarding the adoption and implications brought about by the Initiative on Sustainable Aviation Fuels (SAF). This article is a qualitative study that is to follow in-depth feedback from practitioners by applying semi-structured interviews.

This paper targets five experts with a purposive sampling approach within the Turkish aviation industry. These were experts and stakeholders in their roles concerning aviation sustainability, such as policymakers, airline executives, sustainability officers at the airports, SAF producers, and academic researchers who deal with aviation technology. This selection sought to provide a wide spectrum of perspectives on the implementation of SAF, challenges, and opportunities for implementing it in this sector.

Semi-structured interviews were employed for data collection, thereby having flexibility in the discussion to ensure that all the core issues were covered. Each of the interviews lasted about 60 minutes, and due to logistical considerations, they were done online.

Key questions included:

1. What could be the potential positives and negatives in regard to the sustainability of SAF in aviation?

2. What is the current estimation of SAF in Turkey and its level of global policy assessment?

3. Given this background, according to you, what are the major challenges and hurdles that might take a negative turn in the adoption of SAF in the Turkish aviation sector?

4. In what ways do you think SAF technology could evolve to better meet the needs of the aviation industry?

5. In your view, what should be done in order to increase the adoption level of SAF in Turkey?

It may, however, be mentioned that these interviews were conducted with the prior verbal consent of the participants, tape-recorded, transcribed verbatim, and later analyzed with the help of the NVivo software for conducting the analysis.

Thematic analysis was conducted on the transcript using NVivo to identify themes and code them based on how often and which pattern the concept was referred to by the respondents. This ensures the provision of a systematic and comprehensive analysis of the qualitative data, hence the deep understanding of the views by the stakeholders as regards SAF. Ethical clearance was obtained from the local research ethics committee. The ethical considerations taken in this study involved obtaining prior informed consent from the participants through interviews and questionnaires. The participants were also informed about the aim of the study, their voluntary participation, and the researchers' assurance of upholding the confidentiality of the responses. There are some limitations to this study that are recognized, such as the small sample size and a case country within the region, which may not provide a holistic view. Lessons learned here are truly invaluable toward the understanding of the context of Turkey and to the contribution for general discussions for sustainable aviation practices.

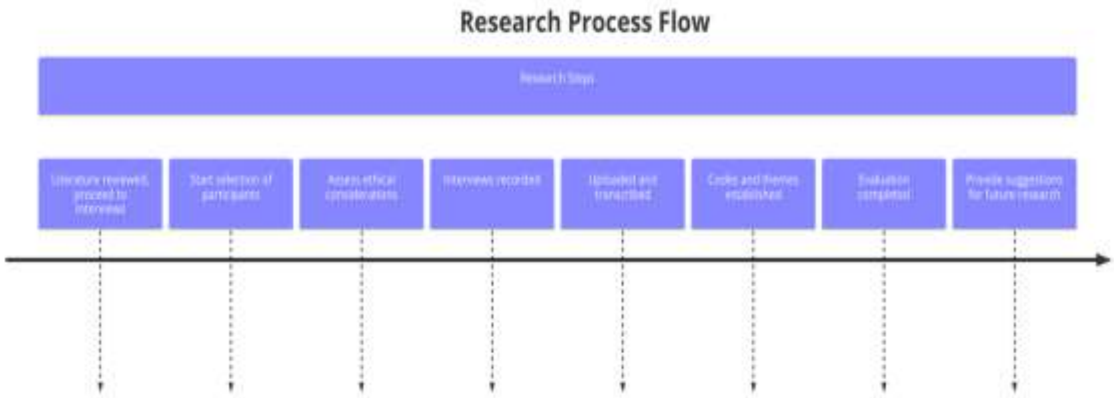

Figure 1. Methodology Workflow

The profile of the respondents is elaborated below in relation to the qualitative study "A Qualitative Impact Analysis of Sustainable Aviation Fuels on Aviation Sustainability". The experts are from the Turkish aviation field. The respondent group represents a great diversity. From this, it follows that the diversity of professional backgrounds, experience, and other factors resulted in diverse subjectivities. Table 1 categorizes the participants into the years they have been involved in the business, their current capacity in the industry, and their ages, giving a snapshot that further aids in understanding the perspectives each contributed toward this research on sustainable aviation fuels.

Table 1. Information about Participants of the Interviews

Participant ID	Experience (Years)	Position	Age
P1	10	Sustainability Officer	42
P2	15	Airline Executive	50
P3	7	Policy Maker	38
P4	20	Aviation Engineer	55
P5	12	Academic Researcher	45

The methodology followed is such that it is designed to have proper, in-depth investigation conducted across the discussions concerning Sustainable Aviation Fuels (SAF). The text data of many dialogues from experts within the Turkish aviation sector was systematically coded and categorized through the powerful software NVivo for qualitative analysis. This was approached through the application of a good number of sophisticated analytical tools, including Word Clouds, Code Relationships Browsers, Frequency Analysis, and many others, each contributing uniquely to the dissection of the complex interplay of themes within the discussions. The method made sure that our present knowledge of the discourse was strengthened and that the derived insights were robust and comprehensive through a methodical mapping of relationships, frequencies, and clusters of themes. With a solid methodological foundation laid, this current paper goes now to the findings of the study. Detailed results from these analyses will be presented, pointing out the critical insights and implications that are apparent for the future of SAF in aviation sustainability.

5. FINDINGS

The paper has put to work a wide array of qualitative analytical tools in trying to dissect and make sense of nuanced discussions taking place on Sustainable Aviation Fuels (SAF) within the aviation industry. This was done systematically, unpacking the themes and subthemes that dominate the discourse by using Word Cloud Analysis, Code Relationship Browsers, Frequency Analysis, Relationship Mapping, Clustering Analysis, and the Single Case Model of Scope Density Relationship analysis. Each analysis approach offered distinction insights, the only varying condition being in respect of the depth and breadth of discussions, which revealed an interconnective nature between the technological, economic, and policy challenges and opportunities pertaining to the adoption of SAF. A multifaceted approach, and comprehensive view—how the stakeholders perceive the impact of SAF on aviation sustainability sets the stage for detailed findings that follow.

Word Cloud Analysis: Word Cloud Analysis for Discussion Themes of Sustainable Aviation Fuels (SAF) presents a visual insight into some of the most discussed issues among the experts pertaining to the Turkish Aviation Sector. The larger words in the word cloud include "SAF," "production," and "policies," indicating the emphasis put forth by the stakeholders.

Figure 2. Word Cloud for SAF Discussion Themes

The fact that "SAF" appears most dominantly in the word cloud is to emphasize that Sustainable Aviation Fuels are prime in importance. These inscribe the importance and urgency of finding alternative sustainable jet fuels to those conventionally derived, especially in discussions on how to reduce aviation-related carbon emissions.

The word "production" comes very often; in fact, it really rises to a very important point: What are the manufacturing and scaling capabilities of SAFs in reality? The real discussion among experts: How can SAF be produced to scale, from the small, pilot plant-level facilities of today, to plants that are of a size sufficient to meet the demands of the aviation industry? This will involve the discussion of current technological constraints, probable areas for technological breakthroughs, and the need for infrastructural developments that can support large-scale production.

This, really, is a key importance marked in the keyword "policies," underlining the idea that the regulatory framework and policy measures are seen as key aspects toward the actualization and adoption of SAF. They will likely include policy matters, the need for government incentives or subsidies, and regulations that will require the use of SAFs, as well as international standards that would make them easier to be adopted worldwide.

For example, the word cloud would, in a visual, give a perception immediately of where the areas of focus in the discussion are without getting into in-depth data analysis. It informs good time for the stakeholders in this case, which deployment elements of SAF need their attention to guide detailed discussion or further research.

These terms stress that only scientific advancements in SAF technology are not enough; equally supporting are enabling policies and scaling up of production capabilities. The "triad" (production, policies) of focus areas is now the holistic approach for sustainable challenges of aviation. This reflects that one improvement area is interdependent on others.

The Word Cloud Analysis gives a snapshot into the collective mentality of the conversation landscape around SAFs and where the attention or action of the stakeholders is focused in efforts to overcome the major hurdles to sustainable aviation fuel adoption. This visual tool helps understand the thematic priorities and can elicit focused discussions aimed at the thematic areas that may be adjudged to be of dire necessity, as identified from the analysis.

Code Relationships Browser: Code Relationships Browser is a complex tool of visualization, used in qualitative research to representationally plot relations between codes of several themes and sub-themes that were identified through discussion or textual data. In analyzing the discussions regarding Sustainable Aviation Fuels (SAF), the browser turned out to be very useful in showing that those different issues are related and therefore shed light on insight into the SAF ecosystem and how complicated its implementation is.

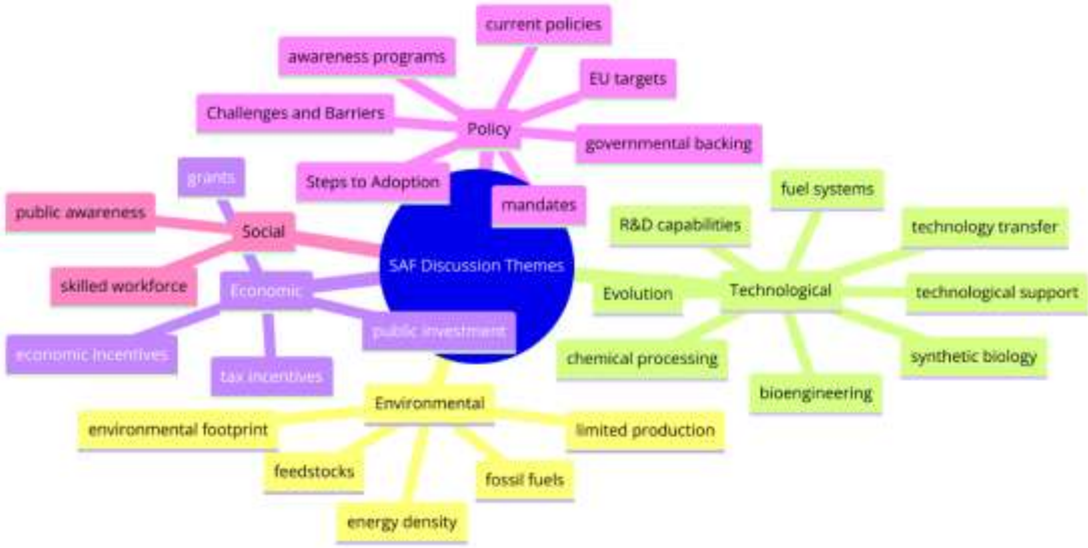

Figure 3. Code Relationships Browser for SAF Discussion Themes

Insights from Analysis of the Code Relationships Browser

The Code Relationships Browser visualizes how main themes like "Benefits and Drawbacks," "Current Policies," and "Challenges and Barriers" are interconnected with various subthemes. For instance, the connection between "Benefits and Drawbacks" and "high costs" directly points to the ongoing dialogue about the economic challenges of producing and implementing SAFs at scale.

The linkage of "high costs" with "Benefits and Drawbacks" not only identifies it as a significant barrier but also places it within the broader context of SAF benefits. This relationship stresses the tension between the environmental benefits of SAFs and the prohibitive costs that could hinder their widespread adoption, illustrating the dual aspects of SAF discussions where economic feasibility is as significant as environmental impact. Here is a link that underscores tension between environmental benefits of SAFs and cost barriers that could prevent their wide use, hence showing a duality of SAF discussions where economic feasibility is as important as an environmental impact.

The browser helps stakeholders understand the multiple interconnections between multiple discussions with visual mapping. It shows not the isolated themes but how themes are often discussed with other themes in relation to them, making visible the multi-dimensional nature of challenges and considerations in SAF development and deployment. The tool highlights the challenges of technological complexity in SAF initiative implementations, by showing how they connect with policy needs and economic realities. For example, the connections can exhibit that discussion about technological developments often accompanies calls for policies that would support such developments or even financial mechanisms, which goes to show the understanding that development in technology is something that has to be accompanied by regulation and financial support.

Understanding these complex interplays should inform the strategy development and policymaking process. Finally, identifying major themes that intersect with each other could be supportive in formulating more wholesome, integrated, and thus effective strategies that could face several dimensions of the SAF implementation challenge at a time.

Last but not least, this visual tool increases the engagement of the stakeholders, clearly reflecting the relevant points of the discussion. Areas of concern, points where they can come together and work in collaboration, and existing communication gaps that need to be looked upon are easily identified by the stakeholders. In a nutshell, the Code Relationships Browser serves as a very important tool for analysis in the study of SAFs because, through a clear and structured view, one can see how different aspects within the discussions are related to each other. This will also act to enhance the understanding of the subject matter discussed and hence make the response to the challenges more focused and effective.

Frequency Analysis: The Code-Based Frequency Analysis is one of the quantitative data analysis approaches that has the sole aim of finding out exactly how frequent a given theme or code occurs within a data set. In this case, it is in light of the theme codes around sustainable aviation fuels (SAFs). This is critical for understanding which topics dominate the discourse and forms the data-driven basis for knowing what the discussion really is about.

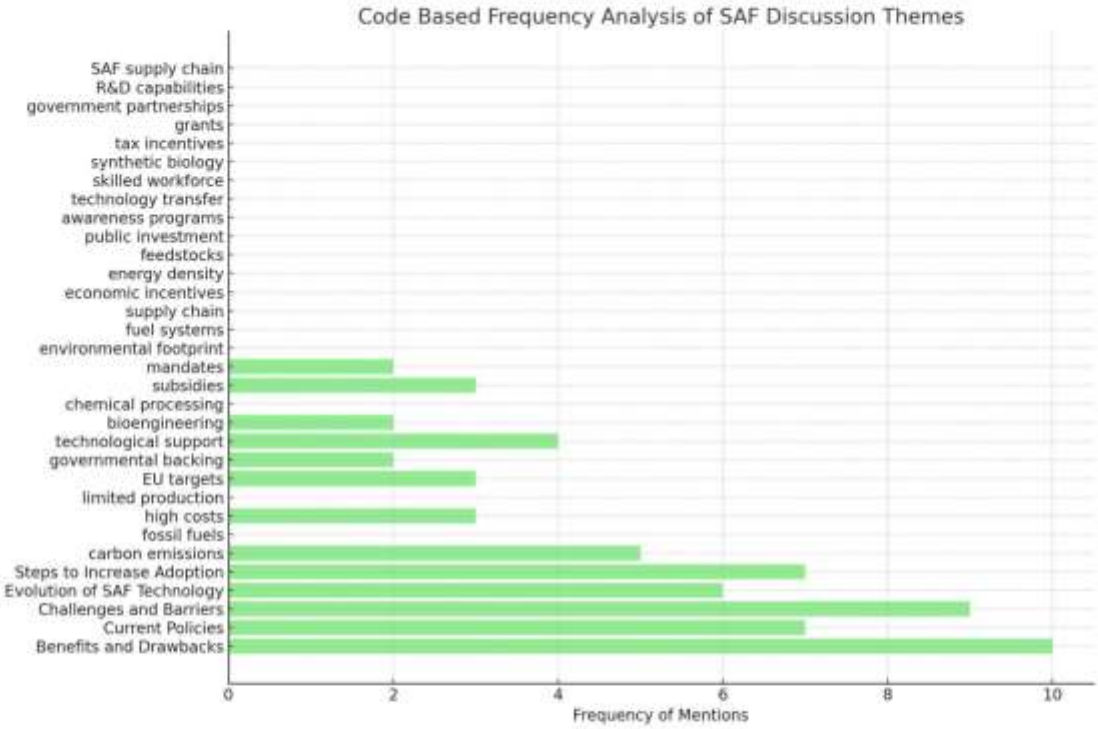

Figure 4. Code Based Frequency Analysis

Insights from the Frequency Analysis:

Words like "SAF," "production," and "policies" were clearly indicating the most dominant concepts. The dominance of "SAF" clearly shows that the discussions were centrally focused on sustainable aviation fuel as discourse; similarly, the frequency of "production" and "policies" will point at the dominance of issues as far as specific areas of concern and interest within the wider framework are concerned.

The reference to "production" is hammered often, which brings big concerns to the ability of manufacturing SAF at a scale enough to meet the aviation industry's needs. This testifies to continuing discussions around technological challenges, the availability of resources, and infrastructural developments needed for efficient and sustainable scaling up of production.

The mere emphasis on "policies" emphasizes that there is some kind of agreement among the stakeholders that supportive regulatory frameworks are indeed key to the successful process of adoption and implementation of SAFs. These include, but are not limited to, government incentives, subsidies for SAF usage, and mandates with respect to international regulations, including the possibility of helping synchronize work among countries.

The frequency of discussion categorization of topics helps stakeholders such as policymakers, heads of industries, and researchers improve themes for research and action, respectively. This points to areas where resources could be best allocated and where more attention is required toward redressing the identified challenges.

In the light of this frequency analysis, this is on 'production' as the key area, and therefore, it gives a clear direction to R&D on improved technologies of production and exploration of new feedstock sources, improved conversion, and the economic viability of the production process.The mention of "policies" at a high frequency, therefore, seems to point at a stronger yearning for more solid policy intervention. This could further impact the shaping of future regulations and support schemes, making possible easier broad adoption of SAFs by avoiding policies not in line with technical and economic realities of SAF production.

This analysis operationalizes the basis to evidence the qualitative insights provided by other analyses, such as the Code Relationships Browser or the Scope Density Relationship. This ensures that the relationship within which emphasis is put on certain themes is supported by factual data in the number of occurrences of those themes, hence giving a more rounded understanding of the discussion dynamics.

Relationship Mapping: The Single Direct Weighted Relationship graph is a special purpose tool applied to qualitative research for describing the strength and directness with which one discussion theme relates to another. More specifically, it contextually analyzes how different themes, including policy and adoption strategies, have been seen to interrelate and influence each other directly within the discourse of Sustainable Aviation Fuels (SAF).

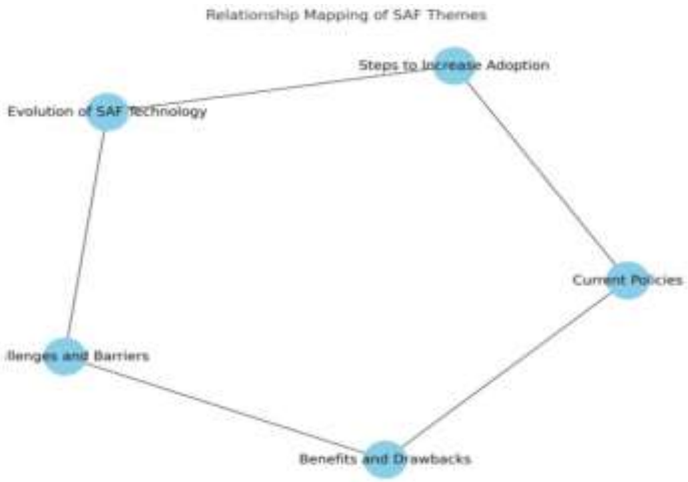

Figure 5. Relationship Mapping of SAF Themes

The following insights emerged from the relationship mapping analysis:

As clear from the graph above, strong, positive links were clearly identified from "Current Policies" to "Steps to Increase Adoption," therefore strongly indicative of a consensus among experts toward the importance of policy measures in the adoption of SAFs. This gives the stakeholders an at-a-glance visual explanation of which themes have the highest ranking in terms of their pivot in driving change and thus enabling the implementation of SAF. The following analysis, therefore, due to the perceived effectiveness, creates a strong linkage between the policies' measures and steps for increasing adoption of SAF.

Such discussions often revolve around how specific policies may directly accelerate the pace of transitioning to SAFs through incentives to produce SAFs, mandates to use them, and support for technological innovation. Those outlined by the graph within the direct links can be ones to guide strategic planning in the industry. The realization that policies directly impact adoption may well be the focus of an effort to press for more supportive policies that lead to better alignment of SAF initiatives with governmental agendas and may even redesign SAF technologies and business models to better fit the already existing and foreseen regulatory environments.

This relation mapping would also help in better positioning for engagement with the stakeholders, whereby it is of need of the hour in terms of policymakers, industry heads, and technology developers to collaborate. By pointing out the direct influences of the policies on strategies of adoption, this would push toward more cohesive approaches by various stakeholders. These weighted relations in the graph suggest not only the linkage between the themes but also the strength of the relations. This is of help for understanding dependencies within the discourse—how, for instance, the "Steps to increase SAF adoption" are dependent on the "evolution of current policies." Cases may be that strengthening one aspect might beneficially affect another.

Clustering Analysis: Clustering Analysis is a very important method in data analysis that groups data points into clusters based on their similarities. It has been used within the frame of discussions on Sustainable Aviation Fuels (SAF) to segment the dialogue into thematic clusters, and it gives an idea about the various topics treated by experts in a structured manner.

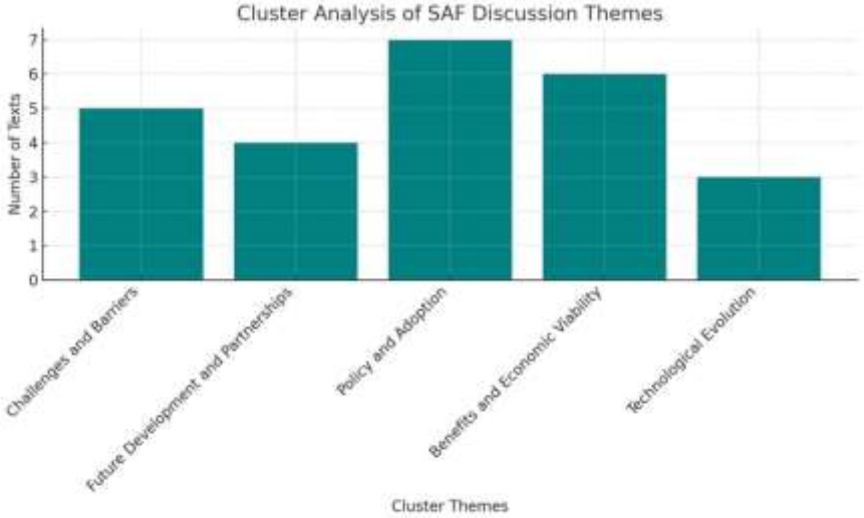

Figure 6. Cluster Analysis of SAF Themes

Insights from Clustering Analysis:

The current analysis has successfully segmented the discussions into relevant clusters with respect to their content, like "Challenges and Barriers" and "Benefits and Economic Viability." Such clusters help in realizing those main topics around which the discussion centers and, in fact, do pinpoint areas of importance, such as addressing economic challenges and issues of harnessing an improved understanding of SAF benefits.

The salience of economic challenges within their own cluster brings forth their importance as a major barrier to the adoption of SAF. This also includes the issues pertaining to the high production cost, economic feasibility of scaling up technologies, and financial risks to stakeholders. Therefore, targeted strategies need to be designed and implemented to minimize these economic barriers, possibly through policy interventions or financial motivations.

The fact that there is formation of a cluster around the environmental benefits of SAFs points towards broad-based recognition of the benefits. It is likely that this cluster involves discussions on the reduction of carbon, lowering environmental impact, and meeting global sustainability goals. If such clear grouping together of these topics points toward a firm consensus on the value of these benefits, it may be used to encourage wider groups of stakeholders to embrace SAF. Clusters also help identify the focal areas, given that targeted interventions should be guided to have the concentration of both resources and efforts. For example, a focus on improving the economic incentive, which in turn helps to solve the set of economic challenges while identification of technology gaps in yet another set of challenges may steer focus toward innovation and research and development. This gives an effective way for the engagement of stakeholders with clear, representative themes clustering the landscape of the discussion.

Scope Density Relationship: The Scope Density Relationship analysis will be used in checking and assessing the depth of the discussions in the datasets and will also be used for checking the dimensions in the dataset with regard to Sustainable Aviation Fuels (SAF). The breadth and depth of each theme consider the measure of the level of discussion by experts in this field on the basis of various topics.

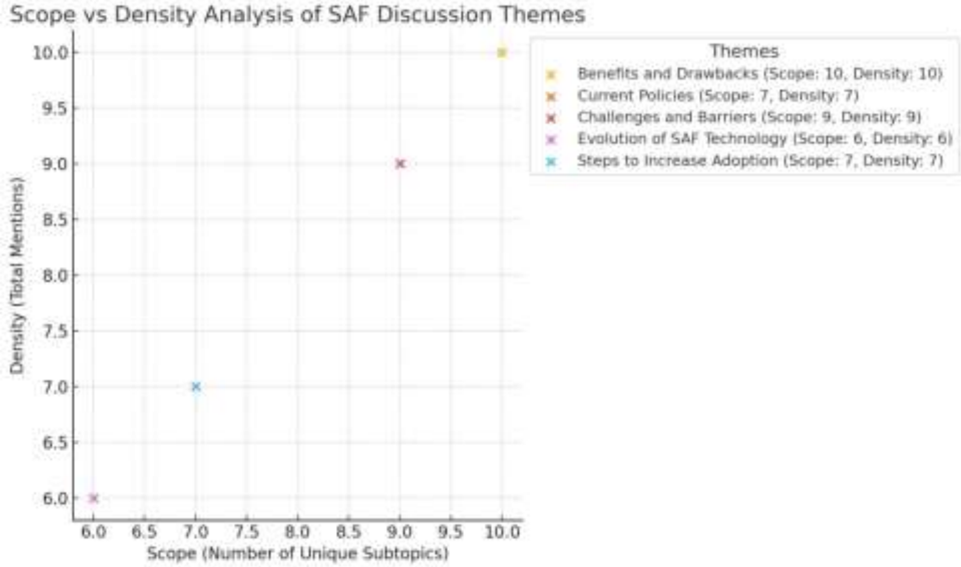

Figure 7. Scope vs Density Analysis of SAF Discussion Themes

Insights from the Scope Density Relationship Analysis:

Scope simply refers to the range of different subtopics or aspects covered under a main theme, indicating the variety of discussions related to that theme. A larger topic simply means that the extent to which the topic is being discussed from very many different contexts or the time it is being viewed from a plurality of perspectives. On the other hand, its density measures the quantity of content or how frequent each mention of the theme is in any space, thus indicating depth of coverage.

The highest density shows the most discussion for the theme at a greater level of detail or emphasis. The theme "Challenges and Barriers" scored high both in scope and density. This means that this theme was widely discussed within the identified sub-themes (such as technological limitations, economic feasibility, and regulatory challenges), and there was a lot of attention and detail drawn towards such discussions. The very high level and importance of this double emphasis illustrate its importance and level of complexity in the discourse on SAF implementation. Themes with high scope and high density are likely to represent areas where stakeholders feel they have very many concerns of significance and hence will need diversely suggested solutions. This is, in fact, a very crucial point for strategic planning, as effectively addressing this point can broadly impact the success of SAF adoption.

This could give a lead to the importance of the assignment of resources; say from funding for research and development or focus of policy. For example, dense discussions around challenges and barriers may give reason to increase the investment for the same to be overcome either by technological innovation or policy reformation. Themes with broad scope need diverse stakeholder engagement as they seek to cover the many important facets of the SAF field. Engaging experts and stakeholders in these areas is key to gaining their invaluable insight and opinion on potential solutions and approaches to further their field.

Single Case Model: The single-case model is a focused analysis approach, used in the explanation of one particular theme or issue. It shall map out and relate its varying facets and interconnections with the co-occurring subthemes and the relevant broader contexts. The other applications of the Single Case Model applied in the discussion of the "Challenges and Barriers" in the context of the Sustainable Aviation Fuels (SAF) theme.

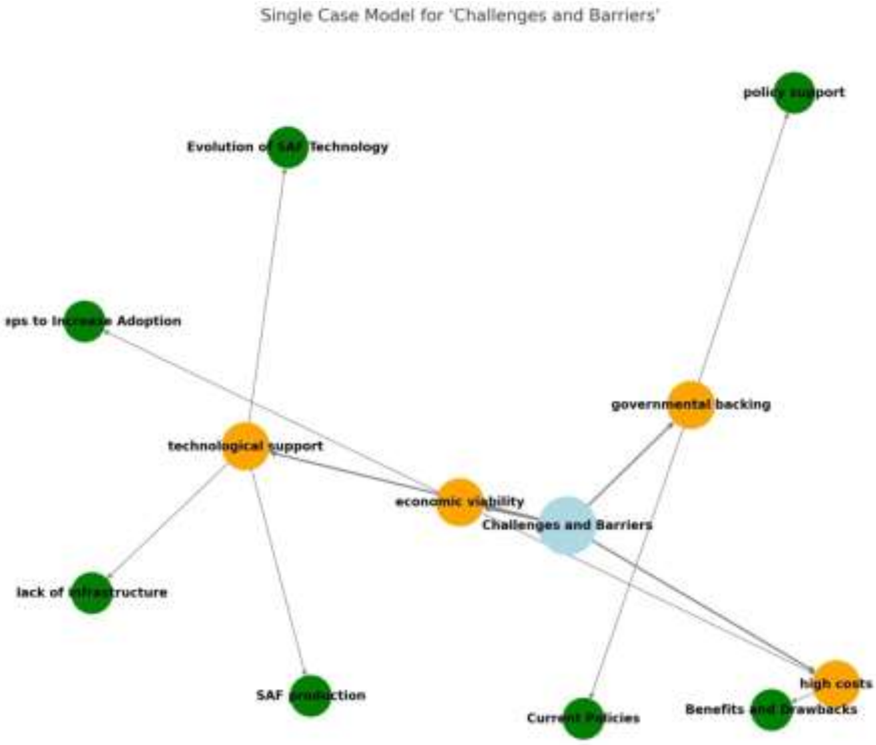

Figure 8. Single Case Model for "Challenges and Barriers"

Insights from Single Case Model Analysis:

This model elaborated critically on the network of subthemes linked to "Challenges and Barriers," among which included technological support, economic viability, regulatory frameworks, and market acceptance. The graphical mapping is helpful for the stakeholders to see vividly not only the main issues but also how those are delicately connected with different operational and strategic factors.

With a focus on certain barriers, such as "technological support" and "economic viability," the model brings to light the most important obstacles that stand in the way of implementing SAF. The technological umbrella includes issues ranging from the need for advanced technologies of production and infrastructure, while the economic viability touches on costs, return on investment, and competitiveness with rival markets.

The Single Case Model lays focus on integrated solutions to face technological and economic challenges simultaneously. This points to a coordinated approach of technology development, combined with financial strategies under policies aspiring for SAF to be both technically feasible and economically attractive for a successful SAF deployment. This would provide the policymakers with a better idea about where legislative and financial support can be the most effective. In doing so, it discloses to the industry leaders the most important areas of investment that would be necessary for the advancement of SAF technology. They pointed out that some technological gaps need to be bridged to support the broader deployment of SAF.

The model guides the policy and research agendas and informs what the major prevailing barriers are and their root causes. For example, it suggested that policies can be drawn to subsidize initial investments in infrastructure or support R&D to bring the production cost down, but rather when the ability to use was most associated with high production costs or poor infrastructure. These findings provide, therefore, a holistic overview of expert perspectives about sustainable aviation fuels, key themes emerging, challenges, and policy interventions that can facilitate the adoption of SAF by the Turkish aviation sector in its totality.

6. CONCLUSION

The comprehensive qualitative analysis of the discussions around Sustainable Aviation Fuels (SAF) offers valuable insights into the multifaceted impact of SAF towards fostering sustainability in aviation. In the process, the panel relied on several analytic tools that dissect the breadth and depth of the conversations and stretch from Word Clouds, Code Relationships Browsers, to more detailed models like Scope Density Relationships, and Single Case Models, to evoke a nuanced understanding of the challenges, benefits, and necessary policy frameworks for SAF implementation.

These analyses, therefore, point to the central role that SAF will play in reducing the aviation industry's carbon footprint while also indicating very high consensus on the environmental benefits and the policy support needed for strong production to realize these benefits. This demonstrates that our review on the subject illuminates, that while the environmental benefits of SAF are well acclaimed and highlighted, the major challenges such as high costs of production, technological gaps, and poor policies still pull their weight to fame. The Code Based Frequency Analysis shows that these themes point to "SAF," "production," and "policies," hence indicating key areas where stakeholders will base their attention.

Further, the Single Case Model of "Challenges and Barriers" exactly helped demonstrate the fact that these were interconnected, integrated solutions which needed to have equal focus over issues related to infrastructure and economic viability to make SAFs more feasible. In summary, the possible efforts needed for speedy adoption of Sustainable Aviation Fuels encompass technology development, financial incentives, and policy enhancements suggested under this study. All these will contribute to ensuring that the adoption of SAF is not representative of any other thing but techno-migration, the broader shift that involves regulatory adaptation, market preparedness, and broad stakeholder engagement. It underscores such a transformation; policymakers and captains of industries have to support an environment interested in fueling innovation, encouraging the subsidizing of early costs, and finally leads to a future for aviation towards sustainability. With further dialogue, research, and collaboration, the SAF potential on aviation sustainability can be fully actualized.

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